**Countermovement Jump and Isometric Strength Test-Retest Reliability in English Premier League Academy Football Players.**

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**Abstract**

*Purpose*: To examine the test-retest reliability of countermovement jump (CMJ) and isometric strength testing measures in elite-level U-18 and U-23 academy football players. *Methods:* 36 players performed three maximal CMJ’s and isometric abductor (IABS), adductor (IADS) and posterior chain (IPCS) strength tests on two separate test days using dual force plates (CMJ and IPCS) and a portable strength testing device (IABS and IADS). Relative (ICC) and absolute (CV, SEM and MDC%) reliability for 34 CMJ, 10 IABS, 10 IADS and 11 IPCS measures were analysed using between-session Best, Mean and within-session methods. *Results*: For all methods, relative reliability was *good* to *excellent* for all CMJ and all IADS measures, and *poor* to *good* for all IABS and IPCS measures.Absolute reliability was *good* (i.e., CV <10%) for 27 (Best) and 28 (Mean) CMJ variables and for 6 (IABS and IADS) and 2 (IPCS) isometric measures. Commonly used CMJ measures (jump height, eccentric duration and FT:CT) had *good* to *excellent* relative reliability and an MDC% range of 14.6% to 23.7%. Likewise, commonly used isometric peak force measures for IABS, IADS and IPCS had *good* to *excellent* relative reliability and an MDC% range of 22.2% to 26.4%. *Conclusions:* Commonly used CMJ and isometric strength measures had good test- retest reliability but might be limited by their MDC%. Rate of force development measures (for all isometric tests) and impulse measures (IPCS) are limited by poor relative and absolute reliability and high MDC%. MDC% statistics should be considered in the context of typical responsiveness.

**Key Words**

Hip Abduction, Hip Adduction, Posterior Chain, Minimal Detectable Change, Neuromuscular Fatigue, Monitoring, Force Plate, ForceFrame

**Introduction**

The countermovement jump (CMJ) and isometric hip abduction (IABS), adduction (IADS) and posterior chain (IPCS) strength tests are commonly used to profile neuromuscular performance and fatigue characteristics in elite level academy football players 1-7. Compulsory inclusion of CMJ testing in English Premier League (EPL) academies and recent technological advancements (i.e., automation of force-time curve analysis and portability of equipment) have increased the popularity of these tests in practice 8.

Countermovement jump height (JH) performance is associated with sprint acceleration, maximal running velocity, and change of direction capacities in young football players; attributed to the contributary effects that stretch shortening cycle qualities exert on both CMJ and football-specific speed performance 9,10. Moreover, match-induced perturbations to CMJ JH 4,6,11 and movement strategy measures (i.e., flight time: contraction time ratio; FT:CT) 3,12,13 are reported to manifest for ~ 72 h post-match in football players. Consequently, the CMJ is used to quantify both neuromuscular performance and fatigue (NMF; i.e., specific reduction to the maximal force generating capacity of muscle) in academy football players 1,5.

Maximal adductor, abductor and posterior chain strength are thought to mitigate hip 14 and posterior chain 2 injury risk in football players, and peak force measures derived from IABS, IADS and IPCS tests have demonstrated sensitivity to football match play 2,15. Indeed, Salter and colleagues 15 reported reductions to IABS and IADS peak force following simulated match play in academy football players and McCall and colleagues 2 reported reductions to IPCS peak force following senior professional match play. Consequently, these measures are also commonly used to profile hip, groin and posterior chain strength qualities and signal NMF in academy football players 1,4-7,15,16

The interplay between the reliability of a physical performance test measure (i.e., its reproducibility when a player repeatedly performs the test) and its responsiveness (i.e., the extent to which the measure changes in response to a football training or match stimulus) should inform test variable selection in practice 17. Indeed, ‘useful’ performance test measures are considered to be those whereby the typical magnitude of change (i.e., induced by the training or match load stimulus) exceeds the minimal detectable change (MDC) of the test 17. However, despite widespread use, no data are available to report the reliability and MDC of CMJ, IABS, IADS or IPCS measures in EPL under 18 (U-18) and under 23 (U-23) football players. These data will help to improve decision making relating to monitoring variable selection in practice. ~~player profiling, and in-turn, help to optimise physical development and mitigate player injury risk. Additionally, limited publicly available normative data are available for these tests.~~ Accordingly, the aim~~s~~ of this investigation was to examine the test-retest reliability ~~and normative values~~ for CMJ, IABS, IADS and IPCS measures in U-18 and U-23 EPL academy football players. We hypothesised that commonly used CMJ JH (i.e., flight time and impulse momentum) (H1) and movement strategy (i.e., FT:CT) (H2) measures and isometric peak force measures for IABS (H3), IADS (H4) and IPCS (H5) would show *good* to *excellent* absolute and relative reliability.

**Methods**

***Study Design***

Thirty-sixplayers from the U-18 (*n* = 20, age = 17.0 ± 0.7; height = 1.82 ± 0.07 m; body mass = 73.5 ± 76 kg) and U-23 (*n* = 16, age = 19.6 ± 1.2; height = 1.81 ± 0.06 m; body mass = 75.8 ± 8.1 kg) age groups from an EPL category 1 academy participated in this investigation. All testing was conducted at 21°C in a temperature-controlled performance centre located at the team’s training facility. To examine test-retest reliability, players attended two testing sessions between 09:00 AM and 10:00 AM on consecutive Friday mornings (i.e., ‘test’ and ‘retest’ days), spanning similar single-game microcycles during the in-season period. Start times were staggered such that the U-18 (09:00 AM) and U-23 (09:30 AM) groups reported separately. In total, each testing session was ~ 30 min inclusive of rest periods. ~~Weekly training and match distribution and load were consistent for both weeks across the experimental period.~~ The organisation of training and match activities and the distribution of training and match volume and intensity were similar within players across the experimental microcycles. We reasoned that testing players on Friday mornings (i.e., one day before match day; MD-1) represented when player readiness (i.e., denoting the interplay between player ‘fitness’ and ‘fatigue’ 18) was optimal for each training week, based on the consistent periodisation of training volume and intensity around games. Players were encouraged to adopt consistent nutritional practices for each day relative to match day across the experimental period.

Prior to all testing, players performed a standardised warm-up consisting of ~ 4 min of dynamic mobility exercises (3 x 10 m heel flicks, hamstring kicks and walking lunges with a 10 m walk recovery between repetitions), followed by three warm-up CMJ’s at 60%, 80% and 100% of perceived maximal effort, separated by ~ 30 s. Test order for the CMJ, IABS, IADS and IPCS tests were randomised for both testing dates. All players had routinely performed the monitoring tests twice per week for at least one full competitive season and were therefore considered to be highly familiar with all testing protocols. Ethical approval for this investigation was provided by the St Marys University, Twickenham, UK Human Research Ethics Committee (application number 2021-22\_230). Written informed consent was obtained from all players and a parent / legal guardian for those under the age of 18.

