Impaired Depth Perception and Restricted Pitch Head Movement Increase Obstacle Contacts When Dual-Tasking in Older People

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Background. Trips are the largest contributor to falls in older people, yet little is known about the underlying physiological mechanisms for safe obstacle negotiation. The aims of the study were to determine (i) the effect of a secondary visual task on obstacle contacts when older people negotiated an obstacle course and (ii) physiological factors associated with obstacle contacts.

Methods. Thirty community-living adults aged 65 years and older walked along a 14.5-m walkway containing 21 obstacles with and without a secondary task. The secondary task required participants to call out a series of letters presented in front of them at head height and the suit of a playing card framed on the sidewalk. Obstacle contacts, secondary task errors, eye peak-to-peak pitch amplitude and head peak-to-peak pitch amplitude (PA-H), and head angle in pitch were measured. Participants also completed assessments of sensorimotor function and balance.

Results. Compared with the obstacle-only trials, participants performed the dual-task trials more slowly (p < .001), contacted more obstacles (p = .032), showed greater PA-H (p < .001), and an extended head position (p < .001). Most participants also made secondary task errors. Regression analysis revealed that depth perception was the only significant determinant of obstacle contacts (explaining 20.6% of the variance) in the obstacle-only task and that depth perception and PA-H were independent and significant determinants of obstacle contacts (explaining 42.3% of the variance) in the dual task.

Conclusion. The findings demonstrate the importance of depth perception and head movement for safe negotiation of obstacles in older people and suggest that depth perception in particular should form part of fall risk assessments.

Key Words: Aged—Depth perception—Gait—Dual tasks—Obstacle avoidance.

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To date, no studies have examined the underlying physiological mechanisms that contribute to safe obstacle course negotiation in older people, either with or without the addition of a secondary task. Such information is important for the selection of relevant sensorimotor screening tests to identify risk factors for trips and stumbles and prevent subsequent falls in older people. The objectives of this study, therefore, were to examine (i) the effect of a secondary visual task on obstacle contact when older people negotiated an obstacle course and (ii) physiological factors associated with obstacle course negotiation (obstacle contacts and trial time) in trials with and without the secondary task.

Methods

Participants
Thirty community-living volunteers aged 65 years and older (women, n = 15; M [±SD] age: 76.7 ± 6.3 years; range: 66–91 years) were recruited from the intervention group of...
the VISIBLE randomized controlled trial (RCT) on the effects of moderating the use of multifocal glasses as a falls prevention strategy (U.S. National Institutes of Health registration number NCT00350389) (13). All participants were independent in activities of daily living, such as dressing, bathing and toileting, and were able to walk 800 m without assistance.

Cognitive functioning was examined using the Mini-Mental State Examination (14), and all participants scored more than or equal to 26, indicating intact cognitive function. Eleven participants reported a history of cataracts (nine in both eyes), and of these, six had undergone surgery. Two participants suffered from macular degeneration, one of them in both eyes. Two participants reported glaucoma. Thirteen participants reported hearing impairment, 6 diabetes, 2 stroke, 6 transient ischemic attack, and 14 arthritis. Sixteen participants reported falling in the previous 12 months and eight of them fell more than once. Concern about falls when carrying out activities was rated using the “Falls Efficacy Scale-International” (FES-I) (15). The mean FES-I score recorded was 24 ± 6 (range 16–39), indicating low concern about falls as this scale ranges from 16 (low fear) to 64 (high fear). The experimental protocol was approved by the University of New South Wales Human Research Ethics Committee (HREC 04229), and all participants gave written informed consent prior to data collection.

**Glasses Conditions**

All 30 participants wore single lens glasses (prescribed by an optometrist to ensure appropriate visual correction) while undertaking the trials. As a major component of the RCT intervention, participants had been wearing these glasses when undertaking activities of daily living outside their homes for a minimum period of 1 month ($M \pm SD$: 8.33 ± 6.53 months) at the time of this study.

