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Test Re-Test Reliability of Countermovement Jump, Single Leg Countermovement Jump, and Countermovement Rebound Jump Force Plate Metrics in Female Football Players

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ABSTRACT

Female football is growing exponentially. Assessing changes in neuromuscular function enables injury risk profiling using single and multiple countermovement jumps (CMJ) in female footballers who are at greater injury risk. Single leg CMJ (SLCMJ) is sensitive to detect such changes, but test-retest reliability is unknown. The aim of this study was to examine test-retest reliability of phase-specific metrics during CMJ, SLCMJ and countermovement rebound (CMJ-R) in female youth footballers. Twenty-six elite female footballers (15.4±1.6 years, 59.2±2.4 kg, 165.8±4.8 cm) performed three, arms akimbo, CMJ, SLCMJ and CMJ-R trials on two sessions seven days apart, using force plates and associated software. System weight, jump momentum and average braking force had good-excellent reliability. CMJ demonstrated greater reliability followed by CMJ-R, dominant limb (DL: preferred kicking limb) SLCMJ and non-dominant limb (NDL) SLCMJ. Jump height had good-excellent reliability for CMJ and CMJ-R. SLCMJ absolute reliability (upper 95 confidence interval [CI] coefficient of variation) was moderate for both limbs. Relative reliability (lower 95 CI interclass correlation coefficient) was good for DL, but poor for NDL. Considering increased injury risk in female athletes, selecting reliable metrics facilitate accurate neuromuscular function assessment for injury risk profiling. This study describes phase-specific test-retest reliability in female youth footballers.

Keywords: Women's Soccer, Force Platform, Repeatability, Vertical jump

INTRODUCTION

Over the past decade, participation in organized female football has grown exponentially to approximately 13.3 million globally, to which approximately 3.12 million are youth female footballers (<18 years)[14]. Scientific research on women's football has also increased, emphasizing anthropometry; nutrition; sociology; psychology; strength and conditioning; and injury, however the quantity of research is much lower than male-specific football research (senior and youth)[44]. Consequently, strength and conditioning provision has increased within youth sport[56], emphasizing performance testing, athlete profiling, fatigue monitoring, long-term athletic development, and tailored interventions[38, 44].

Unfortunately, female athletes are at a greater injury risk compared to male counterparts[24,44,52], in particular non-bone related injuries such as anterior cruciate ligament injury[32, 48]. This has been attributed to multiple risk factors including: age[11], maturation status (especially during periods around peak height velocity)[51], higher body mass index[58], greater joint hypermobility, lower strength levels, in particular lower limb strength[45], increased dynamic knee valgus on landing[23], high training/match exposure[45, 57], time of the season[17], hormonal fluctuations[32], and psychological factors[31]. During adolescence, structural and neuromuscular changes relating to growth and maturation, lead to increases in jump height performance, and subsequently mechanical stress in female youth footballers[13, 50, 54, 62]. These changes occurs at different times and magnitudes, posing a potential problem for strength and conditioning coaches when designing training programs and mitigating injury risk.

Innovative technologies, such as force plates, are being utilized to measure force-time characteristics to test lower limb neuromuscular function (NMF) and profile injury risk in athletes[1, 7]. Force plates popularity has increased, with approximately 50% of football strength and conditioning coaches using these in practice[64]. Across football codes, the bilateral CMJ is the most common test[18]. Force plates provide detailed information including six phases of CMJ tasks, rather than simply jump height[16, 38], with acceptable validity for hardware[2, 30] and software[41]. However, during data collection, instrumentation and biological noise occur, meaning an athlete's 'true' test score cannot be determined. Instead, the observed data should be interpreted alongside the associated measurement error[59]. It is therefore important to investigate the test-retest reliability (rank-order reliability and measurement error) of key CMJ metrics before including these in testing and screening, selecting the appropriate variables and interpreting resultant data.

Test-retest reliability of phase-specific CMJ metrics have been reported in team sport athletes using single and repeated jumps[6, 9, 15-16, 21, 25-26, 40, 62]. Jumping with arms akimbo (hands on hips) and taking the average of 2-3 trials showed greater reliability than the inclusion of arm swing and using the best trial score[21, 25-26, 40]. A number of these studies demonstrated greater test-retest reliability from metrics calculated in the propulsive phase (i.e., upward movement), rather than the countermovement phase (i.e., downward movement, comprised of the unweighting and braking phases) of the jump[16, 21, 25, 40]. Three studies reported test-retest reliability in male youth football players[6, 34, 53]. Two studies reported increased reliability with maturation; Ruff et al.[53] reported coefficient of variation (CV) percentage of less than 10% (a typical cut-off for acceptable reliability) but not for pre-circa athletes whereas Bright et al.[6] reported reliable metrics in pre-circa athletes and superior reliability post-circa. As both studies indicate improved reliability with maturation it could be expected that CMJ force-time metrics for female youth football players post peak height velocity will be reliable. Limitations of these studies include non-elite football players[6], inclusion of the best take-off velocity score from two trials[53] and a sampling rate of 400-500 Hz[34] which is lower than the recommended 1000 Hz[54]. Although athletes were considered trained/developmental[6], athletes in professional academies, and greater athleticism, may achieve greater CMJ reliability. Inclusion of single leg CMJ (SLCMJ) to assess NMF, and injury risk, may be beneficial, and has demonstrated greater sensitivity to detect such changes[20, 42]. Within-session reliability of SLCMJ has been previously reported in recreational athletes using force plates[4]. However, no study to date has explored the test-retest reliability of CMJ, SLCMJ or rebound jump tasks, such as the CMJ rebound (CMJ-R), using force plates in elite female football players.

