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Which Metrics Can I Monitor? Test-Retest Reliability of Countermovement Jump and Countermovement Rebound Jump Force-Time Metrics in Youth Soccer Players In-Season

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ABSTRACT

Objective measures provide the most effective means of monitoring the magnitude and time course of changes in neuromuscular function (NMF) resulting from physical activity if measurements are repeatable (reliability). The aim of this study was to determine the test-retest reliability of a range of ratio, outcome, strategy, and kinetic force plate metrics for the countermovement jump (CMJ) and countermovement rebound jump (CMRJ) tests in youth soccer players in the in-season period. A test-retest repeated-measures design was employed consisting of two testing sessions separated by 7-days. In each testing session, male youth soccer players (N = 43; age 17.9 ± 0.9 years, height 181 ± 5.8 cm, body mass 72.5 ± 6.8 kg) from full-time English Football League academies (categories 2 and 4) performed three maximal-effort CMJs and CMRJs in a randomised order on a Hawkin Dynamics Inc. force plate system sampled at 1000 Hz. Fifteen out of 25 CMJ, 11 out of 19 CMJ portion, and five out of 19 rebound jump (RJ) portion metrics demonstrated acceptable absolute (coefficient of variation [CV] ≤10%) and relative (intraclass correlation coefficient [ICC] ≥0.75) reliability for youth soccer players in the in-season period. The CMJ test is a feasible and reliable slow stretch-shortening cycle (SSC) test which can be utilised for monitoring acute changes in NMF in youth soccer players in-season. Practitioners should consider applying a combination of CMJ outcome, strategy, and kinetic metrics in their monitoring processes. The CMRJ test is a less feasible yet reliable fast SSC test which can be utilised for monitoring acute changes in NMF in youth soccer players in-season and can be considered an appropriate alternative to the drop jump (DJ) test as it overcame issues in DJ fall height variability identified in previous research, where acceptable reliability was demonstrated in CMJ portion bodyweight and all outcome metrics.

Keywords: Sports Science; Strength and Conditioning; Four Corner Model; Physical Corner; Profiling.

INTRODUCTION

Player availability is directly associated with success in team sports [1, 2], where teams experiencing less injuries typically outperform those who experience more injuries throughout the course of a competitive season [3]. In soccer, acute negative alterations in neuromuscular function (NMF) resulting from training and competitive fixtures can immediately effect physical preparedness and increase the potential for non-contact injuries, yet, congested fixture and training schedules are common [4, 5]. To tackle this, a "minimum effective dose" of physical training is often prescribed with the aim to maintain physical preparedness throughout specific periods of a season, where training induced fatigue is minimised in the acute term to reduce the amount of neuromuscular recovery required following training [4, 6]. However, adopting this approach can come at the sacrifice of optimal longitudinal developments in NMF, which is concerning given that low levels of muscular strength can pre-dispose athletes to injury [7], and negatively affect performance in field-based actions [8] such as linear sprint speed [9, 10] and change of direction (COD) speed [9-11]. Objective measures provide the most effective means of monitoring the magnitude and time course of changes in NMF resulting from physical activity [12]. A variety of options are now accessible to researchers and practitioners, such as commercially available force plate systems that have been validated against industry "gold standard" systems [13-15]. Such systems have seen a recent rise in popularity among strength and conditioning coaches in soccer [16-18]. However, force plate data is only beneficial if a test measures what it is supposed to (validity) and if the measurement is repeatable (reliability) [19], where it is recommended that practitioners determine the reliability of tests and force-time metrics of interest within the specific environments, protocols, and cohorts used in practice [20].

The countermovement jump (CMJ) is a slow stretch-shortening cycle (SSC) test and the most commonly utilised assessment of NMF in the football codes [16]. The test-retest reliability of a variety of force-time metrics obtained during different phases of the CMJ has been reported in recent studies involving team-sport athletes [20-25], where better reliability for metrics calculated during the propulsive rather than the countermovement (i.e., the unweighting and braking) phase of the CMJ test have been reported [20, 22, 24-26]. To the author's knowledge, one study has explored the test-retest reliability of force-time metrics obtained during different phases of the CMJ using soccer players [23], where a key suggestion was CMJ test-retest reliability improved with maturation. Specifically, most CMJ parameters demonstrated a coefficient of variation (CV) <10% (a typical cut-off for acceptable absolute reliability [27, 28]) for a post-peak height velocity (PHV) group, but not for a pre-PHV group [23]. This might also represent soccer players with a greater chronological age demonstrating greater reliability due to having more experience with tests from more seasons of testing [19]. A limitation of the study by Ruf et al. [23] was that only one CMJ trial with the highest take-off velocity (TOV) was included in the statistical analyses. If force plate data collection procedures are repeated exactly [29], the reliability of a measure is determined only by equipment error and biological variation [19]. Utilising the average across two or more trials for statistical analyses is suggested as a more reliable approach as an athlete's "true" test score cannot be determined from a single "best" test trial [20-22, 30]. Therefore, the test-retest reliability of CMJ force-time metrics obtained by the chronologically eldest youth soccer player groups (i.e., the U17 and U18 groups) may actually be better than what has been previously reported [23], should the average of multiple trials be considered.

Rebound jump (RJ) tests are commonly applied as assessments of fast SSC capacity with options such as the drop jump (DJ) and countermovement rebound jump (CMRJ) demonstrating similarities in work done at the hip, knee, and ankle [31, 32]. Discrepancies between standardised box height and actual fall height have been reported in previous research utilising the DJ test [33], which would lead to erroneous measures of NMF. Consequently, the CMRJ test may be a better alternative as a box is not needed to conduct the test, where a preliminary CMJ (defined as the CMJ portion) initiates the test and creates the fall height for a single RJ (defined as the RJ portion). Xu et al. [31, 32] identified acceptable absolute (CV <10%) and relative (intraclass correlation coefficient [ICC] >0.75) reliability in metrics such as CMJ portion jump height (JH), countermovement depth, and time to take-off, and RJ portion JH and ground contact time (GCT). However, based on the 95% confidence interval (CI) [34], relative and absolute reliability was not acceptable for CMJ time to take-off (ICC = 0.64) and RJ portion GCT (CV = 10.19%), respectively [31, 32].

