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Reliability of Measures Obtained During Single and Repeated Countermovement Jumps

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Purpose: To establish the reliability of various measures obtained during single and repeated countermovement jump (CMJ) performance in an elite athlete population. ***Methods:*** Two studies, each involving 15 elite Australian Rules Football (ARF) players were conducted where subjects performed two days, separated by one week, of AM and PM trials of either a single (CMJ1) or 5 repeated CMJ (CMJ5). Each trial was conducted on a portable force-plate. The intraday, interday, and overall typical error (*TE*) and coefficient of variation (*CV%*) were calculated for numerous variables in each jump type. ***Results:*** A number of CMJ1 and CMJ5 variables displayed high intraday, interday, and overall reliability. In the CMJ1 condition, mean force (*CV* 1.08%) was the most reliable variable. In the CMJ5, flight time and relative mean force displayed the highest repeatability with *CV* of 1.88% and 1.57% respectively. CMJ1Mean force was the only variable with an overall *TE* < smallest worthwhile change (*SWC*). ***Conclusion:*** Selected variables obtained during CMJ1 and CMJ5 performance can be used to assess the impact of both acute and chronic training and competition. Variables derived from the CMJ5 may respond differently than their CMJ1 counterparts and should provide insights into differential mechanisms of response and adaptation.

Keywords: elite athletes, vertical jump, performance, testing, monitoring

Various forms of the vertical jump (VJ) and mechanical components derived from their performance have been studied previously.[1–13] Although VJ measurement has been described as a key component in any training study,[9,14] limited data exists on the reliability of variables other than jump height and power obtained during performance of these movements in elite team sport athletes. This is despite the suggestion that reliability in physical tests is a critical factor in the ability of tests to determine changes in athletic capacities[9,15,16] and the fact that VJ scores may be dependent on the method of assessment.[14]

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As the neuromuscular performance qualities of muscles have been shown to be similar in VJ and running, VJ performance may be highly relevant for assessing various parameters important in sport where running is a chief component.[17] The use of high speed video technology,[8,14] linear position transducers,[12] and methods involving mathematical assumptions to calculate values for variables such as power have been used.[14] It has been shown that significant differences exist between jump height measured via change in center of mass and jump height calculated using assumptions such as flight time or take-off velocity; however, each method is claimed to possess excellent reliability (*CV* 13.4% to 18.3%).[14] It may be argued that such values do not represent excellent reliability.

In a study to establish the influence of familiarization on reliability in VJ and sprinting, Moir et al[9] tested male recreational athletes in a squat jump (SQJ) and CMJ performed on a timing mat at body weight and with a 10-kg load. The results of this study showed CMJ height during body weight jumps to be highly reliable with a *CV* of 2.4% and an *ICC* of $r = 0.93$. In a similar protocol, Arteaga et al[18] showed displacement of the center of gravity in the SQJ and CMJ performed on a timing mat to be a reliable measure with *CV* of 5.4% and 6.3% respectively. Markovic et al[11] also used a contact mat to determine CMJ reliability and reported an *ICC* of $r = 0.98$ and *TE* values of 2.8%.

It has been proposed that assessing repetitive CMJ power may be valuable in sporting performance.[19] Interestingly, a number of factors have been identified as important in the performance of a VJ, including the contribution of arm swing, sequencing and timing of segmental actions, and speed and amplitude of the countermovement.[1] Any assessment in which a version of a repeated CMJ is used should ensure a technique is chosen that limits the potential for change in, and therefore influence of, these contributing factors. In another technique-related study, Domire and Challis[6] found that although ground contact time increased with squat depth before a VJ, there was no difference in jump heights from a self-selected or imposed deeper position.

