Intra and Intersession Reliability of Balance Measures During One-Leg Standing in Young Adults

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Abstract

Muehlbauer, T, Roth, R, Mueller, S, and Granacher, U. Intra and intersession reliability of balance measures during one-leg standing in young adults. *J Strength Cond Res* 25(X): 000–000, 2011—A study was designed to investigate the intra and intersession reliability during 1-leg standing recorded from a computerized balance platform. Thirty-nine healthy young men ($n = 17$, age range: 20–30 years) and women ($n = 22$, age range: 21–28 years) performed 3 testing sessions, with the second session 30 minutes (intrasession comparison) and the third session 1 week (intersession comparison) after the initial testing session. Within each testing session, participants completed 3 trials of 1-leg standing with their dominant leg. Reliability statistics were calculated using the mean of all 3 trials during each session for 6 balance measures (i.e., total displacements of the center of pressure [CoP], the CoP displacements in mediolateral and anterior–posterior directions, and the CoP speed and CoP area and their *SD*). Test–retest reliability was examined calculating both, intraclass correlation coefficient (ICC) with 95% confidence interval (95% CI) and Bland–Altman plots. In both sexes and irrespective of balance measure, ICC values were ≥0.75 except for 1 parameter in men. This indicates an excellent intra and intersession reliability. Bland–Altman plots confirmed these findings by showing that only 1 or 2 (4.5–11.8%) of the data points were beyond the 95% CI. Practitioners and clinicians are provided with a posturographic test setup that proved to be reliable. Researchers can use these data to identify the range in which the true value of a subject's score lies and estimate a priori sample sizes.

Key Words postural control, center of pressure, test–retest reliability, intraclass correlation

Introduction

According to a study of Schneider et al. (32), 5.6% of adults engaging in regular recreational physical activity received medical treatment for nonfatal sports injuries during the foregoing year. Notably, the injury incidence rate is the highest in the age group 30 years and younger. Dislocations, distortions, and torn ligaments account for 60% of all sports injuries, followed by fractures (18%), contusions, surface wounds, or open wounds (12%) (31). Further, about 62% of all sports injuries resulted in occupational disability and time off work. Thus, sports injuries lay a high financial burden on the public health care system (26). The etiology of sports injuries is multifactorial comprising environmental risk factors (e.g., weather, sports equipment, etc.) and subject-related risk factors or both (25). Yet, one important intrinsic risk factor among others are deficits in postural control (33). Therefore, young adults are an important target group for promoting balance with the purpose of improving individual declines.

In a large number of studies, the effectiveness of particularly balance training (BT) in improving postural control (8,34) and in reducing sports injury rates (14,15) has been demonstrated. To test the effectiveness of BT, it is necessary to repeatedly measure variables of postural control (e.g., before and after a defined training period). For this purpose, high reliability of different balance measures constitutes an important prerequisite to detect training-induced changes that are free from errors in the testing procedure.

Previous studies reported test–retest reliability of balance measures in healthy young adults (11,13,19,30) for either intrasession reliability (i.e., within the same testing day) or intersession reliability (i.e., between testing days). However, a combined analysis of both types of reliability was not conducted. Furthermore, nearly all the above-cited studies applied bipedal balance tasks in their investigation, which may not be appropriate in young adults because of potential ceiling effects (i.e., body sways cannot take on a value higher than some limit because of the lack of severity in the balance test). To the authors' knowledge, there is no study available that investigated the intra and intersession reliability during 1-leg standing in young healthy adults using a computerized

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Table 1. Characteristics of study cohort.*†

Characteristics	Men (n = 17)	Women (n = 22)
Mean age (y)	25.5 ± 3.2	24.6 ± 2.5
Age range (y)	20–30	21–28
Height (cm)	178.7 ± 3.9	169.6 ± 5.3
Mass (kg)	74.7 ± 5.6	63.4 ± 6.1
BMI (kg·m^{-2})	23.4 ± 1.2	22.1 ± 1.6
Footedness (l/r)	2/15	7/15

*l = left footed; r = right footed.
†Values are mean ± *SD*s.

balance platform. Thus, the purpose of this study was to provide reliable data for different balance measures during 1-leg standing in young and healthy adults.

