Influence of Vision on Head Stabilization Strategies in Older Adults During Walking

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Background. Maintaining balance during dynamic activities is essential for preventing falls in older adults. Head stabilization contributes to dynamic balance, especially during the functional task of walking. Head stability and the role of vision in this process have not been studied during walking in older adults.

Methods. Seventeen older adults (76.2 ± 6.9 years) and 20 young adults (26.0 ± 3.4 years) walked with their eyes open (EO), with their eyes closed (EC), and with fixed gaze (FG). Participants performed three trials of each condition. Sagittal plane head and trunk angular velocities in space were obtained using an infrared camera system with passive reflective markers. Frequency analyses of head-on-trunk with respect to trunk gains and phases were examined for head-trunk movement strategies used for head stability. Average walking velocity, cadence, and peak head velocity were calculated for each condition.

Results. Differences between age groups demonstrated that older adults decreased walking velocity in EO (p = .022), FG (p = .021), and EC (p = .022), and decreased cadence during EC (p = .007). Peak head velocity also decreased across conditions (p < .0001) for older adults. Movement patterns demonstrated increased head stability during EO, diminished head stability with EC, and improved head stability with FG as older adult patterns resembled those of young adults.

Conclusions. Increased stability of the lower extremity outcome measures for older adults was indicated by reductions in walking velocity and cadence. Concomitant increases in head stability were related to visual tasks. Increased stability may serve as a protective mechanism to prevent falls. Further, vision facilitates the head stabilization process for older adults to compensate for age-related decrements in other sensory systems subserving dynamic balance.

MAINTAINING balance during dynamic activities is important for preventing falls in older adults. Dynamic balance, the ability to remain balanced while the body is in motion, is a process especially important during the functional task of walking (1,2). Head stabilization provides an important contribution to dynamic balance during walking as head-on-trunk movements respond to lower extremity dynamics to maintain an equilibrium position of the head-in-space (1,2).

Age-related adaptations in lower extremity dynamics minimize the unbalanced portion of the walking cycle (3–6). Older adults decrease walking velocity (3.5–7), hip (5) and knee (6) extension, ankle plantar flexion (5), push-off power (3.5), and knee extensor torque (5). By comparison, long-standing data for young adults demonstrated an efficient walking pattern that is less stable to allow for effective forward and lateral shifting of the body’s center of mass with each step (8–10). These age-related decreases in walking pattern characteristics serve to minimize the unstable portions of the walking cycle. Thus, the capability for older adults to move the body forward during walking is decreased.

While lower extremity adaptations have been thoroughly documented, head stabilization during walking has not been examined for older adults. However, investigations of seated random rotations in the vertical plane have established age-related decrements in head stabilization (11,12). Older adults demonstrated difficulty with head stabilization during seated rotations in darkness (11,12). In response to rotational frequencies of trunk motion ranging from 0.35 Hz to 3.05 Hz, older adults used a strategy to lock the head to the trunk. In young adults, this strategy was reserved for the highest frequencies of trunk motion (>2.2 Hz) where head stability was significantly challenged. When visual feedback was provided, older adults maintained head stability at lower trunk movement frequencies (≤1.0 Hz) (11). In contrast, young adults maintained head stability equally well with or without visual feedback at higher frequencies of trunk motion (≤2.2 Hz). These changes in head stabilization were attributed to age-related declines in sensory systems that occur with age (13–18).

While the role of vision in head stabilization for older adults was studied for tasks of seated rotations, the contribution of vision to head stabilization for this age group has not been determined for the functional task of walking. The purpose of this study was to examine head stabilization strategies used by older adults during walking to compensate for changes in sensory systems that occur with age. Further, be-
because older adults rely on vision to maintain head stability, this study examined adaptations in these strategies while walking under altered visual conditions.

**METHODS**

**Subjects**

Seventeen (6 male and 11 female) healthy, community-dwelling older adults and 20 (9 male and 11 female) young adults participated in this study. Human subjects approval was obtained prior to data collection in this study. Ages of older adults ranged from 67–90 years, with a mean of 76.2 (± 6.9) years. Ages of young adults ranged from 23 to 35 years, with a mean of 26.0 (± 3.4) years. Health status information was obtained through self-report for both groups. These data are summarized in Table 1. None of the subjects reported having diabetes, nervous system deficits, or musculoskeletal disorders that would interfere with walking or head stability.