The reliability of some variables measured during single and relatively high repetition CMJs has been assessed previously.[10,20] These variables have also been used to examine the impact of athletic performance.[2,4,5,19] Power measured during 60 seconds of a repeated maximal CMJ has previously been shown to be reliable (*ICC* $r = 0.95$).[20] Continuous CMJs conducted for 30 seconds on a force plate have also shown mean jump height to be a reliable measure ($r = 0.97$) although peak height scores were less reliable.[10] The authors of this study concluded that this may have been partially due to the requirement to achieve a minimum 90° knee angle during each countermovement. This suggests that a protocol, wherein a self-selected knee angle is used, may provide higher reliability and that a shorter test duration may minimize the error. In another study involving a high number of repetitions, Alemany and Pandorf et al[21] investigated the reliability of mean power, peak power, mean velocity, peak velocity, and work during 30 seconds of continuous SQJs using 30% of 1 repetition maximum. Results revealed *ICC*s of between $r = 0.80$ and $r = 0.96$ with *CV* of between 3.0% and 7.6%.

Little data are available describing the reliability of an extensive number of variables obtained during short duration (~5 seconds) repeated CMJ performance. Bosco et al,[22] used a 5-second repeated CMJ requiring subjects to produce a maximum jump effort with minimal knee bend and reported power variables to have a reliability of $r = 0.95$. The potential exists for variables obtained during short duration (ie, short enough not to be restricted by metabolic limitations) repeated CMJ performance to be valuable in assessing the impact of training programs and performance. For valid conclusions to be drawn regarding changes in pre and post scores, the reliability of the variables in question must first be established. There appears to be no reported data available that provides *TE* or *CV%* data for variables that can be obtained in this type of repeated CMJ performance in elite team sport athletes. Therefore, the purpose of this study was to establish the reliability of a number of variables obtained during the performance of a single and short duration repeated CMJ in an elite athlete population.

Methods

Subjects

Fifteen elite ARF players (Study 1: age 23.3 ± 3.8 years, height 1.91 ± 0.06 m, mass 93.05 ± 7.7 kg; Study 2: age 22.5 ± 2.8 years, height 1.89 ± 0.06 m, mass 91.2 ± 8.0 kg) participated in each study. All subjects were squad members of a team that participates in the Australian Football League (AFL) competition. Players had a minimum of 2 years of full-time training experience at the elite level and regularly performed jumping movements as part of their training routine. The study was approved by the university human ethics committee and all subjects signed an informed consent document.

Design

Two studies were conducted with elite ARF players who completed 2 days of testing, separated by 7 days, of AM and PM trials of a CMJ1 (Study 1) or CMJ5 (Study 2).

Methodology

Subjects performed 3 familiarization sessions followed by an AM (0900–0930) and PM (1530–1600) trial on Day 1, and an AM and PM trial on Day 2. Trial days were conducted 1 week apart, and training in the 48 hours before each trial day and between AM and PM trials was strictly controlled to ensure no influence on performance. Before each trial of the CMJ1 or CMJ5, subjects performed a 2-minute dynamic warm-up consisting of various running patterns including jogging, high knees, heel flicks, and skipping. Subjects were required to progressively increase the intensity and range of motion in running patterns until the end of the warm-up period to ensure they were capable of maximal performance. Subjects then performed 3 submaximal practice CMJs before the measurement trial. A similar warm-up protocol has been shown to positively influence CMJ performance.[23]

Each trial session consisted of one attempt at either the CMJ1 or CMJ5. In each study, subjects completed the trials on a commercially available force plate (400 Series Force Plate—Fitness Technology, Adelaide, Australia) connected to computer software (Ballistic Measurement System—Fitness Technology, Adelaide, Australia) capable of recording vertical ground reaction forces (VGRF) at a sample rate of 200 Hz. In both the CMJ1 and CMJ5 conditions, subjects were required to perform a CMJ with hands held in place on the hips. Based on the influence of arm swing on CMJ performance, previous research has also used this technique.[1,2,9,11,24] In the CMJ1, subjects were instructed to jump as high as possible, while in the CMJ5, subjects were required to jump as high as possible for 5 consecutive efforts without a pause between jumps. Countermovement depth was self-selected by the subject. A self-selected countermovement depth was chosen to assess reliability of variables using a technique requiring minimal intervention thereby maximizing the potential application to practical settings where time limitations may exist. Each trial was then analyzed using custom-designed software (Mathworks, Natick, Massachusetts, USA) capable of automatically detecting values for the variables of interest. To identify different segments of the CMJ1 and CMJ5, a number of critical features were identified. The start of the eccentric phase in the CMJ1 was classified as a reduction of 5% in VGRF and in the CMJ5 as peak VGRF after landing from the previous jump (from jump 2 onwards). The end of the eccentric phase was identified as the minimum VGRF before leaving the force plate in both conditions. This point also served as the marker for the start of the concentric phase. The end of the concentric phase coincided with leave time (VGRF < 5N). Land time was calculated as time when VGRF exceeded 50 N. Typical CMJ1 and CMJ5 force traces are displayed in Figure 1.