Considering the NMF disruptions during maturation coupled with greater injury risk in female athletes, it is imperative that strength and conditioning coaches monitor NMF to assess performance and mitigate injury risk. To achieve this, practitioners must be aware of the phase-specific reliability to that population in order to make informed decisions. Therefore, the aim of this study was to assess the test-retest reliability of phase-specific metrics for CMJ, SLCMJ and CMJ-R in female youth footballers. It was hypothesized that different jump variations would yield different degrees of reliability, especially between limbs in SLCMJ, considering the technical differences and demands of each variation.

MATERIALS AND METHODS

Study Design

Cross-sectional in-season data was collected to assess the test-retest reliability of CMJ, CMJ-R, and SLCMJ in elite youth female footballers. Tests were conducted across two sessions separated by seven days with participants maintaining consistent physical activity prior to testing[9, 21]. Informed consent, and parental consent for participants under the age of 16 years, were obtained prior to the study which was approved by the University of Salford institutional review board (ref. 2090) and conformed with the Declaration of Helsinki.

Participants

Twenty-seven highly trained-to-elite youth female footballers[37], registered at an FA Tier One Plus Accredited Regional Talent Centre volunteered for the study (15.4 ± 1.6 years, 59.2 ± 2.4 kg, 165.8 ± 4.8 cm). All participants had two years or more training experience consisting of two strength and conditioning sessions, three technical training sessions and one competitive match each week and were injury free. Testing was conducted in the nineth month of the season (including pre-season).

Data Collection

All testing was carried out at the Regional Talent Centre training facility in a gymnasium on a solid floor in accordance with good practice recommendations[3] (figure 1). Prior to the testing, all participants completed a familiarization session and had previous exposure to CMJ, SLCMJ and CMJ-R within their training programs. On arrival participants completed a standardized RAMP warm up including 5-minutes low level cycling, dynamic stretches and movements including two sets of eight reps for hip circles, leg swings, high knee and plantar extension march, squats, hip bridging, multi-directional lunges, and two sets of 3 reps for hops, and submaximal jumps. CMJ, SLCMJ and CMR-R tests were conducted using on a dual sensor portable force plate sampling at 1000 Hz (Hawkin Dynamics Inc., Maine, USA). Foam surrounds placed around the force plates for participant safety. In order to reduce order effects, jumps were randomly assigned between participants and sessions. Participants were required to stand centrally on each force plate (centrally on one plate for SLCMJ) with both hands placed on the hips in order to reduce the effect of arm swing. For SLCMJ, tags within the proprietary software were applied for dominant limb (DL) and non-dominant limb (NDL) based on kicking preference to identify each limb[8, 12, 27, 33, 43]. Participants held a still position for a 1-second weighing period before executing the task. Verbal cues were standardized (“jump as high and as fast as possible”), contextualized to the phase of the jump, for example, “jump as fast” refers to performing the countermovement, propulsive and rebound phases as quickly as possible[49]. Any trials that involved hands coming off the hips, a slow countermovement depth, tucking of the knee and /or ankle, and/or use of contralateral limb was excluded from data analysis with a new trail performed.

Data Analysis

Vertical ground reaction force was low pass filtered at 50 Hz in accordance with recommendations[19], while take-off was determined when the vertical force dropped below 25 N during the propulsive phase. All metrics were calculated automatically by the force plate software and are defined in supplementary table 1.

Figure 1. Picture of force plate setup

Statistical Analysis

A two-way mixed effect, absolute agreement intraclass correlation coefficients (ICC, model 3,1) was used to assess relative reliability[28-29, 36, 55]. ICC values were interpreted based on the lower 95% confidence interval (ICC_{-95}) as: poor (<0.50), moderate (0.50-0.74), good (0.75-0.89), and excellent (>0.90), based on recommendations from Koo & Li[28]. Absolute reliability was interpreted from the upper 95% confidence interval for the CV (CV_{+95}) interpreted as: poor (≥15%), moderate (10-15%), good (5-10%) and excellent (≤5%), respectively were considered to represent poor, moderate, good and excellent, respectively. Standard error of measurement (SEM) was calculated by multiplying the was calculated by multiplying the pooled standard deviation (between-subject standard deviation of sessions 1 and 2 combined) by the square root of 1 minus the ICC. Minimal detectable change (MDC) was calculated by multiplying the square root of SEM ^2 by 1.96. This was also expressed as a percentage by dividing MDC by the pooled mean (average of session 1 and 2 combined) and multiplying by 100.

RESULTS

Absolute and relative reliability measures for CMJ, SLCMJ and CMJ-R are displayed in figures 2-4 respectively. Absolute and relative SEM and MDC values for CMJ, SLCMJ and CMJ-R are displayed in table 2.

In the CMJ, good to excellent absolute and relative reliability was observed in the following metrics: system weight; jump height, jump momentum, countermovement depth, force at minimum displacement, average braking force, peak braking force, average propulsive force, peak propulsive force, braking net impulse, take-off velocity, propulsion phase, flight time, average landing force, average braking velocity, peak braking velocity, average braking power, average propulsive power, average relative propulsive power, peak propulsive power and average relative propulsive power (CV_{+95} <10%, ICC_{-95} > 0.75). Poor absolute and relative reliability was observed for landing stiffness and peak landing force (CV_{+95} >15%, ICC_{-95} <0.50, figure 2).

DL SLCMJ had good to excellent absolute and relative reliability for: system weight, jump momentum, force at minimum displacement, average braking force, peak braking force, average propulsive power, peak propulsive power, take-off velocity, flight time, average braking velocity, average propulsive power, peak propulsive power, and peak relative propulsive power (CV_{+95} <10%, ICC_{-95} >0.75). Poor absolute and relative reliability was observed for unweighting phase and landing stiffness (CV_{+95} >15%, ICC_{-95} <0.50, figure 3).

