

1 **Original Article**

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8 **Article Title:**

9 Comparison of a countermovement jump test and submaximal run test to quantify the
10 sensitivity for detecting practically important changes within high-performance Australian
11 rules football.

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22 ***Preferred Running Head:*** Comparison of a CMJ test and SRT.

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1 Abstract

2 **Purpose:** The purpose of this study was to determine the typical variation of variables
3 from a countermovement jump (CMJ) test and a submaximal run test (SRT), along with
4 comparing the sensitivity of each test for the detection of practically important changes within
5 high-performance Australian rules football (ARF) players. **Methods:** 23 professional and
6 semi-professional ARF players, performed six CMJs and three, eight-second 50-meter runs
7 every 30 s (SRT), seven days apart. Absolute and trial-to-trial reliability was represented as a
8 coefficient of variation (CV) \pm 90% confidence intervals (CI). Test-retest reliability was
9 examined using the magnitude of the difference (effect size (ES) \pm 90% CI) from week 1 to
10 week 2. The smallest worthwhile change (SWC) was calculated as $0.25 \times \text{SD}$. **Results:** Good
11 reliability (CVs = 6.6 – 9.3%) was determined for all variables except eccentric displacement
12 (CV = 12.8%), with no clear changes observed in any variables between week 1 and week 2.
13 All variables from the SRT possessed a CV < SWC, indicating an ability to detect practically
14 important changes in performance. Only peak velocity from the CMJ test possessed a CV <
15 SWC, exhibiting a limitation of this test in detecting practically meaningful changes within this
16 environment. **Conclusions:** The results suggest that while all variables possess acceptable
17 reliability, a SRT might offer to be a more sensitive monitoring tool than a CMJ test within
18 high-performance ARF, due to its greater ability for detecting practically important changes in
19 performance.

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21 **Keywords:** test-retest, activity profile, monitoring, reliability

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24 **Introduction**

25 It is critical that when making informed decisions regarding performance, coaches and
26 support staff have knowledge of the typical variation or repeatability of the test being applied
27 ^{1,2}. Gaining an understanding of the meaningful change in performance is reliant on knowing
28 if the observed change is due to the normal variation or is outside the typical variation expected
29 to occur by chance ¹. The greater the reliability the measure has, and therefore, the lower the
30 variability, the more certain one can be that real change in performance has occurred and
31 correct interpretations can be made ^{1,2}.

32 For the valid interpretation of reliability outcomes, a comprehensive knowledge of the
33 typical variation or repeatability of a test needs to account for the relationship between the
34 smallest effect that is considered practically meaningful, and the typical variation of the
35 measurement ¹. The smallest worthwhile change (SWC) is regarded as the smallest worthwhile
36 change in frequency outside of the expected measurement error and the minimum change in
37 performance required to be of meaningful consequence ^{1, 3, 4}. Consequently, it provides
38 information on whether the change observed is ‘real’ or simply due to the error or ‘noise’ of
39 the test. From a practical perspective, the error associated with a performance measure needs
40 to be less than the SWC, as this allows valuable and accurate information on recovery status
41 and can support decisions such as, rotations and recovery practices, within and after games and
42 training ^{1,5}.

43 For the monitoring of neuromuscular fatigue (NMF) within high-performance team
44 sports environments, the countermovement jump (CMJ) test is recognised as the reference
45 standard test ^{6,7}. It has been shown to possess both robust reliability and validity ^{1, 6, 8, 9}, and is
46 generally performed using a digital optical encoder, force plate or contact mat. Due to this
47 technology, the result has been a large number of different kinematic and kinetic variables