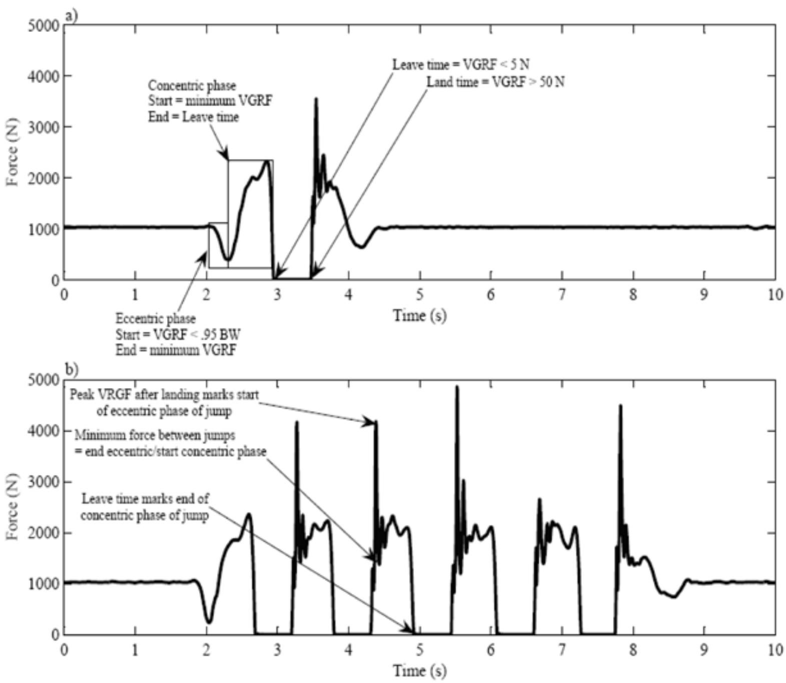

Figure 1 — Typical CMJ1 (a) and CMJ5 (b) force traces with critical features identified.

After identifying these critical features, the following variables were calculated during specific parts of the jump in each trial of the CMJ1 and CMJ5. CMJ5 scores for each variable were calculated as the average score over the 5 jumps of the trial.

Jump height in m: peak height.

Flight time in s: difference between landing and takeoff time.

Peak power in W: highest power generated during the concentric phase.

Relative peak power in w/kg: peak power divided by body mass in kg.

Mean power in W: mean power generated during the concentric phase of the jump.

Relative mean power in w/kg: mean power divided by body mass in kg.

Peak force in N: highest force recorded during the concentric phase.

Relative peak force in N/kg: peak force divided by mass in kg.

Mean force in N: mean force during the concentric phase of the jump.

Relative mean force in N/kg: mean force divided by mass in kg.

Eccentric time in s: length of the eccentric phase measured from the commencement of the countermovement until the commencement of the concentric phase.

Concentric time in s: length of the concentric phase measured from the end of the countermovement phase until the subject leaves the force plate.

Eccentric:Concentric in s: ratio of eccentric time to concentric time.

End eccentric force in N: force at the completion of the eccentric phase.

Flight time:Eccentric time in s: ratio of flight time to eccentric time.

Flight time:Contraction time in s (CMJ1 only): ratio of flight time to contraction time (eccentric + concentric time)

Flight time: Contact time in s (CMJ5 only): ratio of flight time to contact time (eccentric + concentric time).

