Title: Between-Day Reliability and Sensitivity of Common Fatigue Measures in Rugby Players.

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ABSTRACT

This study established the between-day reliability and sensitivity of a countermovement jump (CMJ), plyometric push-up, wellbeing questionnaire and whole blood creatine kinase concentration [CK] in elite male youth rugby union players. The study also established the between-day reliability of 1, 2 or 3 CMJ and plyometric push-up attempts. Twenty-five players]completed tests on 2 occasions separated by 5 days (of rest). Between-day typical error (TE), coefficient of variation (CV) and smallest worthwhile change (SWC) were calculated for the wellbeing questionnaire, [CK] and CMJ and plyometric push-up metrics (peak/mean power, peak/mean force, height, flight-time and flight-time to contraction-time ratio) for 1 maximal effort or taking the highest score from 2 or 3 maximal efforts. The results from this study would suggest that CMJ mean power (2 or 3 attempts), peak force or mean force, and plyometric push-up mean force (from 2 or 3 attempts) should be used for assessing lower- and upper-body neuromuscular function respectively, due to both their acceptable reliability (CV<5%) and good sensitivity (CV<SWC). The wellbeing questionnaire and [CK] demonstrated between-day CV's > 5% (7.1% and 26.1% respectively) and poor sensitivity (CV>SCW). The findings from this study can be used when interpreting fatigue markers to make an objective decision about a player's readiness to train or compete.

Key Words: neuromuscular function, creatine kinase, wellbeing.

INTRODUCTION

In sport, the monitoring of athletes is common practice in order to detect and manage the development of fatigue.[1] The most frequently implemented monitoring tools in high performance sport include wellbeing questionnaires and measures of lower-body neuromuscular function, in particular the countermovement jump (CMJ) test,[2] which have both shown good sensitivity to fatigue in the days following competition in collision-sport athletes.[3-6] Along with the CMJ, the plyometric push-up has also been used to investigate and monitor upper-body neuromuscular function in rugby league players following match-play.[4,7] Furthermore, due to the contact nature of collision-sports, indirect measures of muscle damage, in particular creatine kinase concentration ([CK]) has been used to determine the extent of muscle damage and establish the time-course of recovery in the days following competition.[4,8-10]

In order to correctly interpret the changes that occur in such measures following training or match-play, practitioners need to determine whether a change is real, or the result of testing error. This can only be done when the between-day typical error (TE) or coefficient of variation (CV; TE expressed as a percentage) for a given measure is readily available.[11] A measure must demonstrate a CV <5% to be considered reliable in a given population.[12] In addition, practitioners need to also determine whether a change is of practical significance. The threshold for a change to be deemed practically significant is based on the concept of Cohen's Effect size and is known as the smallest worthwhile change (SWC).[13] The SWC is calculated for a given group of athletes by multiplying the within-athlete standard deviation by 0.2. Measures that exhibit a between-day CV that is lower than the SWC have 'good' sensitivity, while measures that have a between-day CV of equal to, or greater than the SWC have 'OK' or 'poor' sensitivity respectively.[12]

It is important that studies investigating changes in neuromuscular function in collision-sport athletes consider and report the between-day reliability of specific tests, to allow the reader to confidently interpret their data. Studies that report the reliability of tests typically reference published reliability studies undertaken on a different population,[4,5] or report the reliability values from their own data, without describing how this reliability was derived (i.e., within- or between-day).[4,7,14] Furthermore, some studies do not report reliability data.[6,8,15,16] Additionally, when monitoring neuromuscular function (i.e., CMJ or plyometric push-up, there appears to be a lack of consensus regarding the number of repetitions performed. Protocols vary from 1 [4,7,15,17] to 3 [6,8,14] attempts. The variability in the protocol would also likely affect the reliability of the CMJ as a marker of fatigue.

