Contribution of Head Position, Standing Surface, and Vision to Postural Control in Community-Dwelling Older Adults

Fredrick D. Pociask, Rosanne DiZazzo-Miller, Allon Goldberg, Diane E. Adamo

Postural control requires the integration of sensorimotor information to maintain balance and to properly position and orient the body in response to external stimuli. Age-related declines in peripheral and central sensory and motor function contribute to postural instability and falls. This study investigated the contribution of head position, standing surface, and vision on postural sway in 26 community-dwelling older adults. Participants were asked to maintain a stable posture under conditions that varied standing surface, head position, and the availability of visual information. Significant main and interaction effects were found for all three factors. Findings from this study suggest that postural sway responses require the integration of available sources of sensory information. These results have important implications for fall risks in older adults and suggest that when standing with the head extended and eyes closed, older adults may place themselves at risk for postural disequilibrium and loss of balance.


Human balance is a multidimensional construct describing a person’s ability to make automatic postural adjustments under various conditions to maintain stability and avoid falling (Berg, 1989; Winter, 1995). Accordingly, postural control may be defined as the “act of maintaining, achieving or restoring a state of balance during any posture or activity” (Pollock, Durward, Rowe, & Paul, 2000, p. 405). Postural control requires the integration of sensorimotor information to maintain balance and to properly position and orient the body in response to external stimuli. Vestibular, visual, and proprioceptive receptors respond to various external stimuli and, together with postural reflexes, play an integral role in the maintenance of postural control and stability in healthy older adults (Balasubramaniam & Wing, 2002).

Conversely, age-related declines in peripheral and central sensory and motor function contribute to postural instability and falls that, in turn, may portend emergency room visits, hospitalization, morbidity (e.g., hip fractures), and mortality (Boyé et al., 2012; Gelbard et al., 2014). Falls are in fact the leading cause of both fatal and nonfatal injuries among people age 65 yr and older (Centers for Disease Control and Prevention [CDC], 2014). More specifically, nonfatal, unintentional fall injuries in the United States among adults age 65 yr and older have increased from 1,638,883 in 2002 to 2,422,463 in 2012. Approximately 22 million fall injuries occurred between 2001 and 2012, and half of the people admitted for hospitalization will not live another year (CDC, 2013; Rubenstein, 2006). In view of these findings, and noting that the number of adults age 65 yr and older is projected to increase from 40.2 million in 2010 to 88.5 million in...
Recent investigations of age-related changes in postural stability have assessed participants’ ability to maintain their balance while standing on various surfaces (Doumas & Krampe, 2010; Kim, Nussbaum, & Madigan, 2008; Merlo et al., 2012; Tanaka & Uetake, 2005). For example, standing on a foam surface reduces the reliability of somatosensory information and increases postural sway, which is exacerbated when vision is occluded (Vuillerme & Pinsault, 2007). Other investigations have varied the contribution of vision and proprioception (Jackson & Epstein, 1991; Pinsault, Vuillerme, & Pavan, 2008; Stambolieva & Angov, 2010).

In contrast, the contribution of vestibular function to postural control and fall risk in older people has received little attention (Menant, St George, Fitzpatrick, & Lord, 2012), and the available evidence is controversial. Difficulties maintaining a vertical position of the head while seated on a tilt table and being moved side to side, hence utilizing information from vestibular receptors, did not distinguish fallers from nonfallers (Woolley, Czaja, & Drury, 1997). Alternatively, greater frequency of ocular nystagmus, an indication of vestibular asymmetry, after head shaking was associated with falls history for older people (Kristinsdottir, Jarnlo, & Magnusson, 2000). Thus, alterations in vestibular information show differing effects on potential fall risk for older adults. Moreover, it is not possible to quantify the extent to which vestibular information, based on changes in head position alone, contributes to postural sway.