Statistical Analysis

The intraday (AM v PM) and interday (Day 1 v Day 2) reliability of each variable for both the CMJ1 and CMJ5 conditions was calculated to determine *TE* and *CV%* in conjunction with *TE* upper and lower 90% confidence intervals.[25] The average intraday (Day 1 AM v Day 1 PM and Day 2 AM v Day 2 PM) and interday (Day 1 AM v Day 2 AM and Day 1 PM v Day 2 PM) was then calculated. Overall reliability represents the mean of the intraday and interday averages. It has been suggested that it is ultimately up to the researcher to decide if a particular variable is reliable enough for its intended use.[26] It is also possible that the most reliable tests are not necessarily the most effective for monitoring performance in athletes.[27] Numerous earlier studies have reported biomechanical variables with *CV* in the vicinity of 10% as reliable.[28–32] As a result, a *CV* of ≤10% was set as the criterion to declare a variable as reliable. A 10% *CV* cut-off may encourage the examination of variables other than those possessing the highest reliability in future research.

Previous work has suggested that the smallest clinically worthwhile change (*SWC*) represents the smallest change that is of benefit to athletic performance and can be calculated as 0.2 × between-subject *SD*.[15,16] As a result, variables were considered capable of detecting the *SWC* if the *TE* was ≤ *SWC*.[16]

Results

Intraday, interday, and overall reliability for reliable variables (*CV* < 10%) in CMJ1 and CMJ5 conditions are displayed in Tables 1 to 4. Tables show mean, *SD*, *TE* and 90% lower and upper confidence limits, *SWC*, and *CV%*.

Intraday Reliability

Reliable CMJ1 variables are displayed in Table 1. Mean force had a *TE* < *SWC*. Eccentric time and Flight time:Eccentric time showed marginal reliability with *CV%* of 11.6 and 11.4 respectively. Concentric time (*CV* 17.1%) and Concentric time:Eccentric time (*CV* 16.5%) were less reliable. End eccentric force was the most unreliable CMJ1 variable with a *CV* of 92.6%.

Table 2 shows CMJ5 reliable variables. Height appeared extremely unreliable (*CV* 24.7%) while variables such as Flight:Contact (*CV* 13.3%), Mean power (*CV* 11.0%), Relative mean power (*CV* 11.5%) and FLT:ET (*CV* 11.4%) showed marginal reliability. No CMJ5 variables showed a *TE* < *SWC*. Mean power and Relative mean power were reliable in the CMJ1 condition but this was not replicated in the CMJ5 condition. However, End eccentric force proved reliable in the CMJ5 despite poor intraday repeatability in the CMJ1.

Table 1 CMJ1 Intraday Reliable Variables*

	Mean	TE	Lower 90%CI	Upper 90%CI	SWC	CV%
Height (m)	0.488	0.024	0.018	0.035	0.007	5.2
Flight time (s)	0.586	0.017	0.013	0.025	0.006	2.9
Peak power (W)	5014	166	127	242	112	3.5
Relative peak power (W/kg)	54	2	1	3	1	3.6
Mean power (W)	765	52	40	78	20	6.9
Relative mean power (W/kg)	8	1	0.5	1	0.2	7.1
Peak force (N)	2163	77	59	115	41	3.5
Relative peak force (N/kg)	23	0.8	0.6	1.2	0.3	3.4
Mean force (N)	1233	13	10	20	20	1.1
Relative mean force (N/kg)	13	0.16	0.12	0.24	0.1	1.2
Flight time:Contraction time (s)	0.807	0.056	0.043	0.082	0.027	6.1

*Values are reported as mean, TE and 90% lower and upper CI, SWC and CV%. TE reflects noise in test scores generated from biological and technological sources. SWC represents the smallest change that is of benefit to athletic performance.

