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A reliable unipedal stance test for the assessment of balance using a force platform

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***Background*. The aim was to develop a unipedal stance test for the assessment of balance using a force platform.**
***Methods*. A single-leg balance test was conducted in 23 students (mean ± SD) age: 23±3 years) in a standard position limiting the movement of the arms and non-supporting leg. Six attempts, with both the jumping (JL) and the contralateral leg (CL), were performed under 3 conditions: 1) eyes opened; 2) eyes closed; 3) eyes opened and executing a precision task. The same protocol was repeated two-week apart.**
***Results*. The mean and the best result of the six attempts performed each day were taken as representative of balance. The speed of the centre of pressure (CP-Speed) showed excellent reliability for the "best result" analysis in all tests (ICCs 0.87-0.97), except in the test with the eyes closed performed on the CL (ICC<0.4). The CP-Speed had better reliability with the "best result" than with the "mean result" analysis (P<0.05), whilst no significant differences were observed between the JL and the CL (P=0.71 and P=0.96 for mean and best results analysis, respectively). A lower dispersion in the Bland and Altman graph was observed with the eyes opened than closed, and the dynamic test.**
***Conclusion*. The single-leg stance balance test proposed is a reliable method to assess balance, especially when performed in a static position, with the eyes opened and using the best result of six attempts as reference, independently of the stance leg.**

Key words: Postural balance - Muscle strength - Aged.

Balance can be defined as the ability to maintain the center of body mass over its base of support with minimal sway or maximal steadiness.[1, 2] Good balance is fundamental for everyday physical activity and for optimal technical achievement in sports.[3] Enhanced balance may also reduce the risk of injury,[4-12] and balance training is frequently used as physical therapy during post-injury rehabilitation.[7, 13-16] However, there is no gold standard for the measurement of balance.

The single-leg stance balance test has been a common method used to asses postural stability.[3, 17, 18] However, poor test-retest reliabilities have been reported.[7, 19-21] It has been documented that anticipatory postural adjustments of the arms and the non-supporting leg may contribute to this variability.[18] To enhance the reliability of balance test, the average value of several trials has been traditionally used as representative of the balance.[3, 22] However, reliability may be improved by choosing the best result instead of the mean value, as done in other physical fitness tests, as for example jumping test.[23] Little is known about the impact of visual feedback or leg dominance on the reliability of balance test. Discrepancies exist on how to conduct balance test with the eyes opened, closed or both.[24-31] The influ-

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ence of leg dominance on unipedal balance test reliability has not been studied. In some investigations leg dominance is not specified,[7, 32, 34] others assigned the leg dominance to the side of the dominant arm,[32] or leg dominance was indicated but the method used to determine leg dominance is not described.[33] It remains unknown whether a more specific criterion, *i.e*. the stronger leg, could improve reliability during the single leg balance test. Solving these problems may help to develop more reliable unipedal balance tests.

The main purpose of this study was to reduce the variability of current unipedal stance test for the assessment of balance using a tri-axial piezoelectric force platform. To this purpose the differences in reliability depending on visual feedback and lateral dominance together with the impact of the method of analysis (average versus best of several attempts) of unipedal balance tests was examined.

Materials and methods

Study population

Twenty-three healthy physical education students, 15 males and eight females ([mean ± SD] age: 23±3 years, body mass: 69±8 kg, height: 179±6 cm) agreed to participate in the study. Subjects were physically active with no history of neurological disease, major orthopedic lesions, vestibular or visual disturbance; and none of them had sustained any injury to the tested extremities within 1 year before the study. Written informed consent was obtained from each subject after they received a full explanation about the study procedures. The study was performed in accordance with the Helsinki Declaration of 1975, as revised in 2000, being approved by the Ethical Committee of the University of Las Palmas de Gran Canaria.

Procedures

Before the study, the participants received a full explanation of the aims and characteristics of the balance tests. The jumping leg (JL) and the contralateral leg (CL) were also determined by means of a three step jump up. The last leg on the ground before the jump was taken as JL.

The participants performed the single-leg stance balance test on a force platform in 6 different conditions (Table I). The 6 tests were repeated in 2 different sessions during the same day, with a 30 min rest period between sessions. In each session, all tests were repeated 3 times. The same protocol was repeated in two different days, two weeks apart. The same standard position was adopted in all tests (Figure 1A). The participants were barefoot, with one foot placed on the middle of the force platform (supporting leg), pointing straight forward in relation to sagittal plane. The non-supporting leg was flexed 90º at the hip, such that the thigh was parallel to the ground. The heel of the non-supporting leg was placed on top of the patella of the supporting leg, making contact and resting on the upper limit of the patella. In this way the

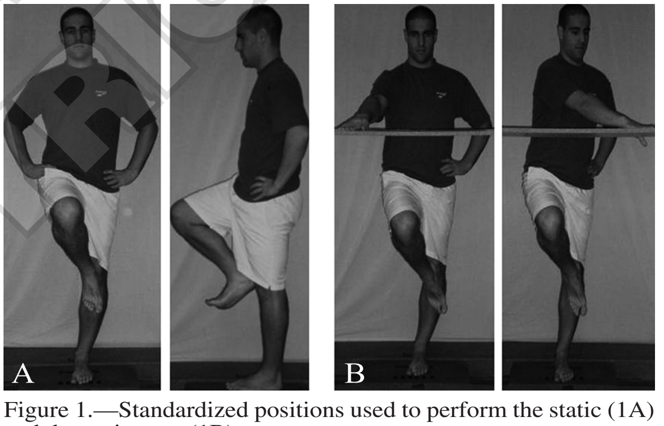

Figure 1.—Standardized positions used to perform the static (1A) and dynamic tests (1B).