The monitoring of player wellbeing with short questionnaires is also common practice within team sports[2] and appear to be sensitive to fatigue in the days post-match.[5,14] Despite the usefulness of monitoring player wellbeing, as with neuromuscular function, the reliability of such questionnaires is often lacking in the collision-sport literature.[4,7,14,15] This also appears commensurate with studies that have investigated the response of [CK] following match-play, which often lack detail as to how the reliability statistics have been calculated (i.e., within- or between-day).[4,8,15,16,18]

Establishing the between-day reliability of the aforementioned markers in a collision-sport population (i.e. rugby players), in addition to establishing the SWC of each measure is required, as the reliability of tests are population specific.[11] Therefore it is paramount that these statistics are available when working with, or conducting research in a specific population. Given the challenge of applied research and practice (i.e., time, player access and equipment availability), it has been deemed acceptable to use a pre-determined CV derived from a similar population.[11,19] This should be derived from a short-term study during which any changes in a subjects' score between trials are not the result of true changes,[13] for example due to training adaptation, detraining or fatigue. However, currently no study has been undertaken to determine the between-day reliability of fatigue measures in rugby players. Therefore the primary aim of this study was to investigate the between-day reliability and sensitivity of CMJ and plyometric push-up variables, a wellbeing questionnaire and [CK] in elite male youth rugby union players. A secondary aim was to investigate the differences in reliability between performing only 1 maximal CMJ and plyometric push-up, or taking the highest score from 2 or 3 maximal efforts.

METHODS

Subjects

Twenty-five elite male youth rugby union players (age 17.6±0.5 years; height 184.4±6.5 cm; body mass 89.4±10.9 kg) were recruited from a professional rugby union club. All players were members of the under-18 academy squad. All players engaged in a structured strength and conditioning programme 3 times per week alongside rugby training 2-3 times per week. Ethics approval was granted by the University ethics committee and written informed consent was acquired from participants along with parental consent.

Design

Measures of upper- (plyometric push-up) and lower-body neuromuscular function (CMJ), wellbeing and whole blood [CK] were collected on two separate days (5 days apart) during a non-training week at the beginning of the pre-season period. The 5-day period was deemed appropriate to assess the short-term reliability,[13] without players detraining.[20] On each testing day, players initially completed a wellbeing questionnaire and gave a whole blood sample. Players then completed a standardised warm-up and performed 3 maximal CMJs, followed by 3 maximal plyometric push-ups. Testing was undertaken at the same time of day (12pm) to ensure diurnal variation did not affect any of the measures. Players did not engage in any training or strenuous activity in the week prior to, or during the testing week. Players completed a 5-day food diary prior to the first testing day, and then repeated this up to the next testing day.

Neuromuscular Function

The CMJ and plyometric push-up were performed on a portable force plate (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) that was attached to a laptop with software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that measured ground reaction forces at 600Hz. A standardised 2-minute warm-up consisting of dynamic stretching (walking lunges, squats, heel flicks, high knees, skipping, legs swings and 3 practice submaximal CMJ and plyometric push-up[15] was performed prior to the CMJ and plyometric push-up. Following the warm-up, players performed 3 maximal CMJ followed by 3 maximal plyometric push-ups with 1-minute rest between each effort. All players were familiar with the warm-up and testing protocol, having regularly undertaken fatigue monitoring in the previous rugby season.

For the CMJ, subjects began standing on the force platform with knees extended and feet in a position of their choice. Subjects were instructed to keep their hands on their hips and jump as a high as possible. The depth of the countermovement was at the discretion of the subject.[21] For the plyometric push-up, subjects began with their elbows extended and hands on the force platform in a position of their choice. Subjects were instructed to perform a push-up as quickly as possible with the aim of their hands leaving the platform.[22] The use of minimalist coaching strategies was favoured in order to assess the reliability of a technique that has application in applied sports settings where testing time is often limited.[21]

CMJ and plyometric push-up metrics included for reliability analysis were chosen based on metrics commonly investigated in the collision-sport literature.[4,6,17] These were;

height, flight-time, peak power, mean power, peak force, mean force and flight time: contraction ratio (FT:C).

Perception of Wellbeing

A 6-item questionnaire was adapted from McLean et al[5] to rate each of sleep, fatigue, muscle soreness (upper- and lower-body), stress and mood on a 5-point Likert scale. Each item was rated from 1 to 5 in 1 score increments and overall wellbeing was assessed by adding up all 6 scores. The questionnaire was administered prior to any other testing being undertaken.[5] Subjects completed the questionnaire on their own in order to prevent any influence from other players.[14]

Creatine Kinase

Whole blood samples were collected from the non-dominant hand, middle fingertip of each subject. Approximately 30 µl of whole capillary blood was collected using a plastic capillary tube (MICROSAFE®, Safe-tec, Numbrecht, Ivyland, USA) and immediately analysed using reflectance photometry (Refletron® Plus, Boehringer Manheim, Germany). Prior to each session, the machine was calibrated using a standardised CK strip to ensure that the machine was analysing correctly. The intra-subject within-sample CV was 5.3% (3.7-10.6%), based on triplicate analysis from six subjects.