Table 2 CMJ5 Intraday Reliable Variables*

	Mean	TE	Lower 90%CI	Upper 90%CI	SWC	CV%
Flight time (s)	0.519	0.009	0.007	0.014	0.003	2.0
Peak power (W)	4740	210	161	306	77	4.4
Relative peak power(W/kg)	52	2	2	3	1	3.8
Peak force (N)	2121	69	53	101	25	3.3
Relative peak force(N/kg)	23	1	0.5	1.0	0.23	2.8
Mean force (N)	821	18	14	26	9	2.4
Relative mean force(N/kg)	9	0.13	0.10	0.19	0.03	1.5
End eccentric force(N)	1034	92	70	134	23	9.5

*Values are reported as mean, TE and 90% lower and upper CI, SWC, and CV%. TE reflects noise in test scores generated from biological and technological sources. SWC represents the smallest change that is of benefit to athletic performance.

Interday Reliability

CMJ1 interday reliable variables are shown in Table 3. They exhibited similar results to the intraday comparison; however, Flight:Contraction (*CV* 10.4%) was less reliable than in the intraday comparison.

Following a similar pattern, CMJ5 interday reliability (Table 4) was comparable to intraday results; End eccentric force (*CV* 18.4%) demonstrated lower reliability. Height continued to show poor reliability (*CV* 31.3%). No CMJ5 variables appear capable of detecting the *SWC* from an interday perspective.

Overall reliability

Overall CMJ1 reliability was identical to the pattern shown in the intraday analysis. Mean force (*CV* 1.1%) displayed an overall *TE* < *SWC* despite Mean force being incapable of detecting the smallest worthwhile change in the interday comparison. Relative mean force was the next most overall reliable variable with a *CV* of 1.2%. Peak force (*CV* 2.8%) and Relative peak force (*CV* 2.7%) were also highly reliable. CMJ1 Height and Flight time had overall *CV%* of 5.1 and 3.1 respectively. Peak power and Relative peak power (*CV* 3.2% and 3.3%) were more reliable than Mean power and Relative mean power (*CV* 6.2% and 6.4%). Flight time:Contraction time (*CV* 8.2%) was the least reliable CMJ1 variable overall.

Analysis of CMJ5 overall reliability shows a number of variables to have acceptable levels of reliability. Relative mean force (*CV* 1.6%) and Flight time (*CV* 1.9%) were the most reliable. Peak power and Relative peak power also displayed good overall reliability (*CV* 5.3% and 4.5% respectively). Mean force (*CV* 2.4%) was more reliable than Peak force (*CV* 3.8%) and Relative Peak Force (*CV* 3.1%). End eccentric force (*CV* 14.1%) became unreliable on the interday comparison and remained this way in the overall analysis. No CMJ5 variables appear capable of detecting the *SWC*.

Table 3 CMJ1 Interday Reliable Variables*

	Mean	TE	Lower 90%CI	Upper 90% CI	SWC	CV%
Height (m)	0.488	0.023	0.018	0.034	0.006	5.0
Flight time (s)	0.586	0.020	0.015	0.029	0.005	3.3
Peak power (W)	5014	147	113	214	76	2.9
Relative peak power (W/kg)	54	2	1	2	1	3.0
Mean power (W)	766	42	32	62	15	5.5
Relative mean power (W/kg)	8	0.5	0.4	0.7	0.2	5.7
Peak force (N)	2163	48	36	71	26	2.2
Relative peak force (N/kg)	23	0.5	0.4	0.8	0.2	2.1
Mean force (N)	1233	12	9	18	11	1.0
Relative mean force (N/kg)	13	0.2	0.1	0.2	0.05	1.3

*Values are reported as mean, TE and 90% lower and upper CI, SWC, and CV%. TE reflects noise in test scores generated from biological and technological sources. SWC represents the smallest change that is of benefit to athletic performance.