NDL SLCMJ had good to excellent absolute and relative reliability for: system weight, jump momentum, and average braking force (CV_{+95} <10%, ICC_{-95} >0.75). Poor absolute and relative reliability was observed for: countermovement depth, mRSI, stiffness, unweighting phase, landing stiffness, average braking power, peak braking power and peak relative braking power (CV_{+95} >15%, ICC_{-95} <0.50, figure 3).

In the countermovement portion of the CMJ-R, good to excellent absolute and relative reliability was observed for: system weight, jump height, jump momentum, countermovement depth, force at minimum displacement, average braking force, peak braking force, braking net impulse, average braking power, average relative braking power, average propulsive power, average relative propulsive power and peak propulsive power (CV_{+95} <10%, ICC_{-95} >0.75). Only poor relative reliability was observed for RSI (ICC_{-95} = 0.44), mRSI (ICC_{-95} = 0.47), and peak relative propulsive power (ICC_{-95} = 0.33) (figure 3).

In the rebound portion of the CMJ-R, good to excellent absolute and relative reliability was observed for: jump momentum, average braking force, average relative braking force, braking net impulse, average braking power, average propulsive power, peak propulsive power and rebound flight time (CV_{+95} <10%, ICC_{-95} >0.75). Poor absolute and relative reliability was observed for: rebound depth, time to peak braking force and rebound and landing stiffness (CV_{+95} >15%, ICC_{-95} <0.50) (figure 4).

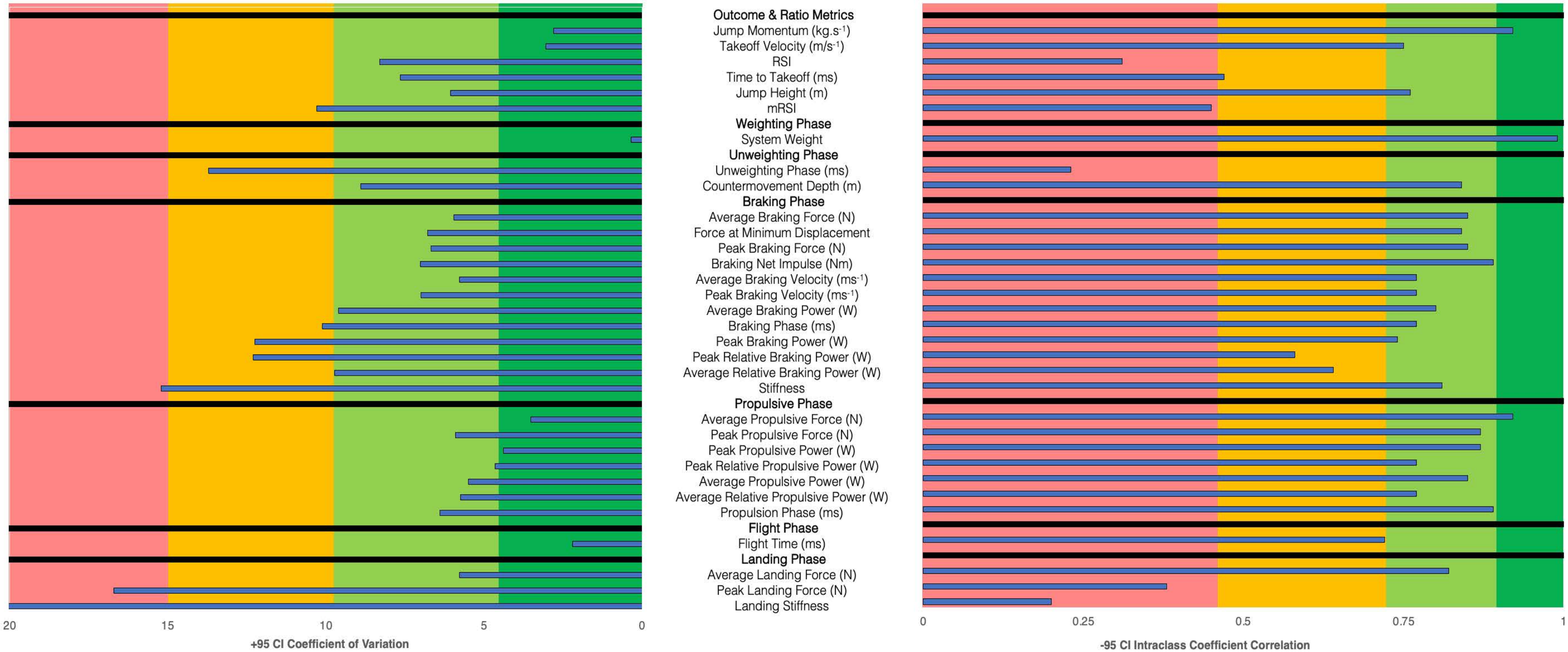

Figure 2. CMJ CV% (dark green = CV_{+95} ≤5%, light green = CV_{+95} 5-10%, amber = CV_{+95} 10-15%, red = CV_{+95} ≥15%) and ICC (dark green = ICC_{-95} ≥0.9, light green = ICC_{-95} 0.75-0.9, amber = ICC_{-95} 0.5-0.75, red = ICC_{-95} <0.5)