Statistical Analysis

The between-day reliability statistic of typical error (TE) was calculated as;

$$S_{diff} / \sqrt{2}$$

where S_{diff} is the standard deviation of the difference score [13] and converted to a coefficient of variation (CV; TE expressed as a percentage) for all tests using a Microsoft Excel spreadsheet.[23] A test was regarded as reliable if it had a CV <5%.[12] In order to determine the sensitivity of each test, the SWC was calculated as 0.2 x between-subject standard deviation and calculated as a percentage of the mean in order to compare with the CV. Sensitivity of each test was classified as follows; good (CV < SWC), OK (CV = SWC) or poor (CV > SWC).[24]

In order to reflect the different methodologies used in the literature, further analysis was conducted on the CMJ and plyometric push-up data to examine the between-day reliability of performing only 1 maximal effort (CMJ1), or taking the highest score from 2 (CMJ2) or 3 (CMJ3) maximal efforts. Additionally, in order to determine whether the absolute performance in CMJ and plyometric push-up differed between these methodologies, the standardised difference was also calculated as;

$$M_1 – M_2 / s_1$$

Differences were ranked as trivial (<0.2) small (0.20–0.59), medium (0.6–1.19), or large (≥1.2).[25]

RESULTS

Reliability statistics for CM1, CMJ2 and CMJ3 are presented in Table 1. Reliability for height, flight-time, peak power, mean power, peak force and FT:C improved when more than 1 maximal CMJ was performed. Only FT:C remained above the threshold of CV <5% for all methods.

Table 1: Summary of reliability statistics for a single (1), best of 2 (2) or best of 3 (3) countermovement jumps. Data are smallest worthwhile change expressed as a percentage (SWC), coefficient of variation (CV) with confidence in intervals in brackets and classification of sensitivity taken from Hopkins [24].

	SWC%	CV%	Sensitivity
Height (1)	2.4	5.2 (4.2-7.1)	Poor
Height (2)	2.4	4.9 (3.9-6.7)	Poor
Height (3)	2.4	4.6 (3.7-6.2)	Poor
Flight-time (1)	1.2	2.6 (2.1-3.5)	Poor
Flight-time (2)	1.2	2.6 (2.1-3.5)	Poor
Flight-time (3)	1.2	2.3 (1.8-3.1)	Poor
Peak Power (1)	3.6	6.3 (5.0-8.5)	Poor
Peak Power (2)	3.3	3.6 (2.9-4.9)	Poor
Peak Power (3)	3.3	3.5 (2.8-4.8)	Poor
Mean Power (1)	3.2	5.3 (4.3-7.2)	Poor
Mean Power (2)	3.3	3.1 (2.5-4.3)	Good
Mean Power (3)	3.3	3.0 (2.4-4.1)	Good
Peak Force (1)	3.9	3.7 (3.0-5.0)	Good
Peak Force (2)	3.9	3.1 (2.5-4.2)	Good
Peak Force (3)	3.9	3.2 (2.6-4.3)	Good
Mean Force (1)	3.1	1.0 (0.8-1.4)	Good
Mean Force (2)	3.1	1.0 (0.8-1.4)	Good
Mean Force (3)	3.1	1.1 (0.9-1.5)	Good
FT:C (1)	6.2	49.6 (38.1-71.9)	Poor
FT:C (2)	2.1	5.8 (4.7-7.9)	Poor
FT:C (3)	2.1	5.5 (4.4-7.5)	Poor

FT:C = flight-time to contraction ratio

Standardised differences were trivial (<0.2) between methods for height (all methods), flight-time (all methods), peak power (CMJ2-1, CMJ3-2), mean power (CMJ3-2), peak force (all methods), mean force (all), FT:C (CMJ3-2). Small differences in performance were seen for mean power (0.2) and FT:C (0.47) between CMJ2 and CMJ1, while peak power, mean power and FT:C differed by a small amount between CMJ3 and CMJ1 (0.21-0.49).