48 available for monitoring, measuring both the concentric and eccentric phase, gross values of
49 movement output (e.g. jump height) and values representing jump strategy (e.g. eccentric
50 displacement) ^{1, 9, 10}. With this enhanced ability to monitor and a large number of variables on
51 offer, it has been recommended to measure variables representing both movement output and
52 jump strategy as this will allow the most sensitive approach to monitoring changes in NMF
53 status ^{1, 9, 10}. Specifically, the variables shown to be most useful in indicating neuromuscular
54 status, are changes within eccentric displacement, jump height, peak velocity, mean power
55 and/or peak force ^{1, 9, 11, 12}. For a variable to be considered useful in monitoring the changes in
56 NMF status it needs to be sensitive enough to detect the impact of fatiguing interventions while
57 also having high reliability ¹³. The above mentioned variables have been shown to be the most
58 dependable in detecting changes in post-exercise NMF in a variety of different environments
59 ^{6, 9, 11, 13}, while also possessing both high reliability and repeatability ^{1, 8, 11, 12}. However, it has
60 also recently been shown that reductions within the individual vectors of 100 Hz triaxial
61 accelerometers during a submaximal run test (SRT) can provide insight into an athlete's state
62 of NMF ¹¹. When monitoring high-performance ARF players, Garrett et al. ¹¹ observed that
63 players in a state of post-match NMF had corresponding reductions in the individual vectors
64 of triaxial accelerometers during a SRT. This recent finding is in conjunction with recent
65 evidence that has suggested that the underlying mechanisms of fatigue may be task specific ^{11,}
66 ¹⁴. Team sports such as Australian rules football (ARF), which involves high- intensity repeat
67 sprint efforts, numerous changes of direction, along with accelerations and decelerations, all
68 interspersed with periods of moderate to low intensity running ¹⁵, may benefit from a method
69 of monitoring NMF via the running gate or activity profile. Therefore, the purpose of this study
70 was to determine the typical variation of a CMJ test and SRT within a high-performance ARF
71 environment and compare the sensitivity of each test for detecting practically important
72 changes within high-performance ARF. Practically, this will provide sport science practitioners

73 with insight into the most sensitive tool for monitoring post-exercise NMF in a predominantly
74 running based team sports such as ARF.

75 **Methods**

76 *Subjects*

77 Participants were twelve professional ARF players (age; 22.5 ± 4.2 years, body mass;
78 87.4 ± 6.8 kg, height; 190.1 ± 6.5 cm, years on an Australian Rules Football (AFL) list; $2.4 \pm$
79 2.9 years) from one Australian Football League club, and eleven semi-professional ARF
80 players (age; 22.3 ± 2.9 years, body mass; 80.9 ± 6.2 kg, height; 184.4 ± 5.8 cm) from one
81 South Australian National Football League club. All participants performed testing as part of
82 their normal training regime and were familiar with procedures prior to the study. To be eligible
83 for inclusion, all subjects were required to be cleared by the club's medical staff to participate
84 in each exercise. Informed, written consent was obtained from all participants and was
85 approved by the University of South Australia's Human Ethics Committee.

86 *Design*

87 To examine the typical variation and sensitivity of variables from a CMJ test and SRT,
88 all subjects performed six CMJs, and three submaximal 50 metre runs (SRT), seven days apart
89 during a normal microcycle within an ARF in-season period.

90 *Methodology*

91 *Countermovement Jump Test (CMJ)*

92 The CMJ test was performed using previously established protocols¹ with an average
93 of six CMJs used for analysis. CMJ performance was obtained for analysis via an optical
94 encoder (GymAware Power Tool, Kinetic Performance Technologies, Canberra, Australia)

95 fixed to the ground and attached via a cable to the 400 g dowel rod. For each jump the variables
96 obtained for analysis were: CMJ height (CMJ_H), peak velocity (PV) and eccentric displacement
97 (ED). These variables were chosen in order to prevent a scattergun approach and have been
98 shown to have a superior capacity in detecting changes in post-exercise NMF in a variety of
99 different environments ^{6,9,11,13}, while also possessing high reliability within high-performance
100 team sport athletes ^{1,8,11,12}.