Prior to testing, subjects’ neck range of motion, visual acuity, balance, and confidence in performing daily activities was assessed. These measures characterized the subject sample and were used to exclude individuals with limited neck range, limited visual acuity, and balance instability. These data are summarized in Table 2.

Standard goniometric procedures were used to assess neck range of motion (19). Subjects were measured in a seated position to allow trunk stability for maximum neck motion. A Snellen chart was used to assess visual acuity. Subjects having corrected vision were tested while wearing corrective lenses. Therefore, scores reflected subjects’ best-corrected visual acuity using both eyes (20,21).

Table 1. Health Status

<table>
<thead>
<tr>
<th>Condition</th>
<th>Older Adults</th>
<th>Young Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthritis</td>
<td>8 (47.1%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>3 (17.7%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Fracture</td>
<td>2 (11.8%)</td>
<td>3 (15.0%)</td>
</tr>
<tr>
<td>Corrective lenses</td>
<td>14 (82.4%)</td>
<td>12 (60.0%)</td>
</tr>
<tr>
<td>Regular eye exams</td>
<td>14 (82.4%)</td>
<td>10 (50.0%)</td>
</tr>
<tr>
<td>Hearing loss</td>
<td>5 (29.4%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Hypertension or heart problems</td>
<td>10 (58.8%)</td>
<td>1 (5.0%)</td>
</tr>
<tr>
<td>Fainting spells</td>
<td>1 (5.8%)</td>
<td>1 (5.0%)</td>
</tr>
<tr>
<td>Assistive device</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Fall in past 6 months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>15 (88.2%)</td>
<td>16 (80.0%)</td>
</tr>
<tr>
<td>1</td>
<td>1 (5.8%)</td>
<td>2 (10.0%)</td>
</tr>
<tr>
<td>2</td>
<td>1 (5.8%)</td>
<td>2 (10.0%)</td>
</tr>
<tr>
<td>Fear of falling</td>
<td>7 (41.2%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Number of medications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 4</td>
<td>3 (17.7%)</td>
<td>16 (80.0%)</td>
</tr>
<tr>
<td>&gt; 4</td>
<td>13 (76.5%)</td>
<td>4 (20.0%)</td>
</tr>
<tr>
<td>Perceived health status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>4 (23.5%)</td>
<td>13 (65.0%)</td>
</tr>
<tr>
<td>Good</td>
<td>11 (64.7%)</td>
<td>7 (35.0%)</td>
</tr>
<tr>
<td>Fair</td>
<td>1 (5.8%)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Poor</td>
<td>1 (5.8%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

Note: *n* = 17 for older adults.  

Table 2. Average Neck Range of Motion, Visual Acuity, Berg Balance Test, and ABC Scale for All Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Older Adults</th>
<th>Young Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck range of motion (degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>41.2 ± 10.3</td>
<td>47.4 ± 6.4</td>
</tr>
<tr>
<td>Extension</td>
<td>44.5 ± 10.5</td>
<td>51.8 ± 6.5</td>
</tr>
<tr>
<td>Right lateral bending</td>
<td>20.5 ± 8.2</td>
<td>31.7 ± 6.5</td>
</tr>
<tr>
<td>Left lateral bending</td>
<td>20.8 ± 9.4</td>
<td>31.3 ± 6.5</td>
</tr>
<tr>
<td>Right rotation</td>
<td>58.0 ± 8.7</td>
<td>70.6 ± 7.2</td>
</tr>
<tr>
<td>Left rotation</td>
<td>55.8 ± 12.9</td>
<td>70.1 ± 6.8</td>
</tr>
<tr>
<td>Visual acuity (Snellen score)</td>
<td>20/30</td>
<td>20/20</td>
</tr>
<tr>
<td>(Range)</td>
<td>(20/20–20/50)</td>
<td>(20/13–20/30)</td>
</tr>
<tr>
<td>Berg Balance Test (range 0–56)</td>
<td>53.1 ± 3.3</td>
<td>56.0 ± 0.0</td>
</tr>
<tr>
<td>ABC (range 0–30)</td>
<td>24.4 ± 4.9</td>
<td>28.4 ± 2.6</td>
</tr>
</tbody>
</table>

Note: ABC = Activities-Specific Balance Confidence scale.