TABLE I.—*Description of the 6 different conditions used to perform the single-leg stance balance test.*

Test	Description
1	Standing on the jumping leg and with eyes opened
2	Standing on the contralateral leg and with eyes opened
3	Standing on the jumping leg and with eyes closed
4	Standing on the contralateral leg and with eyes closed
5	Standing on the jumping leg while executing a precision task with the dominant arm
6	Standing on the contralateral leg while executing a precision task with the dominant arm

variability due to a free moving non-supporting leg is reduced. The environment was controlled to prevent visual or auditory distractions. The participants had one minute of practice time before each test.

In tests 1 to 4 (see Table I) the participants had to maintain the balance during 30 s in the standard position. These tests were performed with and without (eyes closed) visual feedback, to determine balance response due to only vestibular reflexes and propioception, and to determine the influence of visual feedback on the reliability of this new unipedal balance test with eyes closed. Tests 5 and 6 were designed to assess the dynamic components of balance, *i.e.*, to introduce perturbations in the distribution of segmental masses. For this purpose, five numbers from 1 to 5 were written on a wooden board (150 x 15 x 2 cm, length, width and height, respectively) situated 1 m in front the participant, at shoulders level (Figure 1B). The wooden board was supported by two metal bars of adjustable height. The numbers were written inside 10 cm diameter circles, 30 cm inter-space. From the standard position, the participants had to touch, with the dominant hand, a number named by one of the examiners every five seconds.

In all tests when the participants were not able to maintain the balance during 30 s, the test was repeated until a 30 s long recording was obtained.

For each test, the average of the six attempts performed on the same day was taken as representative for the "mean results" analysis, and the best result of the six attempts was taken as representative for the "best results" analysis.

Materials

Balance was assessed with a Kistler Force Platform (AG 9281-B, Winterthur, Switzerland, 600x400 mm). The platform was connected to a computer including a software program (BioWare, Type 2812A1-3, Version: 3.2.6.104) that calculated the center of foot pressure (CP) relative to the platform coordinates. For each sample, the CP was determined using the virtual center of ground reaction forces in a two-dimensional transverse plane. The estimation of the position and displacement of the CP was recorded for 30 s at 200 Hz.

Measurements

Antero-posterior and medio-lateral coordinates of the CP were determined from the ground reaction force and moments recorded at 200 Hz, digitally filtered using a Butterworth fourth-order filter with 7 Hz low-pass cut-off frequency and dual pass to remove phase shift. The first five seconds of each trial were excluded from the analysis. The following variables were calculated: 1) root-mean-square (RMS) medio-lateral (ML) velocity of the CP; 2) root-mean-square (RMS) antero-posterior (AP) velocity of the CP; 3) mean CP speed; 4) sway Area; 5) mean peaks (Figure 2); 6) mean distance (Figure 2); 7) mean frequency ML; 8) 95% power frequency ML; 9) mean frequency AP; 10) 95% power frequency AP.

RMS represents the standard deviation of the CP displacement and velocity.[36] Mean peaks and mean distance are two parameters derived from a sway density plot approach. The sway density plot is computed by counting the number of consecutive time instants during which the postural oscillations remain inside a 2.5 mm radius. The peaks correspond to time instants in which the CP is relatively stable and a shorter mean distance between peaks indicates a more stable CP.[37]

The spectral density function was estimated using the method of Intrator and Kooperberg.[38] From this estimation, we calculated the mean frequency and 95th percentile of the spectral density.

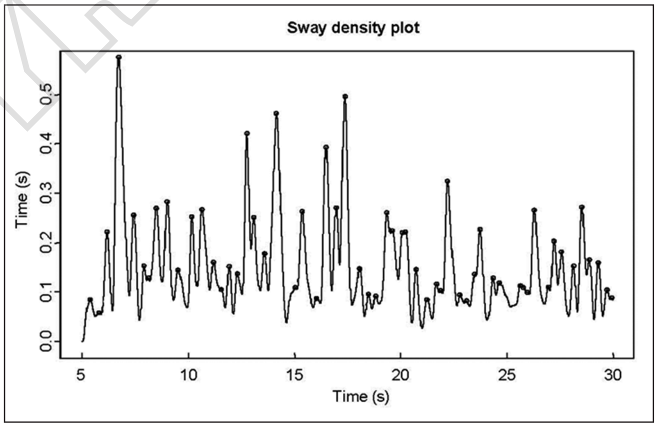

Figure 2.—Baratto *et al.*[37] defined these variables, mean peaks and mean distance, from the sway density plot. The peaks represent the time(s) interval between one peak and other, which is related to the generation rate of posturographic commands. These points mark the peaks corresponding to time points in which the CP is relatively stable. The distance between one peak and another (mm), corresponds to the amplitude of the posturographic commands. A shorter mean distance between peaks indicates a more stable CP.