Table 4 CMJ5 Interday Reliable Variables*

	Mean	TE	Lower 90%CI	Upper 90%CI	SWC	CV%
Flight time (s)	0.519	0.010	0.008	0.015	0.002	1.9
Peak power (W)	4740	278	214	406	56	6.1
Relative peak power (W/kg)	52	3	2	4	0.53	5.2
Peak force (N)	2121	86	66	125	17	4.2
Relative peak force (N/kg)	23	1	0.6	1.2	0.2	3.5
Mean force (N)	821	18	14	27	4	2.4
Relative mean force (N/kg)	9	0.14	0.1	0.2	0.03	1.6

*Values are reported as mean, TE and 90% lower and upper CI, SWC, and CV%. TE reflects noise in test scores generated from biological and technological sources. SWC represents the smallest change that is of benefit to athletic performance.

Discussion

The results of both studies demonstrate that a number of variables obtained during CMJ1 and CMJ5 performance exhibit high reliability ($CV < 10\%$). Despite this, only CMJ1Mean force appears capable of detecting the *SWC* with a $TE < SWC$. A comparison of results from the intra and interday analysis in both the CMJ1 and CMJ5 revealed only minor differences. This suggests that time of day has little influence on either single or short duration repeated CMJ performance. Interestingly, a number of variables not commonly used in CMJ1 analysis such as Flight time:Contraction time proved to have acceptable overall reliability.

Intraday Reliability

The extensive number of CMJ1 and CMJ5 variables with high reliability suggests that performance of these movements remains stable across a single day. Somewhat surprisingly, CMJ1Height was not the most reliable of the variables measured despite the emphasis on jumping as high as possible in the instructions given to subjects. This may be due to the fact that Height reflects a relatively gross performance measure and that even though subjects employed maximum effort; the ultimate outcome is limited by contributing factors that are measured directly by the force-plate. Evidence of this may be found in the high repeatability of both CMJ1 and CMJ5Flight time, which are measured directly by the force-plate. Reliability of Height is therefore likely to be affected by the fact that displacement has not been measured directly, but rather inferred by mathematical assumption.[33] Previous work utilizing a position transducer has demonstrated single CMJ Height to have a *CV* of $< 3\%$.[12] Values of 6.3% and 2.8% have been reported when Height is measured using a timing mat.[11,18] These results are similar to those of the current study despite the different measurement apparatus used.

In contrast to the high repeatability of CMJ1Height, CMJ5Height was extremely unreliable. In a similar fashion, Theodorou and Cooke[10] concluded that mean peak height was significantly different from test to retest. Interestingly, this group found mean Height measured in 7.5-second periods over a 30-second continuous CMJ on force-plate to have a Pearson correlation coefficient of $r = 0.97$, which suggests high reliability; however, *CV%* or *TE* data were not presented. A major difference between the current study and this previous work is the overall length of the repeated CMJ performance (5 seconds versus 30 seconds). A longer performance may result in subjects adopting some type of pacing strategy whereas the CMJ5 may elicit repeated maximal efforts. It is possible that adopting a pacing strategy increases reliability in repeated CMJ tasks. It is also possible that analyzing the 30-second jump task as used by Theodorou and Cooke[10] to incorporate the full length of the trial, rather than in 7.5-second blocks, could alter the reliability. The lack of *TE* and *CV%* data makes comparisons with previous work difficult, but Height reliability in our study appears similar to others who have measured this indirectly. In the current study, any error in the CMJ5 compared with the CMJ1 is likely to be compounded by the repetitive nature of the CMJ5 condition and this may account for the poor *CV%*. It may also be important to consider that previous work has been conducted on an interday comparison basis. It is possible that if these experiments were repeated on an intraday manner that the results could be different. The excellent reliability of CMJ5Flight time, probably due to its direct measurement, suggests that this may be a more appropriate variable than Height for athletic assessment.

The direct measurement of force is likely to be a major component in the high reliability of CMJ1 and CMJ5Mean force and Relative mean force. In both jump conditions, Peak force and Relative peak force also proved to be highly reliable but it appears that mean force values are more reliable. This may be explained by the fact that minor fluctuations in Peak force become inconsequential in the Mean force score, while constituting the full value assigned to Peak force. It has been proposed that measurement of repeated rather than single efforts may increase the reliability of variables because the importance of "one-off" high or low scores is diminished as more repetitions are completed.[27] As Mean force and Relative mean force scores constitute a number of scores averaged across time, rather than a single score, this concept may apply. The slightly higher reliability of the Mean force and Relative mean force scores and the fact that CMJ1Mean force has a $TE < SWC$, suggests these measures may be more sensitive than Peak force measures to small performance changes in athletic populations.