Reliability statistics for 1, 2 and 3 plyometric push-ups are presented in Table 2. Except for peak force, reliability for all metrics improved when more than 1 maximal plyometric push-up was performed. However, height (1-3 plyometric push-ups), flight-time (1 plyometric push-up), peak power (1-3 plyometric push-ups), mean power (1-3 plyometric push-ups), peak force (2 plyometric push-ups), FT:C (1-3 plyometric push-ups) remained above the threshold of CV <5% regardless of the number of attempts used. Only peak force (1 and 3 plyometric push-ups), mean force (1-3 plyometric push-ups) and flight time (2-3 plyometric push-ups) showed acceptable reliability.

Table 2: Summary of reliability statistics for a single (1), best of 2 (2) or best of 3 (3) plyometric push-ups. Data are smallest worthwhile change expressed as a percentage (SWC), coefficient of variation (CV) with confidence intervals in brackets and classification of sensitivity taken from Hopkins.[24]

	SWC%	**CV%**	**Sensitivity**
Height (1)	6.7	17.8 (13.2-28.2)	Poor
Height (2)	6.9	8.5 (6.3-13.1)	Poor
Height (3)	6.8	8.7 (6.5-13.5)	Poor
Flight-time (1)	3.6	8.5 (6.4-13.2)	Poor
Flight-time (2)	3.6	4.2 (3.2-6.4)	Poor
Flight-time (3)	3.6	4.4 (3.3-6.8)	Poor
Peak Power (1)	8.3	50.0 (36.0-85.0)	Poor
Peak Power (2)	5.8	11.1 (8.3-17.3)	Poor
Peak Power (3)	5.2	8.3 (6.2-12.9)	Poor
Mean Power (1)	7.8	43.4 (31.6-70.7)	Poor
Mean Power (2)	5.7	13.0 (9.7-20.3)	Poor
Mean Power (3)	5.2	9.6 (7.2-14.9)	Poor
Peak Force (1)	2.7	4.9 (3.7-7.4)	Poor
Peak Force (2)	2.6	5.9 (4.4-8.8)	Poor
Peak Force (3)	2.7	4.9 (3.7-7.5)	Poor
Mean Force (1)	2.5	3.6 (2.7-5.6)	Poor
Mean Force (2)	2.6	2.6 (2.0-4.0)	OK
Mean Force (3)	2.6	2.0 (1.5-3.1)	Good
FT:C (1)	11.1	57.3 (40.8-98.7)	Poor
FT:C (2)	11.3	53.7 (38.4-91.8)	Poor
FT:C (3)	11.2	55.0 (39.3-94.4)	Poor

FT:C = flight-time to contraction ratio

Small standardised differences (0.26-0.59) between 1 and 2 plyometric push-ups were seen for all metrics except for mean force, which was trivial (<0.2). Small differences (0.29-0.38) were also seen between 1 and 3 plyometric push-ups for all variables except for peak force, which was moderate (0.91). Trivial differences (<0.2) existed between 2 and 3plyometric push-ups for all variables except peak force, which was small (0.32).

Reliability statistics for the wellbeing questionnaire and [CK] are presented in Table 3. Neither wellbeing nor [CK] exhibited a CV of <5%.

Table 3: Summary of statistics for creatine kinase and wellbeing questionnaire. Data are smallest worthwhile change expressed as a percentage (SWC), coefficient of variation (CV) with confidence intervals in brackets and classification of sensitivity taken from Hopkins [24].

	SWC%	CV%	Sensitivity
Creatine Kinase	8.6	26.1 (20.8-35.4)	Poor
Wellbeing	2.1	7.1 (5.8-9.1)	Poor

DISCUSSION

This is the first study to establish the between-day reliability of CMJ, plyometric push-up, a wellbeing questionnaire and [CK] in youth rugby players. This study showed that, with the exception of FT:C, all CMJ metrics were reliable (CV <5%) when assessed with CMJ2 or CMJ3. The flight-time (2 and 3 plyometric push-ups), peak force (1 and 3 plyometric push-ups) and mean force (all methods) demonstrated a CV of <5% for plyometric push-up. The CVs for the wellbeing questionnaire and [CK] were 7.1% and 26.1% respectively. This study also showed that performing 2 CMJ efforts produces similar reliability to performing 3 CMJ efforts. Given the importance of monitoring and managing fatigue in a professional sporting setting, the findings from this study can be used when interpreting fatigue markers, to make an objective decision about a player's readiness to train or compete.