Statistical analysis

The Shapiro-Wilk test was used to verify that all variables were normally distributed. Two unit of analysis were considered for the reliability study, the mean (mean result) and the best (best result) of six attempts score performed on the same day. Reliability analysis was conducted using a two-way random ANOVA with an absolute agreement criterion. In all cases (Test 1-6), the intraclass correlation coefficient (ICC(2,1) in the Shrout and Fleiss's nomenclature) were estimated and 95% confidence intervals were calculated, both for mean result data and for the best result data. To verify whether there was a statistically significant bias between test and retest, a 95% confidence interval for mean difference was evaluated. The Bland and Altman graphs with limits of agreement were also plotted as a statistical method to assess agreement. In order to compare both procedures (mean result and best result) for all control postural variables, resampling-based tests of hypothesis (Thompson, J. 2000), with null hypothesis ICCB ≤ICCM were carried out (ICCB, ICCM denote intraclass correlation coefficients in best and mean procedure, respectively). The paired t-test was applied to examine the differences between legs. A level of $P<0.05$ was selected to indicate statistical significance. Data analysis was performed using the SPSS 15.0 software package (SPSS Inc., Chicago, USA) and R software (R Development Core Team, 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/).

Results

Tables II-IV summarize the mean values and the ICC (95% CI) of every balance parameter for the tests

Table II.—*Test-retest reliability of stabilometric variables during the static tests performed with the eyes opened (values expressed as mean ± SD; N.=23). The intraclass correlation coefficients (ICC, 95% confidence interval) are calculated with the "Mean results" (ICC_M) or with the "Best results" (ICC_B) of day 1 and 2. P-value from resampling-based test of hypothesis with null hypothesis $ICC_B \leq ICC_M$ are show.*

	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
TEST 1: Jumping leg									
RMS ML velocity (mm/s)	4.69 ± 0.97	4.52 ± 1.21	0.83	(0.47-0.94)[e]	4.18 ± 0.94	4.15 ± 1.11	0.90	(0.67-0.96)[e]	0.651
RMS AP velocity (mm/s)	3.75 ± 0.99	3.34 ± 0.90	0.91	(0.72-0.97)[e]	3.34 ± 0.85	3.09 ± 0.79	0.84	(0.51-0.94)[e]	0.325
CP speed (mm/s)	5.02 ± 1.07	4.73 ± 1.20	0.86	(0.58-0.95)[e]	4.51 ± 1.03	4.38 ± 1.10	0.88	(0.63-0.96)[e]	0.079
Sway area (mm²)	7.20 ± 2.76	5.93 ± 1.60	0.77	(0.12-0.90)[e]	6.14 ± 2.12	4.84 ± 1.73	0.87	(0.59-0.95)[e]	0.035
Mean peaks(s)	0.12 ± 0.03	0.13 ± 0.04	0.87	(0.59-0.95)[e]	0.11 ± 0.02	0.12 ± 0.04	0.80	(0.29-0.92)[e]	0.125
Mean distance (mm)	8.43 ± 1.63	7.80 ± 1.56	0.84	(0.53-0.95)[e]	7.77 ± 1.55	7.27 ± 1.58	0.80	(0.41-0.93)[e]	0.442
Mean frequency ML (Hz)	0.71 ± 0.16	0.79 ± 0.18	0.85	(0.53-0.95)[e]	0.62 ± 0.17	0.72 ± 0.16	0.75	(0.26-0.92)[g]	0.761
95% Power frequency ML (Hz)	2.26 ± 0.42	2.48 ± 0.53	0.92	(0.73-0.97)[e]	2.02 ± 0.49	2.37 ± 0.50	0.85	(0.56-0.95)[e]	0.491
Mean frequency AP (Hz)	0.44 ± 0.13	0.39 ± 0.12	0.42	(-0.72-0.81)[g]	0.35 ± 0.13	0.33 ± 0.11	0.68	(-0.13-0.87)[g]	0.001*
95% Power frequency AP (Hz)	1.77 ± 0.39	1.79 ± 0.53	0.23	(-1.32-0.74)	1.45 ± 0.37	1.48 ± 0.47	0.51	(-0.51-0.83)[g]	0.002*
TEST 2: Contralateral leg									
	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
RMS ML velocity (mm/s)	4.42 ± 1.00	3.95 ± 0.71	0.83	(0.42-0.93)[e]	4.00 ± 0.99	3.72 ± 0.71	0.89	(0.61-0.95)[e]	0.056
RMS AP velocity (mm/s)	3.71 ± 0.91	3.25 ± 0.64	0.84	(0.42-0.93)[e]	3.49 ± 1.14	3.12 ± 0.66	0.89	(0.47-0.94)[e]	0.896
CP speed (mm/s)	4.85 ± 1.01	4.29 ± 0.75	0.82	(0.39-0.93)[e]	4.49 ± 1.11	4.11 ± 0.74	0.89	(0.57-0.95)[e]	0.676
Sway area (mm²)	6.08 ± 1.38	5.82 ± 1.70	0.46	(-0.63-0.82)[g]	5.49 ± 2.11	5.21 ± 1.51	0.42	(-0.75-0.79)[g]	0.156
Mean peaks(s)	0.13 ± 0.03	0.14 ± 0.03	0.82	(0.45-0.94)[e]	0.11 ± 0.03	0.13 ± 0.03	0.69	(0.10-0.89)[g]	0.145
Mean distance (mm)	7.78 ± 1.52	7.54 ± 1.28	0.70	(0.09-0.90)[g]	7.25 ± 1.48	7.07 ± 1.25	0.62	(-0.11-0.87)[g]	0.592
Mean frequency ML (Hz)	0.70 ± 0.11	0.65 ± 0.20	0.62	(-0.31-0.85)[g]	0.63 ± 0.15	0.58 ± 0.20	0.60	(-0.20-0.85)[g]	0.371
95% Power frequency ML (Hz)	2.27 ± 0.42	2.15 ± 0.56	0.83	(0.43-0.94)[e]	2.13 ± 0.47	1.96 ± 0.55	0.83	(0.50-0.94)[e]	0.576
Mean frequency AP (Hz)	0.49 ± 0.20	0.43 ± 0.19	0.81	(0.43-0.94)[e]	0.40 ± 0.17	0.37 ± 0.17	0.83	(0.51-0.94)[e]	0.667
95% Power frequency AP (Hz)	1.87 ± 0.44	1.84 ± 0.47	0.59	(-0.22-0.86)[g]	1.57 ± 0.54	1.67 ± 0.48	0.66	(0.03-0.88)[g]	0.506