**Visual Tests**

Corrected visual acuity was assessed binocularly using a 3-m logMAR chart (16). Edge contrast sensitivity was assessed using the enlarged version of the Melbourne Edge Test (17), whereby participants were required to fixate targets placed at ground level, 135 cm in front of them (18). Depth perception was assessed using a Howard–Dohlman depth perception apparatus (19), which requires participants to align two vertical rods (0.8 cm diameter) in depth from a distance of 3 m (18). Error in aligning the rods was measured in millimeters.

**Sensorimotor Function Assessment**

As part of participation in the larger trial, the participants were assessed on a series of sensorimotor tests: proprioception, lower limb strength, simple reaction time, and postural sway, evaluating some key components of the human balance system. Descriptions of the apparatus, procedures, and test–retest reliability for these tests are reported elsewhere (20). In brief, proprioception was assessed using a lower limb–matching task. The angle of error (degrees) was determined using a protractor inscribed on a clear acrylic sheet (60 × 60 × 1 cm) placed between the legs. The average error from five trials was recorded. Simple reaction time (milliseconds) was measured using a handheld electronic timer and involved a light as the stimulus and a finger press as a response; the average of 10 trials was recorded. Knee isometric extension strength was assessed while the participant was sitting with both knee and hip placed at angles of approximately 90°. The best of three attempts was recorded. Postural sway (path length in millimeters) was recorded using a swaymeter that measured the displacement of the body at the level of the waist as the participants stood quietly barefoot on a foam mat (60 × 60 × 15 cm thick) for 30 seconds.

**Experimental Protocol**

Participants walked along a 14.5-m long-level walkway covered with light blue linoleum. They performed six walking trials, three of these were obstacle-only trials and three dual-task trials, presented in a randomized order. Participants wore their everyday shoes and were encouraged to keep walking during the trials.

The obstacle course consisted of 7 foam blocks (smallest [Width × Height × Length]: 100 × 7 × 6.5 cm; largest: 100 × 6.5 × 21 cm) and 14 cardboard strips (100 × 0.5 × 3 cm) matching the floor color. These obstacles were placed across the walkway at intervals ranging from 0.35 to 1.30 m, on one side of a 1.90-m-wide corridor. They were chosen to create a challenging stepping task and placed in a scattered pattern to prevent participants from planning their steps. The first and last obstacles were placed at 1.20 and 12.95 m, respectively, from the start of the walkway. The order of obstacles was kept constant throughout the study.

In the obstacle-only trials, participants were asked to walk along the walkway at a self-selected speed and to avoid contact with the obstacles. The dual-task trials comprised two visual tasks. While negotiating the obstacle course, participants were required to look up and read aloud three letters from a computer screen positioned at approximate head height at the end of the walkway (17.5 m away from the start; Figure 1). A sequence of three letters was

![Figure 1. Experimental setup used for the dual-task trials.](image-url)
presented for more than 1.5 seconds (ie, each letter was presented for 500 milliseconds), and there was a 2-second break between presentation blocks. A distinct auditory cue signaled the imminent appearance of the first letter on the screen. The sequence of letters varied for each trial and, for clarity, each of the three letters in the sequence appeared in a different color: purple, green, and then brown. To ensure that the letters were similarly legible, 10 monosyllabic letters (C, D, E, F, L, N, O, P, T, and Z) from a visual acuity chart were displayed in Arial font. The letters were also of sufficient size: height: 261 mm, width: 224 mm, and line thickness: 34 mm) for participants to read them from the far end of the walkway. The second visual task required participants to glance to the side on two occasions and read aloud the suit of a playing card placed in frames at head height (one on either side of the walkway). A randomly chosen playing card was placed in each frame positioned at 3 and 7.5 m from the start; the cards were changed between each trial. For the dual-task trials, participants were instructed to prioritize avoiding contact with obstacles over successfully identifying the letters and cards.

Participants were not given a practice of the obstacle course but were familiarized with the computer screen display of letters and the auditory cue prior to the first trial. The lighting conditions (267 lux at floor level) were kept constant throughout the walking trials.