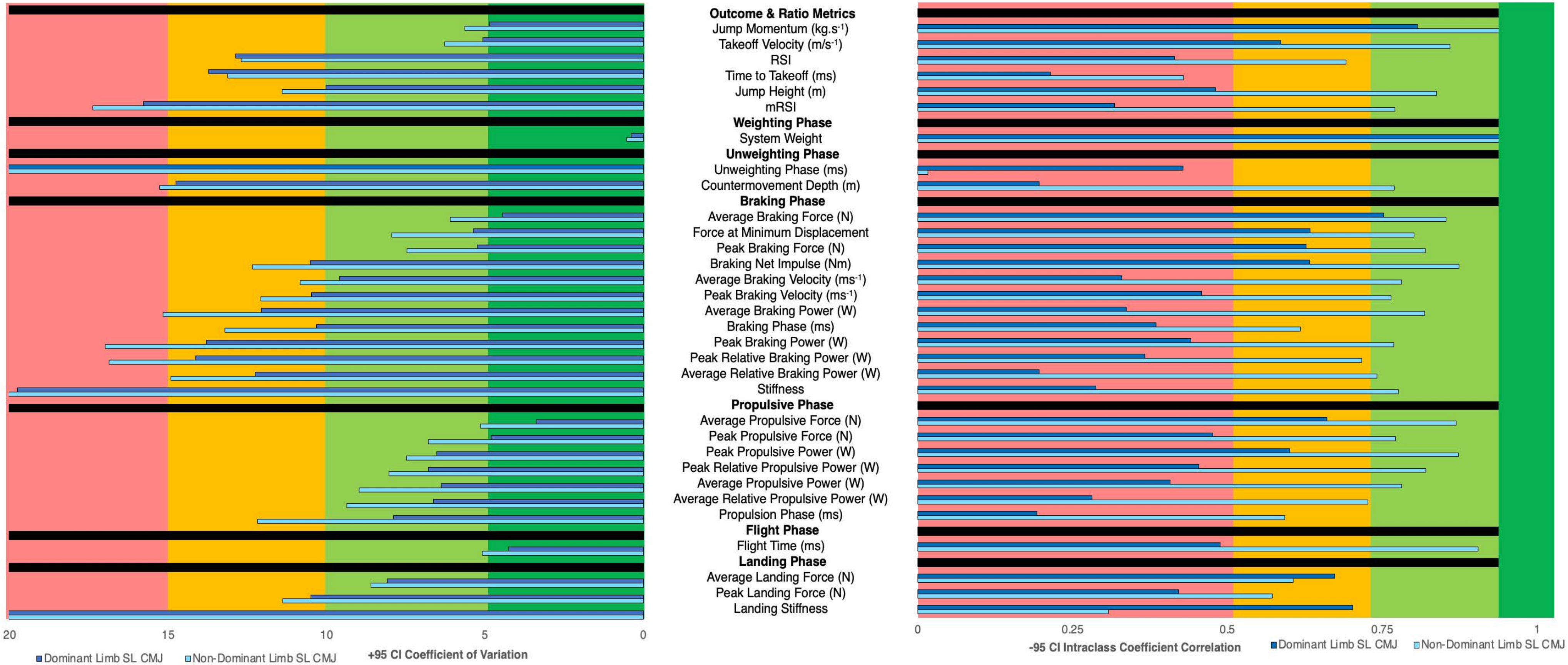

Figure 3. DL SL CMJ CV% (dark green = CV_{+95} ≤5%, light green = CV_{+95} 5-10%, amber = CV_{+95} 10-15%, red = CV_{+95} ≥15%) and ICC (dark green = ICC_{-95} ≥0.9, light green = ICC_{-95} 0.75-0.9, amber = ICC_{-95} 0.5-0.75, red = ICC_{-95} <0.5)