Age-related changes in postural sway are related to a dynamic interplay among head position, standing surface, and vision (Horak, Shupert, & Mirka, 1989), yet the relative contribution of each remains inconclusive. Moreover, poor balance and fear of falling may interfere with a person’s pursuit of daily tasks. For example, fear of falling may lead to activity restriction, impede social interactions, reduce independence in activities of daily living (ADLs), and compromise overall occupational engagement (Elliott et al., 2012; Murphy, 2006). Ultimately, the ability to perform most ADLs relies heavily on the ability to maintain balance and posture.

The purpose of this study was to evaluate the contribution of head position, standing surface, and vision on postural sway in a group of healthy older adults. It was hypothesized that under different combinations of participant visual conditions (i.e., eyes opened [EO] and eyes closed [EC] and standing surface [i.e., firm surface [force plate] and soft surface [force plate plus foam]), sway velocity would be significantly greater with the head extended (HE) than with the head in the neutral position (HN). This problem is a concern because 37% of people older than age 60 yr report moderate to severe vertigo (Neuhauser et al., 2005). Moreover, clinical assessment of vestibular function and its corresponding contribution to fall risks are rarely tested (Menant et al., 2012). Understanding how these factors affect postural sway may contribute to better assessment and intervention practices and outcomes and is especially important for occupational therapy practitioners when determining an objective method for assessing outcomes and directing interventions for ADLs related to balance, fall prevention, and postural control.

Method

A quasi-experimental within-subjects design was used to conduct this study. Twenty-six community-dwelling older adults age 60 yr or older were recruited on a voluntary basis through flyers posted on the Wayne State University campus and at local community sites (e.g., community centers, churches). Participant descriptive statistics are provided in Table 1. All participants included in the study were free from physical and medical difficulties that might influence balance performance. Additionally, all participants completed a medical history questionnaire, acknowledged the ability to stand on both legs independently with EO and EC for 1 min, and were able to extend their head approximately 45° without pain or difficulty, as quantified by the researcher. Potential participants were excluded from the study if they failed to meet any of the stated criteria.

Verbal informed consent was obtained using procedures approved by the Wayne State University institutional Human Investigation Committee. This study was approved by the Human Investigation Committee of Wayne State University and underwent expedited behavioral institutional board review.

Instruments

**Force Plate and Foam Pad.** The NeuroCom® Basic Balance Master® 18-in. × 18-in. force plate (Natus Medical, Pleasanton, CA) was used in this study to record the vertical forces exerted through the participants’ feet to measure center-of-gravity (COG) position and postural sway. The force plate demonstrated high test–retest reliability when testing healthy adults (Pickerill & Harter, 2011). The NeuroCom Balance Master foam pad (Grade C, 3.75 minimum lb/cubic ft, load deflection 25%; Natus Medical, Pleasanton, CA) was placed on top of the force plate for all foam trials.
Table 1. Participant Descriptive Statistics (N = 26)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (%) or M (SD, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>65.5 (4.10, 60–74)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>9 (34.6)</td>
</tr>
<tr>
<td>Female</td>
<td>17 (65.4)</td>
</tr>
<tr>
<td>Height, in.</td>
<td>66.20 (4.05, 61–75)</td>
</tr>
<tr>
<td>Weight, lb</td>
<td>170.02 (32.65, 120.15–260.81)</td>
</tr>
<tr>
<td>Physically active&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (57.7)</td>
</tr>
<tr>
<td>No</td>
<td>11 (42.3)</td>
</tr>
<tr>
<td>Self-reported state of health&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>5 (19.2)</td>
</tr>
<tr>
<td>Very good</td>
<td>14 (53.8)</td>
</tr>
<tr>
<td>Good</td>
<td>7 (26.9)</td>
</tr>
<tr>
<td>Use corrective glasses or contact lenses</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (57.7)</td>
</tr>
<tr>
<td>No</td>
<td>11 (42.3)</td>
</tr>
<tr>
<td>Wore glasses or contact lenses during testing</td>
<td></td>
</tr>
<tr>
<td>Corrective vision participants only</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (100)</td>
</tr>
<tr>
<td>No</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Ambulate independently without assistive device</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>26 (100)</td>
</tr>
<tr>
<td>No</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Falls in past 12 mo</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>19 (73.1)</td>
</tr>
<tr>
<td>1</td>
<td>6 (23.1)</td>
</tr>
<tr>
<td>2</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>History of neck or back pain</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>21 (80.8)</td>
</tr>
<tr>
<td>No</td>
<td>5 (19.2)</td>
</tr>
<tr>
<td>Current neck pain rated on the NPRS&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>23 (88.5)</td>
</tr>
<tr>
<td>1</td>
<td>2 (7.7)</td>
</tr>
<tr>
<td>2</td>
<td>1 (3.8)</td>
</tr>
<tr>
<td>Short-orientation memory concentration score&lt;sup&gt;d&lt;/sup&gt;</td>
<td>24.85 (2.99, 16–28)</td>
</tr>
</tbody>
</table>