**Data Collection**

**Trial time, obstacle contacts, and secondary task errors.**—Time to complete each walking trial was recorded using a stopwatch. The number of obstacles contacted and secondary task errors (letters both missed and incorrectly reported) was recorded during each trial. The number of secondary task errors was expressed as a percentage of the number of letters that had appeared on the screen during the walking trial.

**Eye movements.**—Right eye vertical movements were recorded at 30 Hz using a lightweight custom-built video-based eye tracker firmly mounted to the head with a light plastic frame. This device used infrared pupil reflections to determine visual fixation relative to the head. The eye tracker was calibrated for each participant using a two-point calibration, whereby the participants were asked to alternatively fixate on one of two points vertically aligned on a wall and separated by 20 cm. Participants were seated with their chin resting on a chin rest so that the perpendicular distance between their eyes and the middle of the two points remained constant (106 cm). This ensured that the eye vertical displacement corresponding to switching focus from one point to the other was equal to 10°. The ratio of this known vertical eye movement to that recorded simultaneously by the eye tracker was then computed and used to calibrate the vertical eye movements recorded in the subsequent walking trials.

**Head movements.**—Head movements in pitch were sampled at 25 Hz using an inertial sensor (MTi; Xsens Technologies B.V., Enschede, the Netherlands) fastened to a headpiece at the level of the superior coronal suture. Head movement data were collected through the data acquisition card of a laptop computer into custom written software in LabVIEW (LabVIEW 8.0; National Instruments, Austin, TX). Head movement data were recorded to understand better how head movement affects safe negotiation of a complex environment in older people.

**Data Analysis**

Data analysis was performed using a custom written program in LabVIEW (LabVIEW 8.0; National Instruments). The eye movement data were filtered using a low-pass second-order Butterworth filter with a cutoff frequency of 2.5 Hz to remove blink artifacts. The head movement data were low-pass filtered to isolate the volitional movement by removing the higher frequency components associated with heel contact with the ground (2.5 Hz, second-order Butterworth filter). The overall mean head angle (HA; degrees) in the pitch plane was computed for each trial. Positive angles corresponded to an extended head position and negative angles corresponded to a flexed head position. Mean peak-to-peak pitch amplitudes of the eye (PA-E) and the head (PA-H; degrees), defined as the average movement from each minimum to each maximum over the course of the trial, were computed for each trial. The trial time, secondary task errors, obstacle contacts, HA, PA-E, and PA-H measurements derived from three trials in each task condition were averaged for each participant. The dual-task cost was calculated in terms of percentage increase time taken to complete the trials in the dual task compared with the obstacle-only task according to the following formula:

\[ \text{Dual-task cost} = \left( \frac{\text{trial time in dual-task trials} - \text{trial time in obstacle-only trials}}{\text{trial time in obstacle-only trials}} \right) \times 100. \]

**Statistical Analysis**

To permit parametric analysis, variables with positive skewness, the FES-I, visual acuity, depth perception, hand reaction time, sway path, and obstacle contacts data were log_{10} transformed. Paired t tests were used to assess differences in trial time, obstacle contacts, PA-E, PA-H, and HA between the obstacle-only and the dual-task trials. The relationships among experimental variables and age, FES-I, visual, and sensorimotor function variables were examined with Pearson correlations and partial correlations adjusting for age. Stepwise linear regression analyses were performed to identify independent and significant explanatory variables for obstacle contacts for the two trial conditions. The variables, which showed the strongest significant correlations with obstacle contacts, were entered into the stepwise linear regression with a limitation of one predictor variable per 10 cases. Despite the multiple comparisons made, p values
were not adjusted in this exploratory study as such adjustments may increase Type II errors, especially in studies with small sample sizes (21). All significance levels were set at p < .05. All statistical analyses were performed using SPSS (Version 15.02 for Windows; SPSS Science, Chicago, IL).

**Results**

Table 1 displays the mean (±SD) values for the visual and sensorimotor function variables. These values are consistent with those found in larger population studies of community-living older people (20).