There are some important differences in the reliability of power variables when comparing the CMJ1 and CMJ5. While CMJ1Peak power, Mean power, and their relative values are highly reliable, CMJ5Mean power and CMJ5Relative mean power proved less reliable. This appears in contrast to the findings of others who report average power in repetitive jumping tasks (15-second blocks during a 60-second test) to have a test-retest correlation of $r = 0.95$.[20] Peak power and Mean power has also been measured during 30 repetitions of CMJs with the addition of 30% of body weight and found to produce a *CVs* of 3.2% and 4.4% respectively.[21] These values are considerably lower than those from the CMJ5. A major factor in the results of Alemany and Pandorf et al[21] could be that testing was conducted in a Smith machine rather than free standing. This is likely to decrease positional errors on landing and lead to more consistent performance. The direct measurement of displacement is also likely to have been critical and it also possible that the less homogenous nature of subjects used in other studies may have produced higher *r* values.

Although CMJ5Mean power and Relative mean power intraday values are unreliable at a *CV* cutoff of 10%, they follow a similar pattern to the CMJ1. In the CMJ1, Mean power and Relative mean power are also less reliable than their peak counterparts. It is likely that Mean power is largely affected by changes in contact time brought about by variations in countermovement range and speed. The requirement to repeatedly land, stabilize, and perform the next jump in the CMJ5 condition may be a reason why Mean power and Relative mean power variables display lower reliability compared with CMJ1 values.

The reliability of a number of CMJ1 and CMJ5 variables that have received little previous attention are worthy of discussion. CMJ5End eccentric force displayed much higher reliability than CMJ1End eccentric force. The repeated measure of End eccentric force reported as an average in the CMJ5 may limit the influence of a "one-off" high or low value.[27] End eccentric force is likely to depend considerably on countermovement depth. A decreased range in the countermovement would result in a more rapid stretch of the leg extensor musculature and result in higher End eccentric force. Subjects may vary their countermovement strategy to allow Height to be maintained. It could also be that the short duration of the CMJ5 elicits some type of "pacing strategy" resulting in a far more consistent performance than a one-off maximum effort. Alternatively, subjects may exert more conscious control over their countermovement strategy to allow execution of consecutive ballistic movements.

The ratio of jump height to contact time has previously been proposed as a variable of interest in assessing drop jump performance.[24] As Height in the current study has been calculated using the impulse-momentum relationship and appears unreliable, Flight time:Contact time may be considered a more appropriate measurement reflecting the same qualities. In the CMJ5, intraday analysis revealed this to be an unreliable measure. There is potential for this result to have been influenced by the instructions provided to subjects as has been shown in previous research.[24] In an attempt to maximize jump height it is likely that subjects have manipulated contact time. This is evidenced by the unreliable nature of CMJ5Eccentric time and CMJ5Contraction time (*CV* 21.8% and 19.6% respectively). Although, given the strict pretest control, it is unclear why a change in strategy would be required. An instruction to jump as quickly as possible may have elicited a different response and therefore potentially improved reliability of the CMJ5Flight time:Contact time variable.

It may be argued that the analogous measure to CMJ5Flight time:Contact time is CMJ1Flight time:Contraction time, as this measure provides a ratio of the flight time to the sum of eccentric and concentric contraction time. Interestingly, this measure proved reliable in the intraday comparison. While subjects may have manipulated contraction time to achieve maximum height, the combination with flight time may contribute to the reliability in this ratio measure. It seems that in this case, one effort has resulted in less variation than the repeated efforts of the CMJ5Flight time:Contact time. This is in contrast to the potential reasons why some CMJ5 variables have shown acceptable reliability (ie, average scores negating the influence of variations in peak scores). There may be a complex interaction of factors that result in some variables showing high reliability and other seemingly related variables proving to be unreliable. Repeated performance as occurs in the CMJ5 may increase reliability in some variables and reduce it in others.

