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Original Article

Reliability of countermovement jump estimation using the Chronojump jump mat: intra-session and within-session

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Abstract:
Vertical jump is a fundamental metric for monitoring and regulating lower body capacities, especially in assessing sports performance through the countermovement jump (CMJ). In recent years, various instruments aimed at estimating vertical jump heights have emerged. However, ensuring effective performance monitoring requires that jump mats prove consistency in measuring jumps across repeated tests, i.e., they must prove reliability. This study focuses on evaluating the intra-session and within-session test-retest reliability of the Chronojump jump mat in highly trained female volleyball players. Ten athletes from the Spanish Superliga 2 league participated in 100 CMJs over two sessions spaced a week apart. A repeated measures design collected jump height data using Chronojump jump mat. The protocol included a 10-min warm-up, a 5-min rest, and the execution of 5 CMJs with 2 min of rest between trials. Intra-session test-retest consistency was assessed by analyzing consecutive pairings of the first five trials. The study reveals moderate noise for SEM (1.56 cm) and standardized SEM (0.37), accompanied high SDC (4.33 cm) and SWC (0.44 cm). Correlation analysis indicated very high reliability (ICC =0.89), high concordance (CCC = 0.82) and a moderate CV (5.97%). Regarding within-session reliability, no significant differences were observed (Paired t-test $p = 0.08$; Hedges effect size $g = 0.09$). Additionally, very high correlations between both sessions were observed ($r = 0.86$). Absolute reliability analysis revealed a noise of 1.65 cm (SEM), resulting in high SDC (4.59 cm) and SWC (0.47 cm). Relative reliability, assessed through correlation coefficients, displayed very high values (ICC = 0.89 and CCC =0.89), although a moderate standardized SEM of 0.44 was observed. The Bland-Altman plot indicated systematic errors of the mean of 0.41 cm without substantial dispersion. Linear regression analyses between sessions showed a high correlation ($r = 0.86$), with a systematic error of 6.65 cm (intercept) and a random error of 2.01 cm (SEE). To sum up, the Chronojump jump mat proves reliability in measuring CMJ in female volleyball players across both intra-session and within-session contexts. High reliability suggests that this instrument can be deemed reliable for such measurements.
Key Words*:* **consistency, repeatability, countermovement jump, sensibility, error**

Introduction

Vertical jump (VJ) is widely used to monitor and control lower body capacities (Rantalainen et al., 2020). More specifically countermovement jump (CMJ) has been used to check sports performance, especially in those disciplines in which actions involving high demands of force and power such as jumps, changes of directions or sprints (Alba-Jiménez et al., 2022; Washif & Kok, 2021) are continuously repeated.

In this regard, in recent years, numerous instruments designed to estimate the VJ have proliferated, among them, motion capture systems and force platforms, which are considered the gold standard due to their elevated values of validity and reliability (Rago et al., 2018). However, they are costly and complex to use, therefore their use is restricted to certain environments such as research and high performance. Besides, there are more economical and easier-to-use solutions that allow obtaining values of VJ height with acceptable validity and reliability values in a more economically and simple way. Examples of these would be inertial measurement units (IMU) (Jimenez-Olmedo, Pueo, et al., 2023; Lake et al., 2018), photocells (Jimenez-Olmedo, Penichet-Tomas, et al., 2023), smartphone applications based on photogrammetry (Gençoğlu et al., 2023; Peter Shaw et al., 2021) and the widely used jump mats (Xu et al., 2023).

The widespread use of jumping mats is because they are economical, easy-to-use, and simple to transport devices and consequently, allow on field data collection, getting instant feedback since data can be obtained immediately and does not need a post-treatment. Therefore, these instruments are highly valued, especially in the sporting environment as they allow to obtain metrics associated with the VJ, such as jump height, flight time, contact time, or the reactive force index (Pueo et al., 2020; Yamashita et al., 2020). Jump

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mats estimate VJ from flight time (FT), More specifically, it allows to know the displacement of the center of mass (COM) instead of the height reached, considering this displacement of COM as the VJ (Whitmer et al., 2014). Nevertheless, for truly effective performance monitoring, jump mats must be valid and reliable tools. That is, they should provide measurements as close as possible to the real value (validity), and that are repeatable in multiple tests, (reliability) (W. Hopkins, 2000).

