Does Inability to Allocate Attention Contribute to Balance Constraints During Gait in Older Adults?

Ka-Chun Siu,1 Li-Shan Chou,1 Ulrich Mayr,2 Paul van Donkelaar,1 and Marjorie H. Woollacott1

1Department of Human Physiology, Institute of Neuroscience, and 2Department of Psychology, University of Oregon, Eugene.

Background. Recent research has explored dual-task deficits during locomotion in older adults, yet the mechanisms underlying these deficits are poorly understood. In the current study, we examined one possible factor contributing to these deficits, the inability to flexibly allocate attention between two tasks.

Methods. Twelve healthy young adults and 12 healthy elderly adults performed obstacle avoidance while walking and an auditory Stroop task either alone or simultaneously.

Results. Using an attentional allocation index (AAI) to compare performance of healthy young and older adults and to measure the flexibility of allocation of attention, results showed a tendency in older adults toward a decreased ability to flexibly allocate their attention between the two tasks, with small AAI values. The decreased ability to allocate attention in older adults was found to be more prominent in the auditory Stroop task performance than in the obstacle avoidance task.

Conclusion. This study suggests that an important factor contributing to decreased dual-task performance in older adults when simultaneously performing a postural and secondary cognitive task is a reduced ability to flexibly allocate attention between the two tasks, with the general ability to switch attention flexibly being predictive of the ability to adhere to a prioritized focus.

Key Words: Gait—Attention—Aging.

Many studies have shown that the likelihood for injurious falls increases in the older adult (1-3). Thus, falls represent a significant health risk in the elderly population and are a major cause of death in people older than 75 years (4). Early studies expected to find a single cause of falls for a given older adult (e.g., vertigo, sensory neuropathy, postural hypotension); however, current research indicates that falls have multiple factors (5,6), such as balance control abnormalities (7), deterioration in sensory function (8), and muscle weakness (9,10).

Recent research suggests that an additional factor contributing to instability is impairment in cognitive processes, including attentional processing deficits (11,12). Many falls in older adults occur when they walk and simultaneously perform a secondary task (such as manipulating an object) (13). It has thus been hypothesized that these falls are not caused by balance deficits in isolation, but to the inability to effectively allocate attention to balance in multitask conditions (14,15).

Studies on attentional demands and posture suggest that older adults demonstrate a marked reduction in the ability to perform a postural or gait task and a cognitive task simultaneously (14,16,17). This has been demonstrated as a reduction in the performance of the secondary cognitive task (14,18,19), and/or a decrement in the primary balance task (20-22). In addition, safe and efficient balance in complex environments requires the flexible allocation of attention between walking and a secondary task, such as talking to a companion or scanning a busy street for threats to safety at the same time, according to the changing complexity and requirements of each task.

Although research has clearly demonstrated age-related changes in balance under dual-task conditions, there is still a limited understanding of the mechanisms underlying these problems, including possible limitations in the ability to flexibly shift attention between two tasks. It is possible that older adults have a deficit with “executive control” involving implementing shifts in instructional sets (23,24), and therefore are impaired in appropriately allocating attentional resources between the tasks. The apparent deficit in “executive control” in older adults is supported by research showing that neuropsychological measures probing executive function predict poor performance in obstacle avoidance during gait (25).

Most dual-task studies (14,17-22) have only examined the interaction between the primary task and secondary task without paying attention to the switching capability between two tasks; thus the first purpose of the present study was to investigate how the ability to allocate attention between two tasks may affect balance control. It is possible that older adults have difficulties with “executive control” involving implementing a prioritized focus, and therefore are impaired
ATTENTIONAL DEMANDS DURING GAIT IN AGING