**Comparison of Experimental Variables Between Obstacle-Only and Dual-Task Trials**

Table 2 shows the mean (±SD) values of the experimental measures in the obstacle-only and dual-task trials. The participants walked more slowly (t = 11.52, p < .001) and contacted more obstacles (t = 2.25, p = .032) in the dual-task trials compared with the obstacle-only trials. As expected, PA-H (t = 12.22, p < .001) and mean head position (t = 21.31, p < .001) differed significantly between trials, that is, participants walked with their head flexed in the obstacle-only trials and alternated head flexion and head extension in the dual-task trials. In addition, PA-E (t = 17.69, p < .001) increased during the dual-task trials suggesting more frequent up and down gaze shifts to attend to both tasks. The mean (±SD) dual-task cost in terms of trial time was 37.9 ± 16.1%.

**Physiological Determinants of Obstacle Negotiation Performance**

Table 3 displays the correlation coefficients among sensorimotor, balance, and experimental variables in the obstacle-only and dual-task trials. Only the sensorimotor and balance variables that were significantly associated with at least one experimental variable are presented, and inspection of scatter plots revealed that none of the associations were unduly influenced by outliers.

**Obstacle-only trials.**—Longer trial time was associated with weaker quadriceps strength (p = .024) and with increased postural sway (p = .046). Increased obstacle contacts were associated with poorer depth perception (p = .007). All significant associations remained significant after adjusting for age. Stepwise regression analysis revealed that poor depth perception was the only significant and independent determinant of obstacle contacts. This variable explained 20.6% of the variance in obstacle contacts (adjusted $R^2 = .206$; Table 4).

**Dual-task trials.**—As shown in Table 3, longer trial time was associated with reduced quadriceps strength (p = .007). Increased obstacle contacts were associated with poorer depth perception (p = .001) and reduced PA-H (p = .023). Secondary task errors were associated with longer trial time (p = .021), increased PA-H (p = .015), and a more flexed head position (p < .001). All significant associations with the exception of that between obstacle contacts and PA-H remained significant after adjusting for age. Stepwise regression analysis revealed that poor depth perception and restricted PA-H were significant and independent determinants of obstacle contacts. These two variables explained 42.3% of the variance in obstacle contacts (adjusted $R^2 = .423$; Table 4).

**Concern About Falls and Obstacle Negotiation Performance**

The FES-I scores were negatively correlated with mean head position in the obstacle-only and the dual-task trials (r = −.364, p = .048 and r = −.372, p = .043, respectively) indicating that the greater the concern about falls, the more flexed the head position. The FES-I scores were also positively correlated with increased secondary task errors (r = .500, p = .005) such that participants with increased concern about falls made more secondary task errors. Finally, there was a trend for a relationship between increased concern about falls and slower trial time in both the obstacle-only and the dual-task trials (r = .309, p = .097 and r = .351, p = .057, respectively).

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**Table 1. Visual and Sensorimotor Function Variables**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>M ± SD (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual function</strong></td>
<td></td>
</tr>
<tr>
<td>Visual acuity (logMAR)</td>
<td>0.09 ± 0.12</td>
</tr>
<tr>
<td>Edge-contrast sensitivity</td>
<td>24.27 ± 2.42</td>
</tr>
<tr>
<td>Depth perception (mm)</td>
<td>2.25 ± 1.86</td>
</tr>
<tr>
<td><strong>Sensorimotor function</strong></td>
<td></td>
</tr>
<tr>
<td>Proprioception (error in °)</td>
<td>1.57 ± 1.05</td>
</tr>
<tr>
<td>Quadriceps strength (kg)</td>
<td>25.87 ± 10.85</td>
</tr>
<tr>
<td>Hand reaction time (ms)</td>
<td>240.69 ± 47.84</td>
</tr>
<tr>
<td>Postural sway on foam (mm²)</td>
<td>150.10 ± 74.08</td>
</tr>
</tbody>
</table>