While a number of variables proved to be extremely reliable on an intraday basis, a group of CMJ1 and CMJ5 variables produced results just outside the *CV* 10% cut-off (CMJ1Eccentric time, Flight time:Eccentric time and CMJ-5Flight time:Eccentric). Both CMJ1Flight time:Eccentric time and CMJ5Flight time:Eccentric time represent flight time relative to the time spent in the countermovement phase of the jump and in both jump conditions, Flight time is extremely reliable and Eccentric time less so, possibly due to variations in countermovement depth in an effort to achieve maximum jump Height. In combination, these variables produce a variable of marginal reliability which may prove worthy of further study, as measures displaying the highest reliability are not always the best for monitoring performance changes.[27]

Interday Reliability

CMJ1 and CMJ5 interday reliability was almost identical to that of the intraday analysis. Despite many similarities, CMJ1Flight time:Contraction time (*CV* 10.4%), and CMJ5EEF (*CV* 18.7%) displayed lower repeatability than in the intraday comparison. From this data it seems that these variables may be less able to detect subtle changes in performance from day to day than within a single day. This could be important for coaches and sports scientists when deciding which variables to use in assessing the acute and longer term impact of training and competition.

Overall Reliability

As the overall reliability calculations are the average of intraday and interday results, it is not surprising that analysis revealed identical results to other comparisons. The same mechanisms are likely to be responsible in each case. It is potentially important that CMJ1Mean force has a *TE* < *SWC*. In theory, this variable may have the greatest chance of detecting performance changes. However, the response in elite athletes is unknown.

It is interesting that CMJ1 intraday and overall reliability analyses show the same variables to be reliable, while CMJ5 interday and overall reliability are identical. On strict assessment, it appears that some CMJ1 variables may be more useful on an intraday basis and some CMJ5 variables more able to detect small changes in an interday comparison. In the case of the CMJ1, low intraday Flight time:Contraction time *CV%* contribute positively to overall reliability. Conversely, poor interday reliability of CMJ5End eccentric force negatively influence the overall reliability of these variables. Therefore, the ability of some variables to assess change may depend on the nature of the pre and post comparison.

Practical Applications

Before a measure is used to assess the impact of training or performance, its reliability should first be established. This study is the most comprehensive assessment of performance variables in CMJ performance completed in elite athletes to date. We have demonstrated that numerous CMJ1 and CMJ5 variables possess high reliability from both an intraday and interday perspective, although some variables are more reliable in one comparison than another. Coaches and sport scientists can confidently examine these variables to assess the effect of various interventions in the knowledge that changes are likely to be biological in nature rather than due to noise in the test. It could be valuable to assess responses in single and repeated CMJs to various strength and power training regimens or the impact of elite competition on numerous variables to assess their ability to detect aspects such as fatigue.

Conclusions

A large number of CMJ1 and CMJ5 variables appear to be stable both within and between days. In addition to commonly measured variables such as Flight time and Peak power, variables such as CMJ1Flight time:Contraction time may be valuable in athletic assessment. Interestingly, CMJ5Height was found to be extremely unreliable. This is likely to be because jump height was not measured directly. It is possible that the reliability data obtained in both the CMJ1 and CMJ5 conditions may have differed with the direct measurement of displacement or with different instructions to subjects (eg, jump as quickly as you can). It is also conceivable that controlling countermovement knee angle could have modified the results. Various other jump types such as single leg CMJ and drop jumps may be worthy of similar investigations in elite athlete populations and further research should also look to quantify the kinematic variations and neuromuscular changes associated with modifications in CMJ performance.

A short-duration repeated CMJ such as the CMJ5 may be useful in investigating the impact of training and performance in elite athletes. A number of variables measured in this condition may respond differently than their CMJ1 counterparts and provide insight into mechanisms affecting responses in high level sport.

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