[e] Excellent reliability (95% CI for ICC above 0.75), [g] Good reliability (95% CI for ICC between 0.4 and 0.75)

TABLE III.—*Test-retest reliability of stabilometric variables during the static tests performed with the eyes closed (values expressed as mean ± SD; N.=23). The intraclass correlation coefficients (ICC, 95% confidence interval) are calculated with the "Mean results" (ICC_M) or with the "Best results" (ICC_B) of day 1 and 2. P-value from resampling-based test of hypothesis with null hypothesis $ICC_B \leq ICC_M$ are show.*

	TEST 3: Jumping leg								
	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
RMS ML velocity (mm/s)	13.46 ± 11.33	9.51 ± 2.11	0.41	(-0.83-0.81)[g]	9.43 ± 2.41	9.14 ± 1.99	0.89	(0.66-0.96)[e]	0.003‡
RMS AP velocity (mm/s)	15.78 ± 10.64	9.96 ± 3.98	0.57	(-0.35-0.86)[g]	8.26 ± 2.89	7.80 ± 2.16	0.84	(0.50-0.95)[e]	0.032‡
CP speed (mm/s)	13.67 ± 5.65	10.76 ± 2.44	0.66	(-0.06-0.89)[g]	10.18 ± 2.63	9.77 ± 2.27	0.87	(0.59-0.96)[e]	0.009‡
Sway area (mm²)	59.15 ± 81.38	29.82 ± 17.48	0.36	(-0.99-0.79)	23.83 ± 13.93	18.98 ± 6.09	0.57	(-0.35-0.86)[g]	0.455
Mean peaks(s)	0.05 ± 0.01	0.06 ± 0.01	0.89	(0.66-0.96)[e]	0.05 ± 0.01	0.06 ± 0.01	0.88	(0.63-0.96)[e]	0.342
Mean distance (mm)	19.51 ± 5.76	17.11 ± 3.57	0.42	(-0.82-0.81)[g]	15.50 ± 3.30	15.45 ± 2.67	0.85	(0.55-0.95)[e]	0.042‡
Mean frequency ML (Hz)	0.80 ± 0.43	0.77 ± 0.18	0.43	(-0.76-0.82)[g]	0.67 ± 0.24	0.69 ± 0.21	0.56	(-1.20-0.77)[g]	0.062
95% Power frequency ML (Hz)	2.63 ± 1.17	2.44 ± 0.57	0.47	(-0.64-0.83)[g]	2.36 ± 0.44	2.29 ± 0.70	0.49	(-0.61-0.83)[g]	0.572
Mean frequency AP (Hz)	0.87 ± 0.33	0.70 ± 0.19	0.65	(-0.10-0.89)[g]	0.57 ± 0.18	0.58 ± 0.12	0.76	(-0.70-0.82)[e]	0.675
95% Power frequency AP (Hz)	2.63 ± 0.83	2.26 ± 0.52	0.76	(0.24-0.92)[e]	2.01 ± 0.63	1.98 ± 0.48	0.82	(0.44-0.94)[e]	0.055
	TEST 4: Contralateral leg								
	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
RMS ML velocity (mm/s)	20.56 ± 39.89	29.26 ± 48.20	0.47	(-0.73-0.84)[g]	9.86 ± 2.47	15.26 ± 36.37	0.48	(-0.81-0.85)[g]	0.751
RMS AP velocity (mm/s)	21.46 ± 5.95	6.94 ± 2.60	0.25	(-1.23-0.51)	12.56 ± 9.59	20.21 ± 36.96	0.40	(-0.88-0.81)[g]	0.654
CP speed (mm/s)	22.25 ± 34.77	18.19 ± 23.35	0.13	(-1.87-0.64)	12.34 ± 6.09	17.28 ± 23.71	0.45	(-0.71-0.82)[g]	0.013‡
Sway area (mm²)	118.17 ± 195.56	181.33 ± 661.20	0.10	(-1.89-0.64)	60.03 ± 128.30	102.99 ± 267.00	0.85	(0.53-0.95)[e]	0.321
Mean peaks(s)	0.05 ± 0.01	0.06 ± 0.02	0.71	(0.05-0.91)[g]	0.04 ± 0.01	0.06 ± 0.02	0.68	(-0.01-0.90)[g]	0.291
Mean distance (mm)	25.76 ± 20.36	16.67 ± 9.68	0.39	(-1.55-0.58)	19.49 ± 7.30	15.35 ± 8.44	0.75	(0.23-0.92)[g]	0.007‡
Mean frequency ML (Hz)	0.75 ± 0.44	1.13 ± 1.40	0.57	(-0.42-0.87)[g]	0.57 ± 0.28	1.06 ± 0.97	0.62	(-0.99-0.83)[g]	0.089
95% Power frequency ML (Hz)	2.39 ± 0.85	3.74 ± 5.70	0.66	(-0.12-0.90)[g]	2.04 ± 0.57	2.95 ± 2.08	0.76	(0.17-0.93)[e]	0.537
Mean frequency AP (Hz)	0.84 ± 0.40	0.77 ± 0.70	0.22	(-1.35-0.69)	0.65 ± 0.20	0.77 ± 0.74	0.42	(-0.82-0.80)[g]	0.046‡
95% Power frequency AP (Hz)	2.54 ± 0.70	2.36 ± 1.50	0.28	(-1.38-0.78)	2.17 ± 0.37	2.04 ± 1.77	0.56	(-0.76-0.72)[g]	0.221