Xu et al. [31, 32] stated that their findings may hold limited utility for informing the practice of full-time athletes [32], having recruited 33 sports science students with mixed sports backgrounds who had minimal experience with fast SSC tasks (i.e., plyometrics) [31, 32]. This limited familiarity would also explain why Xu et al. [31, 32] reported average GCTs >300 ms for the DJ and CMRJ tests in both testing sessions, thus failing construct validity as an assessment of fast SSC capacity (i.e., GCT <250 ms [35, 36]). These studies were also limited in their employed methods and depth of analysis, where kinetic (i.e., those relating to force and power) metrics during any phase of the tests were not reported [31, 32]. This is concerning given that Bishop et al. [37] recommended utilising a variety of outcome (i.e., "end result" metrics which correspond with physical capacities that relate to sports performance), strategy (i.e., metrics which relate to the displacement of the centre of mass [COM] during a test or the time taken to perform it), ratio (i.e., metrics which are generally equated by dividing the outcome of a test by the strategy adopted to achieve it), and kinetic (i.e., those relating to force and power, as stated previously) metrics for physical profiling and fatigue monitoring using force plates. Thus, to the author's knowledge, the test-retest reliability of a variety of ratio, outcome, strategy, and kinetic force plate metrics obtained during different phases of the CMRJ test when conducted appropriately (i.e., GCT <250 ms), and with soccer players, has not been explored. Therefore, the utility of this test and its measures to be utilised for monitoring acute changes in NMF with soccer players is yet to be determined.

AIMS

The aim of this study was to determine the test-retest reliability of a range of ratio, outcome, strategy, and kinetic metrics for the CMJ and CMRJ tests in youth soccer players in the in-season period. This information will be useful to researchers and practitioners who currently, or plan to, monitor acute changes in CMJ and CMRJ force-time characteristics of youth soccer players using a commercially available force plate system. It was hypothesised that reliability would be better for propulsive- over countermovement-phase force-time metrics in vertical jumps (VJs) based on previous findings [20, 22, 24, 25]. Additionally, based on previous findings [31, 32], it was hypothesised that the reliability of outcome measures during the CMJ portion of the CMRJ test would be acceptable and thus overcome the issues of variability in fall height previously demonstrated in the DJ test [33, 38, 39].

METHODS

A test-retest repeated-measures design was employed. All testing was held at the same location, at the same time of day, and exactly a week apart. Ethical approval was granted via the University of Salford ethics committee adhering to the principles of the 2013 Declaration of Helsinki. Participants were provided a participant information sheet, consent form, and physical activity readiness questionnaire immediately prior to both testing sessions. Parental assent was sought for all participants under 18 years of age.

Subjects

An a priori sample size estimation was performed for this study [40-43]. Between session relative reliability has been reported for CMJ JH (ICC = 0.98) [31] and CMRJ RJ portion JH (ICC = 0.93) [31] in previous studies (average ICC = 0.96). For a test-retest design (2 sessions), minimum acceptable reliability (ICC) of 0.75 (based on the lower bound 95% CI), excepted reliability (ICC) of 0.96, and an alpha level of 0.05, the minimum required sample size was 15 participants for a statistical power of 0.95 [40]. Forty-three male youth soccer players (age 17.9 ± 0.9 years, height 181 ± 5.8 cm, body mass 72.5 ± 6.8 kg) performed three maximal-effort CMJs and CMRJs in a randomised order on the first and eighth day (i.e., 7-days apart) of the 2021-2022 mid-season formative evaluation period. All athletes were involved in a full-time English Football League academy programme (categories 2 and 4), which involved a minimum of 5 field-based and 2 gym-based sessions per week. Players had previous experience performing CMJ and RJs in previous training and testing sessions.

Procedures

Both testing sessions were immediately preceded by a brief (~10 min) warm-up consisting of linear jogging, bodyweight squats, bodyweight lunges, and a single submaximal effort of each VJ test. Vertical ground reaction force (vGRF) data was collected over six seconds using a Hawkin Dynamics (HD) Inc. force plate system (Westbrook, Maine, 04092, USA) at 1000 Hz. All data was filtered using a low-pass Butterworth filter with a cut-off frequency of 50 Hz, as directed by HD Inc. and integrated into their proprietary software, as it is considered a common and appropriate method for filtering force-time data [44, 45]. A separate HD Inc. force plate system was used for each test to allow for simultaneous data collection. The same system was always used for each test. All trials were conducted on solid, even, non-slip flooring with a fit-to-size foam surround (7 cm height) placed around the force plates. Zeroing of the force plates was performed before every trial to avoid any potential integration drift. Trials were initiated via the tester pressing "start" on the tablet's proprietary software. A "flash and beep" command from the tablet's proprietary software occurred after a minimum of 1s of quiet standing (which is applied to enable the subsequent determination of body weight) to instruct participants to initiate a countermovement. Participants performed all trials with arms akimbo and were instructed to jump "as fast and high as possible". The aim for the verbal cueing was to encourage a rapid and maximal expression of vGRF [46]. Participants were required to maintain their arms position and avoid tucking their legs in flight. The RJ portion of the CMRJ had to be performed with a GCT <250 ms to utilise the "fast" SSC [35, 47]. A between-trial rest period of ~60 seconds was prescribed for every trial. If trials were not performed with the desired criteria they were discarded, participants were reminded of the verbal cues, and up to an additional 2 trials (maximum 5 trials total) were performed to allow for the collection of three acceptable trials.

Data Analysis

Data analysis was automatically performed after each trial via the HD Inc. proprietary software utilising forward dynamics procedures [48]. The impulse-momentum theorem was utilised to calculate JH:

$$JH = TOV^2 / (2 \times \text{gravitational acceleration}) \quad [49, 50]$$

Where JH and TOV represent jump height and take-off velocity, respectively, and gravitational acceleration is calculated as 9.81 m/s^2. The HD Inc. proprietary software defines weighing, unweighting, braking, propulsion, flight, and landing phases for the CMJ test [48, 49]. Phase descriptions for the CMJ test can be found in Table 1 [48, 49, 51-54]. These phase descriptions apply to both the CMJ test and CMJ portion of the CMRJ test. However, the CMJ portion does not include a landing phase as the braking phase of the RJ portion is initiated upon landing [49]. The RJ portion of the CMRJ test included the braking, propulsion, flight, and landing phases [49]. The calculation (i.e., the start and end thresholds) of the propulsion, flight, and landing phases of the RJ portion are the same as those described for the CMJ test in Table 1 [48, 49]. The braking phase of the RJ portion was determined as from the instant that vGRF increased above 25 N for longer than 30 ms (i.e., the instant of touchdown) until the instant that COM velocity equalled zero, which coincides with peak negative COM displacement [49]. The onset of movement threshold for tests was set at ± 5 standard deviations (SDs) of BW [49, 53]. The start of numerical integration was determined via a backwards search of 200 ms (using an optimization loop) from the initiation of movement threshold to the closest value of system weight using methods of the trapezoidal rule [48, 49].

