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Examining the Relationship Between Countermovement and Squat Jump Measures Amongst Elite Development Female Football and Rugby Players

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ABSTRACT

Purpose: In response to the need for a single low cost, relatively quick, minimally invasive test of strength, power, and velocity for elite development standard female football and rugby players requiring minimal staff expertise and sophisticated equipment, with benchmark standards, this study had two aims. Firstly, how countermovement jump (CMJ) and squat jump (SJ) tests associate with commonly used football and rugby strength and velocity tests. Secondly, to propose benchmark standards for elite development level female football and rugby players. **Methods:** Participants were 60 elite development level female football and rugby players. Data were collected as part of the participants' elite pathway development academy programs. Measures included absolute lower body strength (ALS) assessed using three repetition maximum (3RM) trap bar deadlift, relative lower body strength (ALS / body weight), CMJ and SJ using bodyweight only, and running sprint velocities over 10 metre and 40 metre distances. **Results:** For the football sample, CMJ and SJ had significant relationships with RLS ($r=0.742$, $p<0.01$ and $r=0.499$, $p<0.01$ respectively) and 10m sprint velocity ($r=0.579$, $p<0.001$ and $r=0.481$, $p<0.01$ respectively), but not with ALS nor 40m sprint velocity. For the rugby sample, CMJ and SJ also had significant associations with RLS ($r=0.539$, $p<0.01$ and $r=0.449$, $p<0.05$ respectively) and 10m sprint velocity ($r=0.742$, $p<0.001$ and $r=0.797$, $p<0.001$ respectively), as well as with 40m sprint velocity ($r=0.598$, $p<0.01$ and $r=0.651$, $p<0.001$ respectively). **Conclusion:** CMJ and SJ represent low cost, relatively quick, minimally invasive tests of strength, power, and velocity suitable for elite development standard female football and rugby players' performance assessment, benchmarking, and monitoring.

Keywords: female, rugby, football, strength, velocity, benchmark

INTRODUCTION

Successful performance in field-based team sports such as football and rugby require large numbers of intense accelerations, maximum velocity efforts, and rapid changes of direction (Conte, et al., 2015; Delaney et al., 2015; Dos'Santos, Thomas, Comfort,

& Jones, 2018; Harper, Carling, & Kiely, 2019; Scott, Scott, & Kelly, 2016; Wundersitz, Gastin, Robertson, Davey, & Netto, 2015; Yu, Altieri, Bird, Corcoran, & Jiuxiang, 2021). While acknowledging the many factors that contribute to achievement in sport, field-based teams' on-pitch success has been linked to these intense actions during key periods of play (Aughey, 2011; Spencer et al., 2004). For players to successfully execute these intense actions, they need to rapidly apply very large forces to the playing surface (ground); an ability associated with maximal strength (Delaney et al., 2015; Dos'Santos et al., 2018; Harper et al., 2019; Healy, Smyth, Kenny, & Harrison, 2019; Suchomel, Nimphius, & Stone, 2016). The ability to generate these large forces rapidly is a quality commonly described as 'Impulse' and is calculated as a product of both applied force (Newtons) and the time taken to apply it (Suchomel et al., 2016). Reflecting the importance of these on-field abilities, the development of maximal strength, impulse, and velocity are common targets in athletic development programs seeking to support sporting performance (Schuster et al., 2018). To effectively develop such key strength and velocity abilities, repeated and ongoing monitoring of adaptation is required in order to inform prescription, set goals, and assess progress.

