Reliability and validity of the 30-s continuous jump test for anaerobic fitness evaluation

Juliano Dal Pupo a,*, Rodrigo G. Gheller a, Jonathan A. Dias a, André L.F. Rodacki b, Antônio R.P. Moro a, Saray G. Santos a

a Biomechanics Laboratory, Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil
b Sector of Biological Sciences, Physical Education Department/Center for Motor Behaviour Studies, Federal University of Paraná, Curitiba, Paraná, Brazil

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ABSTRACT

Objective: To determine the test–retest reliability and concurrent validity of the 30-s continuous jump (CJ30) test using the Wingate test as a reference.

Design: Descriptive validity study.

Methods: Twenty-one male volleyball players (23.8 ± 3.8 years; 82.5 ± 9.1 kg; 185 ± 4.7 cm) were tested in three separate sessions. The first and second sessions were used to assess the reliability of the CJ30, while in the third session the Wingate test was performed. In the continuous jump test, consisting of maximal continuous jumps performed for 30 s, jump height was determined by video kinematic analysis. Blood samples were collected after each test to determine lactate concentration.

Results: The CJ30 showed excellent test–retest reliability for the maximal jump height (ICC = 0.94), mean vertical jump height (ICC = 0.98) and fatigue index (ICC = 0.87). Peak lactate showed moderate reliability (ICC = 0.45). Large correlations were found between the mean height of the first four jumps of CJ30 and the peak power of the Wingate (r = 0.57), between the mean vertical jump height of CJ30 and the mean power of the Wingate (r = 0.70) and between the lactate peak of CJ30 and Wingate (r = 0.51). A moderate correlation of fatigue index between CJ30 and the Wingate was found (r = 0.43).

Conclusions: The continuous jump test is a reliable test and measures some of the same anaerobic properties as WANt. The correlations observed in terms of anaerobic indices between the tests provide evidence that the CJ30 may adequately assess anaerobic performance level.

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1. Introduction

Assessment of anaerobic fitness is an important parameter in controlling and monitoring sports training performance. A number of tests have been proposed for evaluating anaerobic metabolism, such as the Wingate Anaerobic Test (WAnT), which is one of the most popular. Despite its widespread use, this test does not satisfy the specific demands of sports that do not involve cycling movements. In addition, some motor actions involving a combination of eccentric and concentric muscular actions, i.e., the stretch-shortening cycle (SSC), enhance performance during the final phase (concentric action) of movement when compared to the isolated concentric actions observed in WAnT. SSC is integral to many human movements including countermovement vertical jumps, which are used frequently in several sports.

Some tests share little specificity with sports that require vertical jumps, e.g., basketball and volleyball. In this context, Bosco et al. devised a specific anaerobic power test in which continuous jumps are executed for a period of 60 s. In addition to the test’s simplicity, the parameters obtained (e.g., jump height) may be more representative and have more practical application for coaches and athletes in sports that include such demands.

Continuous jump tests have been extensively used by coaches and physical trainers, but insufficient information has been presented in the literature concerning their validity and reliability. Bosco et al. used only a correlation approach to find evidence for the validity of continuous jump tests applied for 60 s. Additionally, limited or inadequate information about reliability is available. According to Hopkins et al., the two most important aspects of measurement error are concurrent validity and test–retest reliability, which guarantee the quality of a measuring instrument.

A variation of the traditional Bosco test (60 s) using a shorter duration (i.e., 30 s) has recently been studied. The 30 s duration is considered sufficient for eliciting ATP–PC power and capacity, as well as maximal glycolytic power, which may contribute more effectively to sustain the subject throughout the entire test. In addition to causing severe discomfort, anaerobic tests longer

* Corresponding author.
E-mail address: juliano.dp@hotmail.com (J. Dal Pupo).

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than 45 s tend to overestimate at power output because many individuals do not perform at maximum intensity throughout the test.\textsuperscript{4,10,14,15} According to Inbar et al.,\textsuperscript{15} the power generated in a 30-s test was higher than that recorded for the first 30 s in longer tests.

Given that no researchers have reported any information regarding the validity of a shorter continuous jump test (30 s) and the lack of data regarding its reliability in previous studies, this study aimed to determine the test–retest reliability and concurrent validity of the continuous jump test performed over 30 s (CJ\textsubscript{30}), using WAnT as a reference.