Categorisations of "ratio", "outcome", "strategy", and "kinetic" metrics are used [26]. Metric calculations for the CMJ test are reported in Table 2. Body mass was determined as body weight divided by gravitational acceleration (9.81 m/s^2) [49]. All CMJ metric calculations applied to both portions of the CMRJ test. However, in the RJ portion countermovement depth was replaced by braking depth (calculated as the peak negative vertical displacement of the system COM). Additionally, time to take-off was replaced by GCT (calculated as the total time from the instant of touch-down to take-off). Resultantly, flight time contraction time ratio (FT:CT) was calculated as flight time (FT) divided by GCT as opposed to time to take-off, and modified reactive strength index (mRSI) was replaced by reactive strength index (RSI; calculated as JH divided by GCT) [49].

Table 1. Phase Descriptions for the Countermovement Jump Test.

CMJ Phase	Description
Landing	From the instant of touchdown until the instant that vertical GRF is within 5% of system weight for 200 ms.
Flight	From the instant of take-off until the instant that vertical GRF increases above 25 N for longer the 30 ms (i.e., the instant of touchdown).
Propulsion	From as the Instant that COM velocity is positive until the instant that vertical GRF decreases below 25 N during positive COM velocity (i.e., the instant of take-off).
Braking	From (the frame after) the instant of peak negative COM velocity (which coincides with (the frame after) the instant that vertical GRF returns to body weight) to the instant the COM velocity returns to zero (which coincides with the bottom of the countermovement [i.e., the peak negative COM displacement].
Unweighting	From the onset of movement until the frame before the instant of peak negative COM velocity, which is also equal to the instant that vertical GRF returns to body weight.
Weighting	From the instant the trial is initiated (i.e., the moment the tester starts the test on the tablet) to a instant that the SD of GRF is less than 25 N for ≥ 1 s.

Key: CMJ, countermovement jump; mRSI, modified reactive strength index; FC:CT, flight time contraction time; RFD, rate of force development; COM, centre of mass.

Table 2. Metric Calculations for the Countermovement Jump Test.

CMJ Metrics	Unit of Measurement	Metric Category	Calculation
mRSI	Arbitrary Unit (AU)	Ratio	Jump Height divided by Time to Take-off.
FT:CT	Arbitrary Unit (AU)	Ratio	Flight Time divided by Time to Take-off.
Jump Height	Metres (m)	Outcome	The change in system COM position between the instant of take-off and peak positive vertical displacement of the system COM, calculated as take-off velocity squared divided by 19.62.
Flight Time	Seconds (s)	Outcome	The time taken to complete the flight phase.
Jump Momentum	Kilogram-meter per second (kg·m/s)	Outcome	The vertical velocity of the system COM at the instant of take-off multiplied by body mass.
Take-off Velocity	Metres per second (m/s)	Outcome	The vertical velocity of the system COM at the instant of take-off.
Time to Take-off	Seconds (s)	Strategy	The total time taken from the initiation of movement to the instant of take-off.
Mean Propulsive Power	Watts (W)	Kinetic	The average mechanical power applied to the system COM during the propulsion phase (mean force multiplied by mean velocity).
Peak Propulsive Power	Watts (W)	Kinetic	The peak instantaneous mechanical power applied to the system COM during the propulsion phase (peak force multiplied by peak velocity).
Peak Velocity	Metres per second (m/s)	Kinematic	The peak instantaneous vertical velocity of the system COM.
Mean Propulsive Velocity	Metres per second (m/s)	Kinematic	The average vertical velocity of the system COM during the propulsion phase.
Net Impulse Ratio	Arbitrary Unit (AU)	Ratio	Net propulsive impulse divided by net braking impulse.
Mean propulsive Force	Newtons (N)	Kinetic	The average vertical ground reaction force applied to the system COM during the propulsion phase.
Peak Propulsive Force	Newtons (N)	Kinetic	The peak instantaneous vertical ground reaction force applied to the system COM during the propulsion phase.
Propulsive Phase Time	Seconds (s)	Strategy	From when velocity exceeds 0.01 $m \cdot s^{-1}$ (which usually occurs one sample after the instant of zero velocity [i.e., end of the braking phase]), to the instant of take-off.
Countermovement Depth	Metres (m)	Strategy	The peak negative vertical displacement of the system COM.
Braking RFD	Newtons per second (N/s)	Kinetic	The average slope of the vertical ground reaction force applied to the system COM during the braking phase.
Mean Braking Power	Watts (W)	Kinetic	The average mechanical power applied to the system COM during the braking phase (mean force multiplied by mean velocity).

CMJ Metrics	Unit of Measurement	Metric Category	Calculation
Peak Braking Power	Watts (W)	Kinetic	The peak negative instantaneous mechanical power applied to the system COM during the braking phase (peak force multiplied by peak velocity).
Net Braking Impulse	Newtons per second (N/s)	Kinetic	The net vertical impulse applied to the system COM during the braking phase.
Mean Braking Force	Newtons (N)	Kinetic	The average vertical ground reaction force applied to the system COM during the braking phase.
Peak Braking Force	Newtons (N)	Kinetic	The peak instantaneous vertical ground reaction force applied to the system COM during the braking phase.
Braking Force Time	Seconds (s)	Strategy	The period between the (sample after the) instant of peak negative velocity and the instant of zero velocity.
Unweighting Phase Time	Seconds (s)	Strategy	The time taken to complete the unweighting phase.
Body Weight	Newtons (N)	N/A	The lowest 1 second average of the vertical ground reaction force applied to the system COM during the weighing phase, identified via an optimization loop.

Key: CMJ, countermovement jump; mRSI, modified reactive strength index; FC:CT, flight time contraction time; RFD, rate of force development; COM, centre of mass; N/A, not applicable.