Methods

Experimental Approach to the Problem

A single-group, repeated-measure design was used to address the lack of empirical evidence about intra and intersession reliability during 1-leg standing in young healthy adults using a computerized balance platform. The participants performed 3 testing sessions (independent variable), with the second session 30 minutes (intrasession comparison) and the third session 1 week apart from the initial session (intersession comparison). Within each session, participants completed 3

Figure 1. Participant performing the 1-leg stance on the balance platform.

Table 2. Geometric mean and 95% CI for the different balance measures obtained during sessions 1–3 by gender.*

	Session 1		Session 2		Session 3	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
Men (n = 17)						
CoP_ap	759.3	651.0–867.6	699.8	610.3–789.3	738.6	643.7–833.5
CoP_ml	746.8	661.9–831.7	596.1	543.4–648.8	662.5	600.5–724.5
COP_tot	1,223.2	1,070.2–1,376.2	1,017.7	915.0–1,120.3	1,099.3	986.8–1,211.7
COP_C90area	484.3	404.6–563.9	461.1	395.5–526.7	470.1	373.8–566.4
COP_speed	40.8	35.7–45.9	33.9	30.5–37.3	36.6	32.9–40.4
COP_sd	4.5	4.1–4.8	4.3	4.0–4.7	4.3	4.0–4.6
Women (n = 22)						
COP_ap	688.6	620.9–756.4	620.3	566.4–674.2	667.5	600.9–734.0
COP_ml	693.0	614.1–771.9	556.8	507.6–606.0	625.7	558.4–693.0
COP_tot	1,133.1	1,013.2–1,253.0	924.5	847.7–1,001.4	1,013.3	913.1–1,113.5
COP_C90area	426.6	379.1–474.1	411.2	359.2–463.2	420.0	364.8–475.2
COP_speed	37.8	33.8–41.8	30.8	28.3–33.4	33.8	30.4–37.1
COP_sd	4.3	4.1–4.5	4.1	3.8–4.3	4.1	3.8–4.3

*COP = center of pressure; CoP_ap = displacements of the CoP in anterior–posterior direction in mm; CoP_ml = displacements of the CoP in mediolateral direction in mm; CoP_tot = total displacements of the CoP in mm; CoP_C90area = surface area of the CoP in mm^2; CoP_speed = speed of the CoP in mm·s^{-1}; CoP_sd = *SD* of the CoP speed in mm·s^{-1}; 95% CI = 95% confidence intervals.

