

Original investigation

Identifying relevant bilateral countermovement jump parameters for performance profiling, neuromuscular fatigue monitoring and asymmetry testing in Academy soccer players

Running head: Selecting jump parameters in youth soccer

Abstract

Purpose: This study aimed to determine the reliability and relevance of key countermovement jump (CMJ) parameters in Academy soccer players. **Methods:** Twenty-nine bilateral CMJ force-time variables were collected using dual force plates from 63 Academy soccer players. Two analyses were performed: i) test–retest reliability was assessed in a convenience sample of 20 players across two sessions separated by seven days, and ii) principal component analysis (PCA) was conducted in 47 players using their most representative seasonal trial to reduce data dimensionality. **Results:** Most outcome-based variables demonstrated acceptable reliability (intraclass correlation coefficient [ICC] $\geq .81$; coefficient of variation [CV] $\leq 13.7\%$). Nine out of eleven time-based variables showed acceptable reliability (ICC $\geq .67$; CV $\leq 12.9\%$). All asymmetry-based variables showed unacceptable reliability (ICC $\geq .11$; CV $\leq 66.4\%$) while symmetry-based variables generally displayed excellent reliability (ICC $\geq .90$; CV $\leq 11.8\%$). The PCA revealed three principal components within outcome- (force and power production during concentric and eccentric phases) and time-based (temporal ratios, concentric duration, and landing characteristics) variables whereas two principal components were revealed for asymmetry- or symmetry-based variables (related to eccentric, concentric, and landing phases). These explained 83.1%, 76.1%, and 81.9% of the total variance for outcome-, time-and asymmetry or symmetry-based variables, respectively. **Conclusions:** Practitioners involved with bilateral CMJ testing in academy soccer players can rely on the selected parameters presented in our study. Symmetry parameters could be preferred over asymmetry parameters, due to their superior reliability.

Keywords: Kinetics; Force; Power; Impulse; Kinematics

Introduction

The ability to produce and apply large forces quickly is an important physical characteristic for academy soccer players.¹ One of the most common power-based tests adopted in soccer is the bilateral countermovement jump (CMJ) due to the simplicity required to perform the test.² Extensive evidence in academy male soccer players has shown that CMJ-related performance variables are associated with muscle strength, linear and multidirectional sprint capacities.^{3,4} Accordingly, CMJ-derived information can aid practitioners involved in testing academy soccer players to profile players, monitor adaptations and readiness to train and compete, as well as informing decisions during the rehabilitation process.⁵

Force plates are accessible to a wide range of soccer academies, and they are considered the gold standard for assessing vertical forces. Force-time data obtained during the CMJ provides information about a wide range of variables for different purposes (i.e., performance profiling, neuromuscular fatigue [NMF] monitoring and rehabilitation). For example, different CMJ outcome variables (e.g., jump height [JH], peak velocity [PV], peak and/or mean force and power [PF, MF and PP, MP, respectively]) are correlated with performance in strength tests, linear and multilinear speed.⁶ However, outcome-based variables (e.g. JH, PP) have also been the ones to show no post-match changes, whereas time-based measures such as time to take-off and RSI-mod were more sensitive to NMF after a competitive soccer match in youth players.⁷ This is potentially due to movement strategies employed to attain the same outcome under fatigue conditions, potentially masking post-match performance decrements⁸. Accordingly, outcome-based variables are likely appropriate for performance profiling purposes while time-based variables are better suitable for NMF monitoring.^{6,9} Beyond performance profiling and NMF, asymmetry variables intuitively seem important for rehabilitation, showing potential bilateral deficits in jump performance.⁶ Injured professional soccer players have shown greater asymmetries in various bilateral CMJ variables compared with their non-injured counterparts.¹⁰ However, information about the reliability of CMJ-derived parameters in academy soccer players has been limited to JH.

The reliability of different force-time variables in young soccer players has been previously described. Specifically, JH presented good-to-excellent within- and between-session reliability (intraclass correlation coefficient; ICC = .80–.93; coefficient of variation; CV = 2.6–7.7%, respectively).^{7,11} Similarly, concentric peak force (PF) and mean power (MP), peak power (PP), eccentric mean braking and deceleration force, eccentric MP and PF and force at 0 velocity (F@0V) reported good-to-excellent reliability (ICC = 0.89–0.98; CV = 2.4–4.6% and ICC = .75–.97; CV = 4.2–7.1%, respectively).^{7,12} Time-based variables (i.e., reactive strength index modified [RSI-mod], concentric and eccentric duration [Con-Dur and Ecc-Dur, respectively]) moderate-to-excellent within-session reliability (ICC = .72–.93; CV = 5.1–8.1%) and good-to-excellent between-session reliability (ICC = .88–.95; CV = 8.1–10.4%) in young soccer players.^{7,12} Additionally, information about the reliability of different CMJ bilateral asymmetry index is limited to one study of basketball players reporting acceptable reliability (ICC = .74–.77) except for the PF, which reported poor reliability (ICC = .63).¹³ Still, conclusive information about the reliability of asymmetry-based CMJ variables (i.e., the magnitude of asymmetry) is still missing in the literature of young soccer players. Beyond the reliability of CMJ parameters, it is important to provide practitioners with actionable numbers to understand whether a given change

represents a true change in performance or natural fluctuations in performance variability. Consequently, this is why the standard error of measurement (SEM) is useful, but to the authors' knowledge, no available information about CMJ-derived SEM in young soccer players exists.

The numerous CMJ force-time variables available do not necessarily imply an increased value for information, as many variables may be related, thereby providing redundant information. Indeed, a limited number of key performance indicators are generally retained for ease of interpretation.¹⁴ To avoid redundant information, dimensionality reduction techniques can be applied, such as a principal component analysis (PCA), which transforms possibly correlated variables into a smaller set of uncorrelated components (principal components [PC]), enhancing visualization and interpretation. Studies applying PCA in the CMJ force-time variables found that different PCs may help to identify key factors in the CMJ outcome-based and time-based variables and to detect clearer patterns in the variables located within the same PC.^{15,16} Those studies simplified the CMJ force-time variables from 16 force-time variables to 4 PCs¹⁵ and explored the relationship of the CMJ force-time variables with NMF and metabolic fatigue in recreational athletes.¹⁶ Due to the high amount of CMJ outcome-, -time and asymmetry-based variables, the process of dimensionality reduction could streamline data analysis and interpretation for practitioners to monitor performance, NMF and rehabilitation processes in young soccer players, ensuring that time is saved and analysis is confined to only relevant information.

In summary, limited evidence has reported the reliability of CMJ force-time variables in academy soccer players,^{7,11,12} and no information is available about the reliability of bilateral asymmetry. Dimensionality reduction of the numerous CMJ variables is still necessary to enhance data analysis and interpretation yet no study has addressed this in young soccer players. Therefore, this study aimed to determine the reliability and relevance of key CMJ parameters in academy soccer players.

Methods

Subjects

Sixty-three young male soccer players competing in the Tier 4 (Elite/International level, training; training frequency, 4 or 5/week, depending on the weekly fixture) of the participant classification framework¹⁷ participated in the study. All players competed at the National level in the UAE, including international duties. Inclusion criteria were competing for U17 and U19 teams and development categories with clearance for full participation in all activities. Players selected for the analysis remained injury-free at least 3 months before or during the testing period. The methodology conformed to the policy statement in accordance with the Declaration of Helsinki, and the club formally authorized the use of testing data for research purposes. All subjects and their parents/legal guardians were informed of the risks and benefits of the procedure and signed an informed consent form for participation in the study. The institutional ethical board of Catholic University of Murcia approved and recorded the study under the protocol CE102404.

Design

Two independent analyses were conducted. First, reliability was determined using a test-retest design was adopted to collect CMJ force-time over four testing trials (i.e., two test re-test) over two sessions separated by a seven-day period time. Both testing sessions were performed at the same time (10:00) followed by 48 hours rest. In this case, our dependent variables were different force-related parameters available from the CMJ, whereas our independent variables were the testing trial (within- and between-session). Second, a PCA was conducted considering the most representative CMJ (based on the JH) from three seasonal CMJ assessments.

Methodology

Reliability

The reliability of different CMJ force-time variables was determined in a convenience sub-sample of 20 outfield players belonging to development and U17 teams across two separate trials. As a result of dropout ($n=3$ players), seventeen players were available for the second test (between-session reliability, $n=17$ players). Nonetheless, the observations related to players who dropped out (collected on the first occasion) were maintained in the final sample of the within-session reliability analysis. Finally, 34 and 17 individual test-retest observations (instead of the expected 40 and 20) were computed for within- and between-session reliability, respectively. The participants' characteristics have been previously reported.¹⁸

Dimensional reduction

The PCA was performed in the CMJ force-time variables from each category (outcome-based, time-based and asymmetry-based variables). In this analysis, 47 young soccer players from two different age-groups (Under-19 and Under-17; $n=19$ and 28 ; age= $17.3 \pm .9$ and $16.2 \pm .36$ years; estimated maturity offset= $2.9 \pm .8$ and $1.9 \pm .5$ years; height= 177 ± 6.6 and 177 ± 6.3 cm; body mass= 69.0 ± 9.0 and 67 ± 8.9 kg, respectively). The best individual CMJ (based on the higher JH) was retained over 128 individual observations collected during three competitive time points (i.e., early-, mid- and late-season) throughout the 2023-24 season.

Countermovement jump testing

Before the assessments, a standardized warm-up consisting of 5-min biking and dynamic stretching was conducted, followed by two max effort CMJs. Before the test, each participant performed two CMJs attempts to finish the warm-up. After the standardized warm up, a CMJ assessment was conducted using a 1000-Hz dual force plate system (ForceDecks FD Lite, VALD Performance, Brisbane, Australia). After being positioned motionless in an upright stance with their feet shoulder-width apart for a minimum of 1-second, the players performed a CMJ by flexing their knees to a position they perceived to be comfortable (i.e., preferred starting push-off position). The no-arm swing version was used to limit possible variations in posture during the jump that could affect the final assessment. Force-time data derived from the CMJ were instantaneously uploaded into the manufacturer's data administration platform (VALD Hub, VALD Performance, Brisbane, Australia). Three CMJ trials were performed, separated by 45-60 s

passive rest. JH was calculated using the impulse-momentum method which determines the vertical velocity of the center of mass at take-off based on the preceded net vertical impulse. The different phases of the CMJ were recorded according to the manufacturer guidelines, specifically eccentric phase (from the start of the movement [moment when force deviates from steady-state] until velocity equals 0 m·s⁻¹), braking phase (from point of minimum force until velocity equals 0 m·s⁻¹), deceleration phase (from peak negative velocity to 0 m·s⁻¹), concentric phase (from moment of zero velocity to the take-off) and flight phase (from vertical force equals 0 N to start of the movement).

The most representative trial among the three seasonal assessments was selected based on the highest JH, because this metric is considered the most ecologically meaningful jump outcome. Thus, selecting the representative trial based on JH ensures that the chosen attempt very likely corresponded to the athlete's best expression of performance capacity. For between-session analysis, the most representative within-session assessment was based on the maximum value for all variables, except for the Ecc–Dur, Con–Dur and TPP being the minimum value. Regarding asymmetry variables, average values for the three jump trials were used for asymmetries.¹⁹ The equation used to calculate asymmetries was in accordance with previous CMJ studies:²⁰

$$(right\ side\ value - left\ side\ value) / maximum\ of\ (right\ side\ value + left\ side\ value) \times 100.$$

Finally, a total of 29 CMJ variables (8 outcome-based variables, 13 time-based variables and 8 asymmetry or symmetry-based variables) were included for the analysis.⁶ A detailed description of the CMJ variables adopted is reported in **Table 1**.

Please insert Table 1 near here

Statistical analysis

Descriptive values were presented as mean ± standard deviations (SD) for all variables. Statistical significance was set at $P \leq .05$. Reliability analyses of the variables were conducted in Microsoft Excel spreadsheet (Microsoft Corp., Redmond, WA, USA) adapted from Hopkins (Sportsmedicine 19, 36-42, 2015; sportsci.org/2015/ValidRely.htm), and all subsequent statistical analyses, including assumption testing and PCA, were performed using Jamovi software (version 2.3.28; The jamovi project, 2022; <https://www.jamovi.org>).

The systematic bias was described as the mean performance variation between trials with associated 95% confidence intervals (CI). A paired-sample t-test was conducted to assess the test-retest means systematic difference. Hedges g effect sizes with 95% CIs were calculated by dividing the test retest difference by the pooled SD. Reliability was assessed through the ICC, and qualitatively interpreted based on the lower 95% CI boundary based on previous studies: as poor (ICC<.50), moderate (ICC=.50–.75), good (ICC=.75–.90) and excellent (ICC>.90).²¹ Additionally, the coefficient of variation (CV) was calculated by dividing the within-subject SD by the mean and then multiplying by 100. The reliability according to the CV was interpreted based on the upper boundary of the 95% CI: as excellent (CV<5%), good (CV=5–10%), acceptable (CV=10–15%) and poor (CV>15%).²² Thus, the minimum acceptable reliability was determined with non-significant differences between trials, an ICC≥.50 and a CV≤15%. The standard error of measurement (SEM) was calculated by multiplying the within-subject SD by $\sqrt{1-ICC}$.²³ To provide a practical

interpretation of changes in jump data, the smallest worthwhile change (SWC) was calculated by multiplying the between-individual SD by 0.2.²⁴ The ICC and between-trial effect sizes were computed on original values for all variables.

Prior to the PCA, the assumptions of the relatedness between variables were examined. Respectively for the outcome-, time- and asymmetry based variables, the Kaiser–Meyer–Olkin measure of sampling adequacy was 0.612, 0.574 and 0.791, and Bartlett’s test of sphericity was significant ($\chi^2 = 627$; $P < 0.001$; $\chi^2=342$, $P<0.001$; $\chi^2=1190$, $P<0.001$), indicating sufficient shared variance to justify the PCA. The PCA was performed in to identify the principal components accounting for the most variance (i.e., eigenvalues >1.0) with a variable loading matrix (Varimax rotation) generated to identify variables and an individual loading value of ≥ 0.70 . Three independent PCAs were performed for outcome-based, time-based and asymmetry-based variables.

Results

Reliability

The within-session reliability values for most outcome-based variables was good-to-excellent ($ICC \geq .81$; $CV \leq 13.7\%$) except for the unacceptable within-session reliability results reported for the Land–PF (ICC [95% CIs] = .90 [.84–.94] and CV [95% CIs] = 11.7% [8.0–15.5]). Similarly, the between-session reliability of most outcome-based variables was excellent ($ICC \geq .96$; $CV \leq 8.1\%$). Unacceptable levels of between-session reliability were reported for the Ecc–PV and the Land–PF ($ICC \geq .77$; $CV \leq 16.9\%$). A detailed description of the reliability and usefulness of CMJ outcome-based variables is reported in **Table 2**.

The within-session reliability of the time-based variables was good-to-excellent for most of the variables ($ICC \geq .89$; $CV \leq 12.1\%$). Moderate within-session reliability was reported for the FT:CT and RSI–mod ($ICC \geq .67$; $CV \leq 10.0\%$). Unacceptable levels of within-session reliability were reported for the RFD–50 and the FV–AUC variables ($ICC \geq .56$; $CV \leq 46.3\%$). The between-session reliability of the time-based variables was good to excellent for most of the variables ($ICC \geq .78$; $CV \leq 12.9\%$) except for the RFD–50 with unacceptable levels of between-session reliability (ICC [95% CI] = .88 [.80–.92] and CV [95% CI] = 13.5% [8.6–18.4]). A detailed description of the reliability and usefulness of CMJ time-based variables is reported in **Table 3**.

The within-session reliability of asymmetry-based variables was unacceptable in all variables ($ICC \geq .10$; $CV \leq 57.6$). The between-session reliability was unacceptable for all the asymmetry-based variables ($ICC \geq .11$; $CV \leq 66.4\%$). A detailed description of the reliability and usefulness of CMJ asymmetry-based variables is reported in **Table 4**.

The within-session reliability of symmetry-converted parameters was excellent for all the variables ($ICC \geq .90$; $CV \leq 11.8\%$). The between-session reliability of symmetry-converted variables was excellent for all the variables ($ICC \geq .93$; $CV \leq 9.8\%$). A detailed description of the reliability and usefulness of CMJ asymmetry-based variables presented as symmetry is reported in **Table 5**.

Please insert Table 2, 3, 4 and 5 near here

Dimensionality reduction

The PCA of outcome-based variables reported 3 PCs, explaining 83.1% of the total variance in the CMJ performance. The PC-1 (eigenvalue = 4.34; variance = 43.4%) grouped four CMJ force-time variables (PP-Rel, Con-MP, Con-MF and Con-PF), the PC-2 (eigenvalue = 2.22; variance = 22.2%) grouped two CMJ force-time variables (PP and Ecc-MF). The PC-3 (eigenvalue = 1.75; variance = 17.5%) grouped two CMJ force-time variables (Land-PF, Ecc-PV).

The PCA performed in time-based variables reported 3 PCs, explaining 76.1% of the total variance of the CMJ. The PC-1 (eigenvalue = 3.01; variance = 30.1%) grouped three CMJ force-time variables (RSI-mod, FT:CT and MEccConP). The PC-2 (eigenvalue = 2.90; variance = 29.0%) grouped two CMJ force-time variable (Con-Dur, Con-I). The PC-3 (eigenvalue = 1.70; variance = 17.0%) grouped two CMJ force-time variable (RFD-50, Land-I).

The PCA for asymmetry (or presented as symmetry-based) variables reported two PCs, explaining 81.9% of the total variance of the CMJ. The PC-1 (eigenvalue = 5.31; variance = 66.3%) grouped six CMJ force-time variables (Con-I_{Asym}, Con-MF_{Asym}, Ecc-BI_{Asym}, Ecc-DI_{Asym}, Ecc-MF_{Asym} and F@0V_{Asym}). The PC-2 (eigenvalue = 1.25; variance = 15.6%) grouped one CMJ force-time variable (Land-PF_{Asym}). A loading matrix with Varimax rotation for the three analyses is reported in **Table 6**.

Please insert Table 5 here

Discussion

Given the wide range of CMJ force-time variables, reducing the analysis to only those with acceptable reliability can improve efficiency. Most outcome-based variables demonstrated acceptable reliability, except for the Ecc-PV and Land-PF. Similarly, most time-based variables presented acceptable levels of reliability except the RFD-50 and FV-AUC. Furthermore, all asymmetry-based variables showed unacceptable levels of reliability in young soccer players. Notably, when asymmetries were expressed as symmetries, reliability improved with all variables presenting acceptable levels of reliability within- and between-session. Notwithstanding, the outcome- and time-based variables can be reduced to three PCs and asymmetry-based variables showed two PC. Specifically, outcome-based PC-1 included PP-Rel, Con-MP, Con-MF, Con-PF; PC-2 included PP and Ecc-MF; PC-3 included Land-PF and Ecc-PV. Time-based variables PC-1 included RSI-mod, FT:CT and MEccConP; PC-2 included Con-Dur and Con-I; PC-3 included RFD-50 and Land-I. Asymmetry-based variables were grouped into two PCs, PC-1 included Con-I_{Asym}, Ecc-BI_{Asym}, Ecc-DI_{Asym}, Ecc-MF_{Asym} and F@0V_{Asym}; PC-2 included Land-PF_{Asym}.

Outcome-based variables such as JH, PP, MP-Rel, MF-Rel and Ecc-MF generally showed excellent reliability ($ICC \geq .98$; $CV \leq 5.0\%$), partially aligning with previous studies in young soccer, rugby, and collegiate athletes ($ICC = .87-.97$; $CV = .4-10.6\%$).^{7,8,11,25,26} Similarly, PF-Rel and F@0V reported excellent values of within- and between-session reliability which is in line with previous reports in basketball and young soccer players ($ICC = .93-.94$; $CV = 3.3-4.4\%$).^{7,25} The discrepancies found in our study may relate to differences in sample maturity and

jump experience. For example, the maturity offset of the U17 soccer players recruited by [Franceschi, et al.](#)⁷ belonged to a potentially greater competitive standard (i.e., U17 of the Italian Serie A) and with an advanced maturational state (i.e., maturity offset=2.6±.5) compared to our players. Other reliability studies have also examined different athletic populations (e.g., collegiate athletes and rugby players), which may further explain the differences observed. New insights were also provided for Ecc–PV and Land–PF, with Land–PF showing unacceptable levels of between-session reliability ($ICC \geq .83$; $CV \leq 16.1\%$) and Ecc–PV reporting unacceptable levels of within- and between-session reliability ($ICC \geq .77$; $CV \leq 16.9\%$). Our results, especially regarding the values of between-session reliability reinforces the idea that outcome variables remain stable due to compensatory movement strategies that mask underlying neuromuscular changes.⁸ In other words, commonly used outcome-based variables tend to be stable regardless of the jumping strategy adopted.

Most time-based variables showed good-to-excellent levels of reliability ($ICC \geq .89$; $CV \leq 12.1\%$), in line with prior research in young soccer, rugby, and collegiate team-sport athletes.^{7,8,25,26} Curiously, FT:CT and RSI–mod reported moderate within-session reliability results ($ICC \geq .67$; $CV \leq 10.0\%$) but excellent between-session reliability results ($ICC \geq .94$; $CV \leq 8.9\%$) showing good reproducibility over time. Con–Dur and Con–I demonstrated good-to-excellent reliability, which is supported by previous findings in soccer players, suggesting population-specific consistency.⁷ Conversely, Con–Dur reliability was lower (moderate-to-good) in collegiate team-sports athletes.^{8,25} The reliability results of RFD–50 were unacceptable within- and between-session ($ICC \geq .53$; $CV \leq 46.3\%$), which is in line with the values reported in rugby and basketball players ($ICC = .39-.95$; $CV = 33.8-63.9\%$),²⁷ highlighting its limitations by measurement variability.²⁸ Novel findings also include MEccConP, FV–AUC, CMJ–Depth and Land–I, showing good-to-excellent reliability results ($ICC \geq .82$; $CV \leq 12.9\%$) and unacceptable within-session reliability results for the FV–AUC ($ICC \geq .56$; $CV \leq 19.9\%$), a point of special relevance for injury prevention and rehabilitation due the link of Land–I with landing mechanics.⁶

Asymmetry-based variables showed unacceptable reliability results both within- and between-session. Interestingly, lower reliability is expected in impulse-derived variables (i.e., Con–I_{Asym}, Ecc–BI_{Asym}, Ecc–DI_{Asym}, Land–I_{Asym}) being the product of the ground-reactive forces and contact-time, thus any change in the jumping-strategy would alter the time spent in the ground.^{29,30} Notably, when asymmetries were expressed as symmetries (100 – asymmetry), between-session reliability improved substantially with all variables showing excellent reliability results within- ($ICC \geq .91$; $CV \leq 11.8\%$) between-session ($ICC \geq .93$; $CV \leq 9.8\%$). This suggests that shifting from asymmetry to symmetry could reduce the relative impact of small absolute differences within- and between- sessions. Specifically, the CV values improved due to an increased mean value and unchanged standard deviation, reflecting improved relative consistency. Additionally, absolute reliability also improved in some Asymmetry variables, likely reflecting reduced within-subject variability or measurement error. The observed change in ICC between asymmetry and symmetry arises from the fact that ICC, particularly in absolute agreement models, is not invariant to linear transformations; alterations in the mean structure and absolute differences among measurements may have affected reliability. This indicates the measurement became more stable both in relative and absolute terms in asymmetry transformed values because of asymmetry values being inherently more sensitive to small fluctuations. Notably,

expressing data as symmetry could "dampen" these fluctuations, especially if asymmetries are small and tend to cluster tightly near the symmetrical ceiling (i.e., 100%). Therefore, it is recommended that the asymmetry results are reported as symmetries in any performance or rehabilitation setting to increase the reliability of the variables.

Our study offers novel results regarding the different key factors of the CMJ outcome-based and time-based in young soccer players. Three PCs were reported for outcome- and time-based variables while only two PCs were reported for asymmetry-based variables, explaining a total of 83.1% (i.e., PC-1 = 43.4%; PC-2 = 22.2%; PC-3 = 17.5%), 76.1% (i.e., PC-1 = 30.1%; PC-2 = 29.0%; PC-3 = 17.0%) and 81.9% (PC-1 = 69.8%; PC-2 = 15.6%) of the variance, respectively. Therefore, the present findings must be considered for future investigations in young soccer players, as the explanatory power of only two or three components can enhance an efficient representation of the data while retaining most of the original information.³¹ Additionally, the outcome-based variables analysis may be decreased to MP-Rel, PF-Rel and MF-Rel from the PC-1, PP and Ecc-MF from the PC-2 and Land-PF and Ecc-PV from the PC-3. The variables belonging to the third component showed unacceptable levels of reliability and the variables from PC-1 and PC-2 may be preferred over the PC-3 variables. Time-based variables analysis in young soccer players can be streamlined to FT:CT, RSI-mod and MEccConP from the PC-1, Con-Dur and Con-I from the PC-2 and RFD-50 and Land-I from the PC-3. Noteworthy, Land-I may be preferred over RFD-50. The analysis of asymmetry-based variables can be streamlined to two to three variables from the concentric and eccentric phase belonging to the PC-1 (Con-I_{Asym}, Con-MF_{Asym}, Ecc-BI_{Asym}, Ecc-DI_{Asym}, Ecc-MF_{Asym}, F@0V_{Asym}) and variables from the landing phase belonging to the PC-2 (Land-PF_{Asym}) as all showed acceptable levels of reliability. Practitioners could enhance their CMJ analysis by selecting variables that strongly correlate with each component. Therefore, CMJ force-time analysis in young soccer players may be reduced to two or three variables from each PC in each CMJ force-time variables category (outcome-based, time-based or asymmetry-based) selecting the most reliable variables presented in this study.

The main limitation of this study is the relatively small sample of young soccer players. Notwithstanding, Practitioners should be aware that the higher the experience in the test the lower reliability is expected, especially in the time-based variables. The poor reliability observed in asymmetry values might be explained by the fact that the asymmetry was calculated from left- and right-side and ultimately presented as a ratio number as ratio values can be easily influenced by changes in their constituent parts.³⁰ Additionally, different equations have been proposed to calculate asymmetry and the one used to calculate the asymmetries in our study may have affected the reliability of the variables. Caution is recommended when interpreting the results of our PCA as components can be influenced by many factors (i.e., moment of the season, sample). Thus, our results can't be extrapolated to samples from other countries, ages or moments of the season. Lastly, this study lacked the capacity to quantify either the external or internal training load during the testing period.

Practical applications

Practitioners involved with testing young soccer players can confidently rely on our studied variables to assess athletic performance, monitor fatigue / readiness status and track rehabilitation. Only two outcome-based and time-based variables reported unacceptable levels of reliability. However, changes in asymmetry-based variables should be interpreted very carefully due to their poor levels of reliability and their marginal usefulness in detecting true within- and between-session changes. Transforming asymmetry to symmetry values is recommended due to an increase of reliability. CMJ analysis may be limited to three PCs from relevant and reliable outcome-based, time-based and two PCs in asymmetry-based variables. Therefore, the analysis of the CMJ in young soccer players can be reduced to two-to-three reliable variables from two or three PCs in either output-based, time-based and asymmetry-based variables.

Conclusions

The CMJ seems to be a reliable test for profiling athletic performance, neuromuscular fatigue, and injury rehabilitation in young soccer players. Specifically, seven outcome-based variables (JH, PP, MP-Rel, PF-Rel, MF-Rel, F@0V, Ecc-MF) presented acceptable levels of reliability; nine time-based variables (i.e., Con-I, FT:CT, RSI-mod, Ecc-Dur, Con-Dur, MEccConP, TPP, CMJ-Depth and Land-I) presented acceptable levels of reliability; asymmetry-based variables showed not to be reliable when reported as asymmetry but reported excellent levels of within- and between-session reliability between-session in all variables when reported as symmetries. Importantly, the analysis of the CMJ could be reduced to three key factors in the outcome-, time-based variables and two in asymmetry-based variables. This information can interest researchers and practitioners who utilize these variables for different purposes within performance, neuromuscular fatigue monitoring or rehabilitation testing.

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Table 1. Descriptive of the CMJ force-time variables.

Variables (units)	Abbreviation	Description
<i>Output-based variables</i>		
Jump height (cm)	JH	Maximum jump height (calculated using the impulse-momentum method)
Absolute peak power (W)	PP	Greatest power achieved during the jump
Relative peak power (W/kg)	PP-Rel	Greatest power achieved during the jump relative to the athlete's mass
Relative mean power (W/Kg)	MP-Rel	Mean power exerted during the concentric phase relative to the athlete's mass
Propulsive relative peak force (N/kg)	PF-Rel	Peak force exerted during the concentric phase, relative to the athlete's mass
Propulsive relative mean force (N/kg)	MF-Rel	Mean force exerted during the concentric phase, relative to the athlete's mass
Force at 0 velocity (N)	F@0V	Force exerted at concentric phase onset (i.e., velocity is at zero)
Eccentric mean force (N)	Ecc-MF	Mean force exerted during the eccentric phase
Peak Eccentric velocity (m/s)	Ecc-PV	Peak velocity during the eccentric phase
Peak landing force (N/kg)	Land-PF-Rel	Peak force exerted during the landing phase, relative to the athlete's mass
<i>Time-based variables</i>		
Rate of force development (N/s)	RFD-50	The greatest rate of force increases over a 50-ms epoch during the concentric phase
Concentric impulse (Ns)	Con-I	Total force exerted during the concentric phase multiplied by time taken
Flight time: contraction time ratio	FT:CT	Ratio of flight-to-contraction time
Reactive strength index (m/s)	RSI-mod	Jump height divided by time to take off based on impulse-momentum
Eccentric duration (ms)	Ecc-Dur	Time period of the eccentric phase
Concentric duration (ms)	Con-Dur	Time period of the concentric phase
Mean Eccentric +Concentric Power over Time (W/s)	EccConMP	Mean absolute power during the eccentric and concentric phases divided by total duration (ms) of the jump.
Time to Peak Power (s)	TPP	Time from jump initiation to peak power
Countermovement depth (cm)	CMJ-Depth	Maximum displacement between the start of the movement to take off
Area under the force velocity trace (N/ms ²)	FV-AUC	Area under the eccentric phase of the force-velocity trace
Landing impulse (Ns)	LI	Total force exerted during the landing phase multiplied by time taken
<i>Asymmetry-based variables</i>		
Impulse asymmetry (%)	Con-I _{Asym}	Standard percent difference between limbs of the total force exerted during concentric phase multiplied by time taken
Propulsive mean force asymmetry (%)	Con-MF _{Asym}	Standard percent difference between limbs of the mean force exerted during concentric phase
Eccentric braking impulse asymmetry (%)	Ecc-BI _{Asym}	Standard percent difference between limbs of the total force exerted during braking phase multiplied by time taken
Eccentric deceleration impulse asymmetry (%)	Ecc-DI _{Asym}	Standard percent difference between limbs of the total force exerted during deceleration phase multiplied by time taken
Eccentric mean force asymmetry (%)	Ecc-MF _{Asym}	Standard percent difference between limbs of the mean force exerted during eccentric phase
Landing impulse asymmetry (%)	Land-I _{Asym}	Standard percent difference between limbs of the total force exerted during landing phase multiplied by time taken
Landing peak force asymmetry (%)	Land-PF _{Asym}	Standard percent difference between limbs of the peak force exerted during landing phase
Force at 0 velocity asymmetry (%)	F@0V _{Asym}	Standard percent difference between limbs of the force exerted at concentric phase onset (i.e., velocity is at zero)

Table 2. Reliability and usefulness of the CMJ outcome-based variables in Academy soccer players.

Parameter	Test	Retest	Δ (95% CIs)	SEM (95% CIs)	ES (95% CIs)	CV (95% CIs)	ICC (95% CIs)	SWC (95% CIs)
<i>Within-session</i>								
JH [cm]	33.7 $\pm$ 3.6	33.1 $\pm$ 3.9	-0.4 (-1.0; 0.2)	0.1 (0.0; 0.1)	-0.02 (-0.14; 0.09)	3.4 (2.4; 4.4)	.99 (.99; .99) *	0.8 (0.7; 0.8)
PP [W]	2948.2 $\pm$ 532.0	2914.7 $\pm$ 524.7	-21.8 (-57.2; 13.6)	93.9 (79.4; 115.7)	-0.01 (-0.13; 0.10)	2.4 (1.7; 3.1)	1.00 (.99; 1.00) *	106.8 (103.0; 11.5)
MP-Rel [W/kg]	27.8 $\pm$ 3.0	27.2 $\pm$ 3.0	0.4 (-0.9; 0.1)	1.4 (1.1; 1.7)	-0.03 (-0.18; 0.12)	3.3 (2.2; 4.4)	.99 (.98; .99) *	0.6 (0.5; 0.7)
PF-Rel [N/kg]	25.4 $\pm$ 3.1	25.3 $\pm$ 3.1	0.0 (-0.6; 0.6)	1.6 (1.3; 2.0)	0.00 (-0.02; 0.01)	3.6 (2.3; 5.0)	.98 (.97; .99) *	0.6 (0.5; 0.7)
MF-Rel [N/kg]	19.9 $\pm$ 2.0	19.7 $\pm$ 1.8	-0.2 (-0.5; 0.2)	0.1 (0.0; .01)	-0.02 (-0.11; 0.08)	2.7 (1.9; 3.6)	.99 (.99; 1.00) *	0.4 (0.3; 0.4)
F@0V [N]	1523.2 $\pm$ 242.5	1486.5 $\pm$ 316.5	-23.9 (-66.6; 18.9)	113.5 (95.9; 139.8)	-0.03 (-0.14; 0.07)	5.2 (3.2; 7.1)	.98 (.96; .99) *	57.1 (51.8; 62.3)
Ecc-MF [N]	643.0 $\pm$ 90.1	642.7 $\pm$ 90.0	-0.2 (-0.8; 0.4)	1.6 (1.4; 2.0)	0.00 (-0.07; 0.07)	0.2 (0.1; 0.2)	1.00 (1.00; 1.00) *	18.2 (18.1; 18.3)
Ecc-PV [m/s]	-1.0 $\pm$ 0.2	-1.01 $\pm$ 0.3	0.00 (-0.01; 0.00)	0.1 (0.0; 0.1)	-0.06 (-0.14; 0.02)	11.7 (8.0; 15.5)	.89 (.81; .93) *	0.1 (0.0; 0.1)
Land-PF [N/kg]	82.8 $\pm$ 25.0	82.3 $\pm$ 26.7	-0.4 (-5.2; 4.5)	1.3 (1.0; 1.6)	-0.01 (-0.02; 0.00)	1.5 (7.3; 13.7)	.90 (.84; .94) *	5.2 (4.6; 5.8)
<i>Between-session</i>								
JH [cm]	34.5 $\pm$ 4.5	35.8 $\pm$ 3.9	0.5 (0.0; 0.9)	0.1 (0.0; 0.1)	0.04 (-0.16; 0.24)	3.3 (1.7; 4.9)	.99 (.98; .99) *	0.9 (0.8; 1.0)
PP [W]	3019.0 $\pm$ 537.9	3098.2 $\pm$ 511.4	29.7 (5.8; 53.6)	<.1	0.03 (-0.21; 0.26)	2.1 (1.0; 3.2)	1.00 (.99; 1.00) *	107.1 (101.9; 112.2)
MP-Rel [W/kg]	28.5 $\pm$ 3.5	28.5 $\pm$ 3.0	0.0 (-0.3; 0.3)	0.8 (0.7; 1.0)	0.00 (-0.01; 0.01)	2.6 (1.5; 3.6)	.99 (.99; 1.00) *	0.7 (0.6; 0.7)
PF-Rel [N/kg]	26.8 $\pm$ 3.9	25.1 $\pm$ 2.2	-0.7 (-1.3; -0.1)	1.6 (1.3; 1.9)	-0.08 (-0.31; 0.16)	4.9 (2.9; 7.0)	.97 (.96; .99) *	0.7 (0.5; 0.8)
MF-Rel [N/kg]	20.3 $\pm$ 2.3	20.1 $\pm$ 1.6	-0.1 (-0.4; 0.2)	0.7 (0.6; 0.9)	-0.01 (-0.08; 0.05)	3.0 (2.0; 4.0)	.99 (.99; 0.99) *	0.4 (0.4; 0.4)
F@0V [N]	1663.9 $\pm$ 274.9	1517.3 $\pm$ 248.3	-55.0 (-90.8; -19.2)	95.1 (80.4; 117.2)	-0.09 (-0.38; 0.20)	5.4 (2.6; 8.1)	.98 (.96; .99) *	55.3 (46.4; 64.3)
Ecc-MF [N]	654.1 $\pm$ 85.0	653.8 $\pm$ 84.2	-0.1 (-1.8; 1.6)	4.6 (3.9; 5.7)	0.00 (-0.01; 0.01)	0.6 (0.5; 0.8)	1.00 (1.00; 1.00) *	9.3 (8.2; 1.5)
Ecc-PV [m/s]	-1.0 $\pm$ 0.2	-1.0 $\pm$ 0.3	0.0 (-0.1; 0.0)	0.1 (0.1; 0.2)	-0.06 (-0.13; 0.02)	12.5 (8.2; 16.9)	.86 (.77; .91) *	0.1 (0.0; 0.1)
Land-PF [N/kg]	85.2 $\pm$ 23.7	97.9 $\pm$ 31.1	5.4 (1.4; 9.4)	10.7 (9.0; 13.2)	0.17 (-0.08; 0.42)	11.1 (6.0; 16.1)	.89 (.83; .94) *	1.6 (1.4; 1.8)

Abbreviations: Con-PF: concentric peak force; CMJ-Depth: countermovement depth; Ecc-MF: eccentric mean force; Ecc-PV: eccentric peak velocity; F@0V: force at 0 velocity; JH: Jump height; MF: mean force; MP: mean power; Land-PF: landing peak force; PP: peak power. * Denotes $P < 0.01$.

Table 3. Reliability and usefulness of the CMJ time-based variables in Academy soccer players.

Parameter	Test	Retest	Δ (95% CIs)	SEM (95% CIs)	ES (95% CIs)	CV (95% CIs)	ICC (95% CIs)	SWC (95% CIs)
<i>Within-session</i>								
RFD [N/s]	1662.3 $\pm$ 2573.4	2289.2 $\pm$ 3244.6	407.5 (-145.9; 960.9)	1468.8 (1241.7; 1809.6)	0.16 (0.02; 0.29)	4.8 (36.8; 46.3)	.69 (.53; .81) *	594.7 (521.1; 668.4)
Con-I [Ns]	168.2 $\pm$ 27.7	166.8 $\pm$ 26.9	-1.0 (-2.4; .5)	<.1	-0.01 (-0.13; 0.11)	1.7 (1.3; 2.2)	1.00 (1.00; 1.00) *	5.5 (5.4; 5.7)
FT:CT	.71 $\pm$.13	.73 $\pm$.11	-.04 (-.01; .01)	.15 (.12; .18)	-0.13 (-0.27; 0.02)	5.4 (3.3; 7.5)	.81 (.70; .89) *	.02 (.00; .00)
RSI-mod [m/s]	.45 $\pm$.09	.46 $\pm$.08	-.03 (-.06; .01)	.1 (.08; .12)	-0.13 (-0.27; 0.01)	7.3 (4.6; 10.0)	.79 (.67; .87) *	.02 (.00; .00)
Ecc-Dur [ms]	591.8 $\pm$ 92.8	577.8 $\pm$ 158.2	-9.1 (-41.5; 23.3)	86.1 (72.8; 106.1)	-0.03 (-0.08; 0.03)	7.3 (4.1; 10.4)	.94 (.89; .96) *	26.2 (21.5; 31.0)
Con-Dur [ms]	301.8 $\pm$ 45.5	297.1 $\pm$ 51.3	-3.1 (-11.6; 5.5)	.5 (.3; .6)	-0.02 (-0.09; 0.05)	5.2 (3.5; 6.9)	.98 (.97; .99) *	9.8 (8.8; 1.8)
MEccConP [W/s]	1257.8 $\pm$ 323.5	1292.8 $\pm$ 350.9	22.8 (-35.7; 81.2)	155.3 (131.2; 191.3)	0.04 (-0.04; 0.11)	8.6 (6.2; 10.9)	.94 (.90; .96) *	68.2 (61.7; 74.8)
TPP [s]	.82 $\pm$.11	.80 $\pm$.21	-.02 (-.06; .02)	.11 (.09; .13)	-0.03 (-0.11; 0.04)	6.7 (3.6; 9.9)	.95 (.91; .97) *	.03 (.00; .00)
CMJ-Depth	-32.4 $\pm$ 8.1	-32.7 $\pm$ 6.9	-.2 (-1.6; 1.2)	.2 (.1; .2)	-0.01 (-0.04; 0.02)	7.5 (5.4; 9.6)	.95 (.92; .97) *	1.5 (1.4; 1.6)
FV-AUC [N/ms ²]	19.6 $\pm$ 6.7	22.4 $\pm$ 9.8	1.9 (.0; 3.7)	5.0 (4.2; 6.2)	0.20 (0.02; 0.39)	14.1 (8.2; 19.9)	.71 (.56; .82) *	1.7 (1.4; 2.0)
LI [N s]	86.3 $\pm$ 29.4	80.8 $\pm$ 25.1	-3.6 (-7.5; .4)	10.4 (8.8; 12.8)	-0.08 (-0.25; 0.09)	9.9 (7.7; 12.1)	.95 (.91; .97) *	5.5 (5.2; 5.9)
<i>Between-session</i>								
RFD [N/s]	25738.2 $\pm$ 983.0	20232.0 $\pm$ 6167.2	-2064.8 (-3413.5; -716.2)	429.6 (241.3; 617.8)	-0.21 (-0.50; 0.08)	13.5 (8.6; 18.4)	.88 (.80; .92) *	176.6 (1432.5; 2088.8)
Con-I [Ns]	173.6 $\pm$ 27.6	174.6 $\pm$ 26.3	-3.9 (-12.7; 4.8)	3.0 (1.7; 4.4)	-0.06 (-0.15; 0.02)	1.5 (.8; 2.2)	.87 (.78; .92) *	5.5 (5.3; 5.7)
FT:CT	0.80 $\pm$ 0.13	0.74 $\pm$ 0.11	-0.03 (-0.05; -0.01)	0.05 (0.04; 0.06)	-0.10 (-0.37; 0.18)	5.9 (3.5; 8.2)	.97 (.95; .98) *	<.1
RSI-mod [m/s]	0.51 $\pm$ 0.09	0.47 $\pm$ 0.09	-0.01 (-0.03; 0.00)	0.04 (0.03; 0.04)	-0.08 (-0.27; 0.12)	5.5 (2.1; 8.9)	.96 (.94; .98) *	<.1
Ecc-Dur [ms]	511.76 $\pm$ 81.11	553.76 $\pm$ 67.68	17.85 (2.78; 32.92)	40.0 (33.8; 49.3)	0.10 (-0.13; 0.32)	7.2 (5.1; 9.3)	.96 (.93; .97) *	15.75 (13.40; 18.10)
Con-Dur [ms]	28.59 $\pm$ 43.51	287.65 $\pm$ 37.71	3.00 (-2.69; 8.69)	0.3 (0.2; 0.5)	0.03 (-0.07; 0.13)	4.5 (2.3; 6.7)	.98 (.96; .99) *	8.30 (7.20; 9.40)
MEccConP [W/s]	1499.5 $\pm$ 347.6	1313.3 $\pm$ 305.6	-79.1 (-133.0; -25.3)	8.6 (4.8; 12.3)	-0.14 (-0.42; 0.13)	8.9 (5.0; 12.9)	.94 (.89; .96) *	69.1 (57.8; 8.3)
TPP [s]	0.72 $\pm$ 0.13	.78 $\pm$.09	0.03 (0.00; 0.05)	0.06 (0.05; 0.07)	0.10 (-0.12; 0.33)	7.5 (4.6; 10.5)	.95 (.91; .97) *	<.1
CMJ-Depth [cm]	-3.1 $\pm$ 9.2	-3.8 $\pm$ 7.0	-0.3 (-1.3; 0.6)	0.1 (0.1; 0.2)	-0.03 (-0.09; 0.03)	7.5 (4.8; 1.3)	.95 (.92; .97) *	1.7 (1.5; 1.8)
FV-AUC [N/ms ²]	27.2 $\pm$ 3.9	25.1 $\pm$ 2.3	-0.8 (-1.4; -0.2)	0.1 (0.0; 0.1)	-0.08 (-0.34; 0.18)	4.9 (2.4; 7.3)	.98 (.96; .99) *	0.7 (0.5; 0.8)
LI [N s]	77.0 $\pm$ 27.0	71.7 $\pm$ 16.5	-2.2 (-6.0; 1.6)	1.1 (0.6; 1.6)	-0.07 (-0.18; 0.04)	8.7 (5.0; 12.4)	.89 (.82; .94) *	4.6 (3.7; 5.4)

Abbreviations: Con-Dur: concentric duration; CM-Depth: countermovement depth; Ecc-Dur: eccentric duration; FT:CT: flight time contraction time; FV-AUC: area under the force-velocity curve; LI: landing impulse; MEccConP: mean eccentric concentric power over time; RFD: rate of force development; RSI-mod: reactive strength index modified; TI: total impulse; TPP: time to peak power. * Denotes $P < .01$.

Table 4. Reliability and usefulness of the CMJ asymmetry-based variables in Academy soccer players.

Parameter	Test	Retest	Δ (95% CIs)	SEM (95% CIs)	ES (95% CIs)	CV (95% CIs)	ICC (95% CIs)	SWC (95% CIs)
<i>Within-session</i>								
Con-I _{Asym} [%]	5.1 ± 4.2	5.2 ± 3.9	0.1 (-0.7; 1.0)	2.1 (1.8; 2.6)	-0.04 (0.01; 0.07)	30.3 (21.3; 39.4)	.67 (.49; .79) *	0.8 (0.7; 0.9)
Con-MF _{Asym} [%]	5.1 ± 4.2	5.2 ± 3.9	0.1 (-0.7; 1.0)	2.1 (1.8; 2.6)	0.04 (0.01; 0.07)	30.0 (21.0; 39.0)	.67 (.50; .79) *	0.8 (0.7; 0.9)
Ecc-BI _{Asym} [%]	11.1 ± 6.8	9.6 ± 6.6	-1.1 (-2.6; 0.3)	3.9 (3.3; 4.8)	0.16 (-0.30; -0.01)	31.8 (22.0; 41.6)	.72 (.56; .82) *	1.4 (1.2; 1.5)
Ecc-DI _{Asym} [%]	11.1 ± 6.5	10.8 ± 6.4	-0.2 (-1.9; 1.5)	4.4 (3.7; 5.5)	-0.3 (-0.05; 0.00)	29.2 (20.3; 38.2)	.66 (.48; .78) *	1.3 (1.1; 1.5)
Ecc-MF _{Asym} [%]	10.3 ± 5.8	9.5 ± 5.2	-0.6 (-1.9; 0.7)	3.5 (2.9; 4.3)	-0.09 (-0.18; -0.01)	29.2 (21.9; 36.6)	.71 (.55; .82) *	1.1 (1.0; 1.2)
Land-I _{Asym} [%]	13.9 ± 8.3	12.0 ± 9.0	-1.5 (-3.8; 0.9)	6.3 (5.3; 7.8)	-0.16 (-0.27; -0.04)	38.4 (28.0; 48.8)	.57 (.36; .72) *	1.8 (1.5; 2.0)
Land-PF _{Asym} [%]	13.9 ± 10.0	11.8 ± 7.9	-1.5 (-4.5; 1.4)	7.8 (6.6; 9.6)	-0.16 (-0.26; -0.06)	40.1 (29.7; 50.5)	.40 (.15; .60) *	1.8 (1.5; 2.1)
F@0V _{Asym} [%]	8.6 ± 7.1	10.6 ± 6.9	1.5 (-0.6; 3.7)	5.7 (4.8; 7.0)	0.21 (0.08; 0.35)	54.2 (42.0; 66.4)	.36 (.11; .57) *	1.4 (1.2; 1.6)
<i>Between-session</i>								
Con-I _{Asym} [%]	4.9 ± 2.4	3.7 ± 1.9	0.3 (-0.2; 0.8)	2.5 (1.9; 3.9)	-0.12 (-0.14; -0.10)	1.3 (0.6; 2.0)	.65 (.24; .86) *	0.8 (0.7; 1.0)
Con-MF _{Asym} [%]	6.7 ± 4.7	6.9 ± 4.5	0.1 (-0.5; 0.7)	1.5 (1.3; 1.9)	0.03 (0.00; 0.05)	22.0 (12.0; 31.9)	.78 (.65; .86) *	0.9 (0.8; 1.0)
Ecc-BI _{Asym} [%]	14.5 ± 6.2	13.9 ± 6.9	-0.2 (-1.0; 0.5)	0.2 (0.1; 0.3)	-0.04 (-0.09; 0.02)	15.5 (7.6; 23.4)	.89 (.81; .93) *	1.3 (1.2; 1.5)
Ecc-DI _{Asym} [%]	14.1 ± 5.9	14.7 ± 6.5	0.2 (-0.8; 1.2)	0.5 (0.3; 0.8)	0.04 (0.00; 0.08)	16.4 (8.7; 24.0)	.79 (.67; .87) *	1.3 (1.1; 1.5)
Ecc-MF _{Asym} [%]	13.0 ± 5.9	12.5 ± 4.9	-0.2 (-0.9; 0.6)	0.3 (0.1; 0.4)	-0.03 (-0.07; 0.01)	17.8 (9.4; 26.2)	.87 (.79; .92) *	1.1 (1.0; 1.2)
Land-I _{Asym} [%]	20.9 ± 7.8	19.6 ± 7.5	-0.5 (-1.9; 0.8)	3.6 (3.0; 4.4)	-0.07 (-0.14; 0.01)	18.0 (9.9; 26.1)	.81 (.70; .89) *	1.6 (1.3; 1.8)
Land-PF _{Asym} [%]	17.9 ± 10.9	18.1 ± 8.0	0.1 (-1.9; 2.0)	5.2 (4.4; 6.4)	0.01 (0.00; 0.01)	30.5 (17.3; 43.7)	.59 (.38; .73) *	1.9 (1.6; 2.3)
F@0V _{Asym} [%]	8.6 ± 7.1	10.6 ± 6.9	1.5 (-.6; 3.7)	5.7 (4.0; 8.5)	0.21 (0.08; 0.35)	54.2 (42.0; 66.4)	.36 (.11; .57) *	1.4 (1.2; 1.6)

Abbreviations: Con-I_{Asym}: concentric impulse asymmetry; Con-MF_{Asym}: concentric mean force asymmetry; Ecc-BI_{Asym}: eccentric braking impulse asymmetry; Ecc-DI_{Asym}: eccentric deceleration impulse asymmetry; Ecc-MF_{Asym}: eccentric mean force asymmetry; F@0V_{Asym}: force at 0 velocity asymmetry; Land-I_{Asym}: landing impulse asymmetry; Land-PF_{Asym}: landing peak force asymmetry. * Denotes $P < 0.01$.

Table 5. Reliability and usefulness of the CMJ symmetry-based variables in Academy soccer players.

Parameter	Test	Retest	Δ (95% CIs)	SEM (95% CIs)	ES (95% CIs)	CV (95% CIs)	ICC (95% CIs)	SWC (95% CIs)
<i>Within-session</i>								
Con-I _{Asym} [%]	92.9 ± 10.5	95.0 ± 4.0	1.8 (-0.6; 4.1)	6.2 (5.3; 7.7)	0.04 (-0.10; 0.18)	2.3 (-0.2; 4.8)	.98 (.97; .99)	1.6 (1.3; 1.9)
Con-MF _{Asym} [%]	92.9 ± 10.5	95.0 ± 4.0	1.8 (-0.6; 4.1)	6.2 (5.3; 7.7)	0.04 (-0.10; 0.18)	2.3 (-0.2; 4.8)	.98 (.97; .99)	1.6 (1.3; 1.9)
Ecc-BI _{Asym} [%]	88.0 ± 17.0	89.0 ± 6.8	0.8 (-2.9; 4.4)	9.8 (8.3; 12.0)	0.02 (-0.02; 0.06)	5.9 (-0.1; 11.8)	.95 (.91; .97) *	2.6 (2.1; 3.1)
Ecc-DI _{Asym} [%]	88.1 ± 15.1	88.4 ± 6.1	0.2 (-3.0; 3.5)	8.6 (7.3; 10.6)	0.01 (-0.01; 0.02)	4.7 (0.4; 9.0)	.96 (.93; .97)	2.3 (1.9; 2.7)
Ecc-MF _{Asym} [%]	88.0 ± 16.3	89.7 ± 5.6	1.4 (-2.5; 5.3)	10.3 (8.7; 12.7)	0.03 (-0.03; 0.10)	5.5 (-0.4; 11.5)	.94 (.90; .96)	2.5 (2.0; 3.0)
Land-I _{Asym} [%]	88.3 ± 11.0	84.7 ± 8.0	-3.0 (-6.6; 0.5)	9.4 (7.9; 11.5)	-0.08 (-0.24; 0.08)	7.3 (5.4; 9.3)	.94 (.91; .97)	2.0 (1.7; 2.3)
Land-PF _{Asym} [%]	87.4 ± 8.0	86.6 ± 9.8	-0.7 (-3.4; 2.0)	7.2 (6.1; 8.8)	-0.02(-0.06; 0.03)	5.2 (3.8; 6.6)	.97 (.95; .98)	1.8 (1.6; 2.0)
F@0V _{Asym} [%]	89.4 ± 12.4	89.9 ± 7.1	0.4 (-2.6; 3.4)	8.0 (6.7; 9.8)	0.01 (-0.02; 0.03)	4.5 (1.5; 7.4)	.96 (.94; .98)	2.0 (1.7; 2.4)
<i>Between-session</i>								
Con-I _{Asym} [%]	95.1 ± 4.6	95.2 ± 3.5	0.0 (-0.5; 0.6)	1.6 (1.3; 1.9)	0.00 (-.01; .02)	1.3 (0.6; 2.0)	1.00 (1.00; 1.00)	0.8 (0.7; 1.0)
Con-MF _{Asym} [%]	95.0 ± 4.6	95.2 ± 3.5	0.0 (-0.6; 0.6)	1.6 (1.3; 1.9)	0.00 (-.01; .02)	1.3 (0.6; 2.1)	1.00 (1.00; 1.00)	0.8 (0.7; 1.0)
Ecc-BI _{Asym} [%]	87.3 ± 6.8	89.5 ± 7.1	0.9 (-0.2; 1.9)	0.1 (0.0; 0.1)	0.03 (-0.13; 0.18)	3.1 (2.1; 4.1)	.99 (.99; 1.00) *	1.4 (1.3; 1.6)
Ecc-DI _{Asym} [%]	87.6 ± 6.2	89.0 ± 7.1	0.6 (-0.7; 1.8)	0.1 (0.0; .01)	0.02 (-0.07; 0.11)	3.4 (2.1; 4.7)	.99 (.98; .99) *	1.4 (1.1; 1.6)
Ecc-MF _{Asym} [%]	88.8 ± 6.5	89.5 ± 5.5	0.3 (-0.6; 1.1)	<0.01	0.01 (-0.05; 0.07)	2.2 (1.3; 3.1)	1.00 (.99; 1.00) *	1.2 (1.1; 1.4)
Land-I _{Asym} [%]	83.8 ± 9.7	92.6 ± 6.5	3.5 (1.2; 5.8)	6.2 (5.2; 7.6)	0.12 (-0.16; 0.40)	7.2 (4.5; 9.8)	.96 (.93; .98)	1.9 (1.5; 2.3)
Land-PF _{Asym} [%]	86.5 ± 9.5	89.3 ± 6.1	1.0 (-0.9; 2.9)	0.2 (0.1; 0.2)	0.03 (-0.07; 0.14)	5.3 (3.0; 7.7)	.97 (.96; .98) *	1.6 (1.3; 2.0)
F@0V _{Asym} [%]	91.9 ± 6.6	89.7 ± 6.4	-0.9 (-2.2; 0.4)	0.1 (0.0; 0.1)	-0.03 (-0.16; 0.10)	3.6 (2.2; 4.9)	.99 (.98; .99) *	1.3 (1.1; 1.6)

Abbreviations: Con-I_{Asym}: concentric impulse asymmetry; Con-MF_{Asym}: concentric mean force asymmetry; Ecc-BI_{Asym}: eccentric braking impulse asymmetry; Ecc-DI_{Asym}: eccentric deceleration impulse asymmetry; Ecc-MF_{Asym}: eccentric mean force asymmetry; F@0V_{Asym}: force at 0 velocity asymmetry; Land-I_{Asym}: landing impulse asymmetry; Land-PF_{Asym}: landing peak force asymmetry. * Denotes $P < 0.01$.

Table 6. Principal component analysis of the CMJ variables in Academy soccer players.

Variable type	Principal component	Variable	Factor loading	Uniqueness
Outcome-based	1 (variance VAF: 43.4%; Eigenvalue: 4.34)	MP-Rel	0.946	0.0547
		MF-Rel	0.945	0.0988
		PF-Rel	0.895	0.1767
	2 (VAF: 22.2%; Eigenvalue: 2.22)	PP	0.940	0.0289
		Ecc-MF	0.846	0.1092
	3 (VAF: 17.5% Eigenvalue: 1.75)	Land-PF	0.722	0.4769
Ecc-PV		−0.822	0.2053	
Time-based	1 (VAF: 30.1%; Eigenvalue: 3.01)	FT:CT	0.722	0.1369
		RSI-mod	0.966	0.0602
		MEccConP	0.933	0.0679
	2 (VAF: 29.0%; Eigenvalue: 2.90)	Con-Dur	0.970	0.0528
		Con-I	0.938	0.0335
	3 (VAF: 17.0%; Eigenvalue: 1.70)	RFD-50	0.758	0.2816
Land-I		−0.737	0.4412	
Asymmetry-based	1 (VAF: 66.3%; Eigenvalue: 5.31)	Con-I _{Asym}	0.936	0.0991
		Con-MF _{Asym}	0.936	0.0990
		Ecc-BI _{Asym}	0.916	0.1396
		Ecc-DI _{Asym}	0.936	0.1137
		Ecc-MF _{Asym}	0.893	0.1897
		F@0V _{Asym}	0.887	0.2082
		2 (VAF: 15.6%; Eigenvalue: 1.25)	Land-PF _{Asym}	0.946

Abbreviations: Con–Dur: concentric duration; Con–MF: concentric mean force; Con–MP: concentric mean power; Con–I_{Asym}: concentric impulse asymmetry; Con–PF: concentric peak force; Ecc–BI_{Asym}: eccentric braking impulse asymmetry; Ecc–DI_{Asym}: eccentric deceleration impulse asymmetry; Ecc–MF: eccentric mean force; Ecc–MF_{Asym}: eccentric mean force asymmetry; Ecc–PV: eccentric peak velocity; FT:CT: Flight time contraction time; F@0V: force at 0 velocity; F@0V_{Asym}: force at 0 velocity asymmetry; Land–I_{Asym}: landing impulse asymmetry; Land–PF: landing peak force; MEccConP: mean eccentric concentric power over time; RSI–mod: reactive strength index modified; PP: concentric peak power