Statistical Analyses

Statistical analyses were performed using a customized Microsoft Excel spreadsheet (version 16; Microsoft Corp., Redmond, WA, USA) and SPSS software (version 25; SPSS Inc., Chicago, IL, USA). The average of each subject's three CMJ and CMRJ trials (for each metric) on both testing occasions were calculated and taken forward for statistical analysis. Absolute between-session reliability was assessed using Microsoft Excel (version 16; Microsoft Corp., Redmond, WA, USA). For every participant, the mean value from session 1 was subtracted from the mean value from session 2 to calculate the absolute difference for each metric [55, 56]. Then, the sample mean and SD of the absolute difference for each metric was calculated [55, 56]. The standard error of measurement (SEM) method was employed (as seen in health science research [57-59]) to estimate the magnitude of measurement error of metrics [56] by isolating measurement error from the inherent total variability (i.e., the SD) of the absolute difference [59]. The SEM was calculated as:

SD of absolute difference / √ 2 [56-59].

The standard error (SE) of the sample mean was also considered because a value of absolute difference and variability may vary between samples due to sampling distribution [60]. It has been suggested that the SE is most useful when integrated into the method of calculating a CI [60]. The SE considers the SD of absolute difference and the sample size, calculated as:

SD of absolute difference / √ (sample size) [60].

If observed scores follow a normal distribution around the mean, 95% of observed scores should lie within 2 SDs of the mean value [56], with 5% equally scattered above and below these limits [60]. For 95% of observations, the difference between a subject's measurement and the true value would be expected to be less than 1.96 [55]. Therefore, CIs for the SEM were calculated with consideration for the SE rationale [60] and the 2 SD limit of 95% (1.96) [56], calculated as:

1.96 * (SD of absolute difference / √ (sample size)) [56, 60].

The CI was added to the SEM to provide an upper bound 95% CI. The SEM and upper-bound 95% CI of the SEM were also expressed as a percentage and represented as the CV and upper-bound 95% CI of the CV by dividing them by the grand mean of sessions 1 and 2 and multiplying the value by 100 [56]. A CV of ≤5%, >5 to 10%, >10% to 15%, and >15% thresholds were considered to represent excellent, good, moderate, and poor absolute reliability, respectively, based on the upper bound 95% CI [61]. "Acceptable" absolute reliability corresponded with excellent to good (i.e., ≤10%) reliability based on the upper bound 95% CI [27, 28, 34]. The minimal detectable change (MDC) was calculated to provide an estimation of the minimum amount of change required in a metric value for it to be greater than the estimated measurement error, and therefore considered "meaningful" [59]. The upper-bound 95% CI of the SEM was utilised to produce the MDC [58]:

$$SEM +95\% \ CI * \sqrt{2}$$

[56, 57].

The MDC was then also expressed as a percentage, by dividing it by the grand mean of sessions 1 and 2 and multiplying the value by 100 [57]. Relative between-session reliability was assessed using SPSS software (version 25; SPSS Inc., Chicago, IL, USA). A two-way mixed-effects model (average measures) ICC (absolute agreement definition) with upper and lower bound 95% CIs was established. Values of ≤0.5, >0.50 to 0.75, >0.75 to 0.90, and >0.90 (based on the lower bound 95% CI of the ICC estimate) were indicative of poor, moderate, good, and excellent relative reliability, respectively [28]. “Acceptable” relative reliability corresponded with excellent to good (i.e., ≥0.75 based on the lower bound 95% CI) reliability [62]. Metrics were determined as “reliable” if they coherently demonstrated acceptable absolute and relative reliability based on the 95% CI.

RESULTS

The descriptive and reliability statistics for this sample can be found in Tables 3-5. Youth soccer players in the in-season period demonstrated acceptable reliability (i.e., coherently demonstrated acceptable absolute and relative reliability based on the 95% CI) for 15 out of the 25 included CMJ metrics (Table 3), for 11 out of the 19 included CMJ portion metrics (Table 4), and for five out of the 19 included RJ portion metrics (Table 5).

DISCUSSION

The aim of this study was to determine the test-retest reliability of a range of CMJ and CMRJ ratio, outcome, strategy, and kinetic metrics in youth soccer players during the in-season period. To the author’s knowledge, this study is the first to report the test-retest reliability of CMRJ metrics in youth soccer players. The authors accept the original hypotheses as reliability was generally better for propulsive- over countermovement-phase force-time metrics, as seen previously [20, 22, 24, 25], and CMJ portion outcome metrics were reliable, like previous findings [31, 32], confirming the CMRJ test avoids previously reported discrepancies in DJ fall height [33, 38, 39].

Weighing

Variability in the calculation of body weight would affect the calculation of specific measures related to the outcome (i.e., JH) of a VJ test, such as relative force and impulse production, propulsive acceleration, jump momentum, and TOV [63-66]. Body weight demonstrated excellent reliability during the CMJ test in youth soccer players during the in-season period which provides confidence in the reliability reported in other metrics in the present study. Changes in body weight are likely from pre- to post-match in soccer players due to the loss of fluid through perspiration [67], which might induce a change in specific kinetic and outcome measures, and may be incorrectly interpreted as a change in NMF if changes in body weight are not concurrently monitored [68, 69]. Therefore, changes in body weight should always be monitored to provide context of whether changes in kinetic and outcome metrics were due to changes in NMF, body weight, or both [63-65].

Outcome Metrics

Outcome metrics are the most frequently reported force plate metrics in scientific literature [16, 70], likely due to their associations with the performance of a variety of sports tasks (e.g., sprint and COD speed) [71, 72]. In this study, outcome metrics for both tests were typically more reliable than ratio, strategy, and kinetic metrics. Specifically, FT, jump momentum, and TOV demonstrated excellent to good reliability for both tests, and JH demonstrated excellent to good reliability for the CMJ and CMJ portion in youth soccer players in the in-season period. These results mirror those of a recent study by Anicic et al. [26] where CMJ outcome metrics demonstrated acceptable test-retest reliability in a sample of adult male and female physically active participants, and other studies in adult male [73, 74] and female [73-75] participants who demonstrated acceptable absolute and relative reliability for CMJ JH [23, 73-75], FT [74], and jump momentum [75]. To the author’s knowledge, only one previous study has assessed the reliability of CMJ force-time metrics in youth soccer players, which also concluded acceptable reliability for JH in a male “U17” age group [23], similar to the age group of this study’s subjects. However, as the authors did not calculate upper bound 95% CIs in their analyses, a direct comparison of results was not possible [23]. Future studies assessing the reliability of force plate derived metrics should consider calculating and reporting 95% CIs of the CV and ICC to allow

Table 3. Descriptive and Reliability Statistics of Countermovement Jump Test Metrics.