Reflecting the professionalization of performance sport and the importance of athletic development for elite performance, monitoring strength and velocity abilities has become an increasingly developed and specialized discipline. Modern velocity and strength assessments are sophisticated and costly even for clubs and teams with the necessary resources. Some of the more expensive tests include force plates, isokinetic testing systems or the Freelap timing system. Whilst evidence supports the adoption of sophisticated, extensive, and specialized strength and conditioning assessments (Schuster et al., 2018; Vilar, Araújo, Davids, & Button, 2012), the use of and access to such monitoring and testing can be problematic in terms of injury risk as well as logistical and economic issues. Strength testing procedures involving measurements of one repetition maximum (1RM) (e.g., Suchomel et al., 2016) can present increased injury risks (Svensson, Alricsson, Olausson, & Werner, 2018). Extensive testing sessions can also interfere with training and preparation routines and programs (Howatson, Brandon, & Hunter, 2016). Potentially the most substantial barrier to extensive testing procedures for clubs or teams is affordability. This affordability challenge is more likely to be evident for development contexts (Erpiča, Wylleman, & Zupančič, 2004), and reflecting the often disparity between male and female sports funding, more likely for female teams (Shaw & Amis, 2001). Therefore, for women's football and rugby identifying a single test or small battery of tests that are low cost, relatively quick, and minimally invasive, requiring only minimal staff expertise and sophisticated equipment, yet are still relevant to on-field performance and are predictive of a broader spectrum of measures, would have clear utility.

Fortunately, there is evidence, albeit limited in extent, that some on-field velocity and strength qualities in both football and rugby associate with assessments such as Countermovement Jump (CMJ) and Squat Jump (SJ) tests; both of which have been shown to closely associate with power (Cronin & Hansen, 2005; Cunningham et al., 2013; Shalfawi, Sabbah, Kailani, Tonnessen, & Enoksen, 2011). This indicates that either of these tests might provide valuable data which could inform training decisions regarding strength, impulse, and velocity training prescription. Such a test would represent an efficient return on investment for teams with limited training times and budgets. Furthermore, a jump test could provide the least inherent injury risk for football and rugby players accustomed to jumping, loaded or otherwise, as part of regular training and competition with an adequate warm-up (Malone et al., 2017; Ruan, Li, Chen, & Wu, 2018). However, only limited research considers how CMJ and SJ performance associates with other commonly used strength, power, and velocity tests in elite development level female football and rugby players (Panoutsakopoulos, Papachatzis, & Kollias, 2014). Without such evidence supporting the predictive abilities of either a CMJ or SJ test, the use of such tests as representative of broader performance qualities remains unjustified in female football and rugby players.

A further limitation regarding CMJ and SJ tests is the paucity of available benchmark data regarding female elite development football and rugby players. This lack of CMJ and SJ benchmark data makes assessments of developing players' progression towards elite players' levels of strength, impulse, and velocity problematic as there are few published standards to compare to. Additionally, this lack of data also substantially impedes the construction of appropriate targets for developing female football or rugby players.

In response to the need for a single low cost, relatively quick, minimally invasive test of strength, power, and velocity for elite development standard female football and rugby players which require minimal staff expertise and sophisticated equipment, with benchmark standards, this study had two aims: The first aim was to assess how CMJ and SJ tests associate with other commonly used football and rugby strength and velocity tests in elite development level female football and rugby players. The second aim was to develop elite development level benchmark standards for elite development level female football and rugby players.

METHODS

Experimental Approach to the Problem

To address the research aims, a data linkage approach was adopted. Data were collected as part of the participants' elite pathway development academy programs. To address the first research aim, how CMJ and SJ tests associate with other commonly used strength and velocity tests in elite development level female football and rugby players, a cross-sectional correlational design was adopted. For the second research aim, to develop elite development level benchmark standards for female football and rugby players, a descriptive design was used. These correlation and descriptive designs did not necessitate the use of control groups.

Participants

Sixty female athletes volunteered to participate in the study (age 19.4 ± 2.6, 16 - 27 years; body mass 69.3 ± 10.4, 47.5 - 94.0 kg; mean ± SD, range). Participants were from a university in the South West of England and members of its onsite Football (n = 36; age 18.2 ± 1.8, 16 - 22 years; body mass 64.1 ± 8.3, 47.5 - 85.0 kg) and Rugby Academies (n = 24; age 21.2 ± 2.6, 17 - 27 years; body mass 77.3 ± 8.0, 62.3 - 94.0 kg). The elite development pathway programs combine study with full-time training and competition. Evidencing the elite aspect of these development programs, some athletes from the football program played in the FA Women's Super League and National Premier League teams. More than 20 England Under-20s and ten senior England rugby squad members had come through the program, including Women's Rugby World Cup winners. In the current sample two participants played for Women Super League Clubs. Data for this study were collected as part of the participants' routine academy testing, monitoring, and development program. Participants had provided consent for testing as part of their academy scholarship agreements. Prior to data collection participants completed medical screening and the Physical Activity Readiness Questionnaire, including using their de-identified data for research purpusses. Written parental consent was obtained from all participants under the age of 18. This study was conducted according to the guidelines in the Declaration of Helsinki and was approved by the Hartpury University Research Ethics Committee (ethics approval number: ETHICS2020-51).