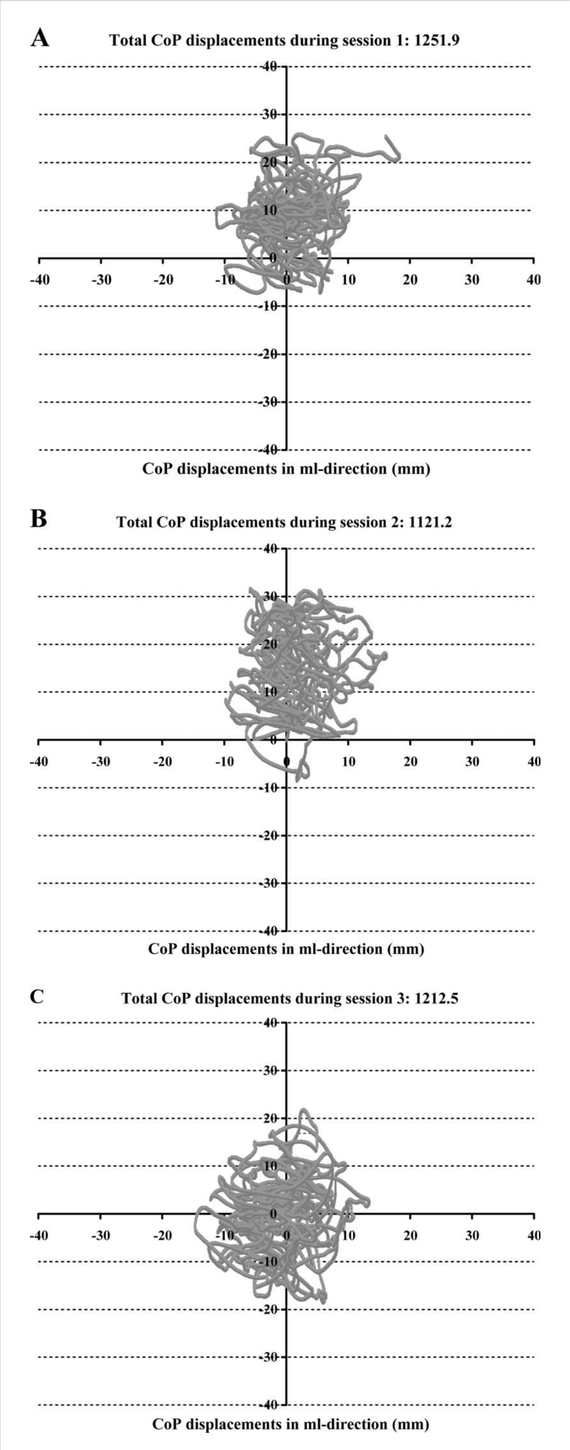

Figure 2. Examples of center of pressure (CoP) displacements in mediolateral and anterior–posterior directions for participant R.L.B. performed during session 1 (A), session 2 (B), and session 3 (C).

1-leg stances with their dominant leg. We used the 1-leg stance for the assessment of postural control because it is a very common balance task applied in young healthy subjects (13,20). In addition, the base of support is reduced during 1-leg standing, which creates a more challenging balance task and may thus be an appropriate tool for the measurement of balance ability in young healthy subjects. Test–retest correlations were computed for 6 frequently used balance parameters (dependent variables).

Subjects

With reference to the studies of Doyle et al. (11) and Rogind et al. (29), an a priori power analysis (17) with an assumed type 1 error of 0.05 and a type 2 error rate of 0.10 (90% statistical power) was conducted, which revealed that 38 persons would be sufficient to test our hypothesis. Forty-two subjects were recruited for the study from which 2 male subjects sustained an injury between sessions 1/2 and session 3 and could not complete this study. Additionally, one more male subject was tested during sessions 1 and 2 but did not show up 1 week later on session 3. Finally, 17 men and 22 women participated in this study after experimental procedures were explained. The characteristics of the subjects are shown in Table 1. None had any history of musculoskeletal, neurological, or orthopedic disorder that might have affected their ability to execute the balance tests. The participants were physically active (ca. 5 $h \cdot wk^{-1}$), being involved in sports such as soccer, basketball, volleyball, or swimming. Participants gave their written informed consent before the start of the study. The study was approved by the ethics committee Beider, Basel, Switzerland. The study was conducted from November to December 2009.

Procedures

Test circumstances (e.g., room illumination, temperature, noise) were in accordance with recommendations for posturographic testing (22). Before testing, all participants underwent a 5-minute warm-up consisting of submaximal plyometrics and skipping exercises. Static postural control was assessed during standing on the dominant leg. The dominant leg was determined according to the lateral preference inventory (7). One-leg standing was shown to be challenging in old and in young adults as indicated by a significant increase in postural sway during 1-leg stance as compared to 2-leg standing and tandem stance (1). For experimental testing, participants were asked to first place their dominant foot with a knee flexion of 30° along the anterior–posterior axis of the plate (Figure 1). Second, they were instructed to flex the knee of the supporting limb at 45° to actively stabilize the center of pressure (CoP) over the base of the support. Third, subjects were now asked to place their hands on the hips and to fix a cross attached to a nearby wall. Starting with 2–3 trials to get accustomed to the testing procedure, the participants performed 3 30-second trials during each of the 3 sessions separated by a 1-minute break between trials (24,27). During all trials, participants were