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**Table 2. Mean (±SD) Values for the Experimental Data in the Obstacle-Only and the Dual-Task Trials**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obstacle-Only Trials (M ± SD)</th>
<th>Dual-Task Trials (M ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial time (s)</td>
<td>18.55 ± 3.87</td>
<td>25.58 ± 6.15*</td>
</tr>
<tr>
<td>Obstacle contacts</td>
<td>1.40 ± 1.35</td>
<td>1.87 ± 1.56†</td>
</tr>
<tr>
<td>Secondary task errors (%)</td>
<td>N/A</td>
<td>5.32 ± 3.78</td>
</tr>
<tr>
<td>PA-E (°)</td>
<td>14.00 ± 5.10</td>
<td>31.70 ± 9.24*</td>
</tr>
<tr>
<td>PA-H (°)</td>
<td>9.98 ± 2.92</td>
<td>23.21 ± 7.53*</td>
</tr>
<tr>
<td>HA (°)</td>
<td>−15.24 ± 6.73</td>
<td>5.37 ± 6.24*</td>
</tr>
</tbody>
</table>

Notes: HA = head angle; PA-E = pitch amplitude of the eye; PA-H = pitch amplitude of the head.

* Significant difference between trial conditions (p < .01).
† Significant difference between trial conditions (p < .05).
‡ These data concerned the dual-task trials only.
IMPAIRED DEPTH PERCEPTION INCREASES OBSTACLE CONTACTS

Table 3. Correlations Coefficients (r) Among Experimental, Visual, and Sensorimotor Variables in the Obstacle-Only Trials (upper half) and in the Dual-Task Trials (bold lower half)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Trial Time</th>
<th>Obstacle Contacts</th>
<th>Secondary Task Errors</th>
<th>pA-E</th>
<th>pA-H</th>
<th>HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstacle Contacts</td>
<td>0.081</td>
<td>—</td>
<td>—</td>
<td>0.69</td>
<td>0.36</td>
<td>—</td>
</tr>
<tr>
<td>Trial time</td>
<td>0.036</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Secondary task errors</td>
<td>0.058</td>
<td>0.291</td>
<td>—</td>
<td>0.16</td>
<td>0.483</td>
<td>—</td>
</tr>
<tr>
<td>pA-E</td>
<td>0.040</td>
<td>0.219</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>pA-H</td>
<td>0.028</td>
<td>0.15</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>HA</td>
<td>0.060</td>
<td>0.50</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Depth perception</td>
<td>0.024</td>
<td>—</td>
<td>—</td>
<td>0.24</td>
<td>0.43</td>
<td>—</td>
</tr>
<tr>
<td>Quadriceps strength</td>
<td>0.056</td>
<td>—</td>
<td>—</td>
<td>0.34</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>Postural sway</td>
<td>0.350</td>
<td>—</td>
<td>—</td>
<td>0.35</td>
<td>0.05</td>
<td>—</td>
</tr>
</tbody>
</table>

Notes: HA = head angle; N/A = not applicable; pA-E = pitch amplitude of the eye; pA-H = pitch amplitude of the head.

*These data concerned the dual-task trials only.
†Significant correlation (p < .05).
‡Significant correlation (p < .01).

Table 4. Determinant Variables Identified by the Stepwise Linear Regression Analysis for Obstacle Contacts

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Determinant Variables</th>
<th>Standardized Beta</th>
<th>Multiple R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstacle contacts (obstacle-only trials)</td>
<td>Depth perception</td>
<td>0.483*</td>
<td>.483</td>
</tr>
<tr>
<td>Obstacle contacts (dual-task trials)</td>
<td>Depth perception</td>
<td>0.543*</td>
<td>.680</td>
</tr>
<tr>
<td>PA-H</td>
<td>-0.362†</td>
<td>-0.362</td>
<td>-0.362</td>
</tr>
</tbody>
</table>

Notes: PA-H = pitch amplitude of the head.
*Significant beta weight (p < .01).
†Significant beta weight (p < .05).