Measures and Procedures

Data for each participant were collected over three sessions in a two-week block. All performance tests used in this research have good absolute and relative reliability levels. Body mass (kg) was assessed using a set of SECA 876 scales (SECA, Hamburg, Germany). After a self-selected warm-up consisting of light aerobic activity and general stretching, each subject completed the battery of tests.

Absolute lower body strength (ALS) was measured using a three repetition maximum 3RM trap bar deadlift (Lockie et al., 2018). The protocols have been described previously (see McCurdy, Langford, Cline, Doscher, & Hoff, 2004). A Body Revolution five feet Olympic Shrug Hexagonal Trap Bar and full sized Olympic Bumper Plates were used. Participants' set-up with feet shoulder-width apart held onto the elevated handles. The deadlift commenced from the plates resting on the floor with a self-selected stance width. A self-selected stance was used to better facilitate transfer between tests and accommodate variability in anthropometric characteristics across the sample. It was also to ensure participants experienced a greater state of readiness during the protocol. Participants completed two warm-up sets of seven at an estimated 50% of 3RM and five repetitions at 80% before attempting a 3RM. After each successful lift the weight was increased until three full repetitions could not be completed. The weight from the last successful 3RM was recorded as the participants' result. Rest between attempts was five minutes. A 3RM was used due to the training age of the athletes and inexperience with 1RM training and testing (Morales & Sobonya, 1996). The successful 3RM weight was then converted to an estimated 1RM using the Epley equation (García-Ramos et al., 2019). To calculate relative lower body strength (RLS; kg/kg), ALS was divided by participants' body mass (kg).

Jump data were collected using the Optojump Modular System (Optojump, Optical Measurement System, Bolanzo, Italy). The protocols have been described previously (see Petrigna et al., 2019). In summary, the jumps were performed on a wooden Olympic lifting platform. The tests included counter movement jump (CMJ) and squat jump (SJ) using bodyweight only. Participants were allowed two practice jumps. Participants maintained hands on hips throughout and squatted to a depth where the knee angle was close to 90 degrees. The CMJ was performed with no pause, and the SJ required a two-second pause at the bottom (Petrigna et al., 2019). Each participant was allowed three attempts for each jump with a rest period of three minutes between each attempt, the best of three attempts was recorded.

Following a ten minute rest period after the jump tests, sprint velocity was assessed on a 4G synthetic turf pitch using Brower TCi timing gate system (Brower TCi Timing System, Brower Timing Systems, Draper, USA) with the beam height set 0.3m above the floor. The protocols have been described previously (Waldron, Worsford, Twist, & Lamb, 2011). Participants started in a split stance 1 metre behind the first gate. Three attempts were allowed over the 40m distance with the best 10m and 40m time used for analysis. Four minutes rest was provided between each effort. Sprint velocities were calculated by dividing distance by sprint time (m/s).

Statistical Analyses

Statistics were performed using Statistical Package for Social Scientists (SPSS version 27, 2021). For the first research aim, Bivariate Pearson's correlation was calculated to establish associations between the measures of CMJ, SJ, ALS, RLS, 10m sprint velocity, and 40m sprint velocity. An alpha value of ≤0.05 was used to indicate statistical significance. Correlation coefficient effect sizes were interpreted as small (r=0.1<0.29), medium (r= 0.3<0.49), and large (r=0.5>0.7) (Cohen, 1988). The normality of the distribution of data was confirmed using the Shapiro-Wilk test. For the second research aim, descriptive statistics were calculated, including quartile scores to establish normative reference values in the study cohort.