TABLE 3. Intraclass correlation coefficients, 95% CI, and f for the different balance measures calculated for intra and intersession reliability by gender.*

	Intrasession reliability			Intersession reliability		
	ICC	95% CI	f	ICC	95% CI	f
Men ($n = 17$)						
CoP_ap	0.97	0.91–0.99	0.31	0.94	0.84–0.98	0.10
CoP_ml	0.76	0.33–0.91	1.10	0.59	−0.13–0.85	0.58
COP_tot	0.88	0.66–0.96	0.81	0.82	0.51–0.94	0.47
COP_C90area	0.77	0.36–0.92	0.16	0.87	0.63–0.95	0.08
COP_speed	0.88	0.66–0.96	0.81	0.82	0.51–0.94	0.47
COP_sd	0.76	0.34–0.91	0.23	0.81	0.46–0.93	0.33
Women ($n = 22$)						
COP_ap	0.92	0.81–0.97	0.50	0.84	0.62–0.94	0.14
COP_ml	0.89	0.73–0.95	0.92	0.79	0.50–0.91	0.41
COP_tot	0.84	0.62–0.94	0.92	0.80	0.51–0.92	0.48
COP_C90area	0.81	0.55–0.92	0.14	0.75	0.40–0.90	0.06
COP_speed	0.84	0.62–0.94	0.92	0.80	0.51–0.92	0.48
COP_sd	0.76	0.42–0.90	0.38	0.85	0.65–0.94	0.39

*COP = center of pressure; CoP_ap = displacements of the CoP in anterior–posterior direction in mm; CoP_ml = displacements of the CoP in mediolateral direction in mm; CoP_tot = total displacements of the CoP in mm; CoP_C90area = surface area of the CoP in mm^2; CoP_speed = speed of the CoP in $mm \cdot s^{-1}$; CoP_sd = *SD* of the CoP speed in $mm \cdot s^{-1}$; ICC = intraclass correlation coefficients; 95% CI = 95% confidence intervals; f = effect sizes.

asked to stand as stably as possible. All balance tests were performed with eyes open (to allow visual input) and without shoes to allow optimal proprioceptive input under the guidance of the same instructor. Intersession testings were conducted at the same time of the day.

Displacements of the CoP in the mediolateral and anterior–posterior directions were recorded with a computerized balance platform (HUR BT4®, HURLABS, Tampere, Finland). Time series signals were filtered using a second-order Butterworth low-pass filter with a cut-off frequency of 10 Hz. Data were acquired for 30 seconds at a sampling rate of 400 Hz. Six parameters were computed from the time series of the CoP displacements: first, the displacements of the CoP in anterior–posterior direction (CoP_ap in mm); second, the displacements of the CoP in mediolateral direction (CoP_ml in mm); third, the total displacements of the CoP, which represent the summed displacements in mediolateral and anterior–posterior directions (CoP_tot in mm); fourth, the CoP C90area, which represents the surface area covered by the trajectory of the CoP with a 90% confidence interval (CI; CoP_C90area in mm^2); fifth, the CoP speed, which indicates the total distances covered by the CoP divided by the duration of the sampled period (CoP_speed in $mm \cdot s^{-1}$); and sixth, the *SD* of the CoP speed, which was derived by calculating the square root of the sum of the square of the deviations about the anterior–posterior and mediolateral directions, divided by the sample size minus 1 (CoP_sd in $mm \cdot s^{-1}$). All of these parameters represent traditional balance measures, which are widely employed in clinical practice to assess individuals' postural control capacities during unperturbed stance.