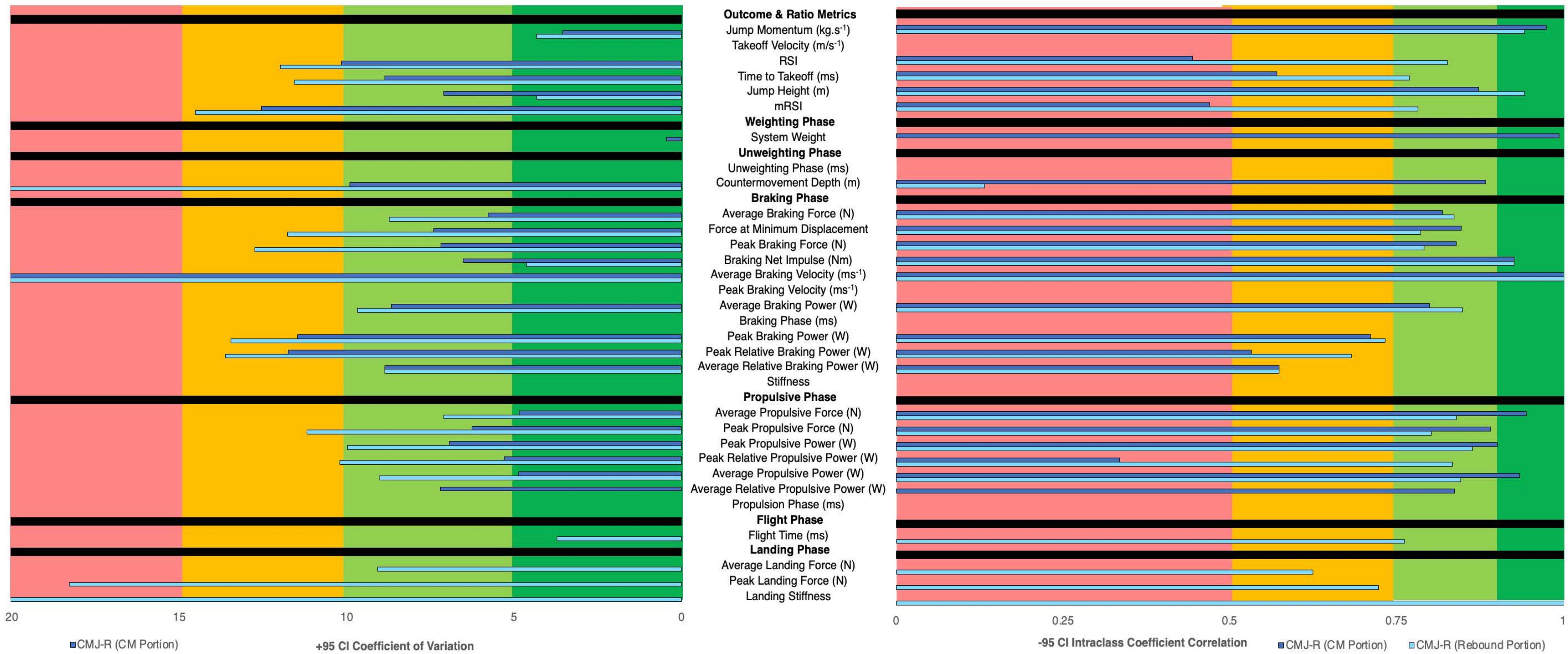

Figure 4. CMJ-R CV% (dark green = CV_{+95} ≤5%, light green = CV_{+95} 5-10%, amber = CV_{+95} 10-15%, red = CV_{+95} ≥15%) and ICC (dark green = ICC_{-95} ≥0.9, light green = ICC_{-95} 0.75-0.9, amber = ICC_{-95} 0.5-0.75, red = ICC_{-95} <0.5)

Table 2. Absolute (and relative) SEM and MDC for CMJ, SL CMJ and CMJ-R

	CMJ		DL SLCMJ		NDL SLCMJ		CMJ-R (CM Portion)		MHJ-R (Rebound Portion)	
Metric	SEM (SEM%)	MDC (MDC%)	SEM (SEM%)	MDC (MDC%)	SEM (SEM%)	MDC (MDC%)	SEM (SEM%)	MDC (MDC%)	SEM (SEM%)	MDC (MDC%)
Outcome & Ratio Metrics										
Jump Momentum (kg.s^{-1})	1.67 (1.23)	4.64 (3.40)	0.59 (0.62)	1.62 (1.71)	1.30 (1.34)	3.62 (3.71)	3.7 (2.82)	10.46	4.63 (3.42)	12.84 (9.48)
Takeoff Velocity (m/s^{-1})	0.02 (0.82)	0.05 (2.27)	0.02 (1.01)	0.04 (2.79)	0.04 (2.17)	0.10 (6.02)				
RSI	0.02 (3.66)	0.07 (10.13)	0.02 (3.78)	0.05 (10.46)	0.03 (5.08)	0.07 (14.08)	0.05 (8.01)	0.15 (22.19)	0.18 (9.46)	0.51 (26.22)
Time to Takeoff (ms)	0.02 (2.96)	0.06 (8.20)	0.04 (5.78)	0.12 (16.02)	0.04 (5.64)	0.12 (15.64)	0.05 (6.99)	0.13 (19.38)		
Jump Height (m)	0.00 (1.57)	0.01 (4.36)	0.00 (2.14)	0.01 (5.94)	0.01 (4.40)	0.02 (12.20)	0.01 (5.58)	0.04 (15.47)	0.02 (7.44)	0.05 (20.63)
mRSI	0.01 (4.01)	0.04 (11.13)	0.01 (3.98)	0.02 (11.04)	0.02 (7.65)	0.04 (21.21)	0.04 (9.89)	0.10 (27.43)	0.13 (11.44)	0.35 (31.70)
Weighting Phase										
System Weight	0.05 (0.01)	0.15 (0.03)	0.08 (0.01)	0.23 (0.04)	0.13 (0.02)	0.37 (0.06)	2.16 (0.37)	5.99 (1.03)		
Unweighting Phase										
Unweighting Phase (ms)	0.02 (6.35)	0.06 (17.61)	0.05 (15.63)	0.14 (43.34)	0.03 (9.69)	0.08 (26.87)				
Countermovement Depth (m)	0.01 (-1.90)	0.01 (-5.28)	0.01 (-3.68)	0.02 (-10.20)	0.01 (-6.45)	0.03 (-17.87)	0.02 (-7.79)	0.05 (-21.60)	0.04 (-31.97)	0.11 (-88.61)
Braking Phase										
Braking Phase (ms)	0.00 (2.57)	0.01 (7.12)	0.01 (3.38)	0.02 (9.37)	0.01 (5.40)	0.02 (14.96)				
Force at Minimum Displacement	19.56 (1.43)	54.21 (3.96)	13.75 (1.33)	38.13 (3.69)	26.88 (2.56)	74.51 (7.11)	80.72 (5.82)	223.74 (16.14)	232.19 (9.28)	643.60 (25.72)
Braking Net Impulse (Nm)	0.92 (1.23)	2.56 (3.41)	0.97 (2.13)	2.69 (5.89)	1.89 (4.00)	5.25 (11.07)	3.70 (5.18)	10.27 (14.36)	4.99 (3.65)	13.83 (10.11)
Average Braking Force (N)	12.96 (1.20)	35.93 (3.33)	7.82 (0.90)	21.69 (2.49)	17.19 (1.94)	47.65 (5.37)	49.47 (4.56)	137.12 (12.63)	127.60 (6.87)	353.70 (19.04)
Peak Braking Force (N)	18.83 (1.36)	52.21 (3.78)	12.34 (1.19)	34.21 (3.29)	25.68 (2.42)	71.18 (6.72)	78.98 (5.66)	218.92 (15.68)	307.42 (10.06)	852.11 (27.89)
Average Braking Velocity (ms^{-1})	0.01 (-1.50)	0.03 (-4.17)	0.01 (-2.31)	0.03 (-6.41)	0.02 (-4.74)	0.07 (-13.14)				
Peak Braking Velocity (ms-1)	0.02 (-1.76)	0.06 (-4.88)	0.02 (-2.67)	0.06 (-7.41)	0.04 (-4.77)	0.11 (-13.21)				
Average Braking Power (W)	17.78 (-2.25)	49.29 (-6.23)	10.75 (-2.71)	29.80 (-7.53)	27.28 (-6.53)	75.62 (-18.09)	51.49 (-6.83)	142.71 (-18.94)	183.12 (-7.61)	507.60 (-21.09)
Average Relative Braking Power (W)	0.41 (-3.10)	1.14 (-8.60)	0.22 (-3.31)	0.61 (-9.18)	0.50 (-7.13)	1.39 (-19.76)	0.88 (-6.98)	2.45 (-19.36)	0.88 (-6.98)	2.45 (-19.36)
Peak Braking Power (W)	36.30 (-3.31)	100.62 (-9.17)	19.54 (-3.51)	54.16 (-9.74)	39.91 (-6.74)	110.62 (-18.67)	94.81 (-9.06)	262.79 (-25.10)	528.20 (-10.63)	1464.09 (-29.46)
Peak Relative Braking Power (W)	0.78 (-4.22)	2.15 (-11.71)	0.38 (-4.00)	1.04 (-11.09)	0.72 (-7.17)	1.99 (-19.87)	1.63 (-9.26)	4.53 (-25.67)	9.04 (-10.77)	25.07 (-29.85)
Stiffness	188.39 (-3.62)	522.20 (-10.03)	323.36 (-4.75)	896.31 (-13.17)	569.38 (-8.35)	1578.25 (-23.16)			19246.11 (-65.65)	53347.49 (-181.96)
Contact Time									24.19 (9.28)	67.06 (25.73)
Time to Peak Braking Force									11.29 (16.13)	31.30 (44.70)