All CMJ metrics, with the exception of FT:C demonstrated acceptable reliability (CV <5%) when assessed using CMJ2 or CMJ3. The difference in reliability between CMJ2 and CMJ3 for all metrics was ≤0.3% Furthermore the difference in absolute performance between CMJ2 and CMJ3 was trivial for all metrics. These findings allow practitioners and researchers who are examining changes in lower-body neuromuscular function to be confident that 2 maximal CMJ attempts yield the same results as 3, which may save time in the field or laboratory. Of note is the fact that the subjects within this study were well trained and familiar with the testing protocol, thus this should be a further consideration for practitioners using the CMJ test with other sporting populations.

The findings of this study show that flight-time, peak force and mean force exhibited acceptable reliability from the

CMJ1. Cormack et al [21] previously examined the reliability of a CMJ1 protocol in elite Australian rules players and found that along with these metrics, peak power and height also demonstrated a CV of <5%. The different findings in the present study reinforce the need for population specific reliability data. Australian rules players have different anthropometry, physical characteristics and activity patterns during match play [26] in comparison to rugby players, which may explain the differences between the studies.

Practitioners should be aware that only mean power (CMJ2 and CMJ3), peak force (all methods) and mean force (all methods) from the CMJ demonstrated an ability to detect the SWC. Similar findings were also reported in the aforementioned study by Cormack and colleagues [21] who observed that only relative mean force was capable of detecting the SWC using a CMJ1 protocol. When practitioners interpret metrics from the CMJ to examine changes in neuromuscular function, the reliability and sensitivity must be taken into account when making inferences about such changes.

When between-day changes in plyometric push-up were investigated, this study showed that flight-time (2 and 3 plyometric push-ups), peak force (1 and 3 plyometric push-ups) and mean force (1-3 plyometric push-ups) all had a CV of <5%. Of note, only mean force (2 and 3 plyometric push-ups) was capable of detecting the SWC, thus this would be the recommended method for monitoring changes in upper-body neuromuscular function. Findings from Hogarth and colleagues[27] demonstrated less reliable results for peak force (CV = 7.6) and flight-time (CV = 6.9) in their study involving 14 sub-elite rugby league players. Furthermore, the only plyometric push-up metrics analysed by the authors to achieve a CV <5% were mean force and impulse. The difference in results from the present study may be explained by the difference in the level of athletes involved, with higher-level athletes demonstrating improved reliability for tests. This emphasises the importance of using reliability statistics from athletes who compete in the same sport and at the same level (i.e. elite). Nevertheless, if practitioners choose to assess upper-body neuromuscular function using the plyometric push-up in rugby union players, consideration must be given to the reliability when interpreting results.

This study showed that [CK] had a between-day CV of 26%, which was greater than the SWC (8.6%) and the threshold for acceptable reliability. The methods used to assess [CK] had an intra-sample CV of 5.3%, thus the large between-day CV is likely representative of the high biological variability in whole blood [CK].[28] Despite the intra-sample CV exceeding the predetermined threshold of 5%, as no other method was available to measure [CK] and this equipment has previously been used in fatigue studies[14], the authors recommend that the larger than desirable CV is a further consideration when interpreting changes in [CK]. To the author's knowledge, the between-day reliability of [CK] has not previously been assessed in the literature. However, Twist and colleagues have reported a similar between-day CV of 27% from unpublished data in rugby league players,[29] which is similar to the CV in the present study. As the findings from this study and the unpublished observations of Twist and colleagues[29] are similar, practitioners and researchers can accept that the between day CV of [CK] is 26-27% in rugby players. Despite [CK] exhibiting a CV of 26.1%, given that changes post-match are often greater than 200% [8,9,14,30] in the first 24 hours post-game, and remain elevated above the CV for between 2 to 5 days,[4,8,9,14,30] the use of [CK] as an indirect marker of muscle damage in collision sport athletes may still be justified. However, the sensitivity of [CK] was poor when making inferences regarding changes in [CK], practitioners and researchers must take into account the high CV and intra-sample CV.

This study showed that the between-day reliability of the wellbeing questionnaire had a CV of 7.1%. Coefficients of variation ranging between 12-25% have previously been reported for similar questionnaires in elite Australian rules football players.[3,31] However, these measures were taken during periods of training and competition, which may explain the higher CV's compared to the present study. Although the players in the present study did not undertake any training during the study period, non-training factors, for example poor sleep or life stress, may have affected some of the questionnaire items. Nevertheless, the CV of the questionnaire in the present study was >5% and must be considered when used to monitor elite youth rugby union players.