Statistical Analyses

The mean of the 3 testing trials was used for statistical analysis. Measures of central tendency and spread of the data were represented as geometric mean and 95% CI. To test our hypothesis of a high reliability when comparing balance performance within and between testing sessions, intra and intersession reliabilities of the CoP measures were quantitatively assessed with the intraclass correlation coefficient (ICC) and their respective 95% CI. According to Fleiss' classification (18) an ICC >0.75 indicates "excellent," between 0.40 and 0.75 "fair to good," and <0.40 "poor" reliability. Furthermore, as a qualitative method, Bland–Altman plots (3) were used to define the magnitude of agreement between test–retest values. Here, the difference of the paired intra and intersession measurements is plotted against the respective average. It is recommended that 95% of the data points should lie within the mean ± 2*SD*s of the differences for the intra and intersession measurements, which corresponds to the 95% CI. Finally, effect sizes (f) were calculated, where f-values of 0.10, 0.25, and 0.40 indicate small, medium, and large effects, respectively (6). All analyses were performed using Statistical Package for Social Sciences (SPSS) version 16.0.

RESULTS

Descriptive data for balance performances shown during sessions 1–3 are provided in Table 2. Irrespective of balance

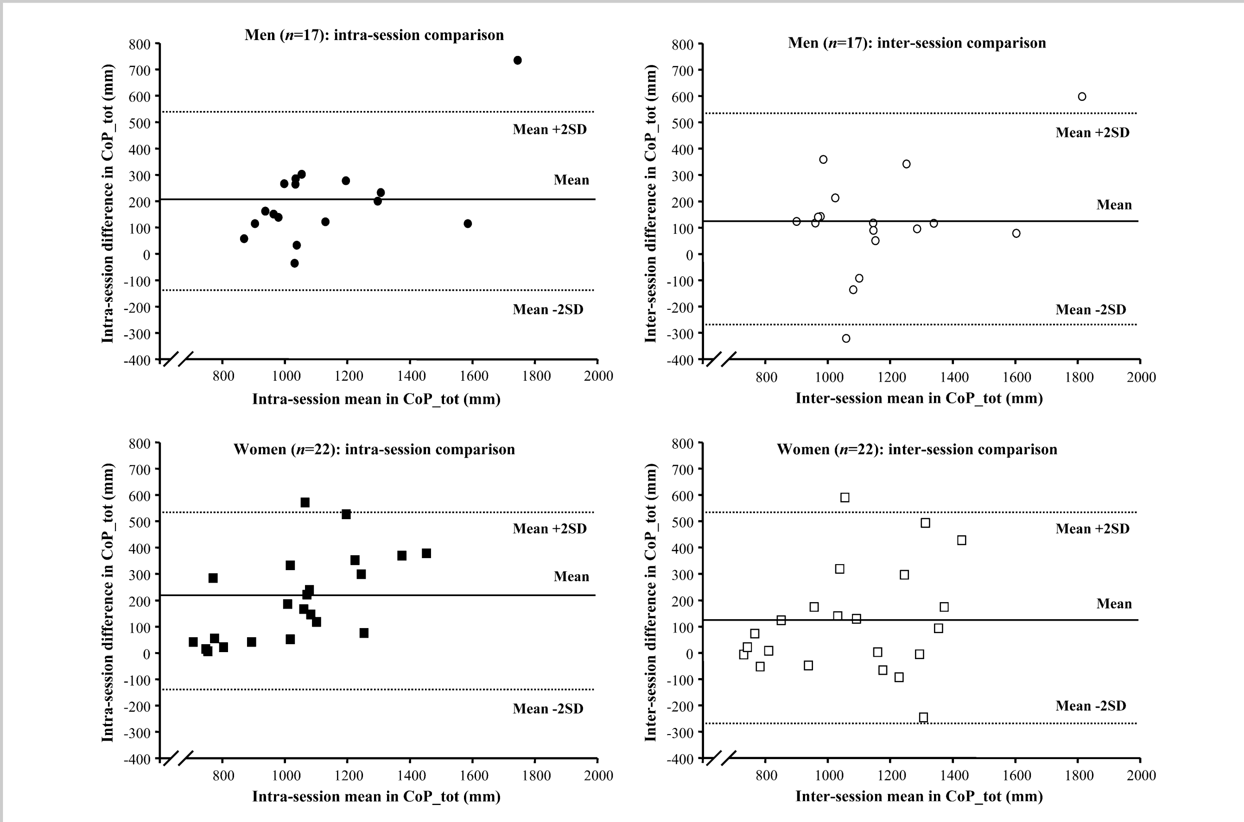

Figure 3. Bland–Altman plots comparing total center of pressure (CoP) displacements during intra (left) and inter (right) session testing for men (above) and women (below). The difference between the intra and intersession measurements is plotted against the mean of the respective measurements. Solid lines indicate the average of the differences. Dotted lines indicate the 95% confidence intervals corresponding to the mean ± 2*SD*s of the differences are shown.

measure, virtually no changes in balance performance could be observed between testing sessions. Examples of CoP displacements in mediolateral and anterior–posterior directions performed during testing sessions 1–3 are given in Figures 2A–C.

The calculated ICC values for the 6 balance measures across the 3 testing sessions are presented in Table 3 for men and women separately. Irrespective of balance measure, ICCs were ≥0.75 in women indicating an excellent intra and intersession reliability. In men, all but one parameter (CoP displacements in the mediolateral direction) showed ICC values ≥0.75 resulting in an excellent intra and intersession reliability. An ICC value of 0.59 was found for CoP displacements in mediolateral direction indicating a fair to good intersession reliability. In men and in women, CoP displacements in the anterior–posterior directions was the most reliable balance measure (ICC values between 0.84 and 0.97).