CMJ Metrics	Session 1		Session 2		Mean Difference	SD	SEM	SEM +95	CV	CV +95	ICC	ICC -95	MDC	MDC %
	Mean	SD	Mean	SD										
mRSI (AU)	0.54	0.10	0.51	0.10	0.03	0.08	0.05	0.08	10.20	14.52	0.83	0.67	0.11	20.53
FT:CT (AU)	0.84	0.15	0.81	0.13	0.03	0.11	0.08	0.12	9.89	14.07	0.79	0.61	0.16	19.90
Jump Height (m)	0.34	0.04	0.34	0.04	0.00	0.02	0.01	0.02	4.25	6.05	0.92	0.85	0.03	8.55
Flight Time (s)	0.54	0.03	0.54	0.03	0.00	0.02	0.01	0.02	2.36	3.36	0.90	0.81	0.03	4.75
Jump Momentum (Kg*m/s)	186.22	18.88	186.50	17.55	0.28	5.81	4.11	5.84	2.20	3.14	0.97	0.95	8.26	4.43
Takeoff Velocity (m/s)	2.59	0.14	2.58	0.14	0.02	0.08	0.05	0.08	2.13	3.02	0.92	0.85	0.11	4.28
Time to Take-off (s)	0.66	0.10	0.69	0.09	0.02	0.08	0.06	0.08	8.31	11.82	0.78	0.59	0.11	16.71
Mean Propulsive Power (W)	2365.86	387.05	2333.61	370.36	32.25	154.95	109.57	155.89	4.66	6.63	0.96	0.92	220.45	9.38
Peak Propulsive Power (W)	3931.68	554.83	3889.55	542.30	42.13	220.55	155.95	221.87	3.99	5.67	0.96	0.92	313.78	8.02
Peak Velocity (m/s)	2.69	0.13	2.68	0.13	0.02	0.08	0.05	0.08	2.04	2.90	0.90	0.82	0.11	4.10
Mean Propulsive Velocity (m/s)	1.64	0.10	1.62	0.10	0.02	0.06	0.04	0.06	2.45	3.49	0.91	0.83	0.08	4.93
Net Impulse Ratio (AU)	2.08	0.30	2.06	0.28	0.01	0.16	0.12	0.17	5.63	8.01	0.91	0.84	0.23	11.33
Mean Propulsive Force (N)	1638.70	237.93	1627.84	225.77	10.86	85.28	60.31	85.80	3.69	5.25	0.97	0.94	121.33	7.43
Peak Propulsive Force (N)	2122.06	445.95	2081.37	434.26	40.69	188.49	133.28	189.62	6.34	9.02	0.95	0.91	268.17	12.76
Propulsive Phase Time (s)	0.21	0.04	0.21	0.04	0.00	0.02	0.01	0.02	5.49	7.82	0.94	0.89	0.02	11.05
Countermovement Depth (m)	0.25	0.06	0.25	0.05	0.00	0.02	0.02	0.02	6.79	9.65	0.95	0.91	0.03	13.65
Braking RFD (N/s)	12782.88	9260.99	11803.97	9215.37	978.91	4778.39	3378.83	4807.08	27.48	39.10	0.93	0.87	6798.24	55.30
Mean Braking Power (W)	1125.14	283.33	1098.64	234.59	26.50	166.26	117.56	167.26	10.57	15.04	0.89	0.79	236.54	21.27
Peak Braking Power (W)	1607.32	482.33	1555.53	389.97	51.80	329.42	232.93	331.40	14.73	20.96	0.84	0.70	468.67	29.64
Net Braking Impulse (N.s)	92.27	16.52	92.57	14.27	0.30	7.21	5.10	7.26	5.52	7.85	0.94	0.90	10.26	11.10
Mean Braking Force (N)	1506.30	325.20	1478.20	272.01	28.10	172.60	122.04	173.63	8.18	11.64	0.91	0.83	245.55	16.46
Peak Braking Force (N)	2063.22	489.34	2019.36	477.96	43.86	238.64	168.74	240.07	8.27	11.76	0.94	0.88	339.51	16.63
Braking Phase Time (s)	0.13	0.04	0.13	0.03	0.00	0.02	0.01	0.02	9.57	13.61	0.93	0.87	0.02	19.25
Unweighting Phase Time (s)	0.33	0.06	0.34	0.06	0.01	0.06	0.04	0.06	12.83	18.26	0.67	0.41	0.09	25.82
Body Weight (N)	704.56	66.18	710.97	66.28	6.41	6.81	4.81	6.85	0.68	0.97	1.00	0.97	9.69	1.37

Key: CMJ, countermovement jump; SD, standard deviation; SEM, standard error of measurement; CV, coefficient of variation; ICC, intraclass correlation coefficient; MDC, minimal detectable change; mRSI, modified reactive strength index; FT:CT, flight time contraction time ratio; min, minimum; RFD, rate of force development; AU, arbitrary unit; m, metres; s, seconds; Kg, kilograms; N, Newtons; W, watts; dark green cell shading, excellent reliability; bright green cell shading, good reliability; orange cell shading, moderate reliability; red cell shading, poor reliability.

Table 4. Descriptive and Reliability Statistics of the Countermovement Rebound Jump Test (Countermovement Jump Portion).