Balance was assessed using the Berg Balance Test (22–24). The Berg Balance Test consists of 14 items and includes tasks like sitting, standing, transferring between chairs, reaching, bending forward, turning 360°, and stepping on a step. Items are scored on a scale of 0 to 4, where 0 indicates inability to perform the task and 4 indicates normal performance.

Performance of daily activities was assessed using the Activities-Specific Balance Confidence scale (24–26). This scale rates level of confidence in performing tasks such as walking indoors and outdoors, bending over, walking up a ramp, using an escalator, and walking on ice. A modified scoring of 0 to 2 for each test item was used (24). The modified scoring was used because older adults, particularly those with limited education, have shown difficulty responding to a 100-point confidence scale (27). A score of 0 indicated no confidence in task performance, and a score of 2 indicated full confidence. The maximum possible score on this test was 30 points.

**Procedures**

Subjects performed three walking tasks. In one task, subjects walked across a large room approximately 10 m in length with their eyes open (EO). In a second condition, subjects fixed their gaze (FG) on a distant stationary target while walking. The target was a red circle 12.7 cm in diameter, placed on the opposite wall at the level of the subjects’ eyes. In a third condition, subjects walked with their eyes closed (EC). In all conditions, subjects were instructed to walk at their natural pace to the opposite side of the room. For EO, subjects were not given any special instructions regarding direction of gaze. For FG, subjects were instructed to stare at the target while walking. The order of conditions was randomized, and three trials of each condition were performed.

Spherical reflective markers were used to define the head and trunk segments in the sagittal plane. The head segment was defined by markers placed at the apex of the skull and the junction between the sixth and seventh cervical vertebrae. The trunk segment was defined by the marker placed at the junction between the sixth and seventh cervical vertebrae and a marker placed at the lumbosacral interspace. The marker at the apex of the skull was fixed to a headband.
worn securely on the subject’s head. The cervical and lumbar markers were taped directly to the skin. Heel contact information was obtained by placing markers on each foot over the calcaneus. Markers were fixed to the side of the foot facing the camera to remain in view for the entire trial.

Data were collected using the MacReflex motion analysis system (Qualysis, Inc., Glastonbury, CT). A single camera was used to obtain sagittal plane locations of the markers in space. From this information, angular velocity of the head and trunk segments in space were calculated. A sampling rate of 60 Hz was used to collect data for each 5-second walking trial. Data collection began after subjects took at least three steps and ended before subjects reached the end of the walkway. Therefore, data reflected continuous walking and not accelerations and decelerations associated with the initiation and cessation of walking. Angular velocity data were digitally filtered using a low-pass Butterworth filter with a cutoff frequency of 20 Hz.

**Analyses**

Average walking velocity was calculated as the average horizontal linear velocity of the marker at the lumbosacral interspace. This marker most closely approximated the center of mass of the body (28). Cadence was calculated from the markers placed over the calcaneus. Successive heel contacts were counted for the duration of the trial and were divided by time to obtain cadence in units of steps per second. Calculation of cadence in steps per second permitted comparison of lower extremity stepping frequency to upper body movement frequency as other investigators have suggested an association between these measures (29,30). Peak head velocity was also determined for each trial. These variables—average walking velocity, cadence, and peak head velocity—were then averaged across trials for each subject within a given condition.

Frequency analyses were used to examine movement patterns used to maintain head stability during the walking tasks. These analyses make use of the Fast Fourier Transform (FFT) to determine the frequency content of complex wave forms, such as those generated by head and trunk movements. Complex waves are decomposed into fundamental and harmonic frequencies found within the wave form. At each of these frequencies, the FFT returns a complex number containing both real and imaginary components. From these real and imaginary numbers, magnitude and phase information is derived to characterize the complex wave form at each fundamental and harmonic frequency (31,32).