Bland–Altman plots for total CoP displacements obtained for intra and intersession comparisons are shown in Figure 3. In men, the charts illustrate that only 1/17 (5.9%) and 2/17 (11.8%) of the data points were beyond the mean ± 2*SD* lines for intra and intersession comparisons, respectively. In women, 1/22 (4.5%) of the data points was beyond the limits in both, intra and intersession comparisons. For the other balance measures, the numbers and percentages of data points, which were beyond the mean ± 2*SD* lines, were in the same range (data not shown).

Discussion

This is the first study that examines intra and intersession reliability during 1-leg standing in young healthy adults using a computerized balance platform. The main finding was that irrespective of gender, nearly all investigated balance parameters showed an excellent intra and intersession reliability, which was qualitatively confirmed by the Bland–Altman plots. This finding varied from those that have been previously published (11,13,19,30). For example, fair to good intrasession reliability was reported using 1-leg (19) and 2-leg (11) standing as balance task, respectively. Differences in results between these 2 studies and our study could be because of the diverse testing duration applied in the studies. We acquired data for 30 seconds, whereas Goldie et al. (19) tested for 5 seconds and Doyle et al. (11) for 10 seconds only.

Le Clair and Riach (24) reported that the longer the test duration, the better the reliability of the measure with a minimum of 30 seconds. In their study, ICC values for most of the investigated balance measures increased from poor for a 15-second trial to fair to good for a 30-second trial. This difference may be attributed to the proportion of the transient component of the CoP signal, which could be prevented by focusing on a sampling duration of <20 seconds (4). Furthermore, the contribution of the low-frequency components of the CoP displacements could be detected with longer but not with shorter sampling durations (4). In another study applying timed 1-leg balance tests, intersession reliability was reported to be also fair to good (13). However, tests were conducted either in eyes closed conditions on a firm and foam surface or on a foam surface with eyes open. This testing setup, in which the visual and proprioceptive input was manipulated, may have influenced intrasubject variation, which could have resulted in reduced ICC values. Furthermore, Santos et al. (30) reported fair to good intersession reliability for CoP speed during 2-leg standing. A rather small sample size ($n = 12$) was applied in their study for comparison, which may have caused bias because of insufficient statistical power.