2. Methods

Twenty-one healthy male volleyball athletes (23.8 ± 3.8 years old; 82.5 ± 9.1 kg; 185 ± 4.7 cm; fat percentage: 12.1 ± 3.5\%) volunteered to participate in this study. They signed a written informed consent form, which was approved by the Human Research Ethic Committee of the Federal University of Santa Catarina in accordance with the Helsinki convention. Participants trained on a regular basis (three sessions per week) during the three years that preceded the study and were currently competing at the college level. Participants did not report injuries or other conditions that prevented them from training or otherwise influenced their maximal physical performance.

Participants were tested in three separate sessions with an interval of 48 h between sessions. The first and second sessions were used to determine the reliability of the CJ\textsubscript{30} (test–retest). The third session was used to perform WAnT, the reference used to determine concurrent validity.

Anthropometric assessments (body mass, height and skinfolds to estimate body fat) were performed in the first session. Participants were allowed a short period (i.e., 10 min) to familiarize themselves with the testing procedures and performed a specific warm-up (described below). Blood samples were collected from the right earlobe after each test to determine lactate concentration. Participants were requested to refrain from training in the 24 h that preceded testing sessions and to maintain their regular diet. Participants were also asked to avoid smoking and caffeinated drinks. All procedures were applied at the same time of day and performed in a 24 °C laboratory environment.

Initially, the CJ\textsubscript{30} were preceded by five static stretching exercises (one set of 10 s) with emphasis on the lower limbs, standardized for all participants. After the stretching exercises, a specific warm-up and familiarization that involved one minute of hopping on a trampoline, three series of ten hops on the ground and eight to ten vertical jumps simulating the real test were performed.

The CJ\textsubscript{30} consisted of maximal continuous vertical jumps performed for 30 s. Participants were required to keep the trunk as vertical as possible, and hands were placed on hips (akimbo). According to recommendations of the protocol,\textsuperscript{2} participants were also asked to flex their knees at ∼90 ° in the transition between the eccentric-concentric phases, which is considered the best angular position to maximize the vertical jump performance.\textsuperscript{2} Verbal feedback was provided to the subject during the test to encourage them to maintain knee angle approximately 90° and maximum performance until the end of the test.

The tests were filmed using a calibrated camera (VPC-HD2000 Xacti, Sanyo Electric Co., Japan) with a resolution of 1920 × 1080 pixels, sampling at 60 frames s\textsuperscript{−1} positioned perpendicularly at six meters from the right sagittal plane of the movement for two-dimensional (2D) kinematics analysis. A set of landmarks was placed on the right side of the participant’s body at the following sites: (1) lateral malleolus, (2) lateral femoral epicondyle of the knee, (3) the most prominent protuberance of the greater trochanter and (4) acromial process. These landmarks were digitized (Skill Stpector, Video4Coach, Denmark) and their coordinates were used to calculate the linear and angular kinematics. The maximal vertical displacement of the greater trochanter marker (analogous to total body center of gravity) was used to determine the vertical jump height, taking into account the initial standing position as a reference.\textsuperscript{16,17} An algorithm implemented in Scilab 5.3.3 software (INRIA, France) was used to identify each maximal jump height.

The maximal jump height (H\textsubscript{MAX}), the mean jump height of the first four jumps (H\textsubscript{MEAN,1}–H\textsubscript{MEAN,4}) the mean jump height of all jumps (H\textsubscript{MEAN}) and the fatigue index were calculated. The fatigue index was obtained considering the first (H\textsubscript{MEAN,1}) and the last (H\textsubscript{MEAN,4}) four jumps of the test,\textsuperscript{14} according to Eq. (1):

\[
\text{Fatigue index} = \frac{H_{\text{MEAN,1}} - H_{\text{MEAN,4}}}{H_{\text{MEAN,1}}} \times 100
\] (1)

The H\textsubscript{MEAN,1} was used as an equivalent of peak power in an attempt to determine an analogous measure in the CJ\textsubscript{30}. This is similar to WAnT and is generally obtained in the first 5 s of the test.

WAnT was performed with a specific cycle ergometer (Excalibur Sport\textsuperscript{6}, Lode, Netherlands), according to the recommendations proposed by Inbar et al.\textsuperscript{15} Initially, the participants performed a warm-up of 5 min in the cycle ergometer with a load of 50 W. A maximal sprint between 3 and 5 s was performed at the end of each minute. The test started 2 min after the warm-up. WAnT was performed at maximal intensity for 30 s with a load corresponding to 7.5% of body mass. Resistance was applied after 3 s of maximal acceleration with no load. Participants were instructed to remain seated throughout the test and received verbal encouragement to sustain their maximum effort throughout the test. A one-minute period of cycling with no load was included at the end of the test.