101 *Submaximal Run Test (SRT)*

102 In order to maintain consistent methodology, the following paragraph mirrors that
103 previously presented by Garrett and colleagues ¹¹ for implementation of a SRT. The SRT
104 involved three x 50-meter runs, each completed in eight seconds in a 30-second cycle. At 10
105 seconds before starting each run, subjects were asked to be ready, with a 3-second countdown
106 given by one experimenter preceding each run. Subjects were instructed to perform the run in
107 strictly eight seconds with a time check at the 25-metre halfway mark to help control for speed
108 of the run. The GPS-embedded triaxial accelerometers unit was worn in a specialized pocket
109 in the training and match guernsey, located between the scapulae of the participant. For each
110 run, the variables obtained for analysis were: player load 1D up (PL1D_{up}) (vertical vector);
111 player load 1D side (PL1D_{side}) (medio-lateral vector); and player load 1D forward (PL1D_{fwd})
112 (anterio-posterior vector). PL metrics have been shown to possess high levels of validity and
113 reliability when monitoring team sport athletes and a detailed explanation on the calculation of
114 these metrics has been described previously ¹⁶.

115 *Analysing the Run*

116 In keeping with the methodology of Garrett et al. ¹¹, GPS-embedded triaxial
117 accelerometer data were sampled at 100 Hz resulting in ~1000 data points for each run effort.
118 The initial 10 s of the run was used for analysis to allow full completion of the run including

119 deceleration. To standardise the beginning of the run for each participant, the run was deemed
120 to have begun once a velocity of $1 \text{ m}\cdot\text{s}^{-1}$ had been reached.

121 *Statistical Analysis*

122 Descriptive statistics were computed for all variables from both the CMJ test and SRT
123 and reported as mean \pm SD. Following previous literature ^{1, 8}, the absolute and trial-to-trial
124 reliability of each variable was quantified via typical error of measurements (TEs) and
125 expressed as a CV (\pm 90% confidence interval (CI)). This was calculated using the spreadsheet
126 for reliability by Hopkins ¹⁷ with further detailed evaluation of calculations to be reviewed
127 elsewhere (for review ^{1, 2}). Test-retest reliability (week-to-week) was analysed by calculating
128 magnitude-based inferences (effect size (ES) statistic \pm 90% CI) between the mean of each
129 measure for week 1 and the mean of each measure for week 2 (i.e., difference between the
130 mean of PL1D_{up} for week 1 and the mean of PL1D_{up} for week 2 etc.). As suggested by Rhea
131 ¹⁸ for highly trained athletes, differences were classified as trivial (< 0.25), small ($0.25 - 0.50$),
132 moderate ($0.51 - 1.0$), and large (> 1.0), and declared practically important where there was a
133 $> 75\%$ likelihood of exceeding the smallest important effect size (0.25) ¹⁹. Differences with less
134 certainty were classified as trivial ²⁰, with the magnitude of the difference considered ‘unclear’
135 where the 90% CI simultaneously overlapped the smallest important ES (0.25) both positively
136 and negatively ¹⁹. The smallest worthwhile change (SWC) was calculated as $0.25 \times \text{SD}$,
137 representing a “small” effect size and the smallest beneficial change of performance ¹.
138 Variables were considered capable of detecting the SWC if the $\text{CV} \leq \text{SWC}$ ^{1, 8}.

139 *Results*

140 For each performance measure, mean values (\pm SD) and reliability estimates are listed
141 in Table 1. Changes in the performance measures from week-to-week are presented in Figure
142 1, while Figure 2 illustrates the difference in the estimated typical variation as the number of

143 trials included increased. There was no apparent change observed in any variables between
144 week 1 and week 2. There was an approximate increase of error for most variables of 1-2%
145 when one trial was included than when three to six trials were included. Low absolute reliability
146 was also observed for all variables with CV's present of less than 10% (range = 6.6 – 9.3%),
147 other than for ED (CV = 12.8%). PV from the CMJ test and all the SRT variables possessed
148 CVs smaller than the SWC.

