Age-Related Differences in Center of Pressure Measures During One-Leg Stance Are Time Dependent

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The aim of this study was to evaluate the changes in center of pressure (COP) movement in four time intervals (5, 10, 15 and 30 s) during a one-leg stance test performed by young and elderly adults. Twelve young adults (mean 20 years) and 12 elderly subjects (mean 68 years) participated in this study. The subjects performed three 30 s trials of an eyes open one-leg stance test on a force platform, in which the COP parameter was computed at four points in time from same original COP signal. Significant differences were found between the young and elderly adults (P < .007) only at the 10, 15 and 30 s intervals. For both groups, COP changes were significantly different between the 5 s time interval and other intervals (10, 15 and 30 s). In conclusion, these results pointed out that age-related difference in COP changes were time dependent. This suggests that the use of longer durations increases the possibility of distinguishing more subtle differences in postural strategy among different groups of subjects.

Keywords: biomechanics, force platform, time series, rehabilitation, aging

Poor balance control has been associated with an increased risk of falls and mobility disability among elderly subjects.1–3 To identify people at high risk of falls, several tools have been used to measure balance, such as timed functional tests,2,3 strength measurement protocols,4 subjective questionnaires5 and postural stability parameters on a force platform.6–8 Regarding force platform measurements, the parameters associated with center of pressure (COP) movement, which is defined as the point location of the vertical ground reaction force vector,9 are often used to identify a balance deficit because they indicate neuromuscular and biomechanical mechanisms of the postural control system in different populations.10–12

Commonly used measures of COP in the time and frequency domains are: sway area of COP or 95% confidence ellipse area of COP, root mean square amplitude, mean or median frequency and mean velocity in both anteroposterior and mediolateral directions. Apparently, the reliability and validity of these parameters are better reported for 95% confidence ellipse area of COP and sway velocity than other COP parameters.7,13,14

However, COP measures can be affected by the sample duration during the data collection of a balance performance task. Some studies have reported a sample duration effect on COP magnitude between 5, 15, 30 and 120 s and have shown that COP changes were dependent on the sampling duration.5,15,16 However, these results occurred only in young adults during bipedal quiet standing with variations of the Romberg test, as in the study by LeClair and Riach.15 Even the bipedal quiet standing task has been proven sensitive for discriminating balance in elderly subjects (static sway of body posture on two legs). Nevertheless, this condition is not a major challenge
Age-Related Differences in Center of Pressure Measures

To our balance control system, which limits the clinical usefulness of data obtained in it. A one-legged stance would be a more appropriate condition for challenging and evaluating equilibrium since, in spite of being a static condition, it can be required in a number of everyday motor tasks (turning, climbing stairs, walking, dressing) when a switch from two- to one-leg standing is necessary. Furthermore, this condition has often been associated with the prediction of falls and/or fall-related injuries.

Few studies have evaluated the effect of sample duration on COP measurements between young and elderly adults during a one-leg stance test. Jonsson et al. showed that age-related differences during different time durations of a one-leg stance task used only the postural steadiness measure related to variability of ground reaction force as main outcome results. It would thus be interesting to know whether these results can also be generalized for a specific and reliable balance parameter such as A-COP during a one-leg stance task over time.

The main purpose of this study was to evaluate changes in A-COP in young and elderly adult subjects during a one-leg stance test on a force platform at four different time intervals (5, 10, 15 and 30 s).

Methods

A convenience sample of 24 healthy volunteers (12 elderly and 12 young adults) participated in this study (Table 1). Elderly subjects were physically independent and participants of a physical exercise program for seniors at the Universidade Norte do Paraná (enrolled for at least one year), while the young adults were from the university community. The evaluation was carried out in the laboratory during the summer vacation (February to March 2010) of the physical activity program for older adults. Criteria for inclusion were as follows: (1) elderly subjects had to be over 60 years old and living independently, with no falls in the past year and cognitive status score > 21 on the Mini-Mental State Examination; (2) young adults had to be between 18 and 30 years old and not enrolled in any physical activity program at the time of study. General exclusion criteria were as follows: self-reported injuries, illnesses, musculoskeletal disorders, neurological degenerative disease, severe labyrinthitis and chronic diseases of the cardiovascular or the respiratory system. All subjects were informed about the experimental protocol and the potential risks of the study and gave written consent before participating. The protocol and the consent form had been previously approved by the local ethics committee.

One session of approximately 2 h was required at laboratory. The same investigator performed the procedures and the tasks with all participants in the same laboratory environment to ensure uniformity. Each participant was familiarized with the experimental protocol and equipment.