The following variables were obtained in WAnT: peak power, mean power, and fatigue index, calculated according to Eq. (2)\textsuperscript{14}:

\[
\text{Fatigue index} = \frac{\text{Peak power} - \text{lowest power}}{\text{Peak power}} \times 100
\] (2)

After WAnT and CJ\textsubscript{30}, a blood sample (25 µl) was collected from the right earlobe with a heparinized capillary tube in the third, fifth, seventh, ninth and eleventh minutes of recovery. Blood samples were stored in 1.0 ml sealed polyethylene tubes with 50 µl solution (sodium fluoride, 1\%) and were subsequently assayed with an electrochemical analyzer (YSI 2700 model Stat Select, Yellow Springs Inc., USA). The equipment was calibrated before each measurement according to the manufacturer’s manual. The highest blood lactate concentration during the recovery period was used for further analysis.

The test–retest reliability was determined by calculating the intra-class correlation coefficient (ICC\textsubscript{2,1}) with a two-way random effects model with absolute agreement. Additionally, the typical error of measurement (TEM) and the Bland–Altman plot were used to verify the measurement agreement between test and retest. The ICC values were classified as follows: <0.4 = poor reliability; 0.4–0.75 = fair to good reliability; and >0.75 = excellent reliability.\textsuperscript{18} The paired t test was used to verify the difference between BIAS and zero (value reference for perfect agreement).

Pearson’s correlation coefficients were used to establish the correlation between WAnT and CJ\textsubscript{30} parameters. Considering the strong reliability of test–retest previously analyzed, the retest data were randomly selected to compare with WAnT parameters. The following criteria were adopted for interpreting the magnitude of correlation between variables: <0.1, trivial; 0.11–0.3, small; 0.31–0.5, moderate; 0.51–0.7, large; 0.71–0.9, very large; and 0.91–1.0, almost perfect.\textsuperscript{9} Additionally, independent t test was used to compare the blood lactate concentration between tests.
The analyses were performed with the Statistical Package for Social Sciences (SPSS Inc. v.17.0, Chicago, USA) and MedCalc® (v. 11, USA) and the level of confidence was set at 5%.

3. Results

The number of jumps (26.6 ± 1.9 vs. 26.6 ± 1.8), and the maximum knee (80.2 ± 10.9° vs. 80.5 ± 10.4°) and hip (61.3 ± 12.3° vs. 60.2 ± 9.9°) flexion angles were similar from test to retest sessions, respectively. Table 1 shows the reliability measurements of the CJ30 parameters, HMAX, HMEAN, fatigue index and lactate peak presented ICC ranging from good to excellent. Higher values of TEM (%) were observed for fatigue index and lactate peak when compared to the performance indexes (HMAX and HMEAN).

The Bland–Altman plots show the degree of agreement between test and retest sessions for HMAX (Fig. 1A: bias = -0.6 ± 2.7 cm), HMEAN (Fig. 1B: bias = 0.3 ± 1.5 cm), blood lactate peak (Fig. 1C: bias = -0.12 ± 1.5 mmol·L⁻¹) and fatigue index (Fig. 1D: bias = -1.4 ± 5.1%) in the CJ30. Most values were within the limits of agreements. The bias was not statistically different from zero (full agreement) for all variables (HMAX, p = 0.32; HMEAN, p = 0.36; lactate peak, p = 0.71; and fatigue index, p = 0.22).

In WANt, the values obtained were: peak power = 17.75 ± 2.63 W·kg⁻¹; mean power = 9.10 ± 0.88 W·kg⁻¹; fatigue index = 67.92 ± 7.37%; and lactate peak = 12.79 ± 1.88 mmol·L⁻¹.

Large correlations were found between Wingate mean power and HMEAN (Fig. 2A), between Wingate peak power and HMEAN (Fig. 2B) and between lactate peak of CJ30 and WANt (Fig. 2C). The fatigue index showed a moderate correlation between CJ30 and WANt (Fig. 2D).