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Insert Table 1 here

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Insert Figure 1 here

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Insert Figure 2 here

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156 **Discussion**

157 In order to make an informed decision regarding athletic performance, a comprehensive
158 understanding of the typical variation or repeatability of the test being applied is vital. The
159 present study showed good reliability for all variables within this study. Furthermore, all SRT
160 variables possessed a CV smaller than the SWC, and are, therefore, potentially more capable
161 of detecting practically meaningful changes.

162 When monitoring an athlete's response to training and their recovery between sessions
163 and/or weekly competitions, the focus should be placed upon short-term variability ¹. This type
164 of reliability is most common for estimating the magnitude of error associated with test-retest

165 designs, such as subjects tested pre- and post-intervention and includes not only the random
166 measurement error but also the biological variation that occurs over time ¹. The results
167 observed in this study showed no differences in performance outcome variables from week 1
168 to week 2 in any of the tested variables. This suggests that fatigue and learning effects did not
169 adversely influence the results between sessions. Consequently, any changes observed when
170 implementing within a normal training environment must be due to influences on performance,
171 such as fatigue or super-compensation. This, therefore, supports any changes observed within
172 regular weekly monitoring of either test can be that of a real change in performance, or of a
173 fatigued state, and not that of random measurement error, or mainly, biological variation.

174 It is also essential to have an understanding of the trial-to-trial reliability due to it having
175 limited scope for biological changes. The error estimate associated with trial-to-trial reliability
176 can, therefore, be attributed to random measurement error alone ². This value allows for an
177 accurate estimation of the true likely range of the chosen outcome variables, which can assist
178 the practitioner in understanding the amount of error that can occur within a single
179 measurement ¹. Our results indicate that when a single trial CMJ test was used, the practitioner
180 can expect an approximate increase of error for most variables of 1-2%, compared to if three
181 to six trials are used. Although it has previously been recommended that at least six jumps are
182 required to reduce variability ^{1,21}, in this population of team sport athlete, it seems that at least
183 three trials are sufficient to maintain acceptable reliability. However, with only an increase of
184 error of 1-2%, using only a single trial may increase the feasibility of the test as a weekly
185 monitoring tool in a sport such as ARF that has large squad numbers. Nonetheless, in order to
186 reduce the estimated error and tighten the reliability of this procedure, from these results, it is
187 recommended to perform at least three trials of a CMJ test. A similar increase of error of
188 approximately 1-1.5% was also observed for the SRT when a single run was used compared to
189 if three runs were used. Yet, due to the small decrease in estimated error as each run was

190 included, it may be that including more run efforts may further reduce the random measurement
191 error of the test. Nevertheless, with the current test taking less than two minutes to complete,
192 the inclusion of more trials may not have a significant impact upon the estimated error but have
193 an adverse effect on the practicality of the test within a high-performance environment.
194 Therefore, it is recommended that the current protocol of the SRT is sufficient to maintain low
195 error estimate and high practicality.

196 Although there is no predetermined standard for acceptable CV values, in practical
197 settings for monitoring tools, it is generally considered that ‘good’ reliability is set at those
198 with CVs <10%^{1, 22}. However, having a set criterion for ‘good’ reliability based simply off a
199 CV alone does not provide information about the meaningfulness of the change¹. A test can,
200 therefore, possess ‘good’ reliability, but where a variable has a CV greater than the SWC, it
201 would indicate reduced practicality of that variable¹. It is generally agreed that the SWC is the
202 minimal practically meaningful change in performance^{1, 5}. In relation to performance, the
203 typical variation (CV) of a test needs to be smaller than the SWC to be considered practically
204 meaningful^{1, 5}. In our analysis, all SRT variables demonstrated a CV < SWC. This would
205 indicate that the variables of the SRT are useful measures when monitoring performance in
206 ARF players. However, although the CMJ test variables possessed ‘good’ reliability, only PV
207 possessed a CV smaller than the SWC. While PV has the ability to detect the smallest
208 worthwhile effect on performance, the inability of the other CMJ variables suggests that this
209 test may be limited as a monitoring tool within this setting. This is not at all surprising
210 considering recent evidence has emerging to suggest that the underlying mechanisms of fatigue
211 are task-specific¹⁴. The results of this analysis would, therefore, support this notion, and
212 suggest that when implementing a testing program to monitoring changes in NMF status in a
213 predominantly running based sport, a greater task-specific test, like the SRT, may be a more
214 useful measure. Nonetheless, a CMJ can still be a viable option within this environment, with

