The role of task constraints in relating laboratory and clinical measures of balance

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Abstract:

This study tested the hypothesis that age-related postural control deficits are more clearly detected from force plate recordings when using postural control tasks with an explicitly defined goal as opposed to the frequently used quiet stance task. Eighteen older adults (over 65) and seventeen younger adults (under 30) stood on a force plate with visual feedback (VFB) of the center of pressure (COP) and without such visual feedback with eyes open (NVFB). In the VFB condition, online visual feedback about the COP was provided and participants maintained that feedback on a stationary visual target for 80 s. We hypothesized that age-related difference in COP variability (standard deviation of COP position and average absolute maximum COP velocity; AAMV) would be more pronounced in the VFB than in the NVFB condition. In addition, we hypothesized that Berg balance scale (BBS) scores for older adults would correlate more strongly with the COP measures in the VFB condition than in the NVFB condition. Results showed that VFB enhanced age-related differences only for AAMV in anterior–posterior direction. Both age groups decreased postural sway when using VFB. Older adults increased AAMV with VFB while young adults did not, indicating that the task modified their postural control strategy stronger than in younger adults. BBS scores were correlated with the AAMV in both feedback conditions, while COP position variability was more clearly correlated with BBS in the VFB condition. These results suggest that the quiet stance task is sufficient to index balance function if velocity-based COP variables are utilized in the analysis.

Keywords: Postural control | Balance | Balance assessment | Visual feedback | Aging

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1. Introduction

Healthy aging leads to numerous changes in the sensorimotor system [1] that are in turn associated with an increased incidence of injurious falls among people older than 65 [2]. A deeper understanding of human balance and how to measure it objectively are highly relevant topics as the population continues to age. In this paper we tested the hypothesis that balance quality is better assessed using protocols that present clearly specified task goals for participants.

Balance quality is frequently operationally defined based on metrics of spatial variability or temporal structure (e.g., stabilogram-diffusion analysis) of force plate-derived variables such as the center of pressure (COP), which is the average point of application of the ground reaction force vector. The COP is most frequently recorded from participants who are instructed to “stand as still as possible” for a limited amount of time, usually for less than a minute—the so-called “quiet stance” paradigm. The objective of this instruction is to examine the stabilizing capacity of the postural control system in the limit—how well the CNS can control the body to remain stationary. In this case, maintaining a still posture depends on the effective use of feedback from the visual, proprioceptive, cutaneous, and vestibular sensory systems and on the integrity of the musculo-skeletal system to correct for postural deviations from the desired position. Greater COP variability and greater COP velocity are traditionally interpreted as signifying impaired postural control and reduced balance quality [3,4]. Older adults have higher COP velocity compared to younger adults [5–7], indicating that balance quality deteriorates with age consistent with many studies [3,8].

However, greater COP variability does not always correlate well with clinical measures of balance function such as the Berg Balance Scale (BBS), Timed Up and Go, or the Tinetti test. Correlations between these scores and COP metrics are typically weak to moderate (Pearson r: .2 to .3) [9]. Berg's original finding for BBS was .55 [4]. Postural tasks other than quiet stance, such as the sensory-organization test (SOT), have been used but the correlation was found to be similarly weak [10]. BBS also weakly correlated with postural sway measures of responses to moving platform perturbations ($r = .38$) [4]. One explanation for the lack of strong associations is that the two types of tests may measure different aspects of balance—force plate measures are more sensitive to specific sensorimotor deficits whereas the clinical scales are more directed to overall balance function [9,11]. Clinical balance tests also have a different level of precision and are typically used to categorize subjects according to their gross functional balance capacity (e.g., needs a walker or not; likely to experience fall or not) as opposed to detecting relatively small changes in postural control.

Another possibility is that the protocols used for force plate assessments during quiet stance insufficiently constrain postural control. The basic requirement of upright stance is to simply maintain the center of mass within the base of support. For bipedal stance the base of support is related to the spatial boundaries of the feet, which provides a substantially large region of permissible COP locations that satisfy the ill-defined goal of quiet stance [12–15]. Moreover, there is an over-abundance of motor system degrees of freedom for postural control (i.e., more muscles and joints are available than minimally necessary to achieve upright stance), which means there are many different combinations of coordination patterns among these degrees of freedom that can lead to the same observed pattern of COP behavior [16]. As a result, COP variability in quiet stance is not straightforwardly related to functional balance quality, and consequently existing balance deficits or age-related changes in postural control may be masked by the redundancy of the postural control system [17]. Our general hypothesis is that postural tasks with an explicit and quantifiable performance goal will constrain the postural control system more and provide a better picture of the stabilizing capacity of the postural control system (and hence balance quality) than quiet stance.