4. Discussion

The first purpose of this study was to verify the test–retest reliability of a continuous jump test over a shorter duration (30 s). The number of jumps and maximum knee and hip flexion angles were similar in the test and retest session, showing the reliability of the test motor pattern. Considering the intra-class correlation, the CJ30 parameters, HMAX, HMEAN and fatigue index showed excellent reliability (Table 1). However, the fatigue index presented higher typical error (%) when compared to the performance variables of test (HMAX and HMEAN), showing greater variability.

The Bland–Altman plots (Fig. 1) showed a good agreement for the variables considering that the most values were within the limits of agreement. Nevertheless, the fatigue index showed the largest bias, providing evidence that this index is less reliable than the other indices of CJ30. The lactate peak of CJ30 was the variable that showed the worst reliability considering two indicators (ICC = 0.45–moderate; TEM = 15.9%), despite good agreement (Fig. 1C) and close mean values (8.22 ± 1.34 vs. 8.34 ± 1.20 mmol·L⁻¹) between the test and retest, respectively. Blood lactate peak showed considerable variance between assessments, therefore the results should be interpreted with caution and further studies are warranted.

The study by Bosco et al. was the only one that previously analyzed the test–retest reliability of a continuous jump test, reporting high mechanical power reliability, but the authors used an inadequate statistical analysis, which might limit their conclusions about reliability. Additionally, the reliability of tests performed in a shorter time period has not been described in the literature.

The second aim of this study was to verify the validity of the CJ30, using WANt as a reference. The lower peak blood lactate concentration obtained in the CJ30 (8.34 ± 1.20 mmol·L⁻¹) with
Thus, a Table 4 J. go respect G both the Reliability test capacity correlation peak blood anaerobic MAX = Model LACPEAK (mmol FI 8.22 ± 1.34) MEAN = (cm) MAX (cm) 'all-out' Despite CJ30, demand (observed 0.53), Nummela to measures while in that anaerobic performance. for this, (2013), this means given values capacity values. In addition to anaerobic capacity, the CJ30 test also enables the assessment of anaerobic power by measuring performance over the first 5 s of the test (i.e., H_{MEAN4I}). During this period, energy is predominantly supplied by the ATP-PC system, with a reduced contribution from glycolytic metabolism. Thus, the large correlation between H_{MEAN4I} and WAnT peak power values provides evidence of the ability of the CJ30 to detect anaerobic peak power levels.

Blood lactate concentrations are commonly employed as an indicator of muscle lactate concentration and anaerobic capacity. However, the method has some limitations because there is no simple causal relationship between glycolytic energy production and blood lactate concentration. As a result, caution should be used when analyzing peak blood lactate values as any conclusion regarding test validity may be limited.

In the first study that determined the validity of 60-s continuous jump tests to assess anaerobic power, a large correlation (r = 0.80) was reported between the mean power obtained in this test and the mean power of the long Wingate test (i.e., 60 s). Sands et al. also found a large correlation between the 60-s continuous jump test and WAnT (i.e., 30 s) when peak power (r = 0.69) and mean power

**Table 1**

Reliability measures of the maximum height, mean height, fatigue index and blood lactate peak between test–retest sessions of the continuous jump test.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Test</th>
<th>Retest</th>
<th>TEM</th>
<th>ICC2,1</th>
<th>CI (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{MAX} (cm)</td>
<td>50.52 ± 5.33</td>
<td>51.12 ± 6.50</td>
<td>1.92</td>
<td>3.78</td>
<td>0.94</td>
<td>0.86–0.98</td>
</tr>
<tr>
<td>H_{MEAN} (cm)</td>
<td>42.64 ± 5.19</td>
<td>42.94 ± 5.69</td>
<td>1.06</td>
<td>2.49</td>
<td>0.98</td>
<td>0.95–0.99</td>
</tr>
<tr>
<td>FI (%)</td>
<td>23.46 ± 6.91</td>
<td>25.46 ± 4.97</td>
<td>2.89</td>
<td>10.82</td>
<td>0.87</td>
<td>0.60–0.94</td>
</tr>
<tr>
<td>LACPEAK (mmol L^{-1})</td>
<td>8.22 ± 1.34</td>
<td>8.34 ± 1.20</td>
<td>1.00</td>
<td>15.91</td>
<td>0.45</td>
<td>0.35–0.78</td>
</tr>
</tbody>
</table>

H_{MAX} = maximal jump height; H_{MEAN} = mean height considering all jumps; FI = fatigue index; LACPEAK = blood lactate peak; TEM = typical error of measurement; Abs = Absolute values.