In order to determine whether a change has occurred that is greater than the SWC, Hopkins [24] proposed a practical method whereby the change score of an individual (± error bars representing the CV) is depicted with the SWC (Figure 1). A change is 'clear' when the CV error bars lie outside of the SWC threshold. Conversely a change is 'unclear' when the error bars cross the SWC threshold. In an applied setting, practitioners can use this simple method to determine the nature of a change in an athlete's measure, and thus make a decision about his readiness to train.

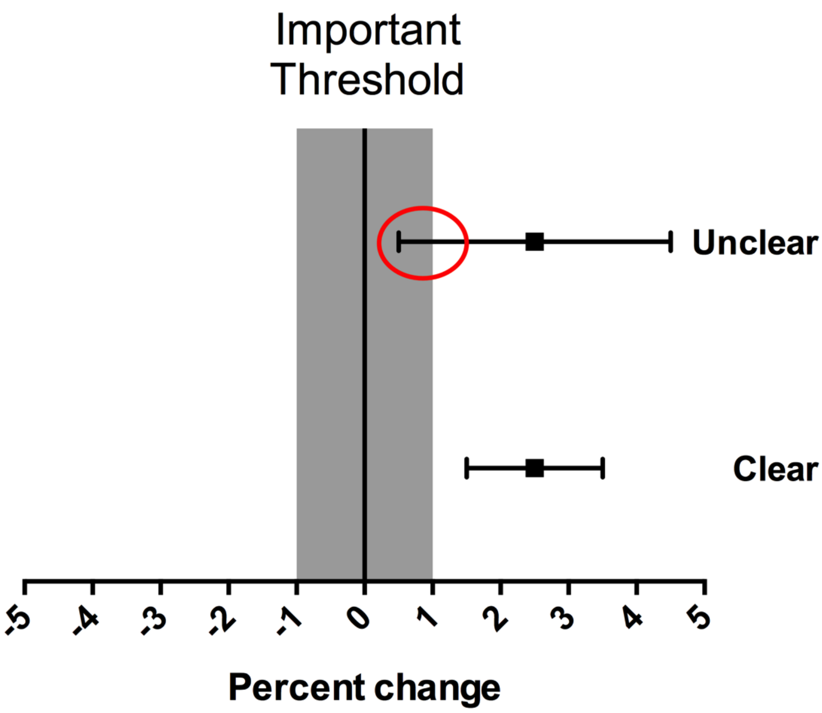

Figure 1: An example of change in the performance of an athlete24. Data ae percentage change in the individual's performance (± CV error bars, 2% and 1% respectively) with the grey area representing the smallest worthwhile change.

PRACTICAL APPLICATIONS

This study presents the between-day reliability of common measures of fatigue in rugby players; CMJ, plyometric push-up, wellbeing questionnaire and [CK]. Data from this study would suggest CMJ mean power (2 or 3 attempts), peak force or mean force, and plyometric push-up mean force (from 2 or 3 attempts) should be used, due to their acceptable reliability and good sensitivity. The wellbeing questionnaire and [CK] demonstrated between-day CV's greater than the acceptable threshold (CV<5%) and poor sensitivity. When measuring CMJ, taking the highest score of 2, rather than 3 jumps, demonstrates similar reliability and may save time in an applied sports setting. In order to determine whether a real change has occurred that is greater than the SWC, individual change scores can be plotted (± error bars representing the CV) with the SWC. If the error bars lie outside of the SWC, the change is clear, whereas if the error bars cross the SWC, the change is unclear.

CONCLUSION

In conclusion, this study examined the between-day reliability of common measures of fatigue in rugby players, demonstrating that CMJ (mean power [2 or 3 attempts], peak force and mean force) and plyometric push-up (mean force from 2 or 3 attempts) have acceptable between-day reliability (CV <5%) and sensitivity. This study also showed that when assessing lower-body neuromuscular function 2 jumps is as reliable as 3. Despite the high between-day CV for a wellbeing questionnaire and [CK], due to the large changes that occur in these measures post-match, practitioners may still find these useful tools when monitoring the fatigue state of athletes. Practitioners need to consider the between-day CV when interpreting fatigue measures, prior to making decisions about a player's readiness to train or compete.

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