To test this hypothesis, we utilized a postural control task in which participants were provided with online visual feedback about their COP and instructed to keep the COP on a predefined target (visual feedback; VFB) or simply stand as still as possible while looking at the same screen but without visual COP feedback (no visual feedback; NVFB). We hypothesized that (1) the VFB condition would reveal greater differences in COP variability between groups of participants with different balance function levels (younger vs. older adults) than the NVFB condition and (2) the correlation between BBS scores and COP variability would be stronger in the VFB than in the NVFB condition within the older adult sample.

2. Method

All experimental procedures were approved by the Institutional Review Board at the University of Cincinnati. All participants gave informed consent to participate.

2.1. Participants

The characteristics of the sample are reported in Table 1. Young adults participated for research credit in the Department of Psychology at the University of Cincinnati. The exclusion criteria for the younger adults were recent musculo-skeletal injuries or a regimen of anti-depressant medication. Community-dwelling older adults were recruited by verbal invitation from Cincinnati Recreation Commission centers where they attended social events or engaged in physical exercise. The inclusion criteria were to be over 65 and perceive themselves as generally healthy. Exclusion criteria for the older adults included impaired or not corrected-to-normal vision, previous diagnosis of a neurodegenerative disease, stroke, diabetes, or a consistent regiment of antidepressant medication. Overall, the sample reflected an active and healthy group of older adults. Seventeen participants self-reported to be physically active: Nine took part in a physical exercise class for seniors at one of the recreation centers (45 min, 3 times a week), two played volleyball, one bowled every week, and five did exercise walking. Four reported having an incident of falling (1, 1.5, 7, and 12 years ago) and seven reported having lost balance without a fall within last year. Two older adults who met these study criteria were later excluded from the analysis and are not included in Table 1: One reported using a cane and the other had a low BBS score (42), which skewed the results of the correlation analyses.

Table 1. Sample characteristics.

Group	*N*	Men/women	Age (years)	Age range (years)	Weight (kg)	Height (cm)
Young adults	17	3/14	19.35 ± 1.32	18–23	62.87 ± 10.98	163.70 ± 10.29
Older adults	18	4/14	72.83 ± 8.92	60–90	78.65 ± 18.22	163.97 ± 13.00

Note: Mean ± SD is presented for age, weight, and height.

2.2. COP measurement and visual feedback display

A force plate (Bertec 4060-NC, Columbus, OH) was used to calculate the anterior–posterior (AP) and medio-lateral (ML) COP signals according to: COPAP = (−h × FML + MAP)/Fz and COPML = (−h × FAP + MML)/Fz, where h is the thickness of the material covering the force plate (h = 0.005 m) and Fz is the ground-normal force. The force (F) and moment (M) data were sampled at 50 Hz. Instantaneous visual feedback about the COP was provided with a gain of 1 on a computer display (17 in diagonal; 1024 × 768 pixels) positioned at eye level 1.5 m in front of the participant. In the VFB condition, participants were required to maintain the feedback dot (15 pixels; 0.5 cm) at the center of a target square (90 × 90 pixel; 3 × 3 cm). The center of the target was marked by the intersection of two lines that bisected it vertically and horizontally (Fig. 1).

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Fig. 1. Experimental setup (left) and visual feedback display (right).

2.3. Procedure

Prior to performing the experimental trials participants self-selected a stance that did not lead to any perceivable forward/backward lean or left/right foot pressure asymmetry when maintaining the feedback dot on the center of the target. The position of the feet (hip-width apart) was outlined and used by the participant for the rest of the experiment.

The instruction in the VFB condition was to maintain the feedback dot at the center of the target as closely as possible. In the NVFB condition, no feedback dot was visible, and the instruction was to stand as still as possible while looking at the target square—this was the standard quiet stance condition. Four trials in each feedback condition (trial duration was 80 s) were presented in a pseudo-randomized order, avoiding 3 or more repetitions of the same condition.

The BBS [18] was administered by the experimenter (first author) after participants completed the primary postural task. Older adults made a series of functional movements such as standing up from a chair, sitting down, transferring from one chair to another, standing still, reaching forward, and stepping up on a step. The scores for each movement ranged from 0 to 4 with a maximum of 56 (corresponding to intact balance). The experimenter was trained by a physical therapist in rating the movements according to the BBS criteria and practiced the scoring method on five young adults prior to data collection.