The frequency analysis used in this study is summarized here and was described in detail elsewhere (1). FFTs were calculated for head-in-space and trunk-in-space angular velocity. An FFT representing head-on-trunk velocity was derived by subtracting the trunk-in-space FFT from the head-in-space FFT. Head-on-trunk with respect to trunk gains and phases were then calculated from the FFT information. Gains were calculated as head-on-trunk magnitudes divided by trunk-in-space magnitudes. Phases were calculated as the difference between head-on-trunk and trunk-in-space phase values. By performing calculations in this manner, the movement pattern describing ideal head stabilization in space was defined as a gain value of 1.0 and a corresponding phase value of 180° (1,11,33–37). These gain and phase values indicated that head-on-trunk angular velocity was equal and opposite to trunk-in-space angular velocity, thereby rendering the head stable in space.

Gains and phases were examined at frequencies where trunk-in-space angular velocity exhibited magnitudes that were at least 25% of the maximum (100%) trunk-in-space magnitude. These frequencies represented the frequencies where head movements were necessary to compensate for trunk motion and maintain head stability (1). These frequencies were referred to as the predominant frequencies of trunk motion. Further, the frequency corresponding to the 100% trunk-in-space magnitude was considered the maximum predominant frequency.

To summarize gain and phase data, trunk-predominant frequencies were first grouped at successive intervals of 1.1 Hz. Each 1.1-Hz interval contained 10 consecutive frequencies. This was done for frequencies ranging to 12.1 Hz. Beyond 12.1 Hz, a single frequency interval was used because a small number of predominant frequencies were identified above 12.1 Hz. Gains and phases were then averaged for each subject within the frequency intervals.

Dependent measures of average walking velocity, cadence, peak head velocity, gain, and phase were compared between age groups and among conditions using analysis of variance (ANOVA). A mixed design was used for analyses (38). In this design, repeated measures ANOVA was used to compare dependent measures among conditions within each age group. A two factor (Age × Condition) ANOVA was used to make comparisons for each condition between age groups. Fisher’s protected least significant difference procedure was used for follow-up comparisons (39).

**Results**

Average walking velocity and cadence were examined to assess changes in the lower extremity outcome measures between age groups and among altered visual conditions (Table 3). Comparisons to young adults demonstrated decreased walking velocity for older adults in EO ($p = .022$), FG ($p = .021$), and EC ($p = .022$). Walking velocity further de-

### Table 3. Average Walking Velocity, Cadence, Predominant Frequency, and Peak Head Velocity

<table>
<thead>
<tr>
<th>Age Group/Condition</th>
<th>Walking Velocity (m/s)</th>
<th>Cadence (steps/s)</th>
<th>Predominant Frequency (Hz)</th>
<th>Peak Head Velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young adults</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td>1.4 ± .2</td>
<td>1.9 ± 0.1</td>
<td>2.5 ± 0.9</td>
<td>51.6 ± 14.7</td>
</tr>
<tr>
<td>Fixed gaze</td>
<td>1.4 ± .2</td>
<td>1.9 ± 0.1</td>
<td>2.3 ± 0.7</td>
<td>54.0 ± 13.8</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>1.5 ± .8</td>
<td>1.8 ± 0.1</td>
<td>2.4 ± 0.6</td>
<td>46.2 ± 11.6§</td>
</tr>
<tr>
<td><strong>Older adults</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td>1.2 ± .2*</td>
<td>1.8 ± 0.2</td>
<td>1.8 ± 0.2</td>
<td>31.7 ± 10.9*</td>
</tr>
<tr>
<td>Fixed gaze</td>
<td>1.2 ± .3*</td>
<td>1.8 ± 0.2</td>
<td>1.8 ± 0.2</td>
<td>30.6 ± 11.4*</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>1.0 ± .3*</td>
<td>1.7 ± 0.2*</td>
<td>1.8 ± 0.2*</td>
<td>28.6 ± 6.5*</td>
</tr>
</tbody>
</table>