CMJ Portion Metrics	Session 1		Session 2		Mean Difference	SD	SEM	SEM +95	CV	CV +95	ICC	ICC -95	MDC	MDC %
	Mean	SD	Mean	SD										
mRSI (AU)	0.54	0.11	0.54	0.12	0.01	0.06	0.04	0.06	7.44	10.59	0.93	0.88	0.08	14.97
FT:CT (AU)	0.88	0.15	0.86	0.16	0.02	0.08	0.06	0.08	6.61	9.41	0.93	0.86	0.12	13.31
Jump Height (m)	0.32	0.04	0.32	0.04	0.01	0.03	0.02	0.03	5.56	7.90	0.87	0.75	0.04	11.18
Jump Momentum (Kg*m/s)	178.55	18.20	180.87	17.12	2.31	7.36	5.21	7.41	2.90	4.12	0.95	0.91	10.48	5.83
Takeoff Velocity (m/s)	2.49	0.16	2.51	0.14	0.03	0.10	0.07	0.10	2.82	4.01	0.87	0.76	0.14	5.67
Time to Take-off (s)	0.60	0.09	0.62	0.10	0.02	0.07	0.05	0.07	8.06	11.46	0.83	0.69	0.10	16.21
Mean Propulsive Power (W)	2396.88	380.98	2371.43	380.31	25.45	157.50	111.37	158.45	4.67	6.65	0.96	0.92	224.08	9.40
Peak Propulsive Power (W)	3952.83	555.76	3940.65	538.32	12.18	210.99	149.19	212.26	3.78	5.38	0.96	0.93	300.17	7.61
Net Impulse Ratio (AU)	2.19	0.37	2.10	0.30	0.09	0.22	0.15	0.22	7.11	10.12	0.87	0.74	0.31	14.31
Mean Propulsive Force (N)	1719.43	249.92	1683.01	244.53	36.42	91.78	64.90	92.33	3.81	5.43	0.96	0.92	130.57	7.68
Peak Propulsive Force (N)	2311.24	506.60	2235.11	512.47	76.13	199.04	140.74	200.23	6.19	8.81	0.96	0.91	283.17	12.46
Countermovement Depth (m)	0.21	0.06	0.23	0.06	0.01	0.03	0.02	0.03	8.70	12.38	0.92	0.82	0.04	17.51
Braking RFD (N/s)	16305.74	10847.69	15009.82	10883.36	1295.92	5245.31	3708.99	5276.80	23.69	33.70	0.94	0.88	7462.52	47.66
Mean Braking Power (W)	1056.61	245.03	1092.74	223.33	36.13	136.96	96.85	137.79	9.01	12.82	0.90	0.82	194.86	18.13
Peak Braking Power (W)	1487.61	436.60	1531.27	367.11	43.67	247.67	175.13	249.15	11.60	16.51	0.90	0.81	352.36	23.34
Net Braking Impulse (N.s)	84.73	16.37	88.45	14.46	3.72	8.10	5.73	8.15	6.62	9.41	0.91	0.82	11.53	13.31
Mean Braking Force (N)	1532.02	283.09	1533.05	263.70	1.03	118.32	83.67	119.03	5.46	7.77	0.95	0.91	168.34	10.98
Peak Braking Force (N)	2194.62	501.25	2144.90	510.13	49.72	216.53	153.11	217.83	7.06	10.04	0.95	0.91	308.05	14.20
Body Weight (N)	705.68	69.16	707.03	67.41	1.35	6.40	4.53	6.44	0.64	0.91	1.00	1.00	9.11	1.29

Key: CMJ, countermovement jump; SD, standard deviation; SEM, standard error of measurement; CV, coefficient of variation; ICC, intraclass correlation coefficient; MDC, minimal detectable change; mRSI, modified reactive strength index; FT:CT, flight time contraction time ratio; RFD, rate of force development; AU, arbitrary unit; m, metres; s, seconds; Kg, kilograms; N, Newtons; W, watts; dark green cell shading, excellent reliability; bright green cell shading, good reliability; orange cell shading, moderate reliability; red cell shading, poor reliability.

Table 5. Descriptive and Reliability Statistics of Countermovement Rebound Jump Test Metrics (Rebound Jump Portion).

RJ Portion Metrics	Session 1		Session 2		Mean	SD	SEM	SEM +95	CV	CV +95	ICC	ICC -95	MDC	MDC %
	Mean	SD	Mean	SD	Difference									
RSI (AU)	1.50	0.45	1.41	0.44	0.09	0.29	0.20	0.29	14.04	19.98	0.87	0.76	0.41	28.25
FT:CT (AU)	2.33	0.55	2.19	0.59	0.15	0.35	0.25	0.35	10.95	15.58	0.88	0.77	0.50	22.03
Jump Height (m)	0.33	0.05	0.33	0.05	0.00	0.03	0.02	0.03	7.22	10.27	0.88	0.77	0.05	14.52
Flight Time (s)	0.52	0.04	0.52	0.04	0.00	0.03	0.02	0.03	3.43	4.88	0.88	0.78	0.04	6.90
Jump Momentum (Kg*m/s)	182.73	18.99	183.78	19.36	1.04	9.12	6.45	9.18	3.52	5.01	0.94	0.89	12.98	7.08
Takeoff Velocity (m/s)	2.55	0.20	2.56	0.20	0.01	0.13	0.09	0.13	3.64	5.18	0.88	0.77	0.19	7.33
Ground Contact Time (s)	0.22	0.06	0.24	0.08	0.02	0.05	0.03	0.05	12.99	18.48	0.87	0.71	0.06	28.43
Stiffness (N/m)	44735.57	55148.24	38184.85	45531.00	6550.71	17647.50	12478.67	17753.46	29.77	42.82	0.94	0.88	25107.18	60.56
Mean Propulsive Power (W)	3247.33	618.56	3121.95	632.18	125.38	394.01	278.61	396.38	8.75	12.45	0.88	0.78	560.56	17.60
Peak Propulsive Power (W)	5309.16	1083.98	5089.25	1078.42	219.92	653.18	461.87	657.10	8.88	12.64	0.89	0.80	929.28	17.87
Net Impulse Ratio (AU)	1.00	0.06	0.99	0.05	0.01	0.05	0.03	0.05	3.28	4.67	0.80	0.63	0.07	6.61
Mean Propulsive Force (N)	2247.84	373.13	2151.76	385.87	96.08	212.67	150.38	213.95	6.84	9.73	0.90	0.79	302.57	13.75
Peak Propulsive Force (N)	3743.44	949.01	3577.79	1039.99	165.65	481.61	340.55	484.50	9.30	13.24	0.93	0.87	685.18	18.72
Braking Depth (m)	0.13	0.06	0.14	0.06	0.02	0.04	0.03	0.04	20.21	28.76	0.88	0.74	0.06	40.67
Mean Braking Power (W)	3499.77	719.22	3422.03	746.10	77.74	434.84	307.48	437.45	8.88	12.64	0.90	0.82	618.64	17.88
Peak Braking Power (W)	6797.29	1308.46	6752.11	1258.29	45.18	829.31	586.41	834.29	8.66	12.31	0.89	0.79	1179.87	17.42
Net Braking Impulse (N.s)	181.97	19.85	185.02	19.32	3.04	8.02	5.67	8.06	3.09	4.39	0.95	0.90	11.40	6.21
Mean Braking Force (N)	2478.37	481.46	2390.72	502.97	87.65	271.68	192.11	273.31	7.89	11.23	0.91	0.83	386.52	15.88
Peak Braking Force (N)	4166.77	955.37	4011.50	1073.03	155.27	523.44	370.13	526.58	9.05	12.88	0.93	0.86	744.70	18.21