On the other hand, reliability can be affected by technological or biological errors, modifying the ability of the instrument to discriminate between changes between athletes over time, and therefore, diminishing its ability to monitor performance (Moir et al., 2008).

Therefore, the protocol and the instrument used will influence this. In this regard, devices based on flight time must pay special attention to the detection of the precise moments of takeoff and landing, since the displacements in the center of mass and the variations in the angles of dorsiflexion of the ankle, hip and knee, may lead to systematic and random bias that affect the validity and reliability of the instrument (Conceição et al., 2022; Wank & Coenning, 2019). For the specific case of jumping mats, we found ICC values of 0.84, CV = 2.93% (Pojskic et al., 2022) in the intrasession test-retest reliability in the CMJ. On the other hand, slightly lower values can be seen in the test-retest between sessions and for the drop jump in the study of Tenelsen et al. (2019) (ICC = 0.81, CV = 6.3%).

In general terms, Xu et al. (2023) in their review of systems intended for the estimation of the VJ, found that the reliability values fluctuate greatly (CV: 4.7–15.94%, ICC: 0.45–0.96), arguing that this variability is derived mainly from the movement detention capability of the jump mats used. Regarding the open source (free software and open hardware) Chronojump mat (Chronojump Boscosystems, Barcelona, Spain),Pueo et al. (2018a) studied the reliability of the instrument, using an oscilloscope to activate and deactivate the circuit, obtaining very high-reliability values with CV less than 0.01%, on the other hand, when using as a sample sixty-three active sportsmen, Pueo et al. (2020) founded CV values of 4.28% in intrasession reliability, but within sessions, reliability was not analysed. Pagaduan (2013) in their study analyzed the reliability between sessions separated for a week in males and females, obtaining ICC =0.86 for men and ICC = 0.93 for women. On the other hand, if the reliability is analyzed in terms of sensitivity for Chronojump, (Patiño-Palma et al., 2022) found a value of minimal worthwhile change (SWC) of 1.40 cm, which on the other hand very similar to those found for a photocell Wheeler (1.41cm) and my jump 2 smartphone application (1.39 cm).

However, in none of the studies the reliability and sensitivity of the instrument within and between sessions were analyzed together to investigate the effect of the possible loss of reliability due to biological or protocol factors. Therefore, this study aimed to examine the test-retest reliability in the intrasession and within-session conditions of the Chronojump mat in female volleyball players when VJ is measured as the height reached in a CMJ, and thus, to determine if the Chronojump platform is a reliable tool with practical interest for strength and conditioning specialists.

Material & methods

Participants

The study was conducted by 10 highly trained female volleyball players (McKay et al., 2022) who were participating in the Spanish Superliga 2 league, (age of 22.0 ± 1.7 years, height of 1.72 ± 0.06 m mass of 65.9 ± 7.6 kg, body mass index (BMI) of 17.3 ± 2.1 kg/cm^2, training experience of 8.9 ± 1.9 years). Participants were free of injuries, and they were instructed to maintain their normal dietary habits. The Ethics Committee at the University of Alicante approved the study (IRB No. UA-2018-11-17) in accordance with the Declaration of Helsinki of The World Medical Association and all subjects gave informed consent before taking part in the study.

Procedure

A repeated measures design was conducted to collect jump height data from the Chronojump jump mat. The procedure consisted of three sessions. In the first session, a familiarisation procedure with the CMJ tests and protocols was performed, in addition, anthropometric measurements of all the participants were carried out. The data was collected in the second and third sessions where the protocols were precisely reproduced. The research was carried out in the facilities of the University of Valencia between September 1, 2022, and February 28, 2023.

Test protocol

Prior to testing, all participants performed a 10-minute standardized warm-up containing: five minutes of jogging, followed by three minutes of dynamic drills and 3 submaximal CMJs in which participants reviewed the jumping protocols. Next to warm up, a resting period of 5 minutes was completed. Lastly, 5 CMJs were executed, resting for two minutes for each attempt to prevent fatigue effects (Read, 1997). VJs were performed starting from the standing position with hands on the iliac crests.