[e] Excellent reliability (95% CI for ICC above 0.75), [g] Good reliability (95% CI for ICC between 0.4 and 0.75).

performed in "day 1" and "day 2". In the "Best result" analysis, the CP-Speed parameter showed an excellent reliability in all tests except in test 4 which showed a good reliability. In the "mean result" analysis the CP-speed showed an excellent reliability in tests 1, 2 and 5, a good reliability in tests 3 and 6, and a poor reliability in test 4. When all tests were considered together, the "best result" analysis showed a better reliability for the CP-Speed parameter than the "mean result" analysis ($P<0.05$). In addition, the "best result" analysis revealed smaller mean differences and dispersion in the Bland and Altman graph for all tests compared to the "mean result" analysis ($P<0.05$). Figures 3-5 show the differences in the CP-speed between day 1 and day 2 in every test, plotted against their mean, with 95% CI and 95% limit of agreement (LOA) (Table V). The static tests with the eyes opened (Figure 3) had a lower dispersion than the dynamic tests (Figure 5), which showed a lower dispersion than the static tests with the eyes closed (Figure 4).

When all tests were analyzed together, no differences between the JL and the CL were found in the CP-speed ($P=0.71$ and $P=0.96$ for mean result and best results analysis, respectively).

Discussion

The present study shows that the unipedal stance test performed in the static position and with the eyes opened is a reliable method to asses balance (Figure 1A). During this test, the ICC of the CP-Speed parameter was between 0.82-0.89, which is indicative of excellent reliability.[40] We also observed that the test performed with the eyes opened had lower dispersion in the Bland and Altman graphs than the test carried out with the eyes closed, and the dynamic test. Moreover, to improve the reliability it was preferable to use the best result rather than the average value of six attempts as a representative measure of

TABLE IV.—*Test-retest reliability of stabilometric variables during the dynamic tests (values expressed as mean ± SD; N.=23). The intraclass correlation coefficients (ICC, 95% confidence interval) are calculated with the "Mean results" (ICC_M) or with the "Best results" (ICC_B) of day 1 and 2. P-value from resampling-based test of hypothesis with null hypothesis $ICC_B \leq ICC_M$ are shown.*