Key: RJ, rebound jump; SD, standard deviation; SEM, standard error of measurement; CV, coefficient of variation; ICC, intraclass correlation coefficient; MDC, minimal detectable change; RSI, reactive strength index; FT:CT, flight time contraction time ratio; AU, arbitrary unit; m, metres; s, seconds; Kg, kilograms; N, Newtons; W, watts; dark green cell shading, excellent reliability; bright green cell shading, good reliability; orange cell shading, moderate reliability; red cell shading, poor reliability.

for appropriate interpretations and comparisons of results. The results of this study indicate that CMJ outcome metrics such as TOV, jump momentum, FT, and JH can be considered reliable for monitoring acute changes in NMF in youth soccer players in the in-season period.

The purpose of the CMJ portion is to achieve a JH which provides a fall height for the RJ portion, which replaces the equivalent fall height from a box as seen in the DJ test. A consistent CMJ portion JH is therefore essential for a consistent fall height, touch-down velocity, and thus performance of the RJ phase. Geraldo et al. [39] reported a DJ fall height of 13.7 ± 1.6 cm and 29.4 ± 2.6 cm from a 20 cm and 40 cm effective box height, respectively, and Badby et al. [33] reported a DJ fall height of 35 ± 4 cm from a 40 cm effective box height, yet, CMJ portion JH, TOV, and jump momentum demonstrated acceptable reliability in this study. The original hypothesis is therefore accepted and the CMRJ may be considered a reliable alternative to the DJ test as it overcame the issues of variability in fall height previously demonstrated in the DJ test [38, 39]. Interestingly, Xu et al. [31] reported that the CMJ test and CMJ portion of the CMRJ test demonstrated similar absolute reliability in metrics such as JH (CV = 4.19% and 4.86%, respectively) and CM depth (CV = 7.20% and 7.01%, respectively), which was also identified for both absolute and relative reliability in this study.

In the RJ portion, FT, jump momentum, and TOV can be considered reliable metrics for monitoring acute changes in NMF in youth soccer players in the in-season period. However, unlike previous reports in student populations [31, 32], JH did not demonstrate acceptable absolute reliability. The most commonly used metric for evaluating NMF during VJ tasks is JH [16], however, TOV demonstrated better absolute reliability in both tests in this study, where the absolute reliability of RJ JH was almost twice that of TOV (10.27% vs 5.18%). This inflation is understandable as JH was calculated as TOV^2 / (2 x gravitational acceleration) [49, 50], thus, TOV might provide a more appropriate representation of outcome reliability over JH for the RJ portion. Flight time demonstrated similar reliability to TOV in both tests but changes in take-off and touchdown posture, and artificially extending the flight phase (e.g., via tucking the legs), can cause erroneous measures of FT [28]. Additionally, jump momentum equals TOV multiplied by body weight [63] so it is understandable that when TOV is multiplied by body weight (which demonstrated the best reliability of all metrics for both tests) the reliability of the resultant jump momentum was acceptable.

Strategy Metrics

Monitoring outcome metrics alone will result in a practitioner missing key information about the strategy adopted to achieve the outcome. For example, a CMJ trial performed with a greater countermovement depth typically corresponds with a greater time to take-off and thus net propulsive impulse, if propulsive force production is not substantially reduced [64]. A greater generation of net propulsive impulse relative to body weight would increase TOV and thus JH [64, 66]. Therefore, despite receiving less attention in the scientific literature when compared to outcome and kinetic metrics [16, 65], strategy metrics provide an opportunity to quantitatively portray the jump strategy used to achieve a given VJ outcome [26, 64], where if not monitored, a change in outcome due to an alteration in strategy may be incorrectly perceived as a change in NMF. Although CMJ countermovement depth and propulsive phase time demonstrated acceptable reliability in youth soccer players in the in-season period, CMJ unweighting phase time, braking phase time, and time to take-off did not, and poor absolute reliability was demonstrated in RJ portion GCT (CV = 18.48%) and braking depth (CV = 28.76%). These findings agree with previous reliability research utilising male and female participants with various sporting backgrounds, where poor reliability in "kinematic metrics" such as unweighting and braking phase time has been demonstrated [26, 74]. It appears strategy metrics generally demonstrate too large variability to be considered for the monitoring of acute change in NMF, despite a necessity to monitor the influence of strategy on the outcome of the task. Only CMJ countermovement depth and propulsive phase time demonstrated sufficient reliability for this purpose in this study.

Ratio Metrics

Ratio metrics have been proposed as an indicator of SSC capacity which are typically calculated by dividing an outcome metric (e.g., JH) by a strategy metric (e.g., time to take-off) to provide information regarding the outcome achieved and strategy performed to achieve this within a single metric (e.g., mRSI) [76] with an arbitrary unit of measurement [26]. Acceptable within-session reliability has been reported for CMJ mRSI and FT:CT in previous research which concluded that both metrics can be utilised reliably, yet it would be unnecessary to report both as they provide theoretically similar information, and they should not be used interchangeably due to distinct differences in calculations [28]. Additionally, CMJ mRSI has demonstrated acceptable test-retest reliability in in adult male and female recreationally active participants [26] and female volleyball athletes [77]. However, these studies interpreted reliability based on the CV% without considering the 95% CIs [26, 77], which might explain the contrasting findings in this study, where CMJ net impulse ratio, FT:CT, and mRSI did not demonstrate acceptable test-retest reliability in youth soccer players in the in-season period in this study. Additionally, CMJ derived net impulse ratio and FT:CT also demonstrated acceptable reliability based only on the CV% and ICC in this study, therefore, the researchers might not have come to this conclusion had they considered the lower bound 95% CIs in their interpretations [26, 77].