Note. Percentages may not total 100 because of rounding. NPRS = Numeric Pain Rating Scale (Williamson & Hoggart, 2005).

<sup>a</sup>Physical activity was defined as regular participation in a weekly exercise routine, training program, or athletics.

<sup>b</sup>Possible choices for self-reported state of health are excellent, very good, good, fair, and poor.

<sup>c</sup>Rating scale: 0 = no pain through 10 = worst pain imaginable; minor and past symptoms did not preclude study participation.

<sup>d</sup>Rating scale: 0–28; higher score indicates better performance.

Cervical Range of Motion Device. A cervical range-of-motion (CROM) device (Performance Attainment Associates, Lindstrom, MN) was used to help ensure that the head was held in neutral or 45° HE positions. Angular displacement of the head was determined through changes in the device, and the device was positioned using prescribed procedures (Performance Attainment Associates, 1988).

Measurements made with the CROM device are reliable in all cardinal plane movement directions, with an intraclass correlation coefficient (ICC) value of .98 (95% confidence interval [CI] [.95, .99]) for extension (Audette, Dumas, Côté, & De Serres, 2010). Intratester reliability for CROM measurements made with the device for participants without cervical pain is satisfactory, with an ICC value of .90 (95% CI [.80, .96]) for extension (Fletcher & Bandy, 2008).

**Testing Booth.** A testing booth (4 ft wide, 8 ft long, 9 ft high) was fabricated with matte-black felt running from floor to ceiling on the walls on either side of the booth to eliminate peripheral vision distractions. A curved surface was constructed between the ceiling and the wall that participants would face during testing (i.e., facing surface) to maintain an equidistant visual surface throughout the arc of the participant’s head movement. A strip of hook-and-loop fastener was attached down the middle of the facing surface to provide attachment points for 1-in. colored discs for HN and 45° HE focus points.

**Forms and Other Items.** Participant screening and interview forms were used to confirm study eligibility and gather biographical data and participant health history (e.g., self-reported state of health, medications), respectively. Additional instruments and materials included a measuring strip to record participant height, a digital scale to record participant weight, two tape measures to position the force plate, and a laser pointer and bubble level to position the CROM device as described in the next section.

**Procedure**

**Data Collection.** Screening and interview questionnaires were completed, and height and weight measurements were recorded. Participants were comfortably dressed and wore socks and flat shoes. The force plate was positioned closer or farther away from the facing surface to maintain approximate equidistance between participants’ eyes and the facing surface as measured from the lateral aspect of orbit. For example, taller participants were positioned farther away from the facing surface to ensure the arc of motion (i.e., distance) was maintained throughout all testing conditions. Participants were then instructed to stand on a designated area of the force plate and to align their medial malleolus with a horizontal line and the lateral aspect of their foot with a vertical line, as labeled on the force plate and foam pad surfaces.

The CROM device was fitted to obtain a HN position, and a laser pointer was attached to the device in the same vertical plane using a bubble level. HN and HE positions were quantified by the CROM device. The device was then used to place four different colored disks (i.e., focus points) on the facing surface for HN and 45° HE testing positions for both standing surface conditions.
Participants were instructed to focus their gaze on the disks to help ensure HN and 45° HE testing positions; the laser pointer was turned off during data acquisition.