**Notes:** Values reflect ± one standard deviation.

*Different from young adults in the same condition ($p < .05$).
†Different from the eyes open condition within the age group ($p < .05$).
‡Different from the fixed gaze condition within the age group ($p < .05$).
§Different from cadence in the same condition within the age group ($p < .05$).
increased for older adults during EC walking when compared with their EO ($p < .0001$) and FG ($p < .0001$) conditions. Cadence remained similar between age groups for the EO ($p = .112$) and FG ($p = .093$) conditions. However, without vision, older adults demonstrated decreased cadence when compared with young adults in the EC condition ($p = .007$).

Comparisons between cadence and the maximum predominant frequency of trunk motion yielded significant differences between these values for young adults in each condition (Table 3). Maximum predominant frequency was greater than cadence for the EO ($p = .004$), FG ($p = .027$), and EC ($p < .0001$) conditions in the young adult subjects. In contrast, older adults demonstrated predominant frequencies that were similar to cadence for EO ($p = .63$), FG ($p = .84$), and EC ($p = .34$). Older adult-predominant frequencies were also significantly less than young adults in EO ($p = .006$), FG ($p = .017$), and EC ($p < .0001$).

Examination of peak head velocity provided an indication of head stability during walking (Table 3). Significant reductions in peak head velocity suggested greater head stability. In young adult subjects, peak head velocity was similar for EO and FG ($p = .25$). However, during EC, young adults’ peak head velocity decreased when compared to their EO ($p = .014$) and FG ($p = .0006$) conditions. Older adults demonstrated decreased peak head velocity when compared to young adults for EO ($p < .0001$), FG ($p < .0001$), and EC ($p < .0001$). Peak head velocity remained similar among conditions within the older adult age group ($p = .403$).

Frequency analyses were used to determine the head stabilization response at predominant frequencies present in the walking pattern. Figure 1 depicts an example of filtered raw data (Figure 1A) and the corresponding frequency spectra (Figure 1B). Graphs depict a single stride from EO for an older adult subject.

Gains and phases were examined for movement strategies used to maintain head stability. Gain and phase diagrams for young adults are found in Figure 2. Average gain and phase values and corresponding standard deviations are provided in Table 4. Young adults demonstrated head stability over the frequency range of 0.5 Hz to 19.7 Hz in EO and EC, and 0.5 Hz to 19.9 Hz in the FG condition. Across frequencies in each condition, gain values were either equal to or slightly above 1.0. Corresponding phase values remained near 180°. Close inspection of the EC condition revealed decreased standard deviations of gain values when compared to EO ($p = .015$) and FG ($p = .021$). Standard deviations of phase values during EC were also decreased when compared to EO ($p = .047$) and FG ($p = .002$).

In contrast to young adults, older adults did not maintain head stability equally well across conditions (Figure 3 and Table 4). Head stabilization was attempted within the frequency range of 0.5 Hz to 17.7 Hz for EO, 0.5 Hz to 16.6 Hz for FG, and 0.4 Hz to 14.2 Hz for EC. During EO, gain values were less than those of young adults ($p = .025$) and more closely approximated a value of 1.0. Phase values remained near 180° and were similar to young adults across frequencies ($p = .102$).

During FG walking, gain values for older adults were similar to those of young adults ($p = .324$) (Figure 3 and Table 4). Standard deviations of these gain values decreased

**Table 4. Average Gain, Gain SD, Phase, and Phase SD**

<table>
<thead>
<tr>
<th>Age group/condition</th>
<th>Gain</th>
<th>Gain SD</th>
<th>Phase (degrees)</th>
<th>Phase SD (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td>1.5</td>
<td>0.8</td>
<td>185.6</td>
<td>36.1</td>
</tr>
<tr>
<td>Fixed gaze</td>
<td>1.5</td>
<td>0.8</td>
<td>187.1</td>
<td>43.5</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>1.4</td>
<td>0.6*‡</td>
<td>177.2</td>
<td>24.4*‡</td>
</tr>
<tr>
<td>Older adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eyes open</td>
<td>1.2*</td>
<td>0.6</td>
<td>187.3</td>
<td>35.9</td>
</tr>
<tr>
<td>Fixed gaze</td>
<td>1.3</td>
<td>0.5*‡</td>
<td>191.5</td>
<td>33.9</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>1.7†</td>
<td>1.5*‡</td>
<td>193.2*‡</td>
<td>43.0*‡</td>
</tr>
</tbody>
</table>

Notes: SD = standard deviation.