215 PV recommended as the variable to monitor due to its ability to detect practically meaningful
216 changes in physical performance. Yet, it must also be noted that this study only utilised ARF
217 players and results may not be indicative of all running based team sport athletes. It is,
218 therefore, recommended that future research should look at including different running-based
219 team sport athletes to confirm these findings.

220 **Practical Application**

221 From a practical perspective, it was shown that a SRT might be a more useful
222 monitoring tool than a CMJ test in predominantly running based team sports such as ARF, due
223 to its enhanced capability of detecting practically meaningful changes in performance.
224 However, when utilising a CMJ test within this environment, is it recommended to monitor PV
225 due to its enhanced ability to detected practically important changes compared to other CMJ
226 variables. Nonetheless, when implementing either test, including at least three trials is
227 suggested in order to reduce the estimated error and maintain the practicality within these
228 settings.

229 **Conclusion**

230 In conclusion, the results suggest that both the CMJ test and SRT offer a useful and
231 reliable measure for monitoring fatigue in high-performance ARF players with CVs observed
232 less than 10%. However, it was determined that a SRT might provide a more useful measure
233 when monitoring changes in NMF status due to its enhanced ability to detected practically
234 meaningful changes in performance. Nevertheless, a CMJ test still offers a viable option within
235 this environment, with PV recommended as the variable to monitor. To confirm these findings,
236 future research should also look at including more running-based team sport athletes.

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Table 1. Mean \pm SD and typical variation estimates represented as CVs (\pm 90% confidence interval) for each performance measure. The SWC is also present for comparison with estimates of typical variation. Abbreviations: CV, coefficients of variation; SWC, smallest worthwhile change; AU, arbitrary unit; PL, player load; Fwd, Forward.

	mean	CV%	SWC (%)
CMJ _H (m)	0.43 \pm 0.05	6.6 (5.3;8.9)	1.1
Peak Velocity (m/s)	3.42 \pm 0.31	6.8 (5.4;9.2)	7.9
Eccentric Displacement (m)	0.61 \pm 0.13	12.8 (10.2;17.2)	3.2
PL1D _{up} (AU)	2.69 \pm 0.41	9.3 (7.4;12.5)	10.2
PL1D _{side} (AU)	1.84 \pm 0.28	6.7 (5.3;9.0)	7.0
PL1D _{fwd} (AU)	2.28 \pm 0.43	9.2 (7.4;12.5)	10.8