	TEST 5: Jumping leg								
	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
RMS ML velocity (mm/s)	5.02 ± 1.12	4.82 ± 1.03	0.95	(0.86-0.98)[e]	4.48 ± 1.04	4.40 ± 1.01	0.96	(0.59-0.98)[e]	0.953
RMS AP velocity (mm/s)	4.07 ± 1.01	3.95 ± 0.74	0.89	(0.69-0.96)[e]	3.55 ± 0.76	3.76 ± 0.73	0.94	(0.81-0.98)[e]	0.371
CP speed (mm/s)	5.37 ± 1.11	5.18 ± 0.97	0.95	(0.86-0.98)[e]	4.79 ± 1.02	4.87 ± 0.95	0.97	(0.77-0.99)[e]	0.667
Sway area (mm^2)	6.05 ± 2.01	5.72 ± 1.42	0.72	(0.20-0.90)[g]	4.86 ± 1.59	5.18 ± 1.38	0.71	(0.16-0.90)[g]	0.518
Mean peaks(s)	0.12 ± 0.04	0.12 ± 0.04	0.92	(0.78-0.97)[e]	0.11 ± 0.03	0.11 ± 0.04	0.92	(0.76-0.97)[e]	0.724
Mean distance (mm)	8.05 ± 1.38	8.18 ± 1.36	0.90	(0.71-0.96)[e]	7.31 ± 1.15	7.56 ± 1.19	0.86	(0.59-0.95)[e]	0.235
Mean frequency ML (Hz)	0.87 ± 0.20	0.89 ± 0.16	0.76	(0.30-0.91)[e]	0.74 ± 0.18	0.80 ± 0.16	0.61	(-0.11-0.86)[g]	0.083
95% Power frequency ML (Hz)	2.63 ± 0.39	2.57 ± 0.41	0.81	(0.45-0.93)[e]	2.33 ± 0.40	2.39 ± 0.39	0.84	(0.49-0.95)[e]	0.084
Mean frequency AP (Hz)	0.56 ± 0.17	0.53 ± 0.12	0.63	(-0.05-0.87)[g]	0.46 ± 0.15	0.46 ± 0.13	0.50	(-0.54-0.84)	0.339
95% Power frequency AP (Hz)	1.95 ± 0.35	1.74 ± 0.34	0.65	(0.01-0.88)[g]	1.75 ± 0.37	1.61 ± 0.36	0.69	(0.03-0.90)[g]	0.946
	TEST 6: Contralateral leg								
	Mean results				Best results				$ICC_B \leq ICC_M$
	Day 1	Day 2	ICC_M	(95% CI)	Day 1	Day 2	ICC_B	(95% CI)	
RMS ML velocity (mm/s)	4.70 ± 0.90	5.04 ± 1.47	0.66	(0.03-0.88)[g]	4.41 ± 0.77	4.40 ± 0.76	0.81	(0.39-0.94)[e]	0.002‡
RMS AP velocity (mm/s)	4.10 ± 0.94	4.38 ± 1.45	0.82	(0.50-0.94)[e]	3.82 ± 0.83	3.83 ± 0.69	0.92	(0.76-0.97)[e]	0.013‡
CP speed (mm/s)	5.24 ± 0.95	5.51 ± 1.62	0.74	(0.26-0.91)[g]	4.89 ± 0.78	4.84 ± 0.70	0.90	(0.69-0.97)[e]	0.001‡
Sway area (mm^2)	5.90 ± 1.53	7.58 ± 5.74	0.45	(-0.56-0.81)[g]	5.21 ± 1.08	5.50 ± 1.78	0.86	(0.58-0.96)[e]	0.001‡
Mean peaks(s)	0.11 ± 0.03	0.11 ± 0.03	0.85	(0.57-0.95)[e]	0.10 ± 0.02	0.11 ± 0.03	0.62	(-0.18-0.88)[g]	0.961
Mean distance (mm)	8.12 ± 1.20	9.16 ± 2.43	0.78	(0.38-0.92)[e]	7.64 ± 0.85	7.88 ± 1.01	0.32	(-1.13-0.78)	0.232
Mean frequency ML (Hz)	0.81 ± 0.16	0.85 ± 0.12	0.71	(0.17-0.90)[g]	0.69 ± 0.16	0.77 ± 0.10	0.66	(-0.05-0.89)[g]	0.484
95% Power frequency ML (Hz)	2.44 ± 0.37	2.45 ± 0.33	0.81	(0.45-0.93)[e]	2.25 ± 0.41	2.32 ± 0.30	0.78	(0.33-0.93)[e]	0.881
Mean frequency AP (Hz)	0.58 ± 0.13	0.53 ± 0.13	0.29	(-1.02-0.75)	0.49 ± 0.14	0.47 ± 0.10	0.17	(-1.39-0.71)	0.385
95% Power frequency AP (Hz)	1.88 ± 0.42	1.78 ± 0.33	0.54	(-0.31-0.84)[g]	1.68 ± 0.45	1.61 ± 0.28	0.65	(-0.01-0.88)[g]	0.372

[e] Excellent reliability (95% CI for ICC above 0.75), [g] Good reliability (95% CI for ICC between 0.4 and 0.75).[40]

TABLE V.—*CP-speed test-retest for the Bland and Altman graph in each test. Data are presented as "Mean results" and "Best results" for the comparison of these two methods of analysis, with the mean difference of the CP-speed (expressed as mean ± SD), the 95% confidence interval (CI) and the 95% limits of agreement (LOA).*

	Mean results			Best results		
	Mean difference CP-speed (mm/s)	95% CI	95% LOA	Mean difference CP-speed (mm/s)	95% CI	95% LOA
Test 1	0.75 ± 1.46	(0.15-1.34)	(-2.12-3.62)	0.45 ± 1.04	(0.02-0.87)	(-1.58-2.48)
Test 2	0.74 ± 0.83	(0.40-1.08)	(-0.89-2.36)	0.57 ± 0.83	(0.23-0.91)	(-1.05-2.19)
Test 3	0.73 ± 2.97	(-0.48-1.94)	(-5.08-6.54)	0.47 ± 2.33	(-0.48-1.42)	(-4.10-5.03)
Test 4	2.59 ± 5.19	(0.47-4.71)	(-7.58-12.77)	2.39 ± 3.80	(0.84-3.95)	(-5.06-9.85)
Test 5	0.21 ± 0.78	(-0.11-0.53)	(-1.33-1.74)	0.15 ± 0.92	(-0.23-0.52)	(-1.65-1.94)
Test 6	-0.11 ± 1.17	(-0.58-0.37)	(-2.41-2.20)	-0.04 ± 0.88	(-0.40-0.32)	(-1.75-1.68)

the balance. Finally, our results show that leg dominance had no influence on balance and therefore both legs may be used interchangeably.