Table 1. Characteristics of Participants and Clinical Measurements

<table>
<thead>
<tr>
<th>Clinical Measurements</th>
<th>Healthy Young Adults</th>
<th>Healthy Older Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Age, y*</td>
<td>22.8 ± 2.7</td>
<td>74.1 ± 5.0</td>
</tr>
<tr>
<td>Gender (% women)*</td>
<td>41.7</td>
<td>75.0</td>
</tr>
<tr>
<td>One or more falls in past year, %</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Report imbalance, %*</td>
<td>0</td>
<td>8.3</td>
</tr>
<tr>
<td>Mini-Mental State Examination score (range 0–30)</td>
<td>30.0 ± 0</td>
<td>29.4 ± 0.6</td>
</tr>
<tr>
<td>Berg Balance Scale score (range 0–56)</td>
<td>56.0 ± 0</td>
<td>55.6 ± 0.7</td>
</tr>
<tr>
<td>Dynamic Gait Index score (range 0–24)</td>
<td>24.0 ± 0</td>
<td>23.4 ± 0.8</td>
</tr>
<tr>
<td>Timed Up &amp; Go, s</td>
<td>8.3 ± 1.0</td>
<td>9.0 ± 1.9</td>
</tr>
<tr>
<td>TMT-A, s*</td>
<td>21.1 ± 8.2</td>
<td>29.4 ± 10.2</td>
</tr>
<tr>
<td>TMT-B, s*</td>
<td>49.1 ± 10.4</td>
<td>83.5 ± 32.2</td>
</tr>
<tr>
<td>Adjusted TMT score, s*:1</td>
<td>149.4 ± 66.9</td>
<td>191.2 ± 88.1</td>
</tr>
<tr>
<td>Activities Balance Confidence Scale, %</td>
<td>98.6 ± 1.8</td>
<td>92.6 ± 11.2</td>
</tr>
</tbody>
</table>

Notes: *p < .05.
1Adjusted TMT score = (TMT-B – TMT-A) × 100/TMT-A.
TMT-A = Trail Making Test-A; TMT-B = Trail Making Test B.

in appropriately allocating attentional resources between two tasks. Thus the second purpose of this study was to test whether impairment in allocating attentional resources would contribute to the dual-task deficits in the elderly population. This study was designed to determine the ability of young versus older adults to simultaneously perform a postural and cognitive task under two instructional conditions: focus primarily on the postural task versus the cognitive task. We hypothesized that older adults would have less ability to flexibly allocate attention between tasks. An attentional allocation index (AAI) (26), testing the extent to which balance performance on the postural and cognitive task changed as a result of instructions to shift attentional priorities between the two tasks, was specifically developed to test our hypothesis.

METHODS

Participants

Twelve young and 12 elderly adults participated in this study and were screened for motor deficits using the Berg Balance Test (BBT), the Timed-Up & Go Test (27) and an Activities-specific Balance Confidence (ABC) Scale (28). Neuropsychological deficits were screened using a Mini-Mental State Examination (MMSE) (29) and the Trail Making Test (30). All elderly participants received medical clearance from personal physicians regarding neurological or musculoskeletal deficits that might contribute to instability. All older adults were older than 65 years. Although the younger group had approximately equal numbers of men and women, we were unable to match this ratio in the older group, which includes 75% women. According to the United States Consensus 2000, there were 26% more women than men in the state of Oregon who were 65 years old or older. Research has shown that older men showed more instability in stance balance than did women, and thus, if this ratio difference affected our results, it may have reduced the difference in balance we observed between the two groups (31). The inclusion criteria for healthy older adults were the following: BBT score of ≥52 (32); Timed Up & Go score <14 seconds (33); ABC scale score >80% (28), and MMSE score >20 (29). Table 1 summarizes demographics for the participants. All procedures were approved by the local Institutional Review Board.

Experimental Apparatus

Three-dimensional marker trajectories were collected by an eight-camera motion analysis system (Motion Analysis, Santa Rosa, CA) with 60 Hz sampling rates as participants walked down a walkway (Figure 1). Twenty-nine reflective markers were placed bilaterally on bony landmarks of the body (34). Specifically, for the lower extremity segments, markers were placed bilaterally over the dorsum of the foot (between the second and third metatarsals heads), posterior aspect of the heel (at the same level with the foot marker), lateral malleoli, distal–lateral aspect of the shank, lateral femoral epicondyline, distal–lateral aspect of the thigh, anterior superior iliac spine (ASIS), and one sacral marker (midway between posterior superior iliac spines) for the posterior aspect of the pelvis. For the trunk and upper extremities, markers were placed over the superior aspects of the scapular acromion processes, lateral humeral epicondyles, and dorsal wrist lines (midway between radial and ulnar styloid). The head–neck segment was indicated by markers placed at the superior apex of the head, and bilaterally over the temple regions (to indicate the superior–inferior midpoint of the head–neck segment), estimating the frontal plane of this segment. Ground reaction forces and moments were collected by two force plates (Advanced Mechanical Technologies Inc., Watertown, MA) located in the center of the walkway. A polyvinyl chloride (PVC) pipe crossbar (1/2 inch diameter) on two standards was used as an obstacle (set at 10% of body height) and placed between the two force plates. Participants wore a safety harness to prevent falls.