***Countermovement Jump***

Countermovement jump testing was performed on dual force plates (ForceDecks FD4000, Vald Performance, Brisbane, AU), sampling at 1000 Hz. Force-time curves were analysed automatically using proprietary software (ForceDecks Version 2.0.8000, Vald Performance, Brisbane, AU) according to methods described previously 8,19,20. Prior to statistical analysis, 32 ~~primary~~ bilateral CMJ variables (i.e., derived from the total vertical ground reaction force) were selected for analysis from the eccentric, concentric, flight and landing phases of the CMJ and included in the main results section (listed in Table 1 and defined previously 20). Variable selection was based on use in similar scientific research literature 8 and known use in practice. Reliability data for a further 69 ~~secondary~~ CMJ variables (101 variables in total, including 70 bilateral, 31 unilateral variables, and 5 asymmetry variables) are available in *supplementary file 1*.

Prior to each testing day, a known mass (20 kg) was used to test the accuracy of force measurement, with ± 0.1 kg considered to be an acceptable level of measurement error 8. The force plates were zeroed prior to all measures. Each player was asked to stand still on the force plates with their hands on their hips for ~ 5 s until a stable body mass was recorded prior to jumping. Players then performed three maximal CMJ trials, each separated by ~ 15 s, keeping their hands on their hips for the entirety of each jump and were cued to ‘jump maximally: as high as they could and to land on the force plates’ as per previous scientific research 8. Players were then asked to reposition their feet between repetitions. All jump testing was conducted by the same experienced practitioner. In cases where a measurement error was observed (i.e., ‘tucking’ or ‘piking’ the legs during the flight phase, a double contact prior to jumping, or if they did not land on the force plates), data were omitted, and the player was asked to perform another repetition.

***Isometric Hip Adductor and Abductor Strength***

Isometric hip abductor and adductor strength were measured using a portable hip strength assessment device (ForceFrame Strength Testing System, VALD Performance, Brisbane, AU), sampling at 1000 Hz (Figure 1), according to methods reported previously 14-16,21-24. This device has previously been shown to provide valid measures of IABS and IADS peak force 25. Force-time curves were analysed automatically using proprietary software (ForceDecks Version 2.0.8000, VALD Performance, Brisbane, AU). One warm up effort at 80% of perceived maximal effort and three maximal tests were conducted for IABS and IADS, which were rotated. For IADS, players were positioned into 45 degrees of hip flexion, confirmed using a hand-held goniometer, with the medial femoral epicondyles of both knees positioned centrally and perpendicular to the medial sensor pads in the force frame. Players were asked to position their feet at hips width, and to keep both feet flat on the floor throughout testing. For IABS this method was repeated, but with the lateral femoral epicondyles of both knees positioned centrally and perpendicular to the lateral sensor pads in the force frame. For both tests, players were instructed to push maximally (‘inwards’ for hip adduction, and ‘outwards’ for hip abduction) for three seconds, whilst keeping their buttocks, hips, and head in contact with the ground and their arms fixed across their shoulders. Cueing for all testing was standardised as “3, 2, 1, push, push, push, relax”. All testing was conducted by the same experienced practitioner. Where a measurement error was observed (i.e., the buttocks, hips or head lifted from the ground, a heel lifted from the floor or the arms lifted away from the shoulders) data were omitted, and the player was asked to perform another repetition.

***Isometric Posterior Chain Strength***

Isometric posterior chain strength was measured using portable force plates (PASCO PS-2141, Roseville, California, UK) sampling at 1000 Hz, positioned on a fixed plinth (Figure 1) according to methods reported previously 2. Force-time curves were analysed automatically using proprietary software (ForceDecks Version 2.0.8000, VALD Performance, Brisbane, AU). Previous scientific research has shown this method to provide valid measures of static and dynamic ground reaction force 26. Prior to each testing day, a known mass (20 kg) was used to test the accuracy of force measurement, with ± 0.1 kg considered to be an acceptable level of measurement error 8. The force plates were zeroed prior to all measures. One warm up effort at 80% of perceived maximum, and three maximal test efforts were alternatively conducted on each limb. The heel of the testing limb was positioned in the middle of the force plate with the knee angle fixed to 30 degrees of flexion; confirmed by a hand-held goniometer (Physio Parts, Twickenham, UK). The heel of the non-testing limb remained in contact with the ground, under the plinth, for the duration of each test. For each test, players were instructed to push maximally, down into the force plate for 3 s, whilst keeping their buttocks, hips, and head in contact with the ground and their arms fixed across their shoulders. Cueing for all testing was standardised as “3, 2, 1, push, push, push, relax”. All testing was conducted by the same experienced practitioner. Where a measurement error was observed (i.e., the buttocks, hips or head lifted from the ground, the non-testing heel lifted from the floor or the arms lifted away from the shoulders) data were omitted, and the player was asked to perform another repetition.

For IABS and IADS, 10 unilateral variables were selected 14-16,21-24 (Table 2). For IPCS, 11unilateral variables were selected 2,27,28 (Table 3). Variable selection was based on use in previous research and current use in practice 2,14-16,21-24,27,28.

*\*\*\* INSERT FIGURE 1 HERE \*\*\**

***Statistical Analysis***

Descriptive statistics (mean, 95% confidence intervals (CI), ± standard deviation (SD)) were calculated at U-18, U23 and combined group (i.e., U-18 and U-23 players combined) levels (*supplementary file 2*). Reliability statistics were calculated using combined group data: two-way mixed-effects models were used to establish the within-session (2,1) and between-session (2,k) ICC reliability of each variable, using the *SimplyAgree* R package 29. Within-session reliability was calculated across the three trials from the second session, whilst between-session reliability was calculated for both the Best result and the Mean result for each variable. Relative reliability was examined using intra-class correlation coefficients (ICC), with 95% CI, as previously described. 30,31 The ICCs were interpreted as: *poor* = < 0.50; *moderate* = 0.50 – 0.74; *good* = 0.75 – 0.89 and *excellent* = > 0.9 16. Absolute reliability was examined by calculating the coefficient of variation (CV; %), using the equation:

where MSE is the mean squared error, and y is the dependent variable. Consistent with previous scientific literature, we applied a threshold of < 10% to define a CV as *good* 32. Standard error of the measurement (SEM) was used to calculate the MDC, presented as MDC% using the equation below 33:

Systematic bias across the two sessions was examined using a paired samples *t*-test. Finally, a Pearson’s R correlation coefficient was used to examine the correlation between body weight and each CMJ variable. All statistical tests were conducted in *R* studio (version 4.0.0, R Foundation for Statistical Computing, Vienna, Austria).

**Results**

***Descriptive Statistics***

Descriptive statistics for the ~~primary~~ CMJ variables for U-18, U-23, combined age group and goalkeeper groups are presented in *supplementary file 2*. Overall, there was a trend for force- dependent, time- dependent and ~~performance- orientated~~ jump height CMJ variables to improve with training age and for greater jump height performances ~~measures~~ in goalkeepers.

Descriptive statistics forIABS, IADS and IPCS variables for U-18, U-23, combined age group and goalkeeper groups are presented in *supplementary file 2*. Overall, there was a trend for peak force, RFD and impulse variables to improve with training age, with best performances across variables typically observed in goalkeepers.