The present study shows that the single-leg balance test performed in the new standard position is a reliable method to asses balance. According to the recommendations of Fleiss,[40] a 95% CI for ICC between 0.4-0.75 indicates good reliability, while values above 0.75 are indicative of excellent reliability. As summarized in Tables II-IV, 91% of the analyzed variables in all the proposed tests (static with eyes opened, static with eyes closed and dynamic) showed ICC values above 0.4, and 50% above 0.75. This good to excellent reliability may be mainly attributed to the fact that in the test we are proposing, potential changes in the position of body segments

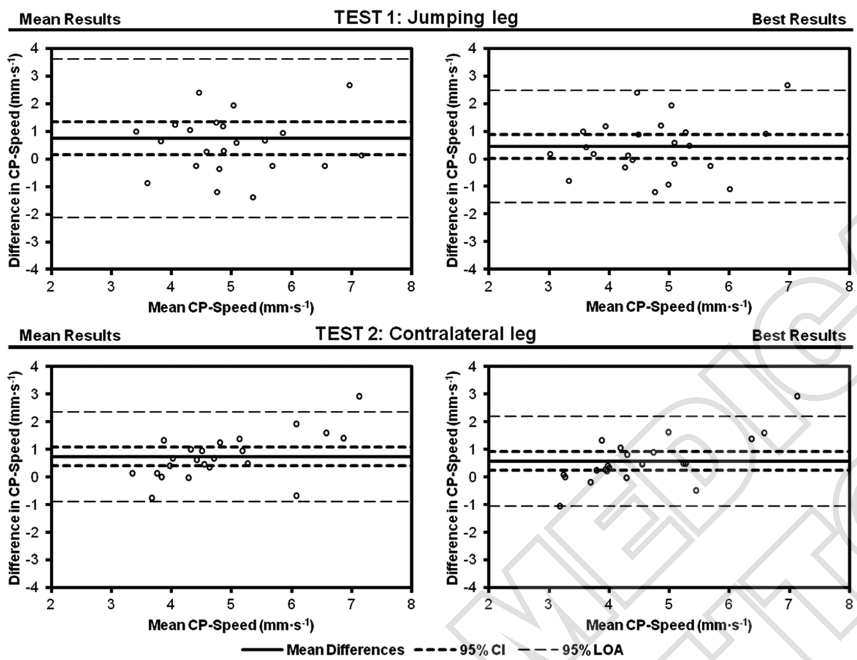

Figure 3.—Differences in the CP-Speed between day 1 and 2, plotted against their mean for each subject (N.=23), with the 95% CI and the 95% LOA. The graphs represent the tests performed with the eyes opened, with the JL (Test 1) and the CL (Test 2), and show the two methods of analysis ("mean result" and "best result").

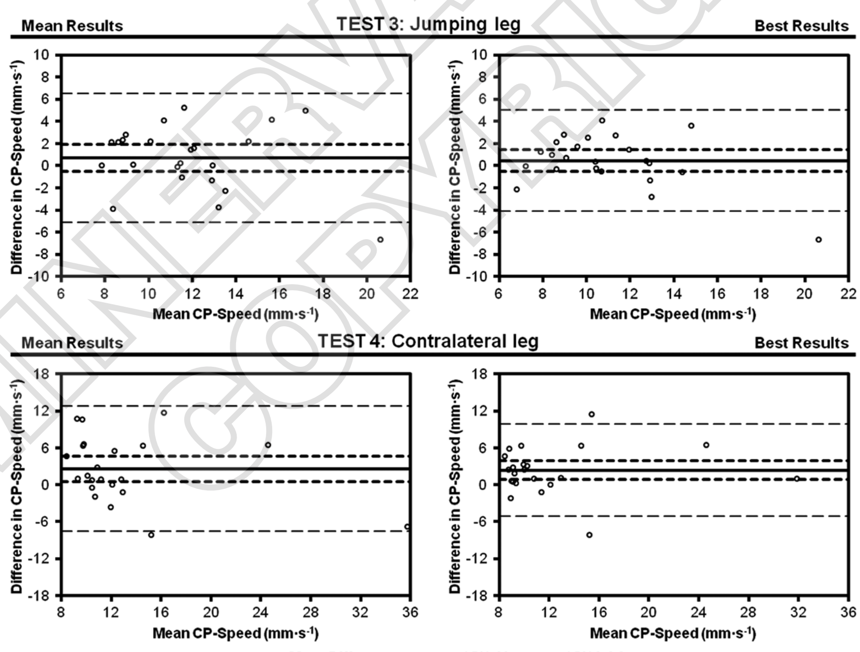

Figure 4.—Differences in the CP-speed between day 1 and 2, plotted against their mean for each subject (N.=23), with the 95% CI and the 95% LOA. The graphs represent the tests performed with the eyes closed, with the JL (Test 1) and the CL (Test 2), and show the two methods of analysis ("mean result" and "best result").