Each surface condition and head position combination was performed with EO and EC. In EO conditions, gaze was directly looking forward for HN positions and looking up for HE positions, using the respective focus points as confirmed by the CROM device. In EC conditions, participants were positioned as in EO conditions and instructed to keep their eyes closed. For foam trials, the foam pad was placed on top of the force plate and feet were aligned with markings as previously described.

Data Acquisition. Output data consisted of postural sway velocity (˚/s), which is the ratio between the total distance traveled in the anterior, posterior, medial, and lateral direction of COG and the duration of each trial (10 s). The output data were taken directly from the NeuroCom Basic Balance Master. Postural sway velocity was assessed under each of the eight combinations of head position (HN and 45° HE), standing surface (firm and foam), and vision (EO and EC) for each participant. Conditions were tested in a randomized order, with three trials performed consecutively for each condition for a total of 24 trials per participant. All researchers underwent extensive training and practice to ensure procedures were done consistently among participants.

Data Analysis
A three-way within-subjects repeated-measures analysis of variance was conducted to test for main and interaction effects for head position (HN and 45° HE), standing surface (firm and foam), and vision (EO and EC) on sway velocity. In cases of significant main or interaction effects, post hoc pairwise comparisons with Bonferroni corrections for multiple comparisons were conducted. Significance was set at $p \leq .05$. Data analysis was completed using IBM SPSS Statistics (Version 21; IBM Corporation, Armonk, NY).

Results
Findings from this study showed that standing surface, head position, and whether vision was on or off affected the magnitude of sway velocity. Main effects were found for standing surface, $F(1, 25) = 345.9, p < .001$; vision, $F(1, 25) = 46.5, p < .001$; and head position, $F(1, 25) = 60.7, p < .001$. Pairwise comparisons showed that sway velocity was significantly greater when standing on foam (1.68˚/s) than on firm (0.53˚/s) surfaces ($p < .05$). Moreover, postural sway was greater with EC than with EO (1.58˚/s and 0.63˚/s, respectively; $p < .001$) and with HE than with HN (1.24˚/s and 0.97˚/s, respectively; $p < .001$).

A significant two-way interaction effect was found between surface and vision, $F(1, 25) = 113.2, p < .001$. Sway velocity was greater when standing on foam with EC (2.50˚/s) than with EO (0.89˚/s). In addition, sway velocity was greater on a firm surface with EC (0.70˚/s) than with EO (0.37˚/s). A significant two-way interaction effect was also found between surface and head position, $F(1, 25) = 21.4, p < .001$. Sway velocity was greater when standing on foam with HE (1.89˚/s) than with HN (1.47˚/s). In addition, sway velocity was greater when standing on a firm surface with HE (0.59˚/s) than with HN (0.47˚/s; $p < .05$). A significant two-way interaction effect was found between head position and vision, $F(1, 25) = 18.3, p < .001$. Sway velocity was greater with HE (1.78˚/s) than with HN (1.37˚/s) when vision was not available ($p < .05$). Likewise, greater sway velocity was found with HE (0.70˚/s) than with HN (0.57˚/s) when vision was available ($p < .05$).

Sway velocity was significantly greater with HE than with HN for each of the four visual–surface conditions (i.e., foam with EO and EC and firm surface with EO and EC; $p < .05$). When standing on foam with EC, a mean difference of 0.64˚/s in sway velocity was found between HE (2.78˚/s) and HN (2.14˚/s) positions ($p < .001$). When standing on foam with EO, a mean difference of 0.19˚/s was found between HN (0.80˚/s) and HE (0.99˚/s) positions ($p < .001$). When standing on a firm surface with EO, a mean difference of 0.07˚/s in sway velocity was found between HE (0.33˚/s) and HN (0.40˚/s) positions ($p < .05$). When standing on a firm surface with EC, a mean difference of 0.17˚/s was found between HN (0.61˚/s) and HE (0.78˚/s) positions ($p < .01$; Figure 1). A significant three-way interaction effect was found among standing surface, vision, and head position, $F(1, 25) = 9.1, p < .01$. The difference in sway velocity between HN and HE positions was greater with EC than with EO ($p < .001$) on foam. However, the difference in sway velocity between the HN and HE positions was similar in EC and EO conditions ($p > .05$) when standing on a firm surface.