***Countermovement Jump Reliability***

For the between-session analyses, 6 CMJ variables had *good* relative reliability and 26 variables had *excellent* relative reliability, for both the Best (ICC range = 0.79 - 0.99) and Mean (ICC range = 0.83 – 1.00) result. For within-session relative reliability, 4 variables were *moderate*, 14 variables were *good*, and 14 variables were *excellent* (ICC range = 0.62 - 1.00) (Table 1). For between-session analyses using the Best result (Table 1), 25 CMJ variables had CVs *<* 10%, whilst 7 variables had CVs > 10% (CV range = 1.1 - 24.6%). Using the Mean result, 26 variables had CVs *<* 10%, whilst 6 variables had CVs > 10% (CV range = 1.1 - 25.9%). Within-session CVs were *<* 10% in 26 variables, and > 10% in 6 variables (CV range = 0.1 - 51.9§%). There was a trend for absolute force- dependent variables to correlate more strongly with player body weight (*supplementary file 1*).

*\*\*\* INSERT TABLE 1 HERE\*\*\**

***Isometric Hip Abduction Strength Reliability***

For the between-session analyses using the Best result method 7, 2 and 1 variables had *good*, *moderate* and *poor* relative reliability (ICC range = 0.49 - 0.86) respectively. Six variables had CVs < 10% and 4 had CVs >10% (CV range = 7.5 – 23.7%) (Table 2). Using the Mean result method 8 variables had *good* and 2 variables had *moderate* relative reliability (ICC range = 0.64 - 0.89). Six variables had CVs < 10% and 4 had CVs >10% (CV range = 6.7 - 22.4%) (Table 2). For the within-session analysis all variables had *good* relative reliability (ICC range = 0.78 - 0.89). Six variables had CVs < 10% and 4 variables had CVs >10% (CV range = 5.1 - 16.9%) (Table 2).

***Isometric Hip Adduction Strength Reliability***

For the between-session analyses using the Best result method 8 variables had *excellent* and 2 variables had *good* relative reliability (ICC range = 0.82 - 0.94). Six variables had CVs < 10% and 4 had CVs > 10% (CV range = 7.6 - 25%) (Table 2). Using the Mean result method 8 variables had *excellent* and 2 variables had *good* relative reliability (ICC range = 0.86 - 0.94). Six variables had CVs < 10% and 4 had CVs > 10% (CV range = 7.9 - 23.3%) (Table 2). For the within-session analysis 6 variables had *excellent* and 4 variables had *good* relative reliability (ICC range = 0.85 - 0.94). Six variables had CVs < 10% and 4 had CVs > 10% (CV range = 6 - 19.6%) (Table 2).

*\*\*\* INSERT TABLE 2 HERE \*\*\**

***Isometric Posterior Chain Strength Reliability***

For the between-session analyses using the Best result method 7 variables had *good*, 10 variables had *moderate*, and 5 variables had *poor* relative reliability (ICC range = 0.24 - 0.88). Two variables had CVs < 10% and 20 had CVs > 10% (CV range = 7.5 - 41.13%) (Table 3). Using the Mean result method, 7 variables had *good,* 13 variables had *moderate*, and 2 variables had *poor* relative reliability (ICC range = 0.34 - 0.87). Two variables had CVs < 10% and 20 variables had CVs > 10% (CV range = 7.8 - 42%) (Table 3). For the within-session analysis, 2 variables had *good*, 13 variables had *moderate*, and 7 variables had *poor* relative reliability (ICC range = 0.22 - 0.85). Two variables had CVs < 10% and 20 variables had CVs > 10% (CV range = 7 - 46%) (Table 3).

*\*\*\* INSERT TABLE 3 HERE \*\*\**

**Discussion**

~~This is the first investigation to report the test-retest reliability and normative data for a broad spectrum of widely used CMJ, IABS, IADS and IPCS measures in elite-level U-18 and U-23 EPL academy football players.~~

The ~~first~~ aim of this investigation was to examine the test-retest reliability for CMJ, IABS, IADS and IPCS measures in elite-level U-18 and U-23 EPL academy football players. We report *moderate* to *excellent* relative reliability and *good* absolute reliability for 26 (Best) and 26 (Mean) of the 32 ~~primary~~ CMJ variables (Table 1). For IABS we report *good* to *excellent* relative and absolute reliability for 6 variables using the Best method, and for 6 variables examined using Mean method (Table 2). For IADS we report *good* to *excellent* relative and absolute reliability for 6 of the 10 variables examined using both methods (Table 2). For IPCS we report *good* relative and absolute reliability for 7 and 2 of the 22 variables examined using both methods (Table 3). Isometric peak force measures had *good* to *excellent* relative and absolute reliability for all tests. Both IABS and IADS impulse measures had *good* to *excellent* relative and absolute reliability, however, IPCS impulse measures ~~were limited by~~ typically had *poor* relative or absolute reliability and high MDC values. For all tests, RFD measures ~~were~~ typically ~~limited by~~ had *poor* absolute reliability and/or noticeably high MDC% values (Tables 1, 2 and 3). Our results provide researchers and practitioners alike with an ecologically valid resource to help inform monitoring variable selection. The results of the investigation support H1, H2, H3, H4 and H5.

***Countermovement Jump Test Reliability***

Importantly, we report similarly high levels of relative and absolute reliability using both the Best and Mean methods. Indeed, most ~~primary~~ CMJ variables demonstrated *good* to *excellent* relative reliability and *good* absolute reliability using these methods (Table 1). This might be explained by the high level of familiarity that participants had accrued with the CMJ testing prior to the experimental period, which in-turn, might serve to reduce kinetic and kinematic variability within participants across the experimental period. Nonetheless, there are some subtle differences between our findings and those reported previously 3,8. Recently, Howarth and colleagues 8 examined the interday reliability of similar CMJ variables in senior professional rugby union players and reported better absolute reliability for the Mean method than the Best method. Moreover, the absolute reliability of CMJ variables herein appear to be slightly lower than what has been reported previously 3,8. Though discrepancies between our findings and others might be explained by sport related differences between cohorts, it is likely that several other factors contribute. For example, Wren and colleagues 34 reported a reduction to CMJ kinematic variability with increasing training age in young athletes, and Nibali and colleagues 35 reported a reduction in the variability of jump kinematics with increased performance level (i.e., professional athletes > college athletes > high school athletes). Consequently, it is possible that senior professional and older athletes examined previously 3,8 exhibit less movement and performance variability during the CMJ than the younger athletes that we tested. Indeed, these factors might help to explain the better absolute reliability reported previously 3,8. Notwithstanding, our results indicate efficacy for both the Best and Mean methods in U-18 and U-23 EPL academy football players.