Gender-specific balance performance was frequently reported in the literature with women showing better results than men did (12,16). In our study, gender differences in test–retest reliability were found during intersession comparison. More specifically, the observed ICC value for the displacements of the CoP in the mediolateral direction was excellent in women but fair to good in men. This finding can be interpreted as preliminary because it was observed in only one balance parameter. Further research using different standing or sensory conditions should reveal whether subjects' gender has an impact on intersession reliability during 1-leg standing.

From a methodological point of view, there is a controversy regarding the number of testing trials. In some studies, it is recommended to use the mean of ≥7 trials (9,23,30), whereas others conclude that 3 trials are sufficient (2,11,27). Furthermore, the applied test duration and sampling frequency vary between studies ranging from 10 to 120 seconds (4,11,23,24) and from 10 Hz to 100 Hz but not higher (2,9–11,28–30). Our finding of an excellent intra and intersession reliability was based on the mean of 3 consecutive trials, each acquired with a sampling duration of 30 seconds, which was in line with some of the above-cited studies. However, contrary to these studies, we used a much higher sampling frequency (400 Hz). Therefore, it is postulated that the level of sampling frequency could have an impact on test–retest reliability. Further research should reveal whether sampling frequency has an effect on intersession reliability of balance measures.

Another major controversial issue comprises the analysis of balance parameters. A large variety of balance measures was used in studies assessing test–retest reliability of static postural control with traditional variables such as length, range, speed, or area of the CoP being most often applied (2,11,23,30). Our finding of an excellent intra and intersession reliability was found during 1-leg standing using traditional balance measures such as total displacements of the CoP, the CoP displacements in mediolateral and anterior–posterior directions, and the CoP speed and area. Overall, care is needed, when generalizing our findings to different sample durations and frequencies, number of trials, and balance tasks or parameters. In addition, our results were obtained with healthy young adults. Therefore, assessment of intra and intersession reliability during 1-leg standing might vary significantly in populations not considered in this study (e.g., athletes, seniors, parkinsonians). In other words, care must be taken when transferring the present findings to other age groups or populations. Furthermore, there was a decrease in the geometric mean values from session 1 to sessions 2 (4–20%) and 3 (3–11%) depending on the respective balance measure considered, which could be because of a possible learning effect or could represent a random or systematic error. Yet, we used the mean of 3 consecutive trials to calculate each balance measure, which is recommended in the literature (27) as a sufficient number to obtain optimal results.

Practical Applications

This study determined that frequently used balance parameters, such as total displacements of the CoP, the CoP displacements in mediolateral and anterior–posterior directions, and the CoP speed/area when measured during 1-leg standing, have an excellent intra and intersession reliability in healthy young adults. In this context, CoP displacements in anterior–posterior directions (i.e., forward/backward sways) proved to be the most reliable balance measure. Testings included only 3 trials over 30 seconds each, which were acquired with a high sampling rate (400 Hz). Consequently, if (a) a coach is attempting to track the progression of balance ability across season, (b) a clinician is attempting to assess lateral ankle trauma rehabilitation, or (c) a teacher is attempting to document BT effects during physical education, the 1-legged stance seems to be appropriate when using the presented test setup. Given the high validity when comparing testing equipments (i.e., computerized balance platforms) from a different manufacturer for the evaluation of balance performance (5,29), it is suggested that practitioners can use these data to identify the range in which the true value of a subject's score lies, irrespective of the computerized balance platform applied. Furthermore, researchers and clinicians can calculate a priori sample sizes for studies assessing balance ability during 1-leg standing recorded from a computerized balance platform (21). In addition, the test–retest reliability was examined using different time intervals (30 minutes and 1 week) that can be used by practitioners, researchers, and clinicians to document acute (i.e., within the same training session) and longer lasting (i.e., between training sessions) changes in balance performance in a reliable way.

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