After an acoustic signal from the instructor, each subject made a self-selected knee flexion before jumping to reach the maximum height. The study considered jumps to be valid if they were completed within the jump mat limits, with a synchronized landing phase, landing on tiptoe, and without imbalance or separating the hands from the iliac crests at any phase of the jump. Chronojump Jump mat was used to collect all records to compare data from both sessions. The within-session test-retest reliability (consistency) was evaluated using the first five jumps of all participants. To complete this analysis, the pairings of each of the consecutive jumps were analyzed, in conjunction with the mean of the test for the two devices.

Instruments

Chronojump consists of a rigid contact mat built in a sandwich-type structure, formed by two isolated electrical plates in an open circuit configuration that is closed when a subject stands on the mat (Pueo et al., 2017). Chronojump estimated hump height from FT according to the equation Jump height = $(FT)^2 \cdot g/8$, where g is gravity acceleration (9.8 m/s^2).

Statistical analysis

A total of 100 jumps were analysed for this study. Descriptive data are reported as mean and 95% confidence limits. A Shapiro-Wilk test was used to explore the normality of data, which resulted in a normal distribution. The *t*-test for paired samples was applied to determine the existence of significant differences between devices (systematic error).

The effect size (ES) of the differences was determined as Hedges' corrected effect size *g*, interpreted as trivial (< 0.19), small (0.2 – 0.59), moderate (0.6 – 1.19), large (1.2 – 1.99), very large (2.0 – 3.99) and huge (> 4.0) (Hopkins et al., 2009).To assess the level of agreement and the presence of systematic error between sessions Lin's concordance index (CCC) was calculated (Lin et al., 2002), categorizing results as poor (≤0.9), moderate (0.90–0.95), substantial (0.95–0.99) and near perfect (≥0.99) (McBride, 2005). Additionally, to determine the relationship between sessions a correlation analysis was conducted by computing Pearson's bivariate correlation coefficient (*r*).

The obtained results of *r* were interpreted according to the following thresholds: trivial (≤0.1), low (0.1–0.29), moderate (0.3–0.49), high (0.5–0.69), very high (0.7–0.89) and almost perfect (≥0.9) (Lake et al., 2018).

The degree of linear dependence between paired data from both sessions was assessed using regression analysis. The calculation of standard error of estimate (SEE) was carried out to verify device accuracy.

The degree of agreement between the two instruments and successive attempts was checked using Bland-Altman plots, leading to the determination of the systematic error and its limits of agreement for 95% (LoA= 1.96×SD). To determine if there were random errors and proportional bias between methods, the bivariate Pearson's product-moment correlation coefficient of the differences was calculated, where an r^2 value greater than 0.1 would indicate their presence.

With the objective of knowing the absolute test-retest reliability within and between sessions, the values of change in the mean, standard error of measurement (SEM), smallest detectable change (SDC) and smallest worthwhile change (SWC) were determined by examining the error magnitude and sensitivity. Moreover, to assess relative reliability in both situations (within and between sessions) the intraclass correlation coefficient (ICC) was used to establish that ICC ≥ 0.7 is an acceptable value of reliability as a criterion. Also, the coefficient of variation (CV) was calculated setting the threshold for its interpretation as CV >10% = poor, 5–10% = moderate, <5% = good, standardized SEM and CCC were calculated to establish relative reliability (Lake et al., 2019). The data analysis was run using MedCalc Statistical Software (v 20.100, MedCalc Software Ltd, Ostend, Belgium.

Results

Within-session *reliability of Chronojump jump mat for CMJ jump height*

The results obtained in terms of changes in the test-retest between sessions are shown in Table 1. No significant differences are appreciated between the results obtained for the CMJ in both sessions (Paired t-test p = 0.08; Hedges effect size g = 0.09). very high correlations between both sessions are observed.