Several CMJ movement strategy variables have demonstrated merit in signalling NMF 12,36, chronic adaptations to training 37,38, deceleration ability 39 and have been shown to relate to previous injury 40 in football players. Of these measures, eccentric deceleration RFD, eccentric duration and FT:CT have received particular research attention and consequently, are now widely used in practice 8. Consistent with similar investigations 3,8,35 we report *good* to *excellent* relative reliability for these variables and CV’s of ~8% (FT:CT and eccentric duration) and ~22% (eccentric deceleration RFD) (*supplementary file 1*). Recent scientific literature suggests that variables with low absolute reliability might have merit in practice if the stimulus (i.e., football match play) results in a change to the variable that is greater than the associated CV 8. To that end, we encourage practitioners to consider the MDC% statistic when selecting CMJ variables (Table 1). For example, despite having *excellent* relative reliability, we report an MDC% of ~60% for eccentric deceleration RFD which might render it less suitable for detecting subtle changes to neuromuscular status in young football players. Comparatively, we report MDC% closer to 20% for eccentric duration and FT:CT, which might make them more suitable for this purpose, depending on their typical level of responsiveness to match play (Table 1).

A novel aspect of this investigation is that we examined the correlation between CMJ variables and body weight. Overall, we observed strong correlations between absolute force variables and body weight and weak correlations between relative force- and time-dependent variables and body weight (*supplementary file 1*). For example, absolute eccentric mean force had *good* to *excellent* reliability and a *perfect* correlation (*r* = 1.00) with body weight. Conversely, relative eccentric mean force had *good* to *excellent* reliability and a weak correlation (*r* = 0.24) with body weight. Interestingly, adjusting mean eccentric force from absolute to relative terms changed the ICC from second highest of the 101 variables (0.99; *excellent*) to second lowest (0.70; *moderate*). Consequently, though further research is required to confirm this finding, it appears that body weight might exert an important effect on the reliability of force-dependent measures. Indeed, though we report that most absolute force variables are highly reliable, a large component of this reliability might be explained by the contribution of body weight alone, and so provide little insight into neuromuscular function. Accordingly, on balance and to ensure validity, we advocate the use of relative as opposed to absolute force dependent CMJ measures in practice.

***Isometric Strength Test Reliability***

Peak force measures are the most widely used measures derived from isometric strength tests in research and practice 2,14,16. Consequently, our findings relating to these are of practical importance. Isometric adductor peak force has received particular research attention owing to the mitigating effect that maximal adductor strength is thought to exert on chronic groin pain and acute injury risk in field sport athletes 14. Moreover, both IABS and IADS peak force measures are proposed to have merit in ~~demonstrated merit in~~ signalling acute changes to neuromuscular status in young football players, indicative of NMF 15. For example, Salter and colleagues 15 reported 6-8% (*likely substantial*) reductions to these measures following simulated match play in U-18 and U-23 year-old academy football players. Importantly, we observed *good* relative and absolute reliability for IABS peak force (ICCs = 0.86 and 0.79; CVs = 7.5% and 7.7%) and *excellent* relative (ICCs = 0.93 and 0.94) and *good* absolute (CVs = 7.7% and 7.6%) reliability for IADS peak force (Table 2); consistent with previous research examining sub-elite young football players 16 and senior professional AFL players 14. Indeed, Desmyttre and colleagues 16 reported *good* relative reliability for IABS and IADS peak force (ICCs = 0.85 and 0.82) and Ryan and colleagues 14 reported *good* to *excellent* relative and absolute reliability for IADS peak force (ICCs = 0.94 to 0.95; CVs = 6.3% to 6.7%). However, the MDC% for these measures (IABS = 22.2% and 26.1%, and IADS = 22.3% and 23.9%) (Table 2) are noticeably higher than the 6-8% level of responsiveness reported by Salter and colleagues following simulated match play 15. Though further research is required to examine the responsiveness of these measures to competitive academy football match play, our results indicate that the efficacy of IABS and IADS measures to signal NMF in U-18 and U-23 EPL academy football players might be limited by their associated MDC%. ~~peak force measures are highly reliable in~~.

Hamstring strains are the most common injury sustained by elite-level football players and place the greatest injury burden on teams 2,41-43. Previous scientific research points to maximal posterior chain strength and fatigue as important modifiable risk factors of hamstring injury 2,44. Consequently, McCall and colleagues 2 examined the reliability of IPCS peak force and its sensitivity to elite-level senior professional football match play. The researchers reported *excellent* relative and absolute reliability (ICCs = 0.86 to 0.93; CVs = 4.8% to 6.3%) and 11-16% (*large*) reductions post-match. As a result, IPCS peak force measures have been widely adopted to profile posterior chain strength characteristics and signal match and training induced NMF in practice. Importantly, we report similarly high levels of relative (ICCs: right: 0.82 and left = 0.88) and absolute (CVs: right = 8.9% and left = 7.5%) reliability for this measure (Table 3). However, we also found that the MDC% for this measure (i.e., right = 26.4% and left = 21.9%) (Table 3) are noticeably higher than the level of responsiveness (11-16%) reported previously 2 for this measure in senior professional players. Consequently, it is evident that further research is required to examine the typical level of responsiveness of this measures to academy football match play in order to confirm its usefulness. Readers are also reminded that the relationship(s) that posterior chain peak force measures share with injury risk and match load are yet to be scientifically examined in young football players. Indeed, this research is also warranted to support to their use in practice.

To our knowledge, no previous research has examined the reliability of IABS, IADS or IPCS impulse or RFD measures. For both IABS and IADS tests, we report *good* to *excellent* relative reliability and *good* absolute reliability for all peak impulse measures (Table 2). However, for IPCS, all impulse measures were limited by either poor relative or absolute reliability, or high MDC% (Table 3). For example, posterior chain right limb impulse at 100 ms had ICC, CV and MDC% values of 0.24, 41.1% and 150%, respectively, which likely renders it an unsuitable measure for detecting subtle changes to neuromuscular status. Despite consistent cueing across the isometric tests, we speculate that this finding might be explained by different strategies that players utilised to achieve peak force across the isometric tests. For example, visual inspection of raw force time curves suggests that players typically adopt a longer ‘ramp’ to achieve peak force in the IPCS test compared to both IABS and IADS. This might be explained by several anecdotal reports of posterior chain discomfort during rapid forceful IPCS test efforts and help to explain why impulse measures were less reliable for the IPCS test. Similarly, for all isometric tests, RFD measures were limited by poor reliability or high MDC% (Tables 2 and 3). Indeed, right limb peak RFD at 100 ms had ICCs of 0.49, 0.83 and 0.74; CVs of 23.7%, 23.5% and 35.4%, and MDC%s of 91%, 72% and 109% for the IABS, IADS and IPCS tests, respectively. In summary, it is evident that IABS and IADS impulse measures can be reliably deployed in practice. However, the poor reliability and high MDC% values observed for all RFD measures and IPCS impulse measures might render them unsuitable for use in practice.