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(r = 0.89) were analyzed. Hoffman and Kang\textsuperscript{23} performed the only study in which the test duration was comparable to the present study (24 s vs. 30 s) and in which 30 maximal vertical jumps were executed. It reported a moderate correlation for mean and peak power (r = 0.55 and r = 0.56, respectively) between the continuous jump test and \textit{WAnT}. These results are similar to those found in the present study.

The fatigue index was the variable that showed the worst correlation (moderate) between \textit{WAnT} and CJ\textsubscript{30} (Fig. 2D). Therefore, the fatigue index seems to be a weaker parameter in terms of discriminating anaerobic capacity compared with other variables in this study. Previous studies have also reported low correlation between the fatigue index and a number of other performance variables\textsuperscript{21,24,25} and low sensitivity to identifying differences in performance levels and assessing training effects.\textsuperscript{26,27} Thus, the fatigue index should be used with care in anaerobic assessment.

Wingate is the more classical anaerobic test and it was chosen as the more appropriate option (reference test) to compare to CJ\textsubscript{30} because it has similar but not identical characteristics. Thus, almost perfect correlations between continuous jump tests and \textit{WAnT} (e.g., greater than 0.9) are hardly ever observed. This is because of the differences in the actions performed (mode of exercise) during each test. The ability to store and reuse elastic energy may increase movement efficiency\textsuperscript{4} and produce higher mechanical power in the continuous maximal countermovement vertical jump test than in cycling.\textsuperscript{2,5,14} where elastic energy has less impact on performance. Moreover, greater muscle mass involvement and the actions of the lower limbs during continuous jumps may have resulted in higher power than in the Wingate test.\textsuperscript{23}

Another factor that may have influenced the comparisons between continuous jump and \textit{WAnT} is the flight time in the continuous jump test, during which no effort is expended. Generally, flight time corresponds to approximately one-third of the total time taken by the effort in continuous jumps, whereas a constant load application is observed in cycling and therefore demands greater energy expenditure.\textsuperscript{2} This is confirmed in the present study by the greater fatigue and blood lactate concentrations in \textit{WAnT} in comparison with continuous jumps.

It is important to highlight that in the present study the jump height was used for comparison or correlation with \textit{WAnT} rather than mechanical power used in other studies.\textsuperscript{2,5,23} because it seems to be a more appropriate measure for assessing and monitoring training outcomes.\textsuperscript{24,28,29} According to Markovic and Jaric,\textsuperscript{28} jump height may be considered as a body-size-independent index of muscle power and has a more practical application and clinical relevance than mechanical power for coaches and athletes. Additionally, jump height is a more direct measure than mechanical power, which may reduce measurement error.\textsuperscript{29}

5. Conclusion

From our findings it can be concluded that the continuous jump performed for 30 s is a reliable test considering the performance variables (\(H_{\text{MAX}}\), \(H_{\text{MEAN,4}}\)). Lactate peak and fatigue index are less reliable variables and should be used with care in anaerobic assessment. Considering that the peak blood lactate concentration obtained in the CJ\textsubscript{30} was lower than that in the \textit{WAnT}, there seems to be less demand for glycolytic metabolism in the former. This suggests that the continuous jump and Wingate tests, although both anaerobic in nature given their characteristics (‘all-out’ for 30 s), measure slightly different aspects of glycolytic anaerobic performance. However, the large correlation found between the indices of anaerobic capacity used in \textit{WAnT} and CJ\textsubscript{30} provides evidence that the latter test is able to adequately detect (rank) the anaerobic capacity level of athletes. Likewise, the large correlation between \(H_{\text{MEAN,4}}\) and \textit{WAnT} peak power shows evidence of the ability of the CJ\textsubscript{30} to detect the anaerobic peak power level. Nevertheless, more studies examining the CJ\textsubscript{30} are needed, including those measuring anaerobic contribution in terms of the maximum accumulated oxygen deficit.

Practical implications

- A 30-s test may be more feasible than other longer tests (e.g., 60-s) as it offers more operational facilities with less discomfort.
- The continuous jump test seems to be more specific for sports that are acyclic and involve participants experiencing the stretch-shortening cycle in their actions, such as basketball, volleyball, gymnastics, etc., all of which involve similar movement patterns.
- The use of a simple variable, i.e., jump height, rather than mechanical power has greater practical application and/or clinical relevance for coaches and physical trainers.
- Because of its simple instrumentation, the CJ\textsubscript{30} test is more economical than other methods of anaerobic power assessment.

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