The primary purpose of evaluating the RJ portion is to assess fast SSC capacity, which is typically done via metrics associated with "reactivity" or "reactive strength" [47]. The findings of this study indicate the CMRJ test is unsuitable for monitoring acute changes in NMF in youth soccer players in the in-season period as key RJ portion metrics such as FT:CT (CV = 15.58%), RSI (CV = 19.98%), and stiffness (CV = 42.82%) demonstrated unacceptable absolute reliability. This was due to JH (CV = 10.27%), GCT (CV = 18.48%), and braking depth (CV = 28.76%) demonstrating unacceptable absolute reliability, despite FT (CV = 4.88%) demonstrating excellent absolute reliability. Alternatively, utilising this test and metrics in formative evaluation periods performed 3 to 4 times per season to profile physical capacity across a squad (i.e., for benchmarking) may still be suitable as good relative reliability was demonstrated for FT:CT (0.77), RSI (0.76), and stiffness (0.88). If utilising ratio metrics (e.g., RSI) for benchmarking, it must be noted that changes in the component parts of a ratio (e.g., JH and GCT) should also be considered to contextualise changes in the ratio measure.

Kinetic Metrics

Where strategy and ratio metrics have demonstrated generally unacceptable reliability across tests, kinetic metrics might present an alternative opportunity to provide in-depth insight into the mechanisms which determine CMJ execution [26, 78]. Additionally, as a change in strategy is a result of altered force-time characteristics, monitoring changes in strategy metrics alone without additional context from monitoring changes in kinetic metrics could cause an oversight in the determination of changes in NMF [64]. Previous research has reported that metrics derived from the downward (i.e., unweighting and braking) phase of the force–time curve tend to have greater variability than the metrics derived from the upward (i.e., propulsive) phase of CMJs [26, 73]. These results are corroborated in the present study where CMJ propulsive phase kinematic metrics such as peak velocity and mean propulsive velocity, and kinetic metrics such as peak propulsive force, mean propulsive force, peak propulsive power, and mean propulsive power, and only net braking impulse, demonstrated acceptable absolute and relative reliability. Force-time characteristics of the propulsive phase directly influences TOV, and thus JH [65, 66], which explains why the outcome demonstrated acceptable reliability. These findings confirm the original hypothesis as reliability was generally better for propulsive phase over braking phase CMJ metrics in this study, similar to conclusions of previous research [26, 73]. To the contrary, research outside of soccer has reported CV values of less than 10% in peak and mean braking force, suggesting that these might be reliable and sensitive enough to determine acute changes in NMF [26, 73]. As critiqued earlier, the researchers formulated these decisions without considering 95% CIs, which would have amplified reliability.

As would be expected following a reliable CMJ portion JH, which generates an equivalently reliable fall height and thus touch-down velocity, RJ portion net braking impulse demonstrated acceptable absolute and relative reliability in this study. Thus, monitoring net braking impulse in the RJ portion could be used alternative to monitoring outcome measures in the CMJ portion to determine fall height consistency, if desired. Besides net braking impulse and the outcome metrics listed previously, only mean propulsive force demonstrated acceptable absolute and relative reliability for the RJ portion in youth soccer players in the in-season period. As previously discussed, jump momentum demonstrated acceptable reliability in the RJ portion, and as it is equal to net propulsive impulse [65], the reliability of each measure is assumed to be the same. Net propulsive impulse (i.e., jump momentum) can be manipulated via changes in test strategy, which is affected by changes in net braking and propulsive force production, braking depth, and GCT [64]. However, because sufficient reliability was not demonstrated in RJ portion strategy metrics, mean propulsive force is seemingly the only RJ portion kinetic metric that can reliably explain acute changes in net propulsive impulse (i.e., jump momentum) in youth soccer players in the in-season period. Based on these results, practitioners may primarily consider propulsive phase metrics such as CMJ peak velocity, mean propulsive velocity, peak propulsive force, mean propulsive force, peak propulsive power, and mean propulsive power, but only RJ portion mean propulsive force, for monitoring acute changes in NMF in youth soccer players in the in-season period.

FUTURE RECOMMENDATIONS

The CMJ test is a feasible and reliable slow SSC test which can be utilised for monitoring acute changes in NMF in youth soccer players in-season. Acceptable reliability was demonstrated in bodyweight, peak velocity, TOV, jump momentum, FT, mean propulsive velocity, mean propulsive force, peak propulsive power, JH, mean propulsive power, propulsive phase time, net braking impulse, net impulse ratio, peak propulsive force, and countermovement depth. Practitioners should consider a combination of these outcome, strategy, and kinetic metrics in their monitoring processes. The CMRJ test is a less feasible yet reliable fast SSC test which can be utilised for monitoring acute changes in NMF in youth soccer players in-season. It can be considered an appropriate alternative to the DJ test as it overcomes previously identified issues in DJ fall height variability, where acceptable reliability was demonstrated in CMJ portion bodyweight and outcome measures such as TOV, JH, and jump momentum. However, only net braking impulse, net impulse ratio, FT, jump momentum, TOV, and mean propulsive force demonstrated acceptable reliability in the RJ portion. These metrics can be utilised for monitoring acute changes in NMF, but the lack of options may represent a greater task complexity in comparison to the CMJ test. Researchers and practitioners can determine meaningful changes in NMF when testing their athletes using the CMJ and CMRJ tests, by deciding whether observed changes in the recommended metrics values exceed the MDCs reported. The authors encourage researchers and practitioners to determine the reliability of measures within their own squads and environments. As testing was conducted on the first and eighth day of an in-season formative evaluation period with no prior contact with the sample, whether prior familiarisation would improve the reliability of strategy and kinetic metrics is unknown. Future research should investigate whether the reliability of CMJ and CMRJ metrics improves using a repeated measures design over consecutive (e.g., 4 to 6) weeks.

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CONFLICTS OF INTEREST

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ETHICAL APPROVAL

Ethical approval was granted via the University of Salford ethics committee adhering to the principles of the 2013 Declaration of Helsinki.

INFORMED CONSENT STATEMENT

Signed informed consent was obtained from all participants involved in the study.

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