	CMJ		DL SLCMJ		NDL SLCMJ		CMJ-R (CM Portion)		MHJ-R (Rebound Portion)	
Metric	**SEM (SEM%)**	**MDC (MDC%)**	**SEM (SEM%)**	**MDC (MDC%)**	**SEM (SEM%)**	**MDC (MDC%)**	**SEM (SEM%)**	**MDC (MDC%)**	**SEM (SEM%)**	**MDC (MDC%)**
Propulsion Phase										
Propulsion Phase (ms)	0.00 (1.13)	0.01 (3.14)	0.01 (2.65)	0.02 (7.35)	0.02 (5.81)	0.05 (16.11)				
Average Propulsive Force (N)	5.73 (0.51)	15.87 (1.42)	5.44 (0.59)	15.07 (1.64)	13.61 (1.44)	37.73 (3.98)	6.93 (0.61)	19.20 (1.68)	20.47 (1.28)	56.75 (3.55)
Peak Propulsive Force (N)	15.76 (1.14)	43.67 (3.15)	11.93 (1.07)	33.06 (2.96)	25.65 (2.20)	71.11 (6.10)	15.52 (1.09)	43.02 (3.02)	60.14 (2.38)	166.71 (6.61)
Average Propulsive Power (W)	16.17 (1.13)	44.82 (3.14)	13.78 (1.55)	38.20 (4.31)	34.18 (3.69)	94.74 (10.22)	78.55 (5.46)	217.74 (15.14)	150.02 (7.10)	415.82 (19.68)
Average Relative Propulsive Power (W)	0.34 (1.44)	0.95 (3.99)	0.27 (1.83)	0.76 (5.07)	0.66 (4.23)	1.84 (11.72)	1.37 (5.67)	3.81 (15.72)		
Peak Propulsive Power (W)	21.55 (0.85)	59.72 (2.35)	18.90 (1.19)	52.39 (3.31)	42.54 (2.55)	117.92 (7.05)	97.00 (3.83)	268.88 (10.60)	268.54 (7.88)	744.36 (21.83)
Peak Relative Propulsive Power (W)	0.50 (1.18)	1.40 (3.28)	0.41 (1.52)	1.13 (4.20)	0.91 (3.22)	2.52 (8.92)	1.78 (4.16)	4.93 (11.53)	4.63 (8.06)	12.82 (22.34)
Flight Phase										
Flight Phase (ms)	0.00 (0.62)	0.01 (1.72)	0.00 (0.70)	0.01 (1.95)	0.01 (1.92)	0.02 (5.33)			13.67 (2.93)	37.89 (8.11)
Landing Phase										
Average Landing Force (N)	9.19 (1.24)	25.48 (3.43)	18.01 (2.66)	49.91 (7.37)	15.82 (2.35)	43.84 (6.52)	54.83 (7.27)	151.97 (20.15)		
Peak Landing Force (N)	191.74 (6.98)	531.47 (19.34)	73.86 (3.63)	204.73 (10.05)	95.26 (4.57)	264.05 (12.67)	399.58 (14.36)	1107.58 (39.82)		
Landing Stiffness	1954.43 (-29.91)	5417.41 (-82.91)	15454.02 (-107.82)	42836.37 (-298.87)	13715.80 (-124.96)	38018.26 (-346.36)	32282.36 (-688.23)	89482.13 (-1907.67)		