Table 1. *Mean, difference of means, Pearson´s correlations, related to session 1 and session 2 test.*

	Session 1	**Session 2**	**Difference**	**ES (*g*)**	***r***
Jump height (cm)	26.48	26.89	0.41	0.09 (trivial)	0.86
95%-CI	25.72 to 27.26	26.00 to 27.79	0.18 to 0.64	0.18 to 0.23	0.79 to 0.90

CI = confidence interval, ES = Hedges' corrected effect size, *r*=Pearson's bivariate, correlation coefficient.

Table 2 shows relative and absolute reliability variables related to the CMJ agreement between sessions. Regarding the absolute values, a noise of 1.65 cm (SEM) is appreciated, which implies high values of SDC and SWC, on the other hand, the correlations indicate very high-reliability values (ICC and CCC), appreciating a noise value of moderate magnitude.

Table 2. *The absolute and relative reliability of Chronojump in the test-retest between sessions.*

Absolute reliability			
	Mean	**Lower CI-95%**	**Upper CI-95%**
Change in mean (cm)	0.42	-0.05	0.88
SEM (cm)	1.65	1.45	1.92
SDC (cm)	4.59	4.02	5.33
SWC (cm)	0.47	0.41	0.54
Relative reliability			
	Mean	**Lower CI-95%**	**Upper CI-95%**
ICC	0.84	0.77	0.89
CCC	0.84	0.77	0.89
ρ (precision)	0.86	–	–
C_b (accuracy)	0.98	–	–
CV (%)	6.60	5.25	7.72
Standardized SEM	0.44	0.38	0.51

SEM= standard error of measurement, DC= smallest detectable change, SWC= small worthwhile change, ICC= Intraclass correlation coefficient, CCC= Lin´s concordance coefficient, ρ= factor of precision in the CCC, C_b= factor of accuracy in CCC, CV= coefficient of variation.

The Bland-Altman plot displayed in Figure 1 (a) helps to better understand the reliability data of Table 2. Systematic errors can be appreciated that coincide with those seen in Tables 1 and 2 (mean difference of 0.41 cm), without appreciating a large dispersion since 94 % of the data are between the limits of agreement. In addition, there is no heteroscedasticity of the data ($R^2 < 0.1$).

On the other hand, the linear dependency between both sessions can be seen in Figure 1 (b) where a high correlation ($r = 0.86$) is appreciated and in which. In addition, elevated systematic (Intercept = 6.65 cm) and random (SEE = 2.01 cm) errors are observed.

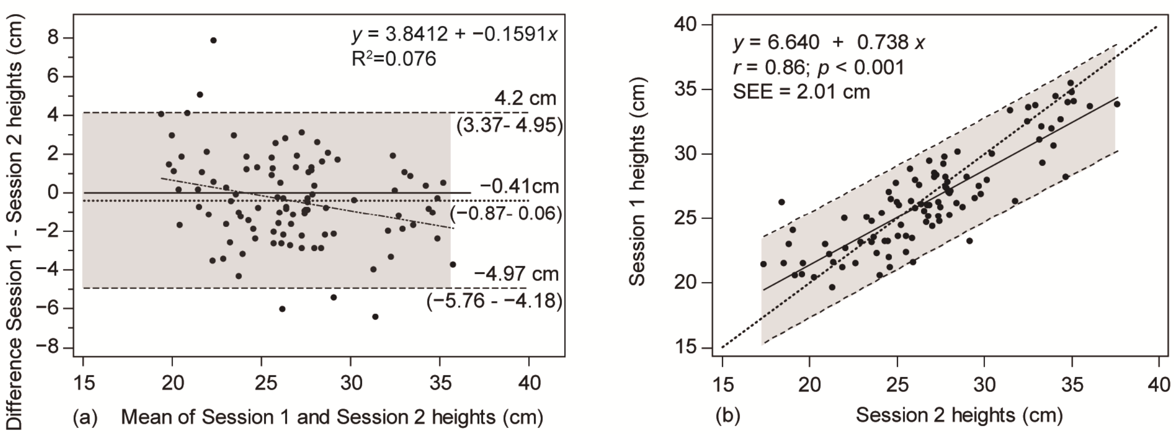

Figure 1.
(a) Bland–Altman plot for the study of the grade of agreement in the jump height obtained between Session 1 versus Session 2. Dotted line: the mean of the differences; shaded areas: confidence intervals for 95% of the mean and LoA; continuous line: the line of perfect agreement; plots and dashed line: the regression line of differences.
(b) Correlation analysis between both sessions. Solid line: regression; shaded area: 95% confidence intervals of the regression line; dotted line: *x*=*y* line; *r:* Pearson's correlation coefficient; SEE= Standard Error of Estimate.