2.4. Data analysis

COP data were low-pass filtered at 4 Hz using a 4th-order Butterworth filter. COP velocity was estimated from the filtered COP position (x) at sample i as $COPAPvel = (COPAP_{i-1} - COPAP_{i+1})/2\Delta t$, where Δt is the sampling period. The standard deviation of the COP position and average absolute maximal velocity of the COP (AAMV) [19] were used as the primary dependent measures. AAMV was calculated in by averaging the absolute velocity values located at the 2.5 and 97.5th percentiles of the velocity time series. This was slightly different than the calculation used by Delignières et al. [19], who used the average of absolute minimum and maximum values in a 2 s moving window.

These dependent measures were averaged across four repetitions of each feedback condition and were analyzed using a two-way ANOVA, with feedback (VFB vs. NVFB) and age group (younger vs. older) as factors. Simple effects were examined using t-tests when the interaction was statistically significant. The alpha level was set at .05.

Pearson correlation coefficients between the BBS scores and the COP measures were calculated for each feedback condition separately to assess the relation between the force plate measures and functional balance capability. Correlations obtained in each feedback condition were statistically compared for each COP variable using a method proposed in [20].

3. Results

3.1. AP SD

Older adults' COP trajectories were more variable than young adults, $F(1,33) = 15.34$, $p < .001$. The main effect of feedback was significant such that AP SD in VFB was lower than in NVFB, $F(1,33) = 30.99$, $p < .001$. There was no significant age × feedback interaction, $F(1,33) = 0.32$, $p = .57$.

3.2. ML SD

Older adults were more variable than young adults, $F(1,33) = 6.78$, $p = .01$. There was a main effect of feedback; ML SD was lower in the VFB than NVFB condition, $F(1,33) = 25.44$, $p < .001$. There was no significant age × feedback interaction, $F(1,33) = 0.40$, $p = .53$.

3.3. AP AAMV[1]

There were main effects of age, $F(1,33) = 4.26$, $p = .05$, and feedback, $F(1,33) = 26.62$, $p < .001$. These effects were qualified by a significant age × feedback interaction, $F(1,33) = 4.97$, $p = .03$. While older adults showed an increase in AP AAMV from NVFB to VFB, $t(17) = 5.89$, $p < .001$, young adults did not, $t(16) = 1.81$, $p = .09$. There was a difference between the age groups in VFB, $t(33) = 2.31$, $p = .026$, but not in NVFB ($p = .09$).

3.4. ML AAMV

There was no main effect of age, $F(1,33) = 0.5$, $p = .82$. The main effect of feedback was significant, $F(1,33) = 13.98$, $p < .001$, but was qualified by the age × feedback interaction, $F(1,33) = 7.64$, $p < .01$. While older adults showed an increase in ML AAMV from NVFB to VFB, $t(17) = 4.59$, $p < .001$, young adults did not, $t(16) = .69$, $p = .50$. There were no age differences in either the VFB, $t(33) = -1.09$, $p = .28$, or NVFB conditions, $t(33) = 0.96$, $p = .35$. Fig. 2 shows the results for all COP metrics.

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Fig. 2. COP measures in the VFB (COP visual feedback) and NVFB (no COP visual feedback with eyes open) conditions. Error bars show the standard error of the mean.

Correlations between COP metrics and BBS scores are reported in Table 2. All correlations were negative and most were statistically significant, apart from AP SD and ML SD in the NVFB condition. However, there was no statistically significant difference between the correlation coefficients in VFB and NVFB for any COP variable, all ps > .05. Fig. 3 presents the correlation plots in each condition.

Table 2. Correlations between COP measures and BBS score.

	Feedback (VFB)	No feedback (NVFB)
AP SD	−0.59*	−0.31
ML SD	−0.69*	−0.43
AP AAMV	−0.62*	−0.66*
ML AAMV	−0.62*	−0.63*

Note: Pearson correlations.
* $p < .05$.

FIGURE 3 IS OMITTED FROM THIS FORMATTED DOCUMENT
Fig. 3. Correlations between the COP measures and the BBS score. The AP and ML are depicted using different scales.

4. Discussion

4.1. Hypothesis 1: aging effect in the VFB and NVFB condition

The results showed that there was no enhanced age difference in the VFB condition compared to the NVFB condition in terms of COP position variables (AP and ML SD), contrary to our hypothesis. Older adults were expectedly more variable than young adults, and both age groups reduced COP variability with the inclusion of visual feedback. A decrease in global COP variability corresponds to a more successful reduction of COM movement during stance [21].