*Different from young adults in the same condition ($p < .05$).
‡Different from the eyes open condition within the age group ($p < .05$).
†Different from the fixed gaze condition within the age group ($p < .05$).

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**Figure 2.** Gain and phase of head-on-trunk with respect to trunk plotted against frequency intervals for young adults in each condition. The data point in each frequency interval represents the average value over all subjects for that interval. Dotted lines represent standard deviations. Solid lines at a gain of 1 and phase of 180° indicate the movement pattern describing perfect head stabilization in space.
compared to their FG condition (p = .251).

In the absence of vision, older adults maximized stability in the EC condition. By decreasing cadence, older adults contributed to the greater decrease in walking velocity observed in the EO condition. This reduction in cadence may have contributed to the greater decrease in walking velocity observed in the EC condition. By decreasing cadence, older adults further increased stability of the walking pattern. Therefore, in the absence of vision, older adults maximized stability in an effort to create a walking pattern more resistant to perturbations.

These changes in lower extremity outcome measures were paralleled by changes in upper body movements. Age-related decreases in the maximum predominant frequency of trunk movement more closely reflected lower extremity motion as predominant frequencies were similar to cadence for older adults in all conditions (see Table 3). These findings indicate that older adults maintain a stronger association between lower extremity and upper body movements during walking.

Concomitant changes in head stability were also evident, as older adults decreased peak head velocity when compared to young adults for each task. This finding suggests an age-related adaptation to increase head stability during walking. The outcome measure of peak head velocity was used successfully by other investigators as an indicator of head stability in young adults (29,40,41). However, examination of corresponding head-on-trunk with respect to trunk gain and phase information for older adults in each visual task revealed changes in head stability that could not be derived from reduction in peak head velocity alone.

During natural walking (EO), decreased gain values for older adults produced a head-trunk movement pattern that ensured head stability (see Table 4 and Figure 3). By decreasing gain, values more closely approximated 1.0 as phases remained near 180°. This pattern of equal and opposite head-on-trunk with respect to trunk movement guarantees head stabilization in space (1,34–37). Therefore, older adults increased stability of both lower extremity and upper body movements. This overall increase in walking pattern stability may serve as a mechanism to protect against falls. Increasing stability, therefore, decreases the likelihood that a perturbing event will cause a fall.

Older adults demonstrated improvements in head stabilization during FG walking. In response to fixing their gaze on a stationary target, head-on-trunk with respect to trunk movements were similar to that of young adults (see Table 4, Figure 2, and Figure 3). Standard deviations of gain values were significantly less than that of young adults, indicating tighter control of head-on-trunk with respect to trunk movements. Therefore, while older adults showed improvements in their movement patterns, they exerted increased control of these movements to meet the demands of the FG task.

In the absence of vision (EC), young adults increased head stability by reducing peak head velocity. Decreased movement variability was also evident as the standard deviations of both gains and phases were diminished from that of the EO condition. Therefore, when young adults relied on vestibular and proprioceptive information, tighter control of head-trunk movements increased head stabilization.

In contrast to young adults, older adults demonstrated significant difficulty maintaining head stability without visual input.