An auditory Stroop task (35) (the prerecorded words “high” or “low” spoken with a high or low pitch) was implemented in SuperLab Pro (Cedrus, San Pedro, CA). The participant’s goal was to indicate the pitch of the voice as quickly and accurately as possible while ignoring the actual word presented. The word stimuli were presented through a pair of speakers at either heel strike or during swing phase of the gait cycle during obstacle crossing. The location of the speakers was fixed and placed behind the participants.
To reduce any disadvantage in hearing the tone for older adults who might have mild hearing loss, we adjusted the volume of the speakers to be as loud as necessary for the participant to clearly perceive it. We also presented some tone samples to test for hearing and pitch discrimination during the prescreening session.

**Experimental Protocol**

This experiment aimed to determine the relative ability of young and healthy older adults to flexibly allocate attention between a postural and cognitive task under three instructional conditions: i) focus on the postural task, ii) focus on the cognitive task, and iii) perform both tasks with no primary focus. We hypothesized that if older adults’ dual-task deficits were caused by a reduced ability to switch attention flexibly, then an instructional set involving a prioritized focus would have a smaller influence on concurrent task performance in old participants than in young participants. We also used a neuropsychological indicator of attention switching, the Trail Making Test A and B (TMT-A and TMT-B), as an index of flexible control of attention with the TMT-A as the control for normalization of TMT-B. “Switch costs” were calculated using TMT-B – TMT-A. Assuming that flexible allocation of attention to either gait or cognitive performance reflects more general executive control ability, we predicted that TMT performance would reflect individuals’ ability to adhere to an instructional set involving prioritized focus.

All participants started with the walking task to establish a comfortable self-selected pace. Then participants randomly completed two blocks (eight trials per block) of each of the following conditions: i) Stroop task and obstacle task with fixed priority instructional set (participants were instructed to focus on both tasks equally); ii) Stroop task and obstacle task with instructions to focus on the obstacle task (participants were instructed to prioritize their attentional focus to the obstacle crossing task, to try not to hit the obstacle and to maintain stability); and iii) Stroop task and obstacle task with instructions to focus on the Stroop task (participants were instructed to prioritize their attentional focus to the Stroop task, and responded to the task as fast and as accurately as possible). Before and after dual-task conditions, participants also completed four trials of two single tasks: performing the Stroop task when seated and the obstacle task.

**Data Processing and Analysis**

Analog signals from the two force plates, Stroop stimulus, and microphone recordings were collected at 960 Hz for 6 seconds per trial. Marker data were filtered (low-pass, fourth-order Butterworth filter, cutoff frequency 8 Hz). Virtual markers were created at joint centers and combined with anthropometric data to determine center of mass (COM) location (36). Gait velocity (GV), stride length, step width, and stride time were also calculated.

For obstacle-crossing trials, the vertical toe-obstacle clearance heights for both limbs (Trailing and Leading [TTOC and LTOC, respectively]) and the horizontal toe-obstacle and heel-obstacle anterior/posterior distances (HTOD and HHOD, respectively) were calculated. Verbal reaction times (VRT) during the Stroop task were calculated, and only trials with correct verbal responses were included for analysis.

Dependent variables included VRT, GV, TTOC, and HHOD. A two-way analysis of variance (ANOVA) with two age groups (healthy young adults [HYA] and healthy older adults [HOA]) and two conditions (single- and dual-task) was used to test for dual-task effects in all dependents variables. In addition, a two-way ANOVA with two age groups and three attention focus conditions (no priority focus [NF], variable priority focus on the obstacle [FO], variable priority focus on the Stroop task [FS]) was used to test for significant differences in VRT and gait performance. To assess attentional allocation, we computed for each variable an AAI (26). The AAI was derived from the equation: AAI = (O – S)/N, where O represents the dependent variable (e.g., GV) in the trial with variable priority-obstacle, S represents the dependent variable (e.g., VRT) in the trial with variable priority-Stroop, and N represents the dependent variable in the trial with both tasks equally attended. Domain-specific AAI scores have a value between 1 and −1, where a value of −1 in the gait velocity signals a complete shift of attentional resources and subsequent performance toward the obstacle. A value of 1 indicates a complete shift away from the obstacle. In contrast, an AAI value of −1 in VRT indicates a complete shift of performance and attentional resources away from the Stroop task, whereas a value of 1 signals a complete shift toward the task. An AAI value of 0 represents no observable shift in performance across conditions of varied attentional focus. We also computed a total AAI score by adding the absolute values of each of the two specific AAI components; the total AAI score reflects the overall ability to switch priorities between the two domains. A Pearson correlation test was used to test the relationship between the total AAI scores and the switch costs (i.e., TMT-A – TMT-B).