RESULTS

Regarding the first research question, the results demonstrate that CMJ and SJ tests associate with other commonly used strength and velocity tests in elite development level female football and rugby players (see Tables 1 and 2). Mean scores for each variable are provided in Table 3, along with quartile scores. For the football sample, there was a significant relationship with a large effect size between CMJ and RLS (r=0.496, p<0.01) and athletes' 10m sprint velocity (r=0.742, p<0.001), but not ALS or 40m sprint velocity. For the rugby sample, there was a significant association with a large effect size between CMJ, and RLS (r=0.539, p<0.01), 10m sprint velocity (r=0.742, p<0.001), and athletes' 40m sprint velocity (r=0.598, p<0.01). As with the football sample, CMJ did not associate with ALS; a similar result was observed in the SJ results. SJ was significantly associated with RLS in both the football (r=0.449, p<0.01) and the rugby samples (r=0.449, p<0.01), both recording medium effect sizes. SJ was significantly associated with 10m sprint velocity in both samples and recorded a medium effect size in the football sample (r=0.481, p<0.01) and a large effect size in the rugby sample (r=0.797, p<0.001). There was no significant relationship between SJ and athletes 40m sprint velocity in the football sample, however, a significant relationship was observed with a large effect size in the rugby sample (r=0.651, p<0.001).

Table 1. Football players' associations between CMJ, SJ, strength, and sprint tests (Pearson bivariate corrections [95% confidence limits]).

	SJ (m)	**ALS (kg) †**	**RLS (kg/kg)**	**10m Sprint velocity (m/s)**	**40m Sprint velocity (m/s)**
CMJ (m)	0.900*** [0.812 - 0.948]	-0.049 [-0.720 - 0.284]	0.496** [0.200 - 0.709]	0.579**# [0.310 - 0.763]	0.177 [-0.161 - 0.477]
SJ (m)		0.009 [-0.321- 0.336]	0.449** [0.144 - 0.678]	0.481** [0.181 - 0.699]	0.220 [-0.177 - 0.511]
ALS (kg)			0.556*** [0.278 - 0.748]	-0.010 [-0.338 - 0.319]	0.322 [-0.008 - 0.588]
RLS (kg/kg)				0.540*** [0.257 - 0.738]	0.375* [0.053 - 0.626]
10 m Sprint velocity (m/s)					0.462** [0.158 - 0.686]

CMJ = counter movement jump; SJ =squat jump; ALS = absolute lower body strength; RLS = relative lower body strength.
†ALS = estimated 1RM from 3RM using the Epley equation (García-Ramos et al., 2019); *p≤0.05;**p≤0.01; ***p≤0.001; n = 36.

Table 2. Rugby players' associations between CMJ, SJ, strength, and sprint tests (Pearson bivariate corrections [95% confidence limits]).

	SJ (m)	**ALS (kg) †**	**RLS (kg/kg)**	**10m Sprint velocity (m/s)**	**40m Sprint velocity (m/s)**
CMJ (m)	0.925*** [0.833 - 0.968]	-0.153 [-0.528 - 0.262]	0.539** [0.173 - 0.774]	0.742*** [0.482 - 0.881]	0.598** [0.256 - 0.807]
SJ (m)		-0.173 [-0.539 - 0.247]	0.449* [0.056 - 0.722]	0.797*** [0.579 - 0.908]	0.651*** [0.336 - 0.836]
ALS (kg)			0.564** [0.208 - 0.788]	-0.290 [-0.621 - 0.129]	-0.327 [-0.645 - 0.088]
RLS (kg/kg)				0.331 [-0.084 - 0.648]	0.243 [-0.177 - 0.589]
10 m Sprint velocity (m/s)					0.741*** [0.482 - 0.881]

CMJ = counter movement jump; SJ =squat jump; ALS = absolute lower body strength; RLS = relative lower body strength.
†ALS = estimated 1RM from 3RM using the Epley equation (García-Ramos et al., 2019); *p≤0.05;**p≤0.01; ***p≤0.001; n = 24.