DISCUSSION

This study is the first to assess the test-retest reliability of CMJ and CMJ-R, and SLCMJ in female youth footballers. Although within-session reliability of CMJ and SLCMJ has been discussed[4], and CMJ test-retest in elite youth male footballers[15], this study provides test-retest reliability statistics of extensive metrics in CMJ, SLCMJ and CMJ-R specific to elite youth female football. The main findings support our hypothesis, showing good to excellent absolute and relative reliability, relating to limb dominance, in several metrics across each test (CV_{+95} <10% $ICC\text{-}_{95}$ >0.75). CMJ demonstrated greater reliability across phase-specific metrics followed by CMJ-R, DL LCMJ and NDL SLCMJ. Notably, metric reliability relates to test selection and the specific phase of the jump, highlighting the importance to consider test-retest reliability when selecting metrics for monitoring (absolute reliability) and benchmarking purposes (relative reliability).

System weight demonstrated excellent absolute and relative reliability for all jump variations (CV_{+95} <0.39%, ICC_{-95} >0.99). Although this may appear minor, accurate calculation of body mass directly impacts the determination of movement onset thresholds and forward dynamics[5, 38, 61]. This becomes more important as anthropometric and jump performance change during maturation[13, 50]. Interestingly, NDL SLCMJ had greater variability compared to all other jump variations including DL SLCMJ (SD_{pooled} 1.85N vs. 2.43N). Further investigation is warranted into SLCMJ, particularly the influence of stability and methodology on system weight and forward dynamics.

Jump height had good to excellent absolute and relative reliability for CMJ and countermovement portion of CMJ-R (CV_{+95} <7.10%, ICC_{+95} >0.94). SLCMJ's had moderate absolute reliability (CV_{+95} <11.39%) across both limbs, good relative reliability for DL (ICC-95 =0.84), but poor for NDL (ICC-95 =0.48). Jump momentum, the product of body mass and take-off velocity, had good to excellent absolute and relative reliability for all jumps (CV_{+95} <5.64%, ICC_{-95} >0.81). Take-off velocity had good to excellent absolute reliability (CV_{+95} <6.27%), and moderate to good relative reliability (CV_{+95}

<6.27%, ICC_{-95} >0.59). Jump momentum has been proposed an effective metric for testing and monitoring[56], as changes in athlete body mass by maturation or hydration status, can influence and jump strategy outcome metrics[38, 47]. Interestingly, NDL SLCMJ jump momentum had good reliability (CV_{+95} =5.64%, ICC_{-95} =0.80) compared to excellent reliability for CMJ and DL CMJ (CV_{+95} =4.86%, ICC_{-95} =0.94). This is important for practitioners and supports earlier observations regarding system weight variability on outcome metrics. Time to take off demonstrated good absolute reliability (CV_{+95} <10%) for CMJ and CMJ portion of the CMJ-R. Relative reliability was good for the rebound portion of the CMJ-R (ICC_{-95} =0.77), but moderate to poor for all jump variations (ICC_{-95} =0.24-0.57). This will most likely have implications for RSI and mRSI reliability, as these include time to take off in their calculations. CMJ mRSI had moderate absolute reliability (CV_{+95} = 10.29%), however this ranged from 5.96 - 10.29%, demonstrating good absolute reliability in most female footballers. The authors wish to remind readers that our reliability interpretations are based on recommendations of CV_{+95} and ICC_{-95} rather than point estimates, to reflect the worst case-scenario for reliability[28]. Practitioners should consider this when selecting metrics for monitoring.

Countermovement depth had good reliability for CMJ and CMJ portion of CMJ-R (CV_{+95} <9.90%, ICC_{-95} <0.84). DL SLCMJ had moderate absolute reliability (CV_{+95} =14.75%) and good relative reliability (ICC_{-95} =0.77), whereas NDL SLCMJ and rebound portion of CMJ-R had poor reliability (CV_{+95} =15.27%, ICC_{-95} =0.20). CMJ countermovement depth reliability values are greater than those previously reported[49], however SLCMJ and CMJ-R is lesser, which may be due to the increased demand and different strategies used during SLCMJ and CMJ-R.

Braking phase metrics had greater reliability in the CMJ followed by CMJ-R, DL SLCMJ, CMJ-R and NDL SLCMJ. CMJ had good absolute and relative reliability for average, and peak braking force and velocity, average braking power, force at minimum displacement, and braking net impulse (CV_{+95} <9.61%, ICC_{-95} >0.78). Bright et al.[6] reported good CMJ reliability using gold standard hardware, except for average braking power, where moderate absolute and reliability was reported (CV_{+95} <10.87, ICC_{-95} >0.68). CMJ-R reliability was good to excellent for average braking force and power, and braking net impulse (CV_{+95} <9.68%, ICC_{-95} >0.80). These findings demonstrate good reliability for several braking metrics during CMJ and CMJ-R which contrasts with other studies reporting CMJ[6, 34, 53]. This may be explained by different cueing, which has been shown to influence force-time characteristics[49]. Participants in this study were cued to "jump as high and as fast as possible," whilst self-selecting their countermovement depth. The "fast" cue may have led to participants constraining their countermovement depth, whereas others[6, 34, 53] instructed participants to "jump as high as possible." This may explain the greater variability in countermovement depth reported by others (CV_{+95} = 10.3 - 16.54%)[34, 52] as participants may have utilized different strategies to achieve maximum jump height.