Discussion
Although the majority of studies investigating postural sway in older adults have varied standing surface and vision, new to this study is the inclusion of either HE or HN head position while a person stands on a foam or firm surface with EO or EC. Including head position aligns with functional tasks that require extending the head when...
reaching for objects placed above eye level. Changes in head position have also been associated with fall risk and can be used to test the contribution of corresponding sensory receptors such as neck proprioceptors (Deshpande & Patla, 2005; Vuillerme, Pinsault, & Bouvier, 2008) and vestibular apparatus (Menant et al., 2012), the sensitivity of which declines with advancing age. Findings reveal that sway velocity was significantly greater with an HE than with an HN position for each of the visual–surface conditions, thereby supporting our hypothesis. With EC, HE position when a person stands on foam showed the greatest sway velocity (2.78˚/s) when compared with all other visual–surface–head conditions. These results have important implications for fall risk in older adults and suggest that when standing with the head extended, older adults may place themselves at risk for postural disequilibrium and loss of balance. This risk appears to be increased when standing on soft surfaces during the absence of vision. In addition, some activities are performed when visual cues are temporarily unavailable (e.g., rinsing hair in the shower, pulling clothes on or off over the head), which may compromise balance, mobility, and stability. Therefore, from a research perspective, postural sway testing of people on a compliant surface, softer than what they may experience in the real world, allows conservative thresholds to be determined for activities that include HE and EC.

Visual Cues

The majority of studies investigating postural sway in older adults have compared the effects of EO and EC (Matheson, Darlington, & Smith, 1999; Simoneau, Leibowitz, Ulbrecht, Tyrrell, & Cavanagh, 1992; Woollacott, Inglis, & Manchester, 1988) when a person stands on firm and foam surfaces (Doumas & Krampe, 2010; Kim et al., 2008; Merlo et al., 2012; Tanaka & Uetake, 2005). Although the contribution of vision to age-related changes in postural sway is well documented (Simoneau et al., 1992), the magnitude of its contribution is controversial and condition specific. For example, Tanaka and Uetake (2005) found that vision was used more to correct for mediolateral than anterior postural sway, possibly because of reduced peripheral vision (Maki, Holliday, & Topper, 1994), which is important because most falls occur in the frontal than in the sagittal plane (Tanaka & Uetake, 2005). In another study, less reliance on visual input was accompanied by a greater dependence on increased cocontraction of the muscles around the ankle joints, revealing the use of a different strategy regardless of visual input (Benjuya, Melzer, & Kaplanski, 2004).

In the current study, when standing on foam with HN, participants had postural sway that was 2.7 times greater with EC than with EO. Standing on the same surface with HE, participants had postural sway that was 2.8 times greater with EC than with EO. Although postural sway was considerably less when participants stood on firm surfaces, a similar change in postural sway was observed when comparing EC and EO conditions for HN (1.8 times greater) and HE (1.9 times greater) postures. These findings show that postural sway was significantly greater when standing on foam than firm surfaces and with HE than with HN. Even so, the contribution of vision to postural sway was most predominant when comparing EO and EC conditions while standing surface and head position were
constant. Similar findings by Lord and Ward (1994) showed that when standing on a foam surface with EO, participants older than 65 yr relied more on vision than peripheral input for balance control.

**Vestibular and Proprioceptive Afferent Information**

Although current findings point to the significance of visual input, vestibular input and proprioception also need to be considered. Vestibular receptors transmit messages regarding head position and orientation in relation to the gravitational axis of the central nervous system (CNS). The utricle otoliths transduce movement in a pre-dominately horizontal plane, and their sensitivity to detecting head displacement is diminished when the plane of the utricular macula is elevated beyond 20° relative to the horizontal (Kogler, Lindfors, Odkvist, & Ledin, 2000). In addition, neck proprioceptors, which provide information about the position and movement of the head relative to the trunk, demonstrate strong neuronal connections with vestibular afferents.