~~The second aim was to report the normative CMJ, IABS, IADS and IPCS data for the U-18, U-23, combined (i.e., U-18 + U-23) and goalkeeper sub-groups. Unsurprisingly,~~ Our descriptive data show a trend for all physical performance measures to improve with chronological age (i.e., U-23 > U-18) and to be best in goalkeepers. For example, ~~on average,~~ CMJ concentric peak force, eccentric peak force, peak power, concentric duration, eccentric duration, eccentric deceleration RFD and jump height measures were greater for the U-23 group than the U-18 group (*supplementary file 2*). Overall, goalkeepers demonstrated the greatest JH performance, which is likely explained by position-specific factors (i.e., the jump-dominant demands of goalkeeper training and match play) giving rise to more advanced neuromuscular adaptations that serve to improve jump capabilities 45. ~~Indeed, mean concentric power was higher for goalkeepers than outfield players, which likely contributes to this finding (~~*~~supplementary file 2~~*~~). Isometric strength measures also typically improved with chronological age and the greatest measures were also observed in goalkeepers. For example Peak force measures for all isometrics tests were higher for the U-23 group than for the U-18 group but highest overall in goalkeepers (~~*~~supplementary file 2~~*~~)~~. The trend for peak isometric force measures to increase with chronological age is consistent with previous research that reported concurrent increases in age and maximal strength in EPL academy football players 46. That these measures were also higher in ~~maximal isometric strength is typically superior~~ goalkeepers is also consistent with previous scientific research literature 45 and is likely explained by anthropometric and position specific training factors 45,47.

**Practical Applications**

Test variable selection should be based on a number of factors including relative and absolute reliability, MDC% and conceptual efficacy 5,18,48. Indeed, chosen variables should have a sound biological basis that theoretically links what is being measured to a desirable performance outcome, or be sensitive to training- and match- load 5,18,48. We have reported the reliability and MDC% for a wide range of CMJ, IABS, IADS and IPCS variables that practitioners ~~can~~ should use to inform variable selection. For these variables we typically observed preferable relative reliability, absolute reliability and MDC% values using the Best (of three maximal repetitions) method (Tables 1, 2 and 3) Consequently, on balance, we recommend this method for monitoring these measures in practice.

Consistent with previous research we standardised cueing across all isometric tests to achieve maximal voluntary contractions, and typically observed good reliability for peak force measures. Interestingly, recent research reported that kinetic and kinematic measures collected during standardised physical performance tests in young football players varied in a manner that was specific to the cueing provided 49,50. Consequently, we recommend that future research should examine the effect of cueing variations on the reliability of isometric strength measures to help refine performance testing methods. Indeed, specific cues to promote RFD and impulse might improve the reliability of these measures in practice.

It was beyond the scope of this investigation to examine the conceptual efficacy of measures and we encourage practitioners to examine the typical responsiveness of variables shown to be reliable herein to football training and match play. These data can then be considered alongside the MDC% values herein to support decision making relating to variable selection. To that end, we note the need for further scientific research of this type in academy football players and suggest that future research examines the acute (i.e., pre- to- post-match) and longitudinal (i.e., cross-season) changes to CMJ, IABS, IADS and IPCS variables in these cohorts to help in this regard.

There are several important limitations to this investigation. Firstly, based on the work of Cormack and colleagues 32, we applied an arbitrary threshold of 10% to define absolute reliability but acknowledge that higher or lower CVs might be acceptable depending on their typical responsiveness to football match play 8. ~~for measures that are particularly sensitive to changes in neuromuscular status~~ ~~8~~~~.~~ Consequently, we stress that variable selection should be based on balanced consideration for reliability, responsiveness and / or the MDC statistic. ~~Overall, consistent with previous work~~ ~~32~~~~, we consider 10% to be a useful threshold when the objective is to detect subtle day- to- day changes to neuromuscular status~~ ~~32~~ ~~(i.e., for longitudinal player monitoring~~ ~~12,36~~~~).~~ We ran an exploratory correlation between CMJ variables and body weight and acknowledge recent scientific debate recommending that two requirements should be fulfilled prior to performing simple ratio calculations. Firstly, that the bivariate regression of the numerator and denominator should yield a straight line that intersects with the origin (y-intercept = 0) of both axes, and secondly, that the relationship between the ratio and its denominator should yield a zero correlation. Since these requirements were not examined herein, we stress that readers should exercise some caution when interpreting the relationship(s) that CMJ variables share with body weight. Unfortunately, we only examined male players from U-18 and U-23 age groups from a single academy. Consequently, we acknowledge that our findings might not be generalisable across female cohorts or younger (i.e., < U-18) and older (i.e., senior professional) male cohorts. As such, we encourage similar research to be conducted in these groups.

**Conclusion**

Commonly used CMJ (i.e., jump height, eccentric duration and FT:CT) monitoring measures have *moderate* to *excellent* relative reliability using the Best, Mean and within-session methods and MDC% ranging between 14.6% and 23.7%. ~~Of note, eccentric deceleration RFD had an MDC% of 60.8%, which might render it unsuitable for signalling subtle changes to neuromuscular status in academy football players.~~ Likewise, isometric peak force (IABS, IADS and IPCS) and impulse (IABS, IADS) measures have *good* to *excellent* ~~absolute and~~ relative reliability and MDC% ranging between 21.9% and 26.8%. However, RFD measures (IABS, IADS and IPCS) and IPCS impulse measures had *poor* to *excellent* relative reliability and MDC% ranging between 41.1% and 150%. Practitioners are advised to consider the MDC% statistics herein alongside typical variable responsiveness to help inform CMJ and isometric strength monitoring variable selection. Though further research is required to examine the response of these measures to elite level academy football match play, useful monitoring measures are considered to be those whereby typical responsiveness (i.e., to match play) is greater than the associated MDC%.

Overall, force orientated CMJ measures had better reliability than power, velocity, RFD and impulse orientated measures. However, force- dependent CMJ measures correlated very strongly with body weight, which ~~appears to~~ might artificially inflate their reliability. Consequently, practitioners are advised to use relative as opposed to absolute CMJ force measures.

**Declarations**

All authors report that they have no conflicting interests.

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A collage of a person lying on a mat

Description automatically generated

**Figure 1,** Participant positioning for Isometric Posterior Chain (left) and Isometric Hip Abduction and Adduction (right) strength testing.