Discussion

The study findings demonstrate that when their attention is divided, older people negotiate obstacles more slowly, contact more obstacles, and elucidate physiological and biomechanical impairments that hinder obstacle negotiation. In the obstacle-only trials, participants shifted their gaze minimally and kept their heads flexed as indicated by the negative value of mean head position and reduced pitch movement amplitude. This strategy would have provided consistent fixation of the floor-level obstacles. Visual acuity and contrast sensitivity were not significantly associated with obstacle contacts, which indicate that the obstacles were sufficiently visible to all. This finding is consistent with that of Patel and colleagues (22) who reported no significant associations between visual acuity, contrast sensitivity, and the percentage of preferred walking speed between a simple walking trial and an obstacle course. However, our findings suggest that ability to accurately judge the position of obstacles as indicated by good depth perception is crucial for obstacle avoidance. This result may help explain the consistent findings from epidemiological studies that impaired depth perception is a strong risk factor for both falls and fall-related hip fractures in older people (23).

The secondary visual task dividing the participants’ attention was used to increase overall task complexity (24) and simulate a distracting environment in which people often amble during everyday life. In this condition, the participants displayed greater PA-H necessary for the more extended head position required to read the letters of the computer screen. The participants took longer to complete the dual-task trials, although, contrary to some previous findings (25), this did not improve stepping accuracy, that is, the participants contacted more obstacles when their attention was divided and also made some secondary task errors. It is likely that the present dual task, involving an obstacle course, was more complex than that of previous studies, which found that older adults prioritized performance either in the gait (11) or in the secondary task (26).

In the dual-task condition, restricted PA-H joined poor depth perception as a significant and independent determinant of obstacle contacts. This suggests that restricted pitch head movement reduces the older people’s ability to safely negotiate a complex walking environment. Interestingly,
Paquette and colleagues (27) demonstrated that older people might be reluctant to excessively and rapidly move their heads when walking in an attempt to minimize ensuing postural instability. In addition, decreased range of motion in the cervical spine with older age has been documented (28), and the prevalence of arthritis and related neck pain in older adults (29) might further limit head movement. It is also possible that participants with lower PA-H values had difficulty attending to both tasks and thus prioritized the obstacle task at all times as instructed. The participants who were the most concerned about falls according to their FES-I scores held their head more flexed throughout the trials; this was likely a cautious strategy to maintain a visual focus on the obstacles that presented a risk of tripping. As a consequence, they made more secondary task errors. This is in agreement with recent research that showed that postural threat elicited gait adaptations in older people concerned about falls (30).

It is acknowledged that despite the range of factors available as possible determinants, more than half of the variance in obstacle contacts was left unaccounted. Other factors that may have added additional information about performance in the task include ankle and knee joint range of motion, tactile sensitivity, and lower limb power. Depth perception and restricted PA-H were not significantly associated with previous falls (data not shown). Such lack of associations may be due to limitations with regard to the retrospective recording of falls and the fact that the participants were regular wearers of multifocal glasses during the falls surveillance period—a factor that influences both depth perception (18) and pitch head movement (31) as well as falls (18).

In conclusion, older adults contacted more obstacles when their attention was divided, despite taking longer time to complete the trials and adapting their head movement strategy. Stepwise regression analysis revealed that depth perception and PA-H explained more than 40% of the variance in obstacle contacts in the dual-task trials. These findings demonstrate that ability to judge depth and pitch head movement are important contributors to safe negotiation of complex walking environments in older people and suggest that depth perception in particular should be included in routine falls risk screening.

Furthermore, the associations between reduced quadriceps strength and increased sway and time to complete the obstacle course are consistent with other studies that have found that measures of lower limb strength and balance are determinants of stair climbing (32) and gait speed (33). There is some evidence that exercise training improves obstacle avoidance abilities (34,35). The present results imply that visual interventions may further enhance older people’s ability to negotiate obstacles in a safe and efficient manner.

**Acknowledgments**

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**References**