Together, neck proprioceptors and vestibular afferents converge on vestibular nuclei to support an integrated functional role of head position relative to spatial orientation (Gdowski & McCrea, 2000). Given the unique and complex interaction between neck proprioceptors and vestibular receptors, it may not be surprising that neck extension postures may affect the working range of vestibular receptors.

The vestibular system’s contribution to postural sway has been tested by altering visual and proprioceptive information, and impaired vestibular function has been linked to risk of falls (Menant et al., 2012). However, Deshpande and Patla (2005) reported that reduced sensitivity of neck proprioceptors rather than reduced sensitivity of vestibular receptors altered path deviation during locomotion, which suggests that reduced sensitivity of proprioceptors may apply to changes in postural sway as well.

In this study, the contribution of head tilt to sway velocity was tested by comparing HN and HE positions. Standing on foam with EC, participants had postural sway that was 1.3 times greater in a HE (0.99˚/s) than in a HN (0.80˚/s) position. Standing on foam with EO, participants had postural sway that was 1.2 times greater in a HE (2.14˚/s) than in a HN (0.80˚/s) position. Similar differences in postural sway between HE and HN were found when participants stood on a firm surface (see Figure 1). Increases in postural sway from HN to HE positions clearly suggest that head position is a significant factor contributing to increased postural sway in older adults and may reflect declines in the sensitivity of the neck proprioceptors and vestibular apparatus (Deshpande & Patla, 2005).

**Sensory Reweighting**

When one source of sensory information is compromised, such as vision or proprioception, the CNS adapts to this change by reweighting the remaining intact sensory sources (Doumas & Krampe, 2010). For example, when a person without vision stands on a surface, corrections to deviations in posture are derived from vestibular and proprioceptive information (Peterka, 2002). Peterka and Black (1990–1991) found no age-related increases in postural sway in study participants who stood on a fixed surface with EO or EC. Older adults were more affected by altered visual cues than somatosensory cues when compared with younger adults. Although sensory reweighting is a factor to consider when testing older adults who may demonstrate declines in sensory information processing, it is beyond the scope of the current work to draw specific conclusions.

**Functional Implications**

Occupational therapy practitioners need to understand the intricate relationship among vision, standing surface, and head position as they relate to balance, safety, and function of older adults because this dynamic interplay may directly affect occupational engagement and independence in ADLs. Implementing safer environmental designs that consider postural demands will reduce the risk of falls. For example, reaching for objects at eye level with HN promotes independence in ADLs and simultaneously allows corresponding sensory receptors to provide feedback within their optimal working ranges.

Although using survey-based fall risk assessments is noteworthy, findings here suggest that measures of postural sway may be more sensitive to detecting loss of balance, particularly when a person is challenged by variations in standing surface, head position, and vision. Moreover, these testing conditions may simulate ADL experiences and provide the practitioner with a more comprehensive assessment of function. Future research should also address barriers to physical environments such as uneven walking surfaces and dimly lit surroundings.

**Limitations and Future Research**

A cross-sectional design, which collects data at one time point, was the principal limitation of this study. Future studies will be longitudinal in nature; include an equal distribution of women and men; explore the effects of
moving surfaces on postural stability; address a range of neck positions for rotation, flexion, and extension; and challenge cognitive load to better address functional mobility issues commonly experienced in pursuit of daily life tasks.

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- Addressing the contributions of postural sway to fall risk can add insight into the understanding of fall-related injuries and possibly inform interventions that may help prevent both fatal and nonfatal injuries among people age 60 yr and older.

- Alterations in postural sway may reduce balance and stability required to perform ADLs and will likely impede a person’s ability to engage in meaningful and purposeful occupations and overall independence in daily living.

- Clinical testing of balance provides an objective method for quantifying aspects of postural control under conditions frequently encountered during the performance of ADLs (e.g., altered surface and visual conditions, changes in head position) and a focus for allocating resources and directing clinical rehabilitation programming. ▲

Acknowledgments

Special thanks to Ellen Hammond, Lauren Kelsch, and Sara Ullenbruch for their assistance with data collection.

References