**Table 1**, Best, Mean and Within-Session reliability of countermovement jump (CMJ) variables. Data are presented as relative reliability: *ICC*, intraclass correlation coefficient (± 95% CI) and absolute reliability: *CV*, coefficient of variation; *SEM*, standard error of measurement and *MDC%*, minimal detectable change (percent). *Abs*; absolute; *Con*, concentric; *CT*, contraction time; *CM*, countermovement; *Dec*, deceleration; *Dur*, duration; *Ecc*, eccentric; *FT*, flight time, *FT: CT*, flight time: contraction time; *F*, force; *Imp*, impulse; *IM*, impulse momentum; *Mvt*, movement; *P*, power; *Rel*, Relative; *RFD*, rate of force development; *RSI*, reactive strength index; *V*, velocity. Variables in bold have both an ICC > 0.75 (i.e., *Good* to *Excellent*) and a CV < 10%.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Best** | | **Mean** | | **Within-Session** | |
| **Variable (Unit)** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** |
| **Body Weight (N)** | 0.99 (0.99-1) | 1.07; 5.52; 2.91 | 0.99 (0.99-1) | 1.07; 5.52; 2.91 | 0 (0-0) | 0; 0; 0 |
| **Con Dur (ms)** | 0.95 (0.91-0.97) | 5.18; 9.02; 14.48 | 0.95 (0.91-0.97) | 5.18; 9.02; 14.48 | 0.86 (0.76-0.92) | 5.83; 15.8; 25.4 |
| **Con Imp (100 ms) (N⋅s)** | 0.96 (0.92-0.97) | 8.73; 7.26; 24.39 | 0.96 (0.94-0.98) | 8.05; 6.34; 22.67 | 0.92 (0.88-0.95) | 9.34; 9.9; 35.8 |
| **Con Mean F (N)** | 0.98 (0.96-0.99) | 3.78; 43.7; 10.43 | 0.98 (0.97-0.99) | 3.2; 36.3; 8.91 | 0.96 (0.93-0.98) | 3.35; 58; 14.4 |
| **Con Mean P (W)** | 0.96 (0.93-0.98) | 6.19; 107.8; 17.45 | 0.96 (0.93-0.98) | 6.04; 103; 17.33 | 0.95 (0.92-0.97) | 5.08; 116; 19.7 |
| **Con Peak F (N)** | 0.95 (0.92-0.97) | 6.1; 90.7; 17.07 | 0.97 (0.94-0.98) | 4.84; 68.6; 13.41 | 0.93 (0.9-0.96) | 5.27; 104; 20.2 |
| **Con Peak Vel (m/s)** | 0.83 (0.7-0.9) | 3.55; 0.08; 10.58 | 0.83 (0.71-0.91) | 3.67; 0.08; 11.03 | 0.87 (0.81-0.92) | 2.38; 0.06; 9.3 |
| **CM Depth (cm)** | 0.93 (0.88-0.96) | -8.44; 1.99; 23.7 | 0.93 (0.88-0.96) | -8.44; 1.99; 23.7 | 0.83 (0.65-0.91) | -7.97; 3.33; 39.7 |
| Ecc Braking Imp (N⋅s) | 0.91 (0.85-0.95) | 10.81; 5.75; 30.76 | 0.93 (0.87-0.96) | 10.38; 4.76; 29.23 | 0.62 (0.47-0.75) | 18.37; 12.3; 75.7 |
| Ecc Dec RFD (N/s) | 0.95 (0.92-0.97) | 20.78; 1434.4; 57.84 | 0.96 (0.93-0.98) | 18.72; 1132; 51.91 | 0.92 (0.87-0.95) | 21.84; 1878; 85.7 |
| **Ecc Dur (ms)** | 0.88 (0.78-0.93) | 8.18; 28; 23.75 | 0.88 (0.78-0.93) | 8.18; 28; 23.75 | 0.82 (0.73-0.89) | 8.53; 39; 33.4 |
| **Ecc Mean Braking F (N)** | 0.95 (0.92-0.97) | 5.17; 38.8; 14.41 | 0.96 (0.93-0.98) | 4.37; 31; 12.11 | 0.84 (0.75-0.9) | 6.51; 67.6; 26.4 |
| **Ecc Mean F (N)** | 0.99 (0.99-1) | 1.07; 5.6; 2.92 | 1 (0.99-1) | 1.05; 5.44; 2.86 | 1 (1-1) | 0.12; 0.9; 0.5 |
| **Ecc Mean P (W)** | 0.93 (0.88-0.96) | 6.35; 26.3; 18.15 | 0.92 (0.85-0.95) | 7.18; 27.7; 20.49 | 0.75 (0.55-0.86) | 7.61; 49.4; 36.3 |
| **Ecc Mean P Rel. (W/kgBW)** | 0.91 (0.84-0.95) | 6.06; 0.34; 17.57 | 0.89 (0.8-0.94) | 7.02; 0.36; 20.33 | 0.68 (0.47-0.81) | 7.75; 0.66; 36.7 |
| **Ecc Peak F (N)** | 0.96 (0.93-0.98) | 6.48; 93.1; 17.97 | 0.96 (0.93-0.98) | 5.78; 79; 16.04 | 0.9 (0.83-0.94) | 6.54; 139; 28.4 |
| **Ecc: Con Peak P** | 0.97 (0.96-0.99) | 9.74; 0.04; 26.94 | 0.97 (0.95-0.98) | 10.07; 0.03; 27.73 | 0.82 (0.66-0.9) | 15.26; 0.09; 72.2 |
| **Ecc Peak V (m/s)** | 0.79 (0.64-0.88) | -10.4; 0.11; 31.42 | 0.89 (0.81-0.94) | -6.94; 0.07; 19.87 | 0.72 (0.5-0.84) | -7.2; 0.13; 35.1 |
| **Ecc: Con Mean Force** | 0.94 (0.9-0.97) | 3.4; 1.17; 9.66 | 0.94 (0.9-0.97) | 3.4; 1.17; 9.66 | 0.89 (0.81-0.93) | 3.24; 1.68; 13.8 |
| **FT (ms)** | 0.93 (0.87-0.96) | 2.55; 10.5; 7.2 | 0.92 (0.86-0.96) | 2.62; 10.79; 7.5 | 0.88 (0.82-0.93) | 2.28; 13.1; 9.1 |
| **FT: CT** | 0.91 (0.84-0.95) | 8.15; 0.05; 23.31 | 0.94 (0.89-0.97) | 6.24; 0.04; 17.49 | 0.9 (0.85-0.94) | 6.11; 0.05; 23.9 |
| **F at Peak P (N)** | 0.99 (0.97-0.99) | 2.82; 35.4; 7.87 | 0.98 (0.97-0.99) | 2.92; 35; 7.99 | 0.94 (0.87-0.97) | 3.58; 72.3; 16.6 |
| **F at Zero V (N)** | 0.95 (0.92-0.97) | 6.57; 92.9; 18.26 | 0.95 (0.92-0.97) | 6.29; 85; 17.51 | 0.92 (0.86-0.95) | 6.17; 126.6; 26.2 |
| **JH - FT (cm)** | 0.93 (0.87-0.96) | 5.16; 1.5; 14.59 | 0.92 (0.87-0.96) | 5.25; 1.51; 15.07 | 0.89 (0.83-0.93) | 4.52; 1.8; 18.1 |
| **JH- IM (cm)** | 0.84 (0.73-0.91) | 7.26; 2.06; 21.53 | 0.84 (0.72-0.91) | 7.6; 2.11; 22.92 | 0.86 (0.8-0.92) | 5.24; 1.83; 20.2 |
| Landing RFD (N/s) | 0.97 (0.95-0.98) | 24.58; 22515; 68.26 | 0.97 (0.94-0.98) | 25.93; 19275; 71.79 | 0.77 (0.67-0.85) | 51.89; 54612; 200.8 |
| Mvt Start to Peak F (s) | 0.81 (0.66-0.89) | 14.95; 0.06; 44.64 | 0.89 (0.8-0.94) | 10.49; 0.04; 30.14 | 0.77 (0.67-0.86) | 12.83; 0.07; 51 |
| **Mvt Start to Peak P (s)** | 0.87 (0.77-0.92) | 8.92; 0.05; 26.01 | 0.92 (0.86-0.96) | 6.41; 0.03; 18.17 | 0.85 (0.78-0.91) | 7.17; 0.05; 28.4 |
| Peak Landing F (N) | 0.92 (0.86-0.95) | 10.44; 324.1; 29.72 | 0.92 (0.86-0.95) | 10.44; 324; 29.72 | 0.69 (0.56-0.8) | 16.8; 703; 65.1 |
| **Peak P Abs. (W)** | 0.98 (0.96-0.99) | 3.89; 117.2; 10.87 | 0.98 (0.96-0.99) | 4.19; 123; 11.77 | 0.97 (0.94-0.98) | 3.08; 142; 13.7 |
| **Peak Power Rel. (W/kgBW)** | 0.95 (0.92-0.97) | 4.17; 1.67; 11.77 | 0.95 (0.91-0.97) | 4.53; 1.77; 12.87 | 0.94 (0.88-0.96) | 3.18; 1.92; 14 |
| **RSI Modified (m/s)** | 0.93 (0.88-0.96) | 7.82; 0.03; 22 | 0.94 (0.89-0.96) | 7.76; 0.03; 21.76 | 0.91 (0.86-0.94) | 7.05; 0.04; 27.2 |