DISCUSSION

Changes in lower extremity outcome measures for older adults demonstrated increased walking stability by minimizing the unbalanced portion of the walking cycle. In tasks where visual input was available (EO and FG), older adults decreased walking velocity and maintained similar cadence as compared to young adults (see Table 3). In doing so, older adults effectively shortened their step length by covering less distance with the same number of steps. The shortened step length indicates that older adults minimized swing phase to reduce imbalance and increase stability of walking. These findings are consistent with results of other investigators who demonstrated age-related decreases in walking velocity (3,5–7). In addition to decreased walking velocity, older adults also decreased cadence when visual information was absent. This reduction in cadence may have contributed to the greater decrease in walking velocity observed in the EC condition. By decreasing cadence, older adults further increased stability of the walking pattern. Therefore, in the absence of vision, older adults maximized stability in

Figure 3. Gain and phase of head-on-trunk with respect to trunk plotted against frequency intervals for older adults in each condition. The data point in each frequency interval represents the average value over all subjects for that interval. Dotted lines represent standard deviations. Solid lines at a gain of 1 and phase of 180° indicate the movement pattern describing perfect head stabilization in space.

(p = .020) for older adults, indicating less variability of head-trunk movements when gaze was fixed. Similarities were found between young and older adults in FG for phase values (p = .441) and corresponding standard deviations (p = .251).

During EC, head stability was challenged for older adults (Figure 3 and Table 4). Gain increased for older adults as compared to their FG condition (p = .011). In addition, gain standard deviation was greater than that of young adults (p = .030), and also greater than the older adult EO (p = .009) and FG (p = .008). Comparisons between older adult and young adult phases for EC showed increased phases (p = .007) and increased standard deviations (p = .002) of these phase values for older adults. Therefore, in contrast to young adults, older adults demonstrated significant difficulty maintaining head stability without visual input.

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movements differed from young adults and showed marked variability. These findings indicate that older adults relied significantly on vision to maintain head stability and cannot easily adapt when vision is removed.

The above findings are consistent with studies of head stabilization during seated random rotations (11,36) where older adults used vision to a greater degree than young adults to control head stabilization. The increased reliance on vision by older adults was attributed to decreased vestibular function with age (15–18). Older adults, therefore, substituted vision to adapt for decreased vestibular function to maintain head stability. In doing so, older adults used vision to derive information regarding the body’s relationship to the external environment.

In contrast to studies of seated random rotations (11,12,34–36), both young and older adults were able to maintain head stability at higher frequencies of trunk motion during walking. This finding was attributed to the ability of subjects to use feedforward mechanisms during volitional activities like locomotion (1). In addition, vision supplements feedforward processes by providing information for online corrections of movement in progress (42,43). Therefore, when young adults were denied vision during walking, they exerted tighter control over head stabilization to adapt for this visual loss. In addition to using visual information for online corrections, older adults also use vision to substitute for vestibular decrements (11). Therefore, when denied vision, they not only lose visual feedback for online movement corrections, they also diminish their ability to compensate for decreased vestibular function.

From a functional perspective, these results indicate an important role for vision in the process of head stabilization for older adults. Indeed, the improvement observed during FG walking as movement patterns became more like those of young adults indicates a role for a combined visual-vestibular strategy to improve head stabilization in older adults.

A strategy that combines both visual and vestibular information may prove more effective in compensating for losses in these systems with age. However, with increasing age, visual and vestibular systems will continue to decline, and the capabilities for head stabilization will decrease. Decreased head stability will compromise sensory and motor processing and may lead to falls in these older adults.

An alternative explanation for the modified head stabilization response observed for older adults may be related to walking velocity. Investigation of treadmill walking at a variety of velocities demonstrated changes in head and trunk movements as young adults fixed their gaze on a distant target (44). When compared to the FG condition in our study, decreased walking velocity between age groups was also associated with decreased peak head velocity (see Table 3). However, declining phase values related to increased walking velocity (44) were not observed for FG walking in our study, as phase remained similar between age groups. Furthermore, estimates of gain from head-on-trunk and trunk angular position data of Hirasaki and colleagues (44) implied that gain would decrease with increased walking velocity. Once again, this was not the case in our study, as gain remained similar between age groups for the FG condition. Therefore, walking velocity alone did not completely account for the modified head stabilization response in older adults.

In summary, increased stability of lower extremity outcome measures was accompanied by increased head stabilization for older adults. Increased stabilization decreases the possibility that a perturbing event will cause a fall. Altered visual conditions demonstrated that head stability improved during FG and diminished with EC. Therefore, older adults rely on vision for successful head stabilization and use vision to compensate for decreased vestibular function.

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