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Reliability of center of pressure measures within and between sessions in individuals post-stroke and healthy controls☆

Vicki L. Gray [a], Tanya D. Ivanova [b], S. Jayne Garland [b,*]

[a] Department of Physical Therapy and Rehabilitation Sciences, University of Maryland, Baltimore, MD 21201, USA
[b] Department of Physical Therapy, The University of British Columbia, Vancouver, BC V6T 1Z3, Canada

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ABSTRACT

Background: Knowing the reliability of the center of pressure (COP) is important for interpreting balance deficits post-stroke, especially when the balance deficits can necessitate the use of short duration trials. The novel aspect of this reliability study was to examine the center of pressure measures using two adjacent force platforms between and within sessions in stroke and controls. After stroke, it is important to understand the contribution of the paretic and non-paretic leg to the motor control of standing balance. Because there is a considerable body of knowledge on COP reliability on a single platform, we chose to examine reliability using two adjacent platforms which has not been examined previously in stroke.
Methods: Twenty participants post-stroke and 22 controls performed an arm raise, load drop and quiet stance balance task while standing on two adjacent force platforms, on two separate days. Intraclass correlations coefficient ($ICC_{2,1}$) and percentage standard error of measurement (SEM%) were calculated for COP velocity, ellipse area, anterior–posterior (AP) displacement, and medial–lateral (ML) displacement.
Results: Between sessions, COP velocity was the most reliable with high ICCs and low SEM% across groups and tasks and ellipse area was less reliable with low ICCs across groups and tasks. COP measures were less reliable during the arm raise than load drop post-stroke. Within session reliability was high for COP velocity and ML displacement requiring no more than six trials across tasks.
Conclusions: The COP velocity was the most reliable measure with high ICCs between sessions and the high reliability was achieved with fewer trials in both groups in a single session.

1. Introduction

Center of pressure (COP) excursions have been used to assess postural stability during quiet stance in older adults [1,2], stroke [3–6] and Parkinson's [7]. The COP reflects a response from the neuromuscular system to correct deviations in the center of mass (COM) [8], which can be measured with a single force platform or two adjacent force platforms placed under each foot. While a single force platform is commonly used to examine postural control [1,2,7,9], this does not allow the examination of the effect of post-stroke hemiparesis on balance responses in each leg. Recently, evidence has suggested that the excursions in the COP reflects an exploratory mechanism to acquire sensory information, indicating postural sway is important for balance [10,11].

COP excursions can be used as a clinical indicator of impairment, distinguishing fallers from non-fallers [12–15]. The COP excursions are correlated with clinical outcome measures, such as the Berg Balance Scale and Timed Up and Go Test, in older adults and persons after stroke [9]. Typically when the COP values increase during quiet stance, this is an indication of impaired postural control. Older adults classified as fallers have a larger medial–lateral (ML) COP displacement [12,13], larger anterior–posterior (AP) COP velocity [14] or larger mean COP velocity [15]. The reliability of the COP measures are important and an acceptable level of reliability ($r > 0.75$) has been reported in younger and older adults during quiet stance for the AP displacement, ML displacement and mean COP velocity on a single force platform [16–19] and two adjacent platforms [20], with the COP velocity being the most reliable parameter in standing [16–18,20].

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* Corresponding author at: Department of Physical Therapy, University of British Columbia, 212-2177 Wesbrook Mall, Vancouver, BC V6T 1Z3, Canada.
Tel.: +1 604 822 7414; fax: +1 604 822 1870.
E-mail address: jayne.garland@ubc.ca (S.J. Garland).

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Although impairments in postural control post-stroke have been demonstrated with the COP measures from a single force platform [3,21], little is known about the COP reliability of the paretic and non-paretic leg when measured on two adjacent force platforms and during internal perturbations which involve movements of the upper limb. There are many sensorimotor impairments after a stroke that compromise postural control and would be reflected in differences in COP between the two legs, such as sensory changes [22], weight bearing asymmetry and difficulty shifting the weight to the paretic limb [23,24]. Thus, the first objective of this study was to determine the reliability of the paretic and non-paretic legs on four COP measures using two adjacent force platforms: (1) mean COP velocity, (2) area of the 95% confidence ellipse (ellipse area), (3) anterior posterior average displacement, and (4) medial lateral average displacement, in persons post-stroke and controls between two sessions during three postural stability tasks: arm raise, load drop and quiet stance. The four COP measures were chosen as they are used commonly to assess balance in persons post-stroke [3–6,21]. The second objective was to examine the reliability within one session to determine how many trials would be required to achieve a stable COP measure during the three postural stability tasks in persons post-stroke and controls.

2. Methods

Twenty individuals with left hemiparesis from a stroke who were 10.6 ± 3.5 weeks post-stroke and 22 subjects without neurological or acute musculoskeletal injuries participated in the study. Subjects in the stroke group were discharged from in-patient rehabilitation within a month prior to testing. The mean height and weight was 172.1 ± 9.6 cm and 81.7 ± 1.6 kg for the stroke group and 174.4 ± 8.8 cm and 78.2 ± 14.8 kg for controls. All subjects gave informed written consent according to the policies of the Review Board for Health Sciences Research Involving Human Subjects at the University of Western Ontario.