Intrasession reliability of Chronojump jump mat for CMJ jump height

To study the consistency in the intra-session test-retest, the consecutive pairings of the first five trials were analyzed (Table 3). In the same way that for the within-session reliability, moderate noise values (SEM=1.56 cm and standardized SEM=0.37) were found, and high values of SDC and SWC. Similarly, the correlations indicate very high reliability values of ICC and high CCC).

Table 3. *The absolute and relative reliability of Chronojump in the test-retest intra-session.*

Absolute reliability							
	2-1	**3-2**	**4-3**	**5-4**	**Mean**	**Lower CI-95%**	**Upper CI-95%**
Change in mean (cm)	0.79	0.28	−1.36	1.25	**0.24**	−	−
SEM (cm)	1.24	1.93	1.66	1.32	**1.56**	1.29	2.01
SDC (cm)	3.43	5.35	4.61	3.67	**4.33**	3.57	5.58
SWC (cm)	0.35	0.55	0.47	0.37	**0.44**	0.36	0.57
Relative reliability							
	2-1	**3-2**	**4-3**	**5-4**	**Mean**	**Lower CI-95%**	**Upper CI-95%**
ICC	0.94	0.82	0.85	0.92	**0.89**	0.78	0.96
CCC	0.91	0.77	0.76	0.84	**0.82**	0.70	0.97
ρ (precision)	0.93	0.77	0.82	0.90	**0.85**	−	−
C_b (accuracy)	0.97	0.99	0.93	0.94	**0.96**	−	−
CV (%)	4.82	7.30	6.22	5.22	**5.97**	−	−
Standardized SEM	0.29	0.54	0.47	0.35	**0.37**	0.31	0.48

SEM= standard error of measurement, DC= smallest detectable change, SWC= small worthwhile change, ICC= Intraclass correlation coefficient, CCC= Lin´s concordance coefficient, ρ= factor of precision in the CCC*,* C_b= factor of accuracy in CCC*,* CV= coefficient of variation.

Discussion

This paper aimed to analyze the within-session and intra-session test-retest reliability of the Chronojump jump mat when estimating the CMJ vertical height, and thus, to determine if the Chronojump platform is a reliable tool with practical interest for strength and conditioning specialists. The major finding of this study is that the levels of consistency in the measurement of the jump height in the CMJ are high, both in the results for the intra-session and within-session test-retest, as well as for the results obtained in separate sessions. Also, moderate random and systematic errors were detected.

One of the fundamental premises for a VJ measure instrument is that it must be reliable, therefore, the device needs to be consistent in the measure, taking into account the repeatability of the results when the measurement is repeated (W. G. Hopkins, 2000). In the case of the Chronojump, seems to be a consistent instrument since in the test-retest between two sessions separated by one week, there are no significant differences between the values of both sessions, with a trivial effect size (p > 0.05; g = 0.09), which indicates that the change between session is not significant (0.41 cm). On the other hand, regarding the absolute reliability, the existence of a systematic error of 0.4 cm is confirmed, both in the mean of change and in the Bland-Altman plot, which also does not show proportionality in error (R^2 =0.08). In addition, a noise of 1.65 cm (SEM) is observed, which means that the SDC and SWC are high (4.56 cm and 0.47 cm). These results are consistent with those obtained by Pojskic et al. (2022) using a self-made jump mat in which an SEM of 1.7 cm was observed. Similarly, Pueo et al. (2017), using Chronojump to estimate the height of CMJ obtained intra-subject variability values of 1.1 cm and a technical error of the jump mat of 1.2 cm, nevertheless, the values obtained were not based on the SEM as they were in our study. In the same line (Cruvinel-Cabral et al., 2018) obtained values of SEM of 1.1 cm, analyzing the reliability of the Chronojump again.