Table 3. Quartile CMJ, SJ, strength, and sprint tests scores for elite female development level football and rugby players.

	CMJ (m)	SJ (m)	ALS (kg) †	RLS (kg/kg)	10m Sprint velocity (m/s)	40m Sprint velocity (m/s)
Footballer players (*n* = 36)						
(Entire group mean ± SD)	0.288 ± 0.047	0.272 ± 0.050	105.81 ± 15.35	1.66 ± 0.19	5.22 ± 0.20	6.72 ± 0.37
Fourth quartile	≥ 0.317	≥ 0.307	≥ 117.31	≥ 1.69	≥ 5.34	≥ 7.04
Third quartile	0.289 > 0.317	0.268 > 0.307	116.19 > 117.31	1.65 > 1.69	5.16 > 5.34	6.80 > 7.04
Second quartile	0.248 > 0.289	0.233 > 0.268	95.4 > 116.19	1.59 > 1.65	5.10 > 5.16	6.49 > 6.80
First quartile	≤ 0.248	≤ 0.233	≤ 95.4	≤ 1.59	≤ 5.10	≤ 6.49
Rugby players (*n* = 24)						
(Entire group mean ± SD)	0.311 ± 0.041	0.290 ± 0.042	134.05 ± 15.67	1.74 ± 0.19	5.09 ± 0.28	7.50 ± 0.62
Fourth quartile	≥ 0.348	≥ 0.327	≥ 141.88	≥ 1.83	≥ 5.21	≥ 8.02
Third quartile	0.305 > 0.348	0.286 > 0.327	132.98 > 141.88	1.72 > 1.83	5.09 > 5.21	7.44 > 8.02
Second quartile	0.277 > 0.305	0.262 > 0.286	121.39 > 132.98	1.60 > 1.72	4.93 > 5.09	7.12 > 7.44
First quartile	≤ 0.277	≤ 0.262	≤ 121.39	≤ 1.560	≤ 4.93	≤ 7.12

CMJ = counter movement jump; SJ = squat jump; ALS = absolute lower body strength; RLS = relative lower body strength.

†ALS = estimated 1RM from 3RM using the Epley equation (García-Ramos et al., 2019)

Other notable significant correlations between jump, strength, and speed variables included the expected relationship between CMJ and SJ in both the football (r=0.900, p<0.001) and rugby players (r=0.925, p<0.001). ALS and RLS correlated in both samples, sharing approximately 30% of variance (r^2) (football r=0.556, p<0.001; rugby r=0.564, p<0.01). The only significant relationship between strength indices and sprint velocities were observed in the football sample for RLS (10m sprint velocity r=0.540, p<0.001, large effect size; 40m sprint velocity r=0.375, p<0.01, medium effect size). 10m and 40m sprint velocities were more strongly associated in the rugby sample (r=0.741, p<0.001, large effect size) compared to the football sample (r=0.462, p<0.01, medium effect size).

With regard to the second research aim, the development of benchmark standards for elite development level female football and rugby players, quartile scores for CMJ, SJ, ALS, RLS, 10m sprint velocity, and 40m sprint velocity are presented in Table 3. With regard to differences between the samples, the rugby players had the higher quartiles scores for CMJ, SJ, and ALS. For RLS the footballers had the higher 1st quartile scores, but the lower 4th quartile scores (football 1st quartile=1.59, 4th quartile=1.69; rugby 1st quartile=1.560, 4th quartile=1.83). For 10m sprint velocities the footballers were faster at each quartile, conversely however the rugby players were faster at each quartile for the 40m sprint velocity. The football sample displayed the greater spread between quartiles for CMJ and ALS, while the rugby players had the greater spread on SJ, RLS, and both sprint distance velocities.