SLCMJ average braking force was the only metric with good absolute and relative reliability for both limbs (CV_{+95} <6.10%, ICC_{-95} >0.75). NDL SLCMJ absolute reliability was good for force a minimum displacement and peak braking force (CV_{+95} <7.94), whereas DL SLCMJ had good absolute and relative reliability for average braking force, force at minimum displacement, and peak braking power (CV_{+95} <9.59, ICC_{-95} ICC >0.78). Greater reliability in DL over NDL during SLCMJ may be related to the lesser variability in system weight and countermovement depth for the former. Force at minimum displacement represents the force at the end of the braking phase, i.e., how hard participants hit the brakes, and is sensitive to detect fatigue in male team sport athletes for CMJ[16]. Our finding provides evidence to support the inclusion of this metric when monitoring NMF in youth female footballers, including SLCMJ.

Countermovement jump, average propulsive force had excellent absolute and relative reliability (CV_{+95} =2.04%, ICC_{-95} =0.93). All remaining CMJ propulsive metrics had good to excellent absolute and relative reliability (CV_{+95} <10%, ICC_{-95} >0.75). Good to excellent propulsion phase reliability may be a result of less computational calculation as there are obtained directly from the force-time curve and are previously reported[6, 63]. CMJ-R, including the CMJ and rebound portions, had good to excellent reliability for average propulsive force (CV_{+95} = 4.85-7.11%, ICC_{-95} =0.84-0.94). All CMJ-R metrics demonstrated good to excellent absolute and relative reliability, except for peak relative propulsive power (ICC_{-95} =0.33). All rebound metrics demonstrated good to excellent absolute and relative reliability, except for peak propulsive force (CV_{+95} =11.19%) and peak relative propulsive power (CV_{+95} =10.20%). Currently, no data exists on the test-retest reliability of CMJ-R. Cormack et al.,[9] demonstrated good reliability mean and peak force and power in repeated CMJs (CV% 2.4 - 5.3), however propulsive phase metric (termed concentric[9]) were sampled at 200Hz and calculated in a different software to that in this study. It appears that mean force scores are more sensitive than peak scores, practically when monitoring[9]. CMJ jump height during the CMJ-R was 17-33cm with good to excellent reliability (CV_{+95} =7.10%, ICC_{-95} = 0.87), compared to drop height 14.87-29.85cm with moderate absolute reliability (CV_{+95} =11.22%) and poor relative reliability (ICC = 0.38)[10]. CMJ-R may serve as an alternative test to drop jump as this allows reliable measurement and monitoring of changes in jump height before the rebound jump. This study provides practitioners several metrics that could be used for monitoring and benchmarking when utilizing CMJ-R.

SLCMJ had good absolute reliability for all metrics in both limbs, except NDL propulsion phase time (CV_{+95} = 12.17%). DL SLCMJ relative reliability was good for all metrics except propulsion phase time and average relative propulsive power (ICC_{-95} = 0.59-0.73). NDL SLCMJ relative reliability was poor to moderate across all metrics (ICC_{-95} =0.28-0.66). Traditional CMJ analysis has often focused on propulsive metrics such as peak power with good reliability[16]. However, there is limited information on SLCMJ, with debate regarding limb dominance classification[35]. Previous SLCMJ research has categorized injured and non-injured limbs, however as participants in this study were injury free and youth female footballers, therefore limb dominance was categorized based on recommendations from previous work[8, 12, 27, 33 43]. As previously suggested, poor relative reliability may be explained by greater variability in earlier phases of the jump. It is plausible that these metrics may influence propulsive metrics as the NDL limb takes longer to stabilize and is unable to effectively maximize the stretch shortening cycle when transitioning from braking to propulsion. Further investigation into SLCMJ methodological and technical components to help further explain reliability statistics, different performance levels, and provide further evidence to guide practitioners when selecting metrics for screening, monitoring and benchmarking performance.

Average landing force had good absolute reliability for CMJ, SLCMJ's and CMJ-R (CV_{+95} <9.07%). Good relative reliability was only achieved for CMJ (ICC_{-95} >0.83). Poor landing stiffness was observed for all jump variations and peak landing force was poor to moderate absolute and relative reliability for all jump variations (CV_{+95} >10.49%, ICC_{-95} <0.72). These findings further support the use of average metrics compared to peak measures for monitoring NMF. However, little instruction was given to the landing portion of the task, which may the variability in these metrics.

Limitations of the study include the timing and homogeneity of maturation status of the participants. Most of the participants were post circa peak height velocity (>95% of predicted adult height). It is possible that these metrics may have differed in less mature participants. Additionally, data collection was conducted in the latter stage of the competitive season which reflects the specific time of testing, despite a sufficient level of training being undertaken.

This study is the first to describe phase-specific test-retest reliability in CMJ, CMJ-R and SLCMJ in female youth footballers. Although reliability studies simply reflect the "noise" of a variable within a specific environment, these findings are similar to those previously reported but represent an audience that has received little attention. As participation in female football, sport and strength and conditioning provisions continues to grow, practitioners should consider these reliability outcomes when selecting metrics for monitoring and benchmarking within similar populations to assess performance and mitigate injury risk. Future research is needed on system weight variability and how reliability may change following greater familiarization before normative and benchmarking data.

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CONFLICTS OF INTEREST

In accordance with journal guidelines and my ethical obligation as a researcher, I have disclosed that JMC is a current supervisor of a PhD studentship, who is not involved with this manuscript, however this studentship is sponsored by Hawkin Dynamics LLC which is the company who make the force plate system that was utilized in the present study. There are no patents, products in development or marketed products associated with this research to declare.

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ETHICAL APPROVAL

Informed consent, and parental consent for participants under the age of 16 years, were obtained prior to the study which was approved by the University of Salford institutional review board (ref. 2090) and conformed with the Declaration of Helsinki.

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DATA AVAILABILITY STATEMENT

Data is available on reasonable request.

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