On the other hand, regarding the sensitivity of the instrument, the high values of SEM detected condition the sensitivity of the instrument, thus the SDC shows values of 4.6 cm, which represents the minimum change in the CMJ that can be determined without the error totally responsible for it (Portney, 2020), this SDC values, in certain environments can be very high. If compared with other studies, these values are somewhat higher, for example, the sensibility obtained by the *Ergojump mat* (MDC = 2.8 cm) is about half, although the drop jump was evaluated in this case (Rago et al., 2018), however, in this same study they obtained SWC values of 1.5 cm, which are higher than those observed in this study (SWC = 0.35 cm) and similar to those obtained by Pojskic et al. (2022) (SWC = 2 cm) and Patiño-Palma et al. (2022) (SWC = 1.4 cm). Based on the above, the reliability in absolute terms is similar to that of other studies analyzed in terms of SEM and change in the mean, but it presents worse sensitivity values.

Concerning relative reliability, within-session consistency shows high ICC and CCC values, the breakdown of CCC values will show a very high accuracy (C_b = 0.96) and worse precision values (ρ = 0.85), therefore, the main source of loss of reliability comes from the lack of precision of the instrument, this can come from causes unrelated to the device, such as the differences in the mechanics of the takeoff and landing (Xu et al., 2023), biological variability, or other related factors, for instance, variations in the fitness level or learning process, that can occur in the time elapsed between sessions (Claudino et al., 2017). Regardless, the results obtained are in line, although somewhat lower than those observed in other studies where ICC values can be seen to fluctuate between high to very high values, examples of this are: *Just jump* mat (ICC = 0.87; CV = 5.6%) (Moir et al., 2008), the jump mat *Kinematic measuring system* (ICC= 0.9-0.99; CV = 2.1 - 3.1%) measuring drop jump (Markwick et al., 2015); *Ergojump* mat (ICC = 0.93; CV = 3.2%) (Rago et al., 2018), and self-manufactured jump mats (ICC= 0.87; CV = 4.8%) (Pojskic et al., 2022). If we focus specifically on Chronojump reliability data are similar to those of other studies with an ICC of 0.95 can be seen, although the CV values are higher (CV = 10%), probably since the attempts were carried out in as many sessions as two (Cruvinel-Cabral et al., 2018).

On the other hand, analyzing the intra-session reliability data obtained, as might be expected, the repeatability values obtained are better, however, these do not differ too much from those obtained for within-session reliability, that is, again, the noise in the acquisition of data is responsible for the loss of reliability. This fact can be verified by comparing the values obtained when the device is activated by an oscilloscope (Pueo et al., 2018) that it is supposed to be exempt from error produced by biological variability, learning or any other attributable factor to human causes (trivial standardized SEM = 0.00 and CV = 0.01%), with the values from this study whit similar conditions (moderate standardized SEM = 0.47 cm, CV = 6%). Therefore, the differences between both studies suggest that the bias in both conditions, within-session and between-session can be attributed to human or protocol factors such as the differences between the landing and takeoff phases, which may be influenced by the different degrees of ankle and knee flexion, translational displacements in the flight phase that will affect the FT or possible modifications in the physical conditions between sessions in the participant. All of these problems can represent a considerable reduction in reliability, and consequently, must be controlled as much as possible to minimize the error.

Conclusions

According to the data obtained, this study shows that the reliability values obtained allow to consider the Chronojump jumping mat as a reliable instrument in the measurement of CMJ, in both situations intra and within sessions, and therefore, showing itself as a useful measuring device to take data on field, allowing to monitor the lower body strength in female volleyball players. However, the low sensitivity of the instrument detected must be taken into account, especially in those cases in which very small changes in the performance of the vertical jump are important, such as high sports performance. nevertheless, this tool allows athletes to be monitored with sufficient reliability by coaches and specialists in physical conditioning, granting more truthful conclusions to be reached. However, it is advisable to review and monitor the protocols as much as possible in order to minimize the sources of error in the measurement process, since they could be the source of the loss of sensitivity.

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Conflicts of interest

The authors declare no conflict of interest.

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