DISCUSSION

The current study had two aims, the first of which was to assess how CMJ and SJ tests associate with other commonly used strength and velocity tests in elite development level female football and rugby players. Against this aim, our findings demonstrate positive correlations between CMJ and SJ height and relative lower body strength, 10m, and 40m sprint velocity. These findings add to previous research (e.g., Cronin & Hansen, 2005; Cunningham et al., 2013) which found similar correlations between jump height and measures of both force and velocity. The correlations between CMJ with SJ and 10m velocity found in the current study is supported by research from Shalfawi et al. (2011), who found correlations between jump height and measure of velocity over 10m, 20m, and 40m distances. Taken together these findings indicate the CMJ and SJ tests could be used as a proxy for both relative strength and sprint velocity testing. However, one limitation of the study by Shalfawi et al. (2011) as reported by the authors, was a high degree of variability in the factors contributing to the velocity attained; as such, it is difficult to assess the impact of jump performance on velocity due to the high technical and coordinative demands of maximum velocity sprinting. Increases in SJ and CMJ would be more indicative of an athlete's capacity to produce high impulse. Conversely, results from our current study contradict the findings of Thomas, Jones, Rothwell, Chiang, and Comfort (2015) who found no association between maximum force, as assessed by an isometric mid-thigh pull (IMTP) and jump height. A further fundamental limitation of the study by Thomas et al. (2015) was the non-dynamic nature of the max force test, which the authors reported as having an impact on the correlation with the dynamic jump test. These findings indicate that CMJ and SJ associate well with both force and velocity measures and could be used by practitioners to assess progress in motor potential when training elite development female football and rugby athletes.

Secondly, our investigation aimed to develop elite development level benchmark standards for female football and rugby players. These data could be useful for coaches looking for key performance variable benchmarks. The 4th quartile would represent the top 25% of a group in that particular variable, while the 1st quartile represents the bottom 25%; therefore, practitioners can use this method to inform future programming decisions. As to the differences found between sports in the current study, we suggest that these results highlight potential differences in the physical demands of both sports. Differences in ALS and RLS between the football and rugby groups may represent greater demand for momentum in rugby as a contact sport (Barr, Sheppard, Gabbett, & Newton, 2014). Conversely, the better performance in 10m sprint velocity yet reduced 40m sprint velocity seen in the football group is potentially representative of the greater demands for repeated short accelerations relative to rugby union (Harper et al., 2019). Measures of strength and power assess force generation but what remains unclear is the athlete's ability to apply force to the ground. Reactive strength and its implications regarding force application would add further insight into correlations found in the present study between CMJ, SJ, RLS, ALS, and speed. A possible avenue for further research would be to include a measure of reactive strength such as the drop jump or single leg drop jump.

A key consideration for practitioners applying these research findings is the potential compromise between internal and external validity, which is not uncommon in applied research (Andrade, 2018; Halperin, Pyne, & Martin, 2015). Test selection was based on equipment availability which may have impacted the reliability of the results due to the difficulty in standardising non-laboratory testing methods (Tomkinson & Olds, 2008). Future research should consider assessing maximum dynamic force, which is easier to standardise, such as an isokinetic test to ensure greater reliability of data (Ball & Scurr, 2008). Furthermore, whilst the participants age range and ability level were not highly variable, there was a greater amount of variance in the relative strength levels and body mass. Using a more standardised sample group may improve internal validity. Another consideration is the participants' physical energy and motivation levels during testing. The testing blocks were completed as part of a regular season, so external factors such as residual fatigue, mental stress, or menstrual cycle may have impacted the testing (Halperin et al., 2015). Whilst each participant was encouraged to give maximal effort in every test, the current study was unable to account for the aforementioned external factors.

CONCLUSION

In summary, meaningful correlations were recorded between SJ and CMJ data with RLS and 10m velocity means. Furthermore, quartile data presents a useful method to inform future training prescription. Given the associations between CMJ and SJ data and measures of relative strength and velocity, these tests can provide useful insight into athletic profiles from which training prescription can be individualised. The jump tests used in the current study are easy to perform, have relatively low cost in terms of time commitment and resources, and have been shown to be highly reliable. The benchmark data provided in the current study offers guidance to coaches who work with elite female football and rugby players and can assist in developing the long term planning needs of these athletes.

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