Finally, we used a data analytic procedure suggested by Strube and Bobko (37) to determine whether one subgroup in a 2 × 2 design differs from the remaining three groups by i) testing that the three similar groups are not different from each other and ii) testing whether the supposedly different group is in fact different from the mean of the remaining groups. If the individual results in any clinical testing were larger than the group mean plus 3 standard deviations (SD), those data were treated as outliers and excluded from statistical analysis.

**Results**

A comparison between single- and dual-task conditions found no significant differences in gait parameters (p > .05), suggesting that the Stroop task did not affect gait stability in healthy older adults. In contrast, there was a significant interaction for VRT between groups and conditions (F1,22 = 9.356, p < .001): Only for older adults, VRT in the dual-task conditions (obstacle crossing while performing the Stroop task) (mean and SD, 1178.8 ± 348.5 ms) was significantly longer than in the single-task condition (Stroop task only) (1046.9 ± 274.1 ms) (p < .05). There was no learning effect across participants when two sets of the
single-task condition were compared. We did not find any differences in our kinematic data, related to where we presented the Stroop task during the obstacle-crossing cycle. There was also no significant anticipatory response in older adults.

Because of the nonsignificant attentional control effects in both TTTOC and HHOD, we only present results on GV. All participants only had ≤5% errors in response to the auditory Stroop task. Thus, <5% of the data were not considered in the data analysis. Figure 2a and b shows VRT and GV across both age groups and instructional conditions. In terms of proportional attentional instruction effects, younger adults showed a 19% (±9%) allocation effect for VRT and a -10% (±8%) for GV. Consistent with expectations, older adults’ respective effects were smaller, 14% (±9%) for VRT and -7% (±8%) for GV, but there were no significant age differences. To analyze these data, we submitted AAI values for each of the two variables to an ANOVA with the factors age and domain (VRT vs GV). The main effect for the domain factor, which reflects the effect of instructional set involving prioritized attentional focus either on the obstacle crossing task or to the Stroop task, was highly reliable (F[1,22] = 74.82, p < .001). However, the interaction with age failed the significance criterion (F[1,22] = 2.07, p = .16). As can be seen from Figure 2c, the overall distribution of allocation values is somewhat more centered for old than for young adults, suggesting a less flexible response to the instruction, but also considerable variability within both age groups.

The TMT-B scores were normalized with respect to TMT-A scores to provide a pure “switch cost” for each participant. This cost showed a significant correlation with
summed VRT and GV AAI values (total group: $r = -0.55$, $p < .01$, young: $r = -0.45, p = .14$, old: $r = -0.59, p < .05$). Furthermore, when using a median split in terms of high versus low switch costs across the entire sample, we found a reliable interaction between domain and the switch factor ($F_{1,22} = 6.47, p < .02$). Nine of the 12 participants with large switch costs were old adults (Figure 2d). Furthermore, inspection of Figure 2d suggests that there is a subgroup of old adults with high switching costs (with a cutoff around 50-second switch costs) that also shows low AAI scores, suggesting that the combination of old age and low switching ability might constitute a particular vulnerability.

Using a data analytic procedure by Strube and Bobko (37), we first compared AAI scores across the three subgroups of young adults with low switch costs and high switch costs as well as old adults with low switch costs (0.30, 0.27, and 0.32, respectively) and found that they did not differ (all $t$ values $< 0.8$). However, the AAI scores for old adults with high switch costs was reliably smaller than the combined score of the remaining three groups [$t(22) = 3.8, p < .01$]. This analysis suggests that, even though there may not be a general, negative age effect on the ability to allocate attention flexibly between gait and cognition, this ability might be compromised in a subgroup of older adults who exhibit a more general decline in flexible switching.

**DISCUSSION**

This study aimed to determine the relative contributions of age-related reductions in the ability to allocate attentional resources between two tasks to age-related reductions in dual-task performance during gait. Healthy young and elderly adults were asked to perform an auditory Stroop task and an obstacle avoidance task either alone or simultaneously under different conditions to examine contributions of the above factors to dual-task interference.

Our results demonstrated that both young and older adults were able to focus on either the obstacle avoidance task or auditory Stroop task under different instructional sets involving prioritized focus. However, not all gait parameters related to the obstacle avoidