

Inter-Day Reliability of Countermovement Jump Metrics in Elite Academy Soccer Players

Ben Lonergan^{6*}, Daniel D. Cohen^{5*}, Sean Williams², Rebecca Lawson¹, David J. Howarth^{3,4} and David M. Johnson^{1,2}

¹West Ham United Football Club Academy, London, England; ²University of Bath, Somerset, England; ³School of Sport, Exercise & Rehabilitation, Faculty of Health, University of Technology Sydney, New South Wales, Australia; ⁴New York City Football Club, New York, USA; ⁵University of Limerick, Ireland; ⁶Brighton and Hove Football Club, Sussex, England

Corresponding Authors: ben_loners@hotmail.com and danielcohen1971@gmail.com

ABSTRACT

The purpose of this study was to determine the inter-day reliability of countermovement jump (CMJ) force plate metrics in elite male academy soccer players. Fourteen players performed 3 CMJ's on 3 separate days over an 8-day period during a typical in-season competition and training period. Absolute (coefficient of variation (CV)) and relative reliability (interclass coefficient (ICC)) were calculated using two inter-day combinations; condition 1: Monday-Tuesday, condition 2: Monday-Monday and using two data treatment methods; mean of trials ("mean3") and single trial with the highest Flight Time:Contraction Time ("BestFT:CT"). In the mean3, Monday-Tuesday condition, all CV's except for peak landing force were < 10%, with most < 5%, while all ICC's were > 0.75 (good), and most ICC's > 0.9 (excellent). Several metrics had lower CV's and higher ICC's in condition 1 than condition 2 and in mean3 than BestFT:CT. Importantly, in the context of using downward "eccentric" phase metrics in monitoring, eccentric deceleration rate of force development, durations, power and displacement within this phase demonstrated good-excellent absolute reliability (CVs between 2.9% and 7.03%). Overall, CV's were substantially lower than most previous studies, but similar to investigations involving elite team sport athletes who also perform the CMJ regularly. Our findings suggest that metric reliability is enhanced by this exposure and by a competitive environment, and that reliability data obtained in populations without these characteristics is not generalizable to the elite setting. Practitioners

should endeavor to assess inter-day reliability within their team. In-season implementation represents an ecologically valid option.

Keywords: Athlete Monitoring, Youth Soccer, Neuromuscular Performance, Force Plate Variables, Coefficient of Variation.

INTRODUCTION

In elite academy soccer, in addition to exposure to the demands created by competition and technical-tactical training, practitioners implement conditioning to develop players' physical qualities. Jump and strength assessments are widely used in the sport to quantify magnitude and direction of load-response in specific neuromuscular performance characteristics in athlete monitoring and development programs (8, 21). Of these assessments, the countermovement jump (CMJ) is one of the most widely used in team sports (25, 4). In English elite academy soccer, it is performed on force plates as it this assessment is part of the English Premier League Elite Player Performance Plan. In team sports, during the competitive season, the CMJ is often performed as part of load-response monitoring (examining the longitudinal response of players). Typically, assessments are performed weekly on matchday (MD) + 2 or + 3, aiming to identify players with poor residual load-response to competition (1, 3, 4, 12, 20, 41), or on MD-1 or -2, timepoints more reflective of recovered neuromuscular status and week to week trends in

neuromuscular performance (8, 24).

Studies examining CMJ metric response to real or simulated match-play, have typically examined jump height and concentric peak power (6, 20). However, Cormack et al (10, 11) and Gathercole et al (18, 19) first established that other CMJ force plate metrics derived from force-time data, such as flight time:contraction time (FT:CT) and eccentric duration, are more sensitive in detecting potential residual fatigue consequent to intense training/competition in team sports. These metrics may also show positive adaptations to training interventions that are not expressed in improvements in jump height or concentric peak power (27, 29). In elite rugby seven's players across a season, Lonergan et al. (29) observed non-significant, trivial changes in jump height ($p=1.0$, $d=0.06$), and concentric peak power ($p=1.0$, $d=0.46$), but significant, large magnitude improvements in a number of other metrics, including FT:CT ($p=0.02$, $d=1.14$), concentric impulse-100 ms (con 100) ($p=0.042$, $d=0.98$) and eccentric deceleration rate of force development (EDRFD) ($p=0.01$, $d=1.03$).

Practitioners might infer that metrics expressing a larger magnitude of response (signal) to a given input are more useful in detecting changes in athlete's neuromuscular status (31, 35) and should be included in athlete monitoring dashboards. When selecting metrics some authors have prioritized reliability – biological and methodological variability (noise) (34). However, when monitoring load-response at a team level, metric selection should consider both the variable's signal and its noise (24, 33). For an observed change to be qualified as "meaningful" therefore depends on whether this value exceeds a bandwidth based on multiples of typical error for that metric - as represented by its coefficient of variation (CV) % (23). Researchers have used an arbitrary reliability threshold of 10% for "good reliability" as an inclusion criterion, which risks excluding valuable metrics that could provide valuable insights into athlete responses (24).

Nonetheless, the poor reliability of eccentric metrics reported in some studies in youth and adult, athletic and active populations (22, 33, 37, 13), may raise concerns about their use in metrics in monitoring. While using arm swing may explain the higher values in two of these studies (33, 37), hands-on-hips CMJ eccentric duration (CV = 12%) and eccentric mean power (CV = 19%) CV's were reported in college basketball players (22) and of 19-20% in academy soccer players (13). In contrast, CV's of 4-5%

were reported for these variables in elite academy soccer players (16) and senior professional Rugby players (24). The large range of CV's suggests that CMJ metric reliability is not a fixed measurement characteristic and is influenced by cohort.

This study aims to determine the inter-day reliability in a comprehensive range of CMJ metrics in elite, male academy soccer players who routinely perform the assessment within monitoring practices.

METHODS

Experimental Approach to the Problem

In this study we aimed to determine interday reliability in a range of CMJ kinetic variables. While assessments on two consecutive days with no intervening training (signal) represents the gold standard method for exclusively examining biological and methodological noise (41), such an approach can be difficult to implement in elite sport. Instead, "ecological reliability approach" was used, which involved assessments conducted during a period where players were participating in training (24). We examined absolute (coefficient of variation) and relative (intraclass coefficient) reliability across two-day combinations (conditions) based on three assessments implemented within an 8-day period during the season. Reliability was determined using two data treatment methods; the mean and the best jump (24). The best jump was the trial with the highest Flight Time:Contraction Time, representing an index of "neuromuscular efficiency" time spent in air after takeoff relative to time taken to leave the ground. This data treatment method also removes inadequate eccentric peak velocity (i.e. slow countermovement) jump trials that do not represent the athletes stretch shortening cycle capacity.

Subjects

Fourteen male soccer players from an English category 1 academy who compete in the English U18 Premier League were invited to participate in this analysis. From this group, 2 players were not able to participate during the testing period because of injuries they sustained during training. The mean (SD) age, stature and body mass of the 12 players included in the study was 17 ± 1.1 years, 179.7 ± 8.3 cm and 71.8 ± 7.0 kg, respectively. All players were well familiarized with the CMJ testing protocol used due to their regular participation using this assessment during the previous 2 seasons. Ethical

approval was obtained from the University of Bath (reference number 1548-1471) and the subjects and parents signed an institutionally approved consent form.

Procedures

Assessments were completed during a competition and training period in-season, in February. During the assessment week, players were encouraged to maintain their habitual daily and weekly routines. Testing was completed in the same individual 15-minute period, with all tests taking place between 8.15-8.45am, prior to training. Players schedule shown in Table 1. Before testing, the following standardized warm-up was completed: (a) self-selected soft tissue and mobility work, (b) 8 bodyweight goblet squats, (c) 5 reverse lunges each side (d) 10 pogo jumps, and (e) 3 warm-up CMJs (70, 80, 90% effort). CMJs were performed on a dual force plate system (ForceDecks, Vald Performance, Newstead, Australia) connected to a Lenovo i5 laptop computer. A known weight (20 kg) was used to check the accuracy of force measurement every testing day before the testing period. The acceptable error on weighing the plate was ± 0.1 kg. To begin the test, players stood with one limb on each platform with hands on hips and remained still for 5 seconds to obtain a stable BM measurement. Before jumping, a maximal performance focus was established with each player through verbal cueing to “dip as fast as you can and jump as high as you can and land on the plates.” External attentional focus was used as the previous literature supports this methodology for maximizing performance of athletic tasks (43). This verbal cue was used throughout all testing with staff consciously avoiding additional or varied “coaching” cues regarding jump strategy. Immediate visual feedback of jump height was provided through instantaneous trial by trial

feedback displayed by the software (ForceDecks Jump). A competitive environment was developed to motivate players to provide maximal effort using a leaderboard (ForceDecks Leaderboard) and with squad encouragement. Players performed 3 maximal CMJs separated by 10–15 seconds, during which they repositioned their feet and prepared for another maximal effort. Every CMJ was visually monitored by an experienced staff member, and any jumps deviating from the standard protocol (e.g., players attempted to “tuck” their legs during the flight phase, double jump/prejump, and did not land on the force plates) were excluded, and another jump was performed to ensure 3 acceptable trials. The same staff member supervised all tests.

Statistical Analysis

Data was exported from ForceDecks software (v2.0.7418; Vald Performance, Newstead, Australia) and statistical analysis was performed in R (version 4.2.1) Absolute reliability was calculated using coefficients of variation (CV) ($<10\%$ Good, $<5\%$ Excellent) and relative reliability with intraclass coefficient (ICC) (23). ICC estimates were calculated based on a mean-rating ($k = 3$), absolute-agreement, 2-way mixed-effects model for mean of trials comparison and single measurement, absolute-agreement, 2-way mixed-effects model for best trial comparison. ICC values less than 0.5 are considered to be indicative of poor reliability, between 0.5 and 0.75; moderate, between 0.75 and 0.9; good, and greater than 0.90; excellent. Two data treatment methods were applied to the three trials performed on each day: (a) the mean outputs for each metric across all trials: “Mean3” (6) and (b) the output for each metric taken from the trial with the highest flight time: contraction time (FT:CT): “BestFT:CT”. Reliability was calculated using 2 combinations (“conditions”) of the 3 assessments

Table 1. Testing and training schedule

Time	Monday ¹ ¶, ‡	Tuesday ¹ ¶	Wednesday	Thursday	Friday	Saturday	Sunday	Monday ² ‡
09:00	CMJ Testing	CMJ Testing						CMJ Testing
11:00	Soccer Training (60min low intensity and volume)	Education	Gym (1 st Years *)	Soccer Training (75 min medium Intensity and Volume)	Soccer Training (60min low intensity and volume)	Gameday	No Training	Soccer Training (60min low intensity and volume)
13:00	Gym (Full Squad)		Gym (2 nd Years *)	Analysis				Gym (Full Squad)
14:00		Soccer Training (75 min high intensity and volume)	Education					

¶ CMJ data used in condition 1 (Monday-Tuesday)

‡ CMJ data used in condition 2 (Monday-Monday)

* 1st Years Scholars are U17 Age Group, 2nd Years Scholars are U18 Age Group

performed on Monday, Tuesday of first week of testing and the Monday of the 2nd week of testing condition 1 (Monday¹-Tuesday), condition 2 (Monday¹-Monday²).

RESULTS

For each CMJ phase, ranges for inter-day CV for concentric variables were 1.93–8.22% (Mean3) and 1.45–14.47% (BestFT:CT), and eccentric variables were 1.57–13.51% (Mean3) 3.63–16.56% (BestFT:CT), and landing: 11.93–12.20% (Mean3) 9.24–12.48% (BestFT:CT).

Mean3 inter-day CV for both inter-day combinations can be found in Table 1, whereas, BestFT:CT inter-day CV for both inter-day combinations can be found in Table 2. Overall, CV's were lower and CI's higher for the mean compared to the bestFT:CT data treatment approach, for concentric (upward phase) versus eccentric (downward phase) metrics and for the Mon-Tues versus the Mon – Mon conditions.

DISCUSSION

We evaluated the inter-day reliability of CMJ force plate metrics in elite male academy U18 soccer players during the in-season period. In the condition and data treatment method with the lowest CV (mean, Monday1-Tuesday1) all metrics except for peak landing force exhibited absolute reliability (CV%) below 10% and good to excellent relative reliability (ICC's > 0.75), most displaying excellent CV's (< 5%) and ICC's (> 0.9). Importantly, with respect to monitoring, downward "eccentric" phase metrics including EDRFD, durations, power, and displacement, demonstrated good-excellent absolute reliability (CV's between 2.9% and 7.0%), in addition to jump height and upward "concentric" phase metrics. Previous studies in high performance athletes show that eccentric metrics are amongst those variables highly sensitive to load (8, 19, 29, 33). However, practitioners may lack confidence in using them based on poor reliability reported in some studies (13, 22, 37). In the context of such findings, our results demonstrate that eccentric metric reliability data from these studies is not generalizable to players who routinely perform these assessments in monitoring and emphasizes the cohort-specific nature of reliability. This underscores the importance of measuring inter-day CV's, along with signal, at a cohort/team level – contributing to a data informed, systematic and objective approach

to metric selection and to calculations of meaningful change in load-response monitoring.

The present cohort's condition 1 (mean) CV's represent some of the lowest reported in the literature, particularly with respect to eccentric phase metrics. The only studies with comparable values are in elite (U17) academy soccer players (16) and professional Rugby union players (24). In metrics common across all three, eccentric deceleration phase duration, force at zero velocity (F0V) and eccentric mean power CV's were between 5.6% and 8.8%, 3.8% and 6.0%, and 4.6% and 6.0% respectively in those studies, compared to 3.1%, 1.6% and 3.7% in the present study. Howarth et al also reported eccentric peak velocity, countermovement depth and EDRFD, with CV's of 4.3%, 4.1% and 11.6%, compared to 3.0%, 4.7% and 7%, respectively in the present study. Substantially higher CVs are reported for these metrics in younger soccer players (5, 13, 39), college basketball players (22) and physically active males (9, 14) with values of between 8–12% for countermovement depth, and as high as 36% for EDRFD. The CV's of metrics such as jump height, concentric peak power and RSI_{mod} and FT:CT were also higher in these studies, but differences were of smaller magnitude than that noted in the eccentric phase.

Differences between conditions

Players performed 3 CMJ assessments across an 8-day in-season period which included 4 on-pitch and gym-based training sessions and 1 match. This allowed the comparison of CV's calculated using the Monday1-Monday2 CMJ's assessments from the team's routine weekly matchday +2 (MD +2) monitoring cycle (Condition 2) with a Monday1-Tuesday1 condition (Condition 1) requiring an additional assessment outside of this routine. Most metrics exhibited small differences in CVs between conditions. For example, for mean3 Monday1-Tuesday1 CVs for jump height and FT:CT were 2.69% (CI: 1.73 - 3.65) and 4.50% (CI: 3.22 - 5.77) respectively, compared to 2.98 (CI: 1.58 - 4.37) and 4.73% (CI: 2.77 - 6.68) respectively, in the Monday-Monday condition. In contrast, the Monday-Monday CV's of eccentric deceleration phase metrics such as F0V (5.53%, CI:4.08 - 6.98) and EDRFD (13.51%, CI:7.79 - 19.24) were nearly substantially higher in the Monday-Tuesday condition, a difference that was significant in the case of F0V (1.64% CI:0.67 - 2.61) and EDRFD (7.03%, CI:4.03 - 10.04). Similarly, in pro Rugby players Howarth

Table 2. Inter-day absolute (CV) and relative reliability (ICC) and 95% confidence intervals of countermovement jump metrics determined using mean of 3 trials.

Variable	Mean (±SD)	Condition 1 Monday ¹ -Tuesday		Condition 2 Monday ¹ -Monday ²	
Overall		CV	ICC	CV	ICC
Jump Height (Flight Time) (cm)	41.34 (±3.78)	2.69 (1.73 – 3.65)	0.97	2.98 (1.58 – 4.37)	0.86
Jump Height (Imp-mom) (cm)	39.99 (±3.68)	4.56 (2.86 – 6.27)	0.91	4.50 (2.57 – 6.42)	0.77
Flight Time:Contraction Time	0.95 (±0.13)	4.50 (3.22 – 5.77)	0.86	4.73 (2.77 – 6.68)	0.85
RSI-modified [m/s]	0.67 (±0.10)	4.84 (3.29 – 6.38)	0.90	5.10 (2.55 – 7.66)	0.84
Downward (Eccentric)					
Countermovement Depth [cm]	-28.25 (±5.32)	4.66 (-6.97 - -2.35)	0.89	5.66 (-8.75 - -2.56)	0.85
Lower Limb Stiffness [n/m]	7275.15 (±2365.84)	6.37 (3.51 – 9.21)	0.96	9.77 (4.52 – 15.01)	0.82
Force at Zero Velocity [N]	1953.35 (±327.74)	1.64 (0.67 – 2.61)	0.98	5.53 (4.08 – 6.98)	0.92
Eccentric Deceleration Impulse [Ns]	105.72 (±12.57)	3.15 (2.00 – 4.31)	0.95	2.41 (1.45 – 3.38)	0.79
Eccentric Deceleration RFD / BM [N/s/kg]	145.72 (±66.64)	7.03 (4.03 – 10.04)	0.97	13.51 (7.79 – 19.24)	0.89
Eccentric Peak Velocity [m/s]	-1.46 (±0.11)	2.97 (-4.45 - -1.49)	0.91	4.49 (-6.63 - -2.35)	0.53
Eccentric Duration [ms]	401.30 (±46.12)	5.14 (3.89 – 6.39)	0.76	4.95 (3.23 – 6.66)	0.78
Eccentric Deceleration Phase Duration [s]	0.13 (±0.03)	3.11 (1.34 – 5.04)	0.95	6.19 (2.90 – 9.4)	0.88
Eccentric Mean Deceleration Force [N]	1546.04 (±217.33)	5.70 (3.82 – 7.59)	0.98	1.90 (0.87 – 2.93)	0.84
Eccentric Mean Power / BM [W/kg]	6.84 (±0.67)	3.72 (2.46 – 4.98)	0.84	4.34 (2.19 – 6.48)	0.75
Eccentric Peak Power / BM [W/kg]	26.19 (±5.64)	5.31 (2.59 – 8.04)	0.97	11.60 (6.76 – 16.44)	0.50
Eccentric Peak Force (N)	1985.15 (±338.40)	1.57 (0.68 – 2.47)	0.99	6.46 (4.92 – 8.00)	0.88
Upward (Concentric)					
Concentric RPD/BM [W/s/kg]	397.41 (±129.17)	7.75 (5.15 – 10.35)	0.93	8.22 (4.38 – 12.05)	0.91
Concentric Peak Velocity [m/s]	2.90 (±0.13)	2.12 (1.37 – 2.88)	0.92	1.93 (1.02 – 2.84)	0.81
Concentric Duration [ms]	225.42 (±39.03)	4.44 (2.78 – 6.11)	0.96	3.98 (1.69 – 6.26)	0.91
Concentric Mean Power / BM [W/kg]	34.58 (±4.65)	3.45 (2.10-4.80)	0.93	3.99 (1.96-6.01)	0.88
Concentric Peak Force [N]	2042.65 (±342.64)	2.20 (1.11 – 3.29)	0.98	3.63 (1.95 – 5.31)	0.94
Concentric Impulse [Ns]	202.15 (±22.71)	2.06 (1.26 – 2.87)	0.98	2.41 (1.45 – 3.38)	0.97
Concentric Impulse-100ms [Ns]	119.33 (±31.91)	4.58 (2.41 – 6.75)	0.97	4.77 (1.53 – 8.00)	0.95
Concentric Peak Power / BM [W/kg]	60.55 (±5.83)	2.79 (1.56 – 4.02)	0.91	3.11 (1.71 – 4.51)	0.87
Landing					
Peak Landing Force / BM [N]	67.64 (±16.83)	12.20 (7.81 – 16.58)	0.73	11.93 (8.32 – 15.53)	0.73

Mean (SD) = Mean (SD) of Monday¹, Tuesday and Monday² Mean³. RFD = rate of force development, RPD = rate of power development and BM = body mass.

Table 3. Inter-day absolute (CV) and relative reliability (ICC) and 95% confidence intervals of countermovement jump metrics determined using single BestFT:CT trial

Variable	Mean (±SD)	Condition 1 Monday ¹ -Tuesday		Condition 2 Monday ¹ -Monday ²	
Overall		CV	ICC	CV	ICC
Jump Height (Flight Time) (cm)	41.38 (±3.16)	4.09 (2.75 – 5.43)	0.73	3.40 (1.96 – 4.84)	0.75
Jump Height (Imp-mom) (cm)	40.62 (±3.11)	3.27 (1.33-5.20)	0.76	4.73 (2.63-6.83)	0.47
Flight Time:Contraction Time	0.71 (±0.12)	4.47 (2.39 - 6.55)	0.88	5.57 (1.74 - 9.39)	0.76
RSI-modified [m/s]	0.96 (±0.15)	5.32 (3.37 - 7.27)	0.82	6.36 (2.87 - 9.85)	0.69
Downward (Eccentric)					
Countermovement Depth [cm]	-26.31 (±5.08)	11.67 (-15.49 - -7.85)	0.47	10.63 (-15.92 - -5.34)	0.53
Lower Limb Stiffness [n/m]	8009.92 (±3155.15)	9.88 (5.57 – 14.19)	0.89	15.50 (6.18 – 24.82)	0.53
Force at Zero Velocity [N]	2000.06 (±400.18)	3.85 (1.85 - 5.85)	0.93	6.02 (2.12 - 9.93)	0.80
Eccentric Deceleration Impulse [Ns]	101.93 (±12.57)	7.64 (4.24 - 11.04)	0.50	5.26 (2.81 - 7.71)	0.66
Eccentric Deceleration RFD / BM [N/s/kg]	6.72 (±0.65)	7.14 (4.08 - 10.20)	0.37	5.36 (2.79 - 7.94)	0.50
Eccentric Peak Velocity [m/s]	163.67 (±91.24)	9.42 (4.96 - 13.88)	0.96	16.56 (5.56 - 27.57)	0.61
Eccentric Duration [ms]	-1.42 (±0.13)	7.33 (-10.87 - -3.79)	0.33	5.06 (-7.38 - -2.74)	0.38
Eccentric Deceleration Phase Duration [s]	381.22 (±51.29)	6.73 (4.50 - 8.96)	0.67	6.83 (3.09 - 10.58)	0.54
Eccentric Mean Deceleration Force [N]	0.13 (±0.03)	6.41 (3.07 – 9.75)	0.85	3.84 (1.79 – 5.89)	0.80
Eccentric Mean Power / BM [W/kg]	1564.79 (±259.99)	3.63 (1.56 – 5.70)	0.92	6.23 (3.38 – 9.08)	0.76
Eccentric Peak Power / BM [W/kg]	25.90 (±7.92)	11.24 (4.72 - 17.75)	0.81	14.55 (8.39 - 20.70)	0.66
Eccentric Peak Force (N)	2033.92 (±425.73)	4.36 (7.54 - 21.25)	0.92	7.24 (2.69 - 11.79)	0.72
Upward (Concentric)					
Concentric RPD/BM [W/s/kg]	441.71 (±171.86)	11.56 (7.96 - 16.06)	0.80	14.47 (6.08 - 22.86)	0.57
Concentric Peak Velocity [m/s]	2.93 (±0.11)	1.45 (0.58 - 2.31)	0.77	2.27 (1.21 - 3.32)	0.46
Concentric Duration [ms]	215.42 (±37.96)	6.85 (4.32 - 9.38)	0.74	7.38 (4.04 - 10.72)	0.80
Concentric Mean Power / BM [W/kg]	35.98 (±4.96)	2.93 (1.62-4.24)	0.93	5.13 (2.19-8.06)	0.77
Concentric Peak Force [N]	2123.25 (±406.86)	3.65 (1.41 - 5.90)	0.93	6.16 (2.41 - 9.90)	0.77
Concentric Impulse [Ns]	202.99 (±21.33)	1.69 (0.79 - 2.59)	0.97	1.68 (0.87 - 2.50)	0.96
Concentric Impulse-100ms [Ns]	126.48 (±34.99)	6.00 (2.53 - 9.48)	0.93	8.03 (4.85 - 11.22)	0.87
Concentric Peak Power / BM [W/kg]	62.44 (±6.05)	2.51 (1.36 - 3.66)	0.90	4.32 (1.86 - 6.78)	0.67
Landing					
Peak Landing Force / BM [N]	66.78 (±15.33)	12.48 (6.50 - 18.47)	0.49	9.24 (4.12 - 14.36)	0.68

Mean (SD) = Mean (SD) of Monday¹, Tuesday and Monday² Mean³. RFD = rate of force development, RPD = rate of power development and BM = body mass.

et al observed significantly higher CV's in EDRFD and other eccentric phase metrics using Monday-Monday versus within-week (Tuesday-Thursday) preseason conditions (24). The relative reliability of most metrics was also slightly lower in the Monday-Monday condition. The ICCs for jump height and most eccentric phase metrics demonstrated good, rather than excellent, reliability in Condition 1. In contrast, concentric force and impulse metrics exhibited less variability between conditions.

Metric outputs on the second Monday test of condition 2 were influenced by the cumulative load-response from a full week of training in contrast to a single, soccer training and gym session between assessments in the Monday1-Tuesday1 condition. Both conditions were preceded by a match approximately 48 hours earlier – with the potential to drive a residual (fatigue) response (36, 40, 42). However, the Monday1-Monday2 condition introduces greater potential variation in values due to differing levels of match-play exposure in the 48 hours prior to each measurement. The intended quantification of methodological and biological variation, or “noise” in condition 2 is therefore more contaminated by “signal” – i.e. the players' true response to match load. As such the intended measurement of methodological and biological variation, or “noise” in condition 2 is therefore more contaminated by “signal” – i.e. true response to load and recovery cycles. A “pure” measurement of metric biological noise implies that the two assessments are performed without intervening training, and neither follows intense activity. Such an approach was implemented by Thorpe et al (41) in professional players, requiring attendance on the day prior to preseason for their first assessment, a schedule that might not be feasible in many professional settings. As an alternative “ecological” assessment of reliability, Howarth et al (24), implemented repeated CMJ assessments during the first week of preseason. The present in-season approach represents another ecological alternative. For teams who routinely perform weekly CMJ's in weekly MD+2 monitoring, condition 2 represents a low burden and convenient means to calculate reliability - without additional assessments. However, our results suggest that this approach inflates the CV's of specific variables used in monitoring. Introducing inflated CV's into a signal:noise or minimal detectable change calculation reduces the likelihood that a given observed change (signal) will exceed the threshold to qualify it as meaningful, biasing towards false negative conclusions. In an in-season CV analysis, a Monday1-Tuesday1

approach is therefore recommended. However, if logistical constraints prevent this, and a week-to-week analysis is used instead, practitioners should be aware of wider, signal driven, bandwidths for specific variables.

Mean v best jump

We calculated CV's both using a single “best” trial based on highest FT:CT (Table 3) and the mean of the 3 trials performed in both conditions (Table 2). For the majority of metrics the CV's for mean3 were slightly lower with narrower confidence intervals than the CV's for best FTCT, but the majority were also below 10% For example, in condition 1, jump height mean was 2.7% (CI:1.7 – 3.7) v 4.1% (CI:2.8 - 5.4) using BestFT:CT, the Con 100 mean3 was 4.58% (CI:2.4 – 6.8) versus 6.0% (CI:2.5 - 9.5) using Best FT:CT and the eccentric duration mean3 was 5.14% (CI:3.9 – 6.39) compared to 6.73% (CI:4.50-8.96) using BestFT:CT. However, other metrics showed far larger differences across the two methods, for example the CV's based on means and BestFT:CT for eccentric mean power were 3.72% (CI:2.46 – 4.98) and 7.14% (CI:4.08 - 10.20) and for countermovement depth were significantly different; -4.66% (CI:-6.97 - -2.35) and -11.67% (CI:-15.49 - -7.85) respectively. In finding that overall, the mean is more reliable than using a best trial, our results broadly align with the conclusion of previous studies that compared mean with best jump data treatment approaches in athletes (24, 26, 32). However, as decisions on metric selection for monitoring should be guided not only by consideration of noise but also signal within the cohort the choice of data treatment method should be informed by such an analysis. Theoretically, BestFT:CT could yield a larger signal than using the mean, depending on the specific characteristics and load exposure of the cohort being monitored. As such, firm conclusions cannot be reached regarding the best data treatment or the most useful metrics in the present cohort until the magnitude of response to loading has also been evaluated.

The substantially lower CVs observed in the present study, along with those reported by Franceschi et al (16) and Howarth et al, (24) compared to the broader literature, highlights the importance of conducting cohort-specific reliability assessments. These findings also challenge the notion that certain metrics are intrinsically unreliable, suggesting instead cohort characteristics and assessment conditions exert a large influence on the absolute reliability (CV) of metrics. This may explain the

large differences in CV's across studies and raises questions about the characteristics of these cohorts and factors that contribute to the reliability of these assessments. Two factors directly shown to influence reliability (5, 39) - age and cues - are very similar in the present players (17 ± 1.1) and the elite academy soccer players in Francesci's et al study (16.7 ± 0.3) (16) and both were cued to jump "high and fast". In contrast, the professional Rugby players in Howarth's study were substantially older (mean age 24 ± 4) and only instructed to "jump as high as possible" (24). The only feature common to all three studies is that the participants were all professional team sport players who regularly performed CMJs as part of club monitoring practices. We infer that repeated practice of the specific hands-on hip CMJ assessment task, is likely to improve the consistency of its technical execution. It is reasonable to speculate that this learning effect may be the most important determinant of reliability.

The importance of adequate "training age", and exposing athletes to maximal jumping as part of assessments and or conditioning has previously been highlighted (24, 37). Indeed, Ferreira et al compared CMJ reliability in similar aged combat fighters and physically active individuals measured under the same conditions and noted significantly higher CV's in a range of CMJ metrics in the latter. Amongst the metrics sampled eccentric peak force displayed one of the largest differences in reliability between the athletic (4.0% CI: 3.0 - 5.8) and active groups (21.8% CI: 16.0 - 33.8). In a recent study in active young adults reported CV's for jump height of 5.7% (CI: 5.1 - 8.1), 18.4% (CI: 16.6 - 26.2) for eccentric peak velocity and eccentric deceleration RFD for 34.7% (CI: 31.4 - 49.4) (9), values several fold higher than in the present study. The pattern of these differences appears to support the notion that, regarding the reliability of certain metrics, within-study familiarization is not equivalent to a distinct longer-term 'learning effect' associated with consistently performing the assessment over extended durations.

It is also well established that the instructions or cues given to athletes regarding how to perform the jump can affect performance and kinetics (28, 38). Cohen et al suggested that performing a jump with a fast descent and achieving an adequate eccentric peak velocity is fundamental to creating sufficient deceleration demands to obtain valid and representative measures of eccentric qualities, in metrics as eccentric deceleration RFD and eccentric peak or mean power (7). Krzyzskowski et

al demonstrated that cues that specifically focused on performing the downward phase rapidly were associated with higher values for deceleration phase force metrics (28). Players in the present study were cued to jump high and fast, common to reliability studies across the full spectrum of CV values (5, 13, 14, 16). Exceptions to this were studies with players instructed to give "maximal effort" (22) or to "jump as high as possible" (24). Speculatively, compared to Howarth et al., the lower CV's of several eccentric phase metrics in the present sample may be related to the inclusion of cueing on speed of execution. Indeed, it is noteworthy that Howarth et al observed relatively low eccentric phase CV's despite not specifically cueing for speed of execution. However, the authors highlight the high level of encouragement and creation of a competitive environment which motivated players to repeatedly give maximal effort across trials. They argue that these factors were likely to be key contributors to the reliability observed, compensating for the absence of explicit reference to the speed of execution.

Players in the present study also received between-trial feedback on performance (jump height) - shown to improve CMJ performance (17) - as well as leaderboards and peer encouragement. A feedback rich and competitive assessment culture appears to be an important ingredient for achieving lower CV's. The aforementioned factors should be considered when interpreting and generalizing the results of reliability studies. The specifics of the present cohort and conditions under which they were assessed creates the main limitation of the present study - its limited generalizability beyond elite cohorts that are involved in routine testing.

CONCLUSIONS

This evaluation of inter-day reliability of metrics derived from the hands-on-hips CMJ in elite academy soccer players using two inter-day conditions and two data treatment methods yielded some of the lowest CVs reported, particularly for eccentric metrics. The most reliable condition and treatment method was Monday-Tue (mean3) CV's. In the Monday-Monday condition and when a single trial best FT:CT data treatment was used instead of the mean across trials, the CV's of a number of metrics were higher and ICC's lower. Taken together with specific prior research studies (16, 24), our findings suggest that the absolute reliability of CMJ metrics, particularly, is substantially better in athletes who are regularly

monitored using this assessment in a competitive setting than in athletic or non-athletic populations without extensive exposure to the task or assessed in “sterile” environments. Data from populations with these distinct characteristics should not be used interchangeably. In the context of prior literature, our findings highlight the large variability in metric reliability and suggest this is not a purely intrinsic or fixed measurement characteristic but one that is modifiable, dynamic and highly influenced by population characteristics and other contextual factors.

PRACTICAL APPLICATIONS

When selecting CMJ metrics to include in monitoring dashboards, both reliability and response to training and competition should be considered. The first step within this systematic approach is a cohort-specific evaluation of inter-day reliability. This allows practitioners to establish metric bandwidths with which to define meaningful change in longitudinal neuromuscular load-response monitoring. The present approach cannot be characterised as a “pure” assessment of metric reliability or biological noise, due to player load exposures prior to and between assessments. However, it does however provide practitioners with alternative to conducting a reliability analysis within or prior to the preseason period which may accommodate potential scheduling challenges in some team settings. The in-season approach also ensures that all players within the group have had significant exposure to the protocol which, along with “high and fast” cueing, real-time player feedback to drive individual and cohort motivation and competition, factors which appear to enhance metric reliability, particularly in the eccentric phase. Practitioners should make efforts to implement inter-day reliability within their cohort. However, if such an analysis cannot be conducted, the present results may be utilized as a reliability reference for elite academy players with significant testing experience, assessed using the same protocol and cues, under feedback rich, motivating, competitive conditions, as this data is unlikely to be representative of reliability in populations without these characteristics.

ACKNOWLEDGEMENTS

The authors acknowledge the generous participation of all athletes in this research study and the contribution of West Ham United Football

Club’s staff.

CONFLICTS OF INTEREST

Daniel Cohen co-founded the force plate software and hardware (ForceDecks) used in this research project. Daniel no longer has any commercial or financial interest in this product. The authors have no conflicts of interest to declare.

FUNDING

This study received no specific funding in order to be completed.

ETHICAL APPROVAL

Ethical approval was obtained from University of Bath (reference number 1548-1471) and the subjects and parents signed an institutionally approved consent form.

DATES OF REFERENCE

Submission - 22/01/2025

Acceptance - 10/07/2025

Publication - 14/11/2025

REFERENCES

1. Akyildiz Z, Ocak Y, Clemente MF, Birgonul Y, Günay M, Nobari H. Monitoring the Post-match Neuromuscular Fatigue of Young Turkish Football Players. *Scientific Reports* 12(1): 13835, 2022.
2. Alba-Jiménez C, Moreno-Doutres D, Peña J. Trends assessing neuromuscular fatigue in team sports: a narrative review. *Sports* 10(3) 33, 2022.
3. Andersson H, Raastad T, Nilsson J, Paulsen G, Garthe I, Kadi F. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med and Science in Sports and Exercise* 40(2):372-80, 2008.
4. Beere M, Jeffreys I. Physical testing and monitoring practices in elite male football. *Prof. Strength and Cond.* 29-42, 2021.
5. Bright TE, Handford MJ, Hughes JD, Mundy PD, Lake JP, Daggart L. Development and Reliability of Countermovement Jump Performance in Youth Athletes at Pre-, Circa- and Post-Peak Height Velocity. *International Journal of Strength and Conditioning* 3(1), 2023
6. Claudino JG, Cronin J, Mezêncio B, et al. The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport* 20:397-402, 2016.
7. Cohen D, Burton A, Wells C et al. Single vs double leg

- countermovement jump tests: Not half an apple! *Aspetar Sports Med J* 9: 34–41, 2020.
8. French D, Ronda LT. NSCA's Essentials of Sport Science. In: Kinetics and Force Platforms. D Cohen and C Kennedy. Champaign, IL: Human Kinetics, 2022
 9. Collings TJ, Lima YL, Dutailis B, Bourne MN. Concurrent validity and test-retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. *Journal of Science and Medicine in Sport* 27(8): 572 – 580, 2024
 10. Cormack SJ, Mooney MG, Morgan W, Mcguigan, MR. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian Football players. *International Journal of Sports Physiology and Performance*, 8, 373–378.
 11. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of elite players to a Australian rules football match. *Int J Sports Physiol Perform* 3(3):359-74, 2008
 12. Deely C, Tallent J, Bennett R ET AL. Etiology and Recovery of Neuromuscular Function Following Academy Soccer Training. *Front Physiol.* 2022
 13. Donegan ML, Eustace S, Morris R, Penny R, Tallis J. (2022). The Effects of Soccer Specific Exercise on Countermovement Jump Performance in Elite Youth Soccer Players. *Children* 30: 9-12, 2022.
 14. Ferreira ARP, Macedo VOC, Boullosa D, Vieira A. Identifying Consistent Metrics from the Force-Time Curve of the Countermovement Jump in Combat Fighters and Physically Active Men. *Int J Exerc Sci* 16(4):1038-1051, 2023
 15. Focke A, Strutzenberger G, Jekauc D, Worth A, Woll A, Schwameder H. Effects of age, sex and activity level on counter-movement jump performance in children and adolescents, *European Journal of Sport Science*, 13:5, 518-526, 2013.
 16. Franceschi A, Robinson MA, Owens D, Brownlee T, Ferrari Bravo D, Enright K. Reliability and sensitivity to change of post-match physical performance measures in elite youth soccer players. *Front. Sports Act. Living* 5:1173621, 2023
 17. García-Ramos A, Janicijevic D, Cobo-Font J, et al. Knowledge of results during vertical jump testing: An effective method to increase the performance but not the consistency of vertical jumps. *Sports Biomech*: 1–13, 2020.
 18. Gathercole R, Sporer B, Stellingwerff T, Sleivert G. Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *Int J Sports Physiol Perform* 10(1):84–92, 2015a.
 19. Gathercole R, Stellingwerff T, Sporer B. (2015b). Effect of acute fatigue and training adaptation on countermovement jump performance in elite snowboard cross athletes. *Journal of Strength and Conditioning Research* 29(1): 37–46, 2015b.
 20. Hader K, Rumpf MC, Hertzog M et al. Monitoring the Athlete Match Response: Can External Load Variables Predict Post-match Acute and Residual Fatigue in Soccer? A Systematic Review with Meta-analysis. *Sports Med Open* 5(1): 48, 2019.
 21. Haller N, Blumkaitis JC, Strepp T et al. Comprehensive training load monitoring with biomarkers, performance testing, local positioning data, and questionnaires - first results from elite youth soccer. *Front. Physiol* 13, 2022
 22. Heishman AD, Daub BD, Miller RM et al. Countermovement jump reliability performed with and without an arm swing in NCAA Division 1 intercollegiate basketball players. *J Strength Cond Res* 34: 546–558, 2020.
 23. Hopkins W, Schabert E, Hawley J. Reliability of power in physical performance tests. *Sports Med* 31: 211–234, 2001.
 24. Howarth DJ, Cohen DD, McLean BD, Coutts AJ. Establishing the noise: Interday ecological reliability of countermovement jump variables in professional rugby union players. *Journal of strength and conditioning research* 36(11): 3159-3166, 2022.
 25. Howarth DJ, McLean BD, Cohen DD, Coutts AJ. Sensitivity of Countermovement Jump Variables in Professional Rugby Union Players Within a Playing Season. *J Strength Cond Res* 37(7):1463-1469, 2023.
 26. Kennedy RA, Drake D. Improving the Signal-To-Noise Ratio When Monitoring Countermovement Jump Performance. *J Strength Cond Res* 35(1):85-90, 2021.
 27. Kijowski KN, Capps CR, Goodman CL et al. Short-term resistance and plyometric training improves eccentric phase kinetics in jumping. *The Journal of Strength & Conditioning Research* 29(8): 2186-2196, 2015.
 28. Krzyszowski J, Chowling LD, Harry JR. Phase-Specific Verbal Cue Effects on Countermovement Jump Performance. *J Strength Cond Res* 36(12):3352-3358, 2022.
 29. Lonergan B, Price P, Lazarczuk SL, Howarth DJ, Cohen DD. A comparison of countermovement jump performance and kinetics at the start and end of an international Rugby Sevens season. *The Journal of Sport and Exercise Science* 6(2), 79-89, 2022.
 30. Malone JJ, Murtagh C, Morgans R et al. Countermovement jump performance is not affected during an in season training microcycle in elite youth soccer players. *J Strength Cond Res* 29(3):752–757, 2015.
 31. McLean BD, Coutts AJ, Kelly V et al. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perform* 5(3):367–383, 2010.
 32. Mercer RAJ, Russell JL, McGuigan LC et al. Understanding 'monitoring' data-the association between measured stressors and athlete responses within a holistic basketball performance framework. *PLoS One* 17(6), 2022.
 33. Mercer RAJ, Russell JL, McGuigan LC et al. Finding the signal in the noise—interday reliability and seasonal sensitivity of 84 countermovement jump variables in professional basketball players. *J Strength Cond Res* 37(2): 394–402, 2023.
 34. Merrigan JJ, Stone JD, Hornsby WG, Hagen JA. Identifying Reliable and Relatable Force-Time Metrics in Athletes-Considerations for the Isometric Mid-Thigh Pull and Countermovement Jump. *Sports (Basel)* 9(1):4, 2020.
 35. Mooney MG, Cormack S, O'Brien BJ et al. Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *J Strength Cond Res* 27(1):166–173, 2013.
 36. Nedelec M, McCall A, Carling C et al. The influence of soccer playing actions on the recovery kinetics after a soccer match. *J Strength Cond Res* 28(6):1517-23, 2014.
 37. Nibali ML, Tombleson T, Brady PH, Wagner P. Influence of familiarization and competitive level on the reliability of countermovement vertical jump kinetic and kinematic variables. *J Strength Cond Res* 29: 2827–2835, 2015.
 38. Pérez-Castilla A, Rojas FJ, Gómez-Martínez F, García-Ramos A. Vertical jump performance is affected by the velocity and depth of the countermovement. *Sports Biomech* 20(8):1015-1030, 2021.
 39. Ruf L, Drust B, Ehmann P et al. Poor Reliability of

- Measurement Instruments to Assess Acute Responses to Load in Soccer Players Irrespective of Biological Maturity Status. *Pediatr Exerc Sci.* 34(3):125-134, 2022.
40. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform* 12:227–234, 2017.
41. Thorpe RT, Strudwick AJ, Buchheit M et al. Monitoring fatigue during the in-season competitive phase in elite soccer players. *Int J Sports Physiol Perform* 10(8):958–964, 2015.
42. Varley I, Lewin R, Needham R, Thorpe RT, Burberry R. Association between Match Activity Variables, Measures of Fatigue and Neuromuscular Performance Capacity Following Elite Competitive Soccer Matches. *J Hum Kinet* 60:93-99, 2017.
43. Winkelman N. Attentional Focus and Cueing for Speed Development. *Strength and Conditioning Journal* 40(1):13-25, 2018.