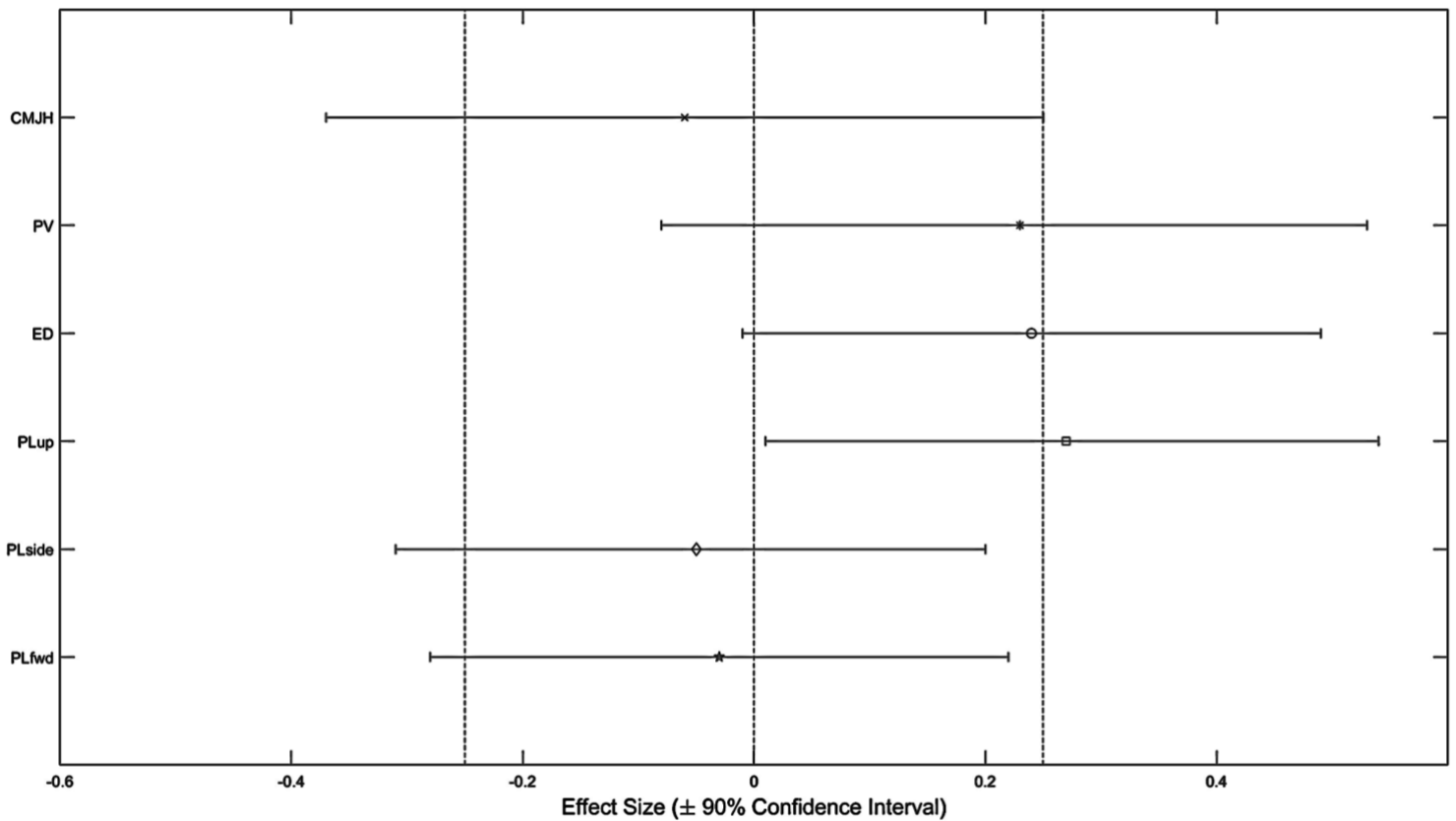


Figure 1. Mean changes in variables from week-to-week represented as an effect size (\pm 90% confidence interval). Vertical lines represent a small (0.25) effect size both positively and negatively and effect size at 0. Where the 90% CI simultaneously overlapped the smallest important ES (0.25) the magnitude of the difference was considered “*unclear*”, with a <75% likelihood of exceeding the smallest important ES (0.25) classified as trivial (for example PL1D_{up}). Abbreviations: CMJ height, CMJ_H; peak velocity, PV; eccentric displacement, ED; player load 1D up, PL1D_{up}; player load 1D side, PL1D_{side}; player load 1D forward, PL1D_{fwd}.