**Table 2**, Best, Mean and Within-Session reliability of isometric hip abduction (IABS) and hip abduction (IADS) strength variables. Data are presented as relative reliability: *ICC*, intraclass correlation coefficient (± 95% CI) and absolute reliability: *CV*, coefficient of variation; *SEM*, standard error of measurement and *MDC%*, minimal detectable change (percent). *Abd*, abduction; *Abs*; absolute; *Add*, adduction; *Imp*, impulse; L, left leg; *ms*, millisecond; *RFD*, rate of force development; R, right leg; *Vert*, vertical. Variables in bold have both an ICC > 0.75 (i.e., *Good* to *Excellent*) and a CV < 10%.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Best** | | **Mean** | | **Within-Session** | |
| **Variable (Unit)** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** |
| **L Abd Peak Force (N)** | 0.79 (0.55-0.89) | 7.67; 25.51; 26.1 | 0.8 (0.56-0.9) | 7.49; 24.29; 25.81 | 0.88 (0.82 - 0.93) | 5.4; 21.6; 14.9 |
| **L Abd Peak Imp 100 ms (N⋅s)** | 0.78 (0.55-0.89) | 7.76; 2.58; 26.46 | 0.8 (0.55-0.9) | 7.58; 2.46; 26.24 | 0.89 (0.82 - 0.93) | 5.2; 19.7; 14.3 |
| **L Abd Peak Imp 200 ms (N⋅s)** | 0.78 (0.54-0.89) | 7.85; 5.2; 26.82 | 0.8 (0.55-0.9) | 7.69; 4.96; 26.56 | 0.89 (0.83 - 0.93) | 5.1; 38.6; 14.1 |
| L Abd Peak RFD 100 ms (N/s) | 0.68 (0.36-0.83) | 19.82; 34.54; 70.35 | 0.81 (0.63-0.9) | 17.36; 23.82; 56.27 | 0.79 (0.68 - 0.87) | 16.9; 27; 46.9 |
| L Abd Peak RFD 200 ms (N/s) | 0.78 (0.6-0.88) | 14.44; 30.19; 43.73 | 0.84 (0.71-0.91) | 13.43; 24.51; 39.37 | 0.78 (0.68 - 0.86) | 12.9; 32.3; 35.8 |
| **L Add Peak Force (N)** | 0.93 (0.86-0.97) | 7.7; 26.58; 23.99 | 0.93 (0.85-0.96) | 8.29; 27.29; 25.79 | 0.94 (0.9 - 0.96) | 6.2; 26.3; 17.3 |
| **L Add Peak Imp 100 ms (N⋅s)** | 0.93 (0.85-0.96) | 7.82; 2.73; 24.71 | 0.93 (0.84-0.96) | 8.43; 2.79; 26.55 | 0.93 (0.9 - 0.96) | 6.4; 26.8; 17.6 |
| **L Add Peak Imp 200 ms (N⋅s)** | 0.93 (0.84-0.96) | 8.01; 5.57; 25.39 | 0.92 (0.84-0.96) | 8.6; 5.69; 27.19 | 0.93 (0.89 - 0.96) | 6.4; 54.1; 17.9 |
| L Add Peak RFD 100 ms (N/s) | 0.82 (0.67-0.9) | 25.02; 40.71; 76.59 | 0.88 (0.78-0.93) | 22.56; 29.74; 65.84 | 0.87 (0.8 - 0.92) | 19.6; 34; 54.3 |
| L Add Peak RFD 200 ms (N/s) | 0.92 (0.86-0.96) | 14.25; 30.46; 41.87 | 0.93 (0.87-0.96) | 14.2; 27.39; 42.1 | 0.87 (0.8 - 0.92) | 15.2; 40.2; 42 |
| **R Abd Peak Force (N)** | 0.86 (0.76-0.92) | 7.46; 23.86; 22.16 | 0.89 (0.8-0.94) | 6.7; 20.57; 19.85 | 0.88 (0.82 - 0.93) | 5.4; 21.6; 14.9 |
| **R Abd Peak Imp 100 ms (N⋅s)** | 0.86 (0.76-0.92) | 7.48; 2.38; 22.16 | 0.89 (0.8-0.94) | 6.74; 2.05; 19.84 | 0.89 (0.82 - 0.93) | 5.3; 21.4; 14.8 |
| **R Abd Peak Imp 200 ms (N⋅s)** | 0.86 (0.75-0.92) | 7.51; 4.76; 22.24 | 0.89 (0.8-0.94) | 6.81; 4.11; 20 | 0.89 (0.83 - 0.93) | 5.3; 42.4; 14.7 |
| R Abd Peak RFD 100 ms (N/s) | 0.49 (0.08-0.71) | 23.7; 50.55; 91.36 | 0.64 (0.35-0.8) | 22.37; 36.57; 77.18 | 0.82 (0.73 - 0.89) | 16.3; 28.5; 45 |
| R Abd Peak RFD 200 ms (N/s) | 0.67 (0.38-0.82) | 15.57; 41.41; 54.04 | 0.74 (0.53-0.85) | 15.8; 34.87; 50.4 | 0.82 (0.73 - 0.89) | 11.4; 30.5; 31.7 |
| **R Add Peak Force (N)** | 0.94 (0.89-0.97) | 7.56; 24.98; 22.3 | 0.94 (0.89-0.97) | 7.91; 24.77; 23.06 | 0.94 (0.9 - 0.96) | 6; 25.5; 16.7 |
| **R Add Peak Imp 100 ms (N⋅s)** | 0.94 (0.88-0.97) | 7.59; 2.52; 22.57 | 0.94 (0.89-0.97) | 7.92; 2.49; 23.31 | 0.93 (0.89 - 0.96) | 6.2; 26; 17.1 |
| **R Add Peak Imp 200 ms (N⋅s)** | 0.94 (0.88-0.96) | 7.71; 5.12; 23.03 | 0.94 (0.89-0.97) | 8.03; 5.06; 23.76 | 0.93 (0.89 - 0.96) | 6.3; 52.9; 17.4 |
| R Add Peak RFD 100 ms (N/s) | 0.83 (0.69-0.91) | 23.53; 39.42; 72.66 | 0.86 (0.75-0.92) | 23.25; 31.9; 69.09 | 0.86 (0.79 - 0.92) | 19.3; 33.8; 53.4 |
| **R Add Peak RFD 200 ms (N/s)** | 0.9 (0.82-0.95) | 15.36; 32.76; 44.14 | 0.91 (0.84-0.95) | 15.81; 30.23; 45.68 | 0.85 (0.78 - 0.91) | 15.4; 40.9; 42.6 |