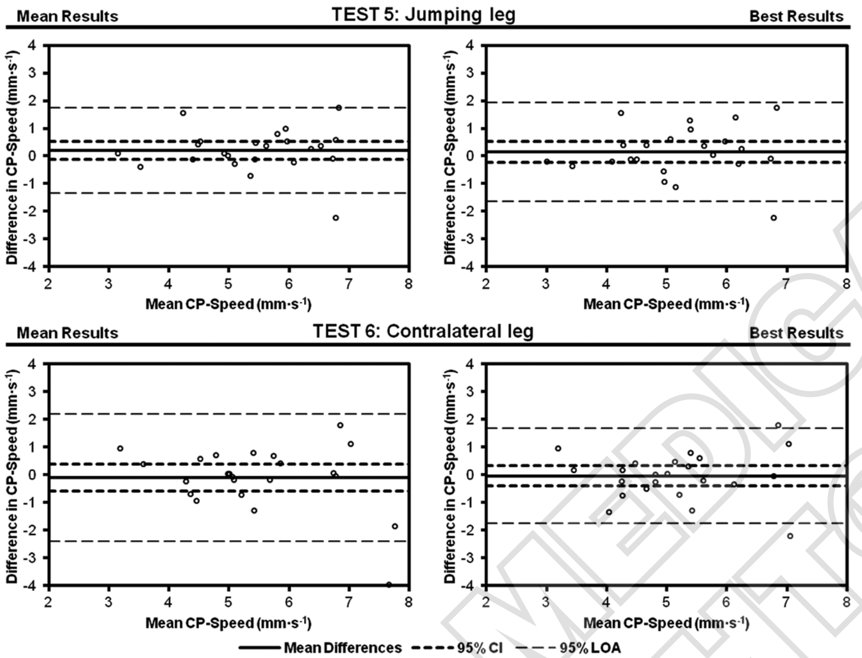

Figure 5.—Differences in the CP-Speed between day 1 and 2, plotted against their mean for each subject (N.=23), with the 95% CI and the 95% LOA. The graphs represent the dynamic tests, performed with the JL (Test 1) and the CL (Test 2), and show the two methods of analysis ("mean result" and "best result").

during the test are minimized by placing the arms on the hips and the non-supporting leg on the top of the patella of the supporting leg.[18] It has been documented that when the single leg balance test is performed with the arms and the non-supporting leg free, anticipatory postural adjustments of these extremities can increase variability.[18] In support, several studies have found poor test-retest reliabilities when the tests were performed under these conditions.[3, 7, 19-21]

Several parameters can be derived from recordings of the CP,[37] among which the CP-Speed has been considered a sensitive and discriminant variable of postural stability.[35-37, 42, 43] In the present investigation, the ICC of the CP-Speed parameter during the static test carried out with the eyes opened was very high (between 0.82-0.89). Therefore, the CP-Speed can be considered an adequate variable to asses balance during this test.

Several studies had conducted unipedal stance balance measurements with the subjects performing a dynamic activity.[2, 7, 21, 24, 44, 45] However, no previous tests have addressed the influence of upper limb motor tasks on unipedal stance balance. As depicted in figures,[3-5] in the present study the static test performed with the eyes opened showed lower dispersion in the Bland and Altman graph than the dynamic test (also performed with the eyes opened), which indicates a lower variability during the static test. Interestingly, static and dynamic tests (performed with the eyes opened) also had lower dispersion in the Bland and Altman graphs than the static test carried out with the eyes closed. This result is in concordance with previous studies showing that test modalities with the eyes opened yield more reliable results than with eyes closed.[24-31]

Several studies have reported similar results when the single leg balance test is performed with the dominant and non-dominant legs.[4, 7, 16, 25-35] In the present research, we distinguished between the jumping and the contralateral leg, which are submitted to different coordination orders.[46] In our study all subjects but three used the non-dominant leg as the jumping leg. Despite jumping leg had lower dispersion than the contralateral leg in the Bland and Altman graphs, no significant differences between JL and CL were found when all tests were considered together.

The present investigation shows that choosing the best result of six attempts conferred higher reliability to the single-leg stance balance test than using the mean value. When all tests were considered together the "best result" analysis showed smaller mean differences and dispersion in the Bland and Altman graph compared to the "mean result" analysis. Studies using the average value as representative of the balance during the single-leg stance balance test have shown that small changes in an individual's performance in this test could not be detected.[3, 22] In other physical fitness tests, *i.e.*, jumping performance, the reliability improved when using the best result instead of the mean value.[23] Arteaga *et al*.[23] showed that biological variability and learning effects associated to physical fitness tests were limited when the best result was used during jumping performance tests. Similarly, our study clearly demonstrates that the best result represents the balance more reliably than the mean result during the single-leg balance test.

Although some studies have reported learning effects with balance test repetition,[47-49] this was not the case in the present investigation, most likely due to low number of repetitions per day in each test modality examined.

In conclusion, the standard position proposed in the present study to conduct the single-leg stance balance test is a reliable method to assess balance. It was noted that the balance could be assessed with higher reliability when using as a representative the CP-Speed parameter, and that the reliability increased when considering the best result of six attempts rather than the mean result. The present study also shows that tests performed with the eyes opened are more reliable and have lower dispersion than with eyes closed, or when executing a dynamic task with the eyes opened. Nevertheless, the three types of balance test have enough reliability to determine the balance in healthy population.

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