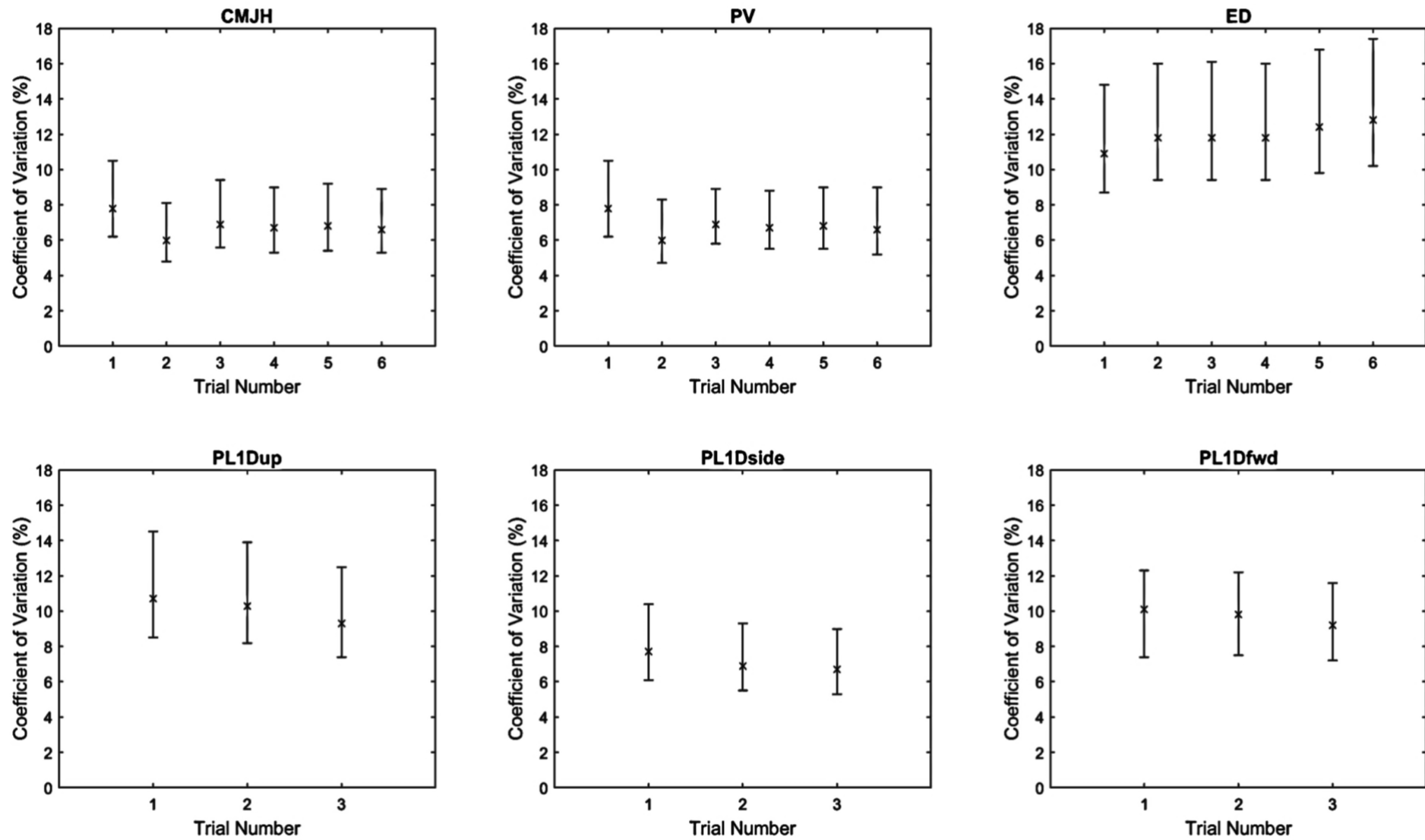


Figure 2. Mean coefficients of variation \pm 90% confidence intervals for CMJ height (CMJ_H), peak velocity (PV), eccentric displacement (ED), player load 1D up (PL1D_{up}), player load 1D side (PL1D_{side}) and player load 1D forward (PL1D_{fwd}) and the number of trials performed.