**Table 3**, Best, Mean and Within-Session reliability of isometric posterior chain strength (IPCS) variables. Data are presented as relative reliability: *ICC*, intraclass correlation coefficient (± 95% CI) and absolute reliability: *CV*, coefficient of variation; *SEM*, standard error of measurement and *MDC%*, minimal detectable change (percent). *Abs*; absolute; *Imp*, impulse; *L*, left leg; *ms*, millisecond; *RFD*, rate of force development; *R*, right leg; *Vert*, vertical. Variables in bold have both an ICC > 0.75 (i.e., *Good* to *Excellent*) and a CV < 10%. Variables in bold have both an ICC > 0.75 (i.e., *Good* to *Excellent*) and a CV < 10%.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Best** | | **Mean** | | **Within-Session** | |
| **Variable (Unit)** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** | **ICC (95% CI)** | **CV; SEM; MDC%** |
| L Abs Imp 100 ms (N.s) | 0.47 (0.09-0.7) | 30.72; 3.2; 106.94 | 0.67 (0.41-0.81) | 22.54; 1.65; 71.94 | 0.22 (0.05-0.41) | 38.73; 3.6; 153.03 |
| L Abs Imp 150 ms (N.s) | 0.53 (0.2-0.73) | 25.31; 4.57; 87.02 | 0.72 (0.5-0.84) | 19.1; 2.49; 59.74 | 0.23 (0.06-0.42) | 33.45; 5.63; 131.92 |
| L Abs Imp 200 ms (N.s) | 0.59 (0.28-0.76) | 21.69; 5.81; 73.26 | 0.75 (0.55-0.86) | 17.58; 3.5; 54.12 | 0.31 (0.13-0.5) | 28.87; 7.47; 113.49 |
| L Force 100 ms (N) | 0.58 (0.27-0.76) | 23.41; 32.74; 80.22 | 0.72 (0.51-0.84) | 20.26; 20.5; 63.39 | 0.29 (0.12-0.48) | 33; 43; 129.39 |
| L Force 200 ms (N) | 0.71 (0.49-0.84) | 16.93; 30.4; 53.1 | 0.77 (0.58-0.87) | 17.3; 25.86; 52.5 | 0.57 (0.41-0.71) | 20.41; 39.34; 78.91 |
| L Net Force 100 ms (N) | 0.68 (0.44-0.82) | 37.41; 24.41; 120.09 | 0.69 (0.45-0.82) | 42.23; 19.86; 132.95 | 0.63 (0.48-0.75) | 44.98; 27; 173.13 |
| L Net Force 200 ms (N) | 0.75 (0.55-0.86) | 22.97; 27.21; 70.26 | 0.7 (0.47-0.83) | 29.89; 29.62; 92.95 | 0.71 (0.59-0.82) | 25.72; 32.26; 100.12 |
| L Net Peak Vert Force (N) | 0.77 (0.58-0.87) | 11.32; 25.73; 34.32 | 0.87 (0.77-0.93) | 7.84; 19.33; 22.74 | 0.6 (0.44-0.73) | 14.66; 39.23; 58.12 |
| **L Peak Vert Force (N)** | 0.88 (0.78-0.93) | 7.53; 19.66; 21.87 | 0.75 (0.56-0.86) | 12.93; 26.72; 39.53 | 0.85 (0.78-0.91) | 6.72; 21.93; 25.76 |
| L RFD 100 ms (N/s) | 0.68 (0.44-0.82) | 37.39; 244.2; 120.06 | 0.69 (0.45-0.82) | 42.25; 198.78; 133.03 | 0.63 (0.48-0.75) | 45.05; 270.47; 173.38 |
| L RFD 200 ms (N/s) | 0.75 (0.55-0.86) | 22.96; 136.09; 70.25 | 0.7 (0.47-0.83) | 29.84; 147.82; 92.79 | 0.71 (0.59-0.82) | 25.71; 161.21; 100.05 |
| R Abs Imp 100 ms (N.s) | 0.24 (-0.37-0.57) | 41.13; 4.25; 150.03 | 0.34 (-0.18-0.63) | 29.49; 2.31; 104.14 | 0.43 (0.25-0.6) | 32.54; 2.72; 125.72 |
| R Abs Imp 150 ms (N.s) | 0.32 (-0.23-0.62) | 33.04; 6.04; 117.64 | 0.45 (0.01-0.69) | 25.62; 3.62; 87.49 | 0.46 (0.29-0.63) | 28.63; 4.49; 110.67 |
| R Abs Imp 200 ms (N.s) | 0.4 (-0.07-0.66) | 28.3; 7.7; 98.17 | 0.55 (0.2-0.75) | 23.17; 4.97; 76.41 | 0.54 (0.37-0.69) | 25.29; 6.25; 97.83 |
| R Force 100 ms (N) | 0.42 (-0.04-0.68) | 29.92; 41.96; 103.07 | 0.54 (0.17-0.74) | 26.26; 28.38; 86.98 | 0.47 (0.3-0.64) | 30.14; 37.35; 116.48 |
| R Force 200 ms (N) | 0.66 (0.39-0.81) | 19.74; 37.13; 62.65 | 0.73 (0.52-0.85) | 19.56; 30.83; 60.4 | 0.68 (0.55-0.79) | 20.37; 39.85; 79.15 |
| R Net Force 100 ms N) | 0.74 (0.54-0.85) | 35.41; 25.62; 109.63 | 0.72 (0.51-0.84) | 41.11; 21.33; 127.47 | 0.59 (0.44-0.73) | 46.33; 29.3; 180.16 |
| R Net Force 200 ms (N) | 0.77 (0.59-0.87) | 24.07; 31.46; 73.32 | 0.75 (0.56-0.86) | 27.75; 29.99; 85.32 | 0.72 (0.59-0.82) | 26.35; 35.7; 103.43 |
| R Net Peak Vert Force (N) | 0.74 (0.53-0.85) | 11.42; 27.51; 35.02 | 0.72 (0.51-0.84) | 12.16; 27.15; 37.65 | 0.69 (0.55-0.8) | 11.1; 31.04; 42.95 |
| **R Peak Vert Force (N)** | 0.82 (0.68-0.9) | 8.9; 24.58; 26.38 | 0.85 (0.74-0.92) | 7.83; 20.14; 22.88 | 0.82 (0.72-0.88) | 6.88; 23.55; 26.73 |
| R RFD 100 ms (N/s) | 0.74 (0.54-0.85) | 35.35; 255.87; 109.45 | 0.72 (0.51-0.84) | 41.12; 213.3; 127.48 | 0.59 (0.44-0.73) | 46.32; 292.71; 180.07 |
| R RFD 200 ms (N/s) | 0.77 (0.58-0.87) | 24.1; 157.49; 73.42 | 0.75 (0.56-0.86) | 27.75; 149.95; 85.31 | 0.72 (0.59-0.82) | 26.31; 178.27; 103.25 |