For safety, all subjects wore a "chest and sit" mountain climbing harness, attached to a ceiling track-trolley system that allowed free movement. The harness system did not provide body weight support and did not interfere with the balance tasks. Because a standardized foot placement was not possible for all subjects post-stroke, the subjects stood in a comfortable position with bare feet on two adjacent AMTI OR6-6-1000 force platforms (Advanced Mechanical Technology Inc, MA) and the outlines of the feet were traced on paper taped to the force platforms to ensure the same position on the two testing days. Postural stability was assessed with three tasks: (1) unilateral arm raise [3–5] (2) load drop [21,25] and (3) quiet stance [3–5]. Briefly, in the unilateral arm raise task, subjects raised the right arm to horizontal as fast as possible. In the load drop task, subjects held a 2.2 kg load in their right hand with the arm extended horizontally in front of them and dropped the load. The arm raise and the load drop tasks were repeated 10 times. In the quiet stance task, subjects stood as still as possible and five trials of 10 s were recorded. The three tasks were performed on Day 1 and then repeated on Day 2 which typically occurred 2–3 days after the first testing session. The data were coded to ensure the analysis was blinded to group and day of testing.

The Berg Balance Scale (BBS) comprised of 14 tasks scored on a five-point scale was used to assess functional balance. The BBS is a valid and reliable measure of functional balance in persons post-stroke [26]. Motor recovery post-stroke was assessed by the leg and foot subscales of the Chedoke McMaster Stroke Assessment (CMSA) Impairment Inventory (1–7, 7 representing normal movement), which were totaled for a maximum score of 14.

Force and moment signals from the force platforms (six from each platform) were sampled at a rate of 100 Hz and filtered with 20 Hz 2nd order low-pass Butterworth filter. The COP measures: mean COP velocity, ellipse area, AP average displacement and ML average displacement were calculated using the AMTI BioAnalysis software. The measures for the arm raise and the load drop tasks were recorded for 2 s starting at 0.7 s (arm raise) or 1 s (load drop) before the onset of movement, as determined by a linear accelerometer taped to the right hand. The quiet stance measures were recorded for 10 s.

The relative reliability of each COP measure (mean COP velocity, ellipse area, AP average displacement, ML average displacement) was quantified using intraclass correlation coefficient ($ICC_{2,1}$; two-way random-effects model), and 95% confidence intervals (CI). ICCs ranged from 0 (no reliability) to 1 (perfect reliability), and reliability was interpreted by thresholds suggested by Cicchetti & Sparrow [27]: 0.00–0.39 poor, 0.40–0.59 fair, 0.60–0.74 good, and 0.75–1.00 excellent. The absolute reliability was assessed by the percentage standard error of measurement (SEM%) based on the formula, $SEM\% = SD\sqrt{1 - ICC}/Mean_{test1\&test2} \times 100$, where SD is the standard deviation and ICC is the intraclass correlation coefficient. The SEM provides an estimate of the precision of the measurement and SEM%, which is independent of the units of measurement, is used to enhance the application of the findings to other force platforms. The $ICC_{2,1}$ for between-session reliability for the arm raise and the load drop task was calculated based on the 10 averaged trials from Day 1 and Day 2 for each force platform. Quiet stance was calculated based on the five averaged trials from Day 1 and Day 2 for each force platform.

The $ICC_{2,1}$ and 95% CI for a single session were calculated for the first two trials and subsequent trials were added one at a time until the ICCs were calculated for all 10 trials for the arm raise and load drop tasks or five trials for quiet stance. The ICC and/or CI were considered stable when a plateau was reached and the addition of another trial did not influence the ICC or CI. The force platforms are described as ipsilateral to arm movement (right, non-paretic) and contralateral to arm movement (left, paretic).

3. Results

The stroke group was 60.4 ± 13.4 years of age (13 male) and the control group was 59.5 ± 13.2 years (14 males). All subjects in the control group scored 56/56 on the BBS and the stroke group scored 50.6 ± 5.0. The CMSA score for the leg/foot motor recovery was 10.4 ± 2.4.

3.1. Reliability between sessions

3.1.1. Arm raise task

The ICCs for the control group was 0.89–0.97 for the contralateral leg and 0.69–0.96 for the ipsilateral leg (Table 1). In the stroke group, the ICC for the paretic leg ranged from 0.12 to 0.78 and from 0.44 to 0.80 for the non-paretic leg. The mean COP velocity was the most reliable in both groups as illustrated in Fig. 1A by the mean COP velocity scatter plot on Day 1 and Day 2 in both groups.

The SEM% of the mean COP velocity for the control (5.5–6.3%) and stroke group (14.4–15.4%) was small (Table 1) indicating a small measurement error and good absolute reliability. The SEM% of the ellipse area, and AP and ML average displacement tended to be above 25% in the stroke group and less than 25% in the control group (Table 1) for the arm raise.

3.1.2. Load drop task

The ICCs for the control group ranged from 0.44 to 0.97 for both legs (Table 2). In the stroke group, the ICCs ranged from 0.78 to 0.85 for the paretic leg and from 0.81 to 0.89 for the non-paretic leg. The mean COP velocity was the most reliable as illustrated in the scatterplot of Day 1 and Day 2 mean COP velocity for both groups (Fig. 1B).

The SEM% of the mean COP velocity and AP average displacement was less than 25% in the stroke group (10.4–21.6%) and the control group (5.8–16.2%) (Table 2). For the ellipse area and ML average displacement, the SEM% values were greater than 25% in both groups, with the exception of ML average displacement on the ipsilateral side of control subjects.

3.1.3. Quiet stance

The mean COP velocity was the most reliable for the control and stroke groups, as indicated by the scatterplot of the data on Day 1 and Day 2 (Fig. 1C). The ICCs in the control group ranged from 0.35 to 0.94 for both legs and were from 0.52 to 0.82 for