All participants performed three 30 s one-leg stance trials on a force platform (BIOMEC400, EMG System do Brazil, Ltda SP), with a rest period of approximately 30 s between each trial. Three trials were used because, according to Pinsault & Vuillerme, increasing the number of trials and retaining the average increases the reliability of data. During all trials, the participants were instructed to stand on the leg of their preference under the following standardized conditions: barefoot, eyes opened and looking at a target (cross) placed on a wall at eye level 2 m away, arms at their sides or parallel to their trunk (see Figure 1). To prevent falls in testing, an investigator stood close by the participant during all experimental tasks.

Table 1 Subjects’ characteristics

<table>
<thead>
<tr>
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<th>Elderly (n = 12)</th>
<th>Young Adults (n = 12)</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>68.5 ± 4.6</td>
<td>20.4 ± 3.7</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.58 ± 9.1</td>
<td>1.68 ± 7.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.9 ± 6.4</td>
<td>63.7 ± 1.8</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>24.8 ± 3.6</td>
<td>22.1 ± 4.9</td>
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<tr>
<td>Cognitive Status*</td>
<td>27 ± 2</td>
<td>—</td>
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Note. Values are mean ± standard deviation (SD). BMI—body mass index.

*Mini-Mental State Exam (normal range above of the cutoff > 21).

Figure 1 — Subject’s position on a force platform during one-leg stance task.
The vertical ground reaction force data from the force platform were sampled at 100 Hz. All force signals were filtered with a 35 Hz low-pass second-order Butterworth filter. The signals from the four force platform sensors were converted into COP data using computerized stabilography, which was compiled with MATLAB routines (The Mathworks, Natick, MA). Stabilographic analysis of COP data led to the computation of the main balance parameter: the 95% confidence ellipse area of COP (A-COP in cm²), which represents an ellipse area that includes 95% of all COP position data for a given trial. The COP area (A-COP) has been proven sensitive to age-related differences, which confirms its usefulness for the current study. A-COP was calculated over the entire 30 s during the three trials and the mean across trials was then retained for statistical analysis. A-COP was computed for each trial at the following four different time intervals that had been partitioned from the same original COP signal: Interval #1 between 0.1 and 4.99 s (representing a total of 5 s); Interval #2 between 0.1 and 9.99 s (representing 10 s); Interval #3 between 0.1 and 14.99 s (15 s) and Interval #4 including the entire duration of a maximum of 30 s. Timing began (0.1 s) the moment that the subject’s leg was positioned at approximately 90°.

For statistical analysis, the Shapiro-Wilk test was used to confirm the normal distribution of data. Two-way analysis of variance (ANOVA) for repeated measures (TIME factor) was used to assess the magnitude of A-COP changes between the two groups (elderly and young adults) and among the four time intervals (5, 10, 15 and 30 s), henceforth referred to as the TIME effect, as well as the interaction effects. A post hoc Bonferroni test was used when necessary to locate the differences in TIME factor. All statistical analysis was performed SPSS software (version 15, SPSS Inc, Chicago, IL) with an alpha of 0.05 for statistical significance.

**Results**

ANOVA results showed no significant interaction ($F_{(3,88)} = 2.41; P = .072$) between the groups and time intervals (TIME factor), although it almost reached significance (Table 2). Significant differences ($F_{(1, 88)} = 7.73; P = .007$) were found between groups, which elderly group showed poorer postural balance (higher A-COP values) than young adults in interval #2 (7.47 vs. 4.88 cm²; $P = .008$), #3 (7.70 vs. 5.79 cm²; $P = .001$) and #4 (8.83 vs. 6.66 cm²; $P = .001$) respectively.

ANOVA results also showed significant differences between the time intervals (TIME factor: $F_{(3,88)} = 10.9; P = .001$) for both groups (Table 2). Post hoc comparisons revealed that the mean A-COP values over the first 5 s (Interval #1) was significantly lower than during the other three intervals: 10, 15 and 30 s in both groups (Figure 2). There were no statistical differences between intervals 10 s and 15 s as well as for 15 s and 30 s of time intervals.

**Discussion**

This study aimed to investigate the changes in A-COP between young and elderly adult subjects over four different time intervals (5, 10, 15 and 30 s) in a one-leg stance test. A-COP changes over time were similar in

![Figure 2](image-url)  
*Figure 2 — Changes in 95% confidence ellipse area of COP parameter (A-COP in cm²) with P values during the four time intervals (5, 10, 15 and 30 s) between elderly and young adults.*

| Variable | Intervals | Elderly | Young Adults | P ANOVA
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<tbody>
<tr>
<td>A-COP (cm²)</td>
<td>5 s</td>
<td>3.29 ± 3.96</td>
<td>4.22 ± 1.94</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>10 s</td>
<td>7.47 ± 3.69</td>
<td>4.88 ± 1.76</td>
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<tr>
<td></td>
<td>15 s</td>
<td>7.70 ± 0.96</td>
<td>5.79 ± 2.15</td>
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<td></td>
<td>30 s</td>
<td>8.83 ± 2.12</td>
<td>6.66 ± 2.19</td>
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*Note. A-COP: the 95% confidence ellipse area of the center of foot pressure. Values are presented as mean ± SD. Significant differences (P < .05) are identified with bold characters.*

Table 2 ANOVA results for groups and time factors in the A-COP values.
both groups; that is, the A-COP magnitude increased with increased time. However, regarding the effect, greater A-COP values were observed among elderly subjects than young adults, specifically at times 10, 15 and 30 s.

Hageman et al\(^2\) showed that parameters of postural control measured over the entire 20 s of a bipedal stance were greater in older adults than young adults, which agrees with the results of the current study despite differences in experimental protocol. As stated earlier, even the bipedal quiet standing task is sensitive for discriminating balance in elderly subjects (static sway of body posture on two legs) although it is not a major challenge to our balance control system and is sometimes not required for everyday motor tasks.\(^3\) The results of the current study have many implications for both prevention and rehabilitation programs for the elderly that involve balance assessment. In general, age-related differences associated with balance could be explained by muscular weakness and/or poor endurance.\(^4,5\) It is well known that aging is associated with neuro-musculoskeletal alterations and decreased physiological function, which in turn can lead to problems such as lack of mobility, weakness, sensory-motor deficits and consequent loss of balance and falls.\(^6\)

However, few studies have evaluated the effect of sample duration on COP measures between young and elderly adults during the one-leg stance test. To the authors' knowledge, this is the first time that age-related differences have been documented by using A-COP computed at four different time intervals that were partitioned from the same original COP signal. In the current study, differences between the elderly and young adults were observed only in the second (10 s), third (15 s) and fourth (30 s) intervals. Five seconds of measurement was not enough to demonstrate any differences in postural control (reported here as A-COP changes) between the groups. Unlike the current study, Jonsson et al\(^7\) showed difference in vertical force variability between elderly and young adults during the first time interval (5 s) on a force plate. These authors considered this interval a dynamic phase of postural adjustment for stabilizing posture during the task of one-leg stance test. However, the vertical force variability between groups was recorded using two equal force plates (ie, each foot on one force plate) and the data signal during the experimental protocol started 2–3 s before of participant lifted his or her leg. This procedure explains the difference in findings between the studies, since in the current study the A-COP variable was computed only at the moment the subject’s leg was positioned at approximately 90°.

Apparently, age-related differences do not occur during the transition phase (0.1 to 5 s) of postural adjustment but occur instead during the static phase, which begins 5 to 10 s after adopting the new posture. At this point, motor control strategies as well as real balance deficits from muscular weakness or sensory-motor impairment become more evident between groups. In other words, it is possible that both populations performed similar short-term postural adjustments but that the older subjects’ long-term motor control programming for balance is poorer than that of young people due to postural dyscontrol resulting from changes to the sensorimotor system with aging.\(^8,9\)

TIME effects were significant in the current study, which indicates that as time increases, the magnitude of A-COP also increases (Figure 2). LeClair & Riach\(^10\) compared five different times (10, 20, 30, 45 and 60 s) in a group of young adults and also demonstrated a significant time effect on COP variables. Although these authors did not evaluate a single-leg stance, their COP measurements at 10 s were significantly lower than at 20 s and beyond. However, their participants performed each time interval of the test (10, 20, 30, 45 and 60 s) separately during two sessions at the laboratory, which consequently limits comparison with the results of the current study, in which the TIME factor was analyzed using data partitioned from the same original COP signals.

Our main findings agree with those of Carpenter et al\(^7\) in young adults (19–34 years), who demonstrated that COP stability was significantly influenced by sampling duration and that COP sway was significantly lower during the first 15 s than at other times (30, 60–120 s). These authors pointed out that the reliability of COP data are also increased when the sample duration is extended, which suggests that using longer time intervals for balance assessments will increase the possibility of finding more subtle differences in postural strategy among different groups (eg, young adults, elderly subjects and patients undergoing rehabilitation) The advantage of the current study over that of Carpenter, who evaluated subjects in an upright stance, is that we chose a condition (single-leg support) that is assumed to be more challenging and of greater importance for assessing movement patterns of postural control.

Finally, some limitations should be addressed. The overall results of this study cannot necessarily be generalized to all elderly adults because the sample of subjects was not large enough to well represent the heterogeneity of older people with different alterations due to the aging process. Another limitation of the study is that maximum times exceeding 30 s (eg, 45, 60–120 s) were not tested. This would have all been useful for discussion of the results.

In conclusion, age-related differences in A-COP were time dependent during the one-leg stance task. Five seconds was not enough time to distinguish between the young and elderly adults for postural control with COP measurement. This suggests that the use of longer durations increases the possibility of distinguishing more subtle differences in postural strategy among different groups of subjects. These results add to the literature concerning measurement tools and protocol development (task, sampling duration, or acquisition time) aimed at evaluating balance deficits in elderly as well as in young adults.

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References