However, both of the COP velocity variables (AP and ML AAMV) revealed a significant age × feedback interaction, providing partial support for our hypothesis. While the absolute magnitude of the age-related differences in each feedback condition was not as consistent (statistically significant for AP, but not for ML AAMV), one robust finding was that older adults increased both AP and ML COP velocity fluctuations when performing the task with visual feedback while young adults did not. Variables that highlight the high-frequency COP components (such as AAMV or other velocity-based metrics, as well as the high frequency spectral component of COP position) could be interpreted as providing an index of local corrections to the COM position [19], as suggesting “tighter” postural control of body sway [22], or as indexing the overall muscular activity to maintain upright stance [21]. The pattern of simple effects for the AAMV suggests that this task constraint had a greater impact on the process of postural control in older adults, highlighting the reduced adaptability of their postural control systems. It is possible that VFB led to a change in the coordination among the major joints in the postural chain, especially the hip and the ankle [23]. On the one hand, increased COP velocity variability may indicate that older adults increased the reliance on open-loop control by stiffening the ankle and other joints. On the other hand, it may indicate that they actively over-corrected their posture. These possibilities could be disentangled using kinematic and EMG analyses. The decreased adaptability to VFB in the older adult group likely stems from sensorimotor decrements in the visual-motor loop, but other factors such as a decrease in lower extremity strength [24], loss of somatosensory perceptual sensitivity [25], or lessened capacity to dual-task [26] could also play a role. Increases in the high-frequency component of the COP with the introduction of VFB have been observed in young adults [21,22,27], suggesting that the task demand in this study may have been too easy to influence their postural control strategy [22].

While young adults reduce COP variability when provided with VFB [22,28], there is surprisingly little consensus about the effects of VFB on COP position variability in older adults. In our study both young and older adults reduced COP variability in AP and ML in a similar degree. Dault et al. [22] reported no modulation of COP variability in healthy elderly with VFB, while Freitas and Duarte [23] reported increased AP COP variability. Pinsault and Vuillerme clarified that older adults may benefit from VFB only when higher feedback gains are used [29]. The discrepancies among the studies may be due to the differences in the exact properties of the feedback gain, its delay, and task constraints such as target size and foot placement.

4.2. Hypothesis 2: relation between force plate measures and BBS scores

The results showed that lower BBS scores (indicating lower balance quality) were generally associated with greater COP position variability and greater COP velocity in both AP and ML planes. Contrary to our hypothesis, the correlations were not statistically different between the VFB and NVFB conditions. However, the correlations were more pronounced for AP SD and ML SD when visual feedback was present (−0.59 and −0.69) compared to when it was not present (−0.31 and −0.43). Previous studies have reported modest correlations between BBS and force plate measurements in quiet stance. In a large-scale study of older adults, Nguyen et al. [9] reported statistically significant correlations of about 0.3 for ML mean sway, ML root mean square, COP area, AP path length, and mean sway speed. Desai et al. [10] reported that the sensory organization test (SOT) composite score in both the ML and AP directions was correlated with BBS ($r \sim .3$ and .2, respectively). Berg et al. [4] found average correlations of .55. Our results showed stronger correlations between the COP velocity metrics and BBS, suggesting that there is some overlap between balance function assessed by the clinical tests and COP metrics during quiet stance. However, there are some limitations to our study such as a small sample size, non-blinded testing of the subjects on the BBS, and a small range of BBS scores skewed toward high scores.

When considered together, our results for the age-related differences in COP and COP-Berg correlations suggest that velocity-based COP variables may be more indicative of the integrity of postural control function than the COP-position based variables regardless of the task constraints. This finding motivates further investigation of COP velocity as an important variable for postural control. Other recent findings have indicated that postural control may be intermittently controlled based on a velocity threshold [19,30].

5. Conclusion

Our results showed that providing visual feedback highlights age differences only for AP AAMV (a variable indexing the range of COP velocity). Older adults modulated their postural control strategy more than young adults with the inclusion of VFB as indicated by the increase in both AP and ML AAMV. The results also suggest that functional measures of balance are not independent of force plate measures as hypothesized previously [9,11].

Our findings motivate the use of visual feedback tests of balance function in older adults, but this methodology cannot used for older adults with compromised visual functioning. Another limitation of the present results with regard to the clinical significance of the results is that while we found statistically significant age-related differences, the magnitude of the differences was rather small.

Conflict of interest

There are no conflicts of interest associated with this publication.

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Notes

1. A similar pattern of results was obtained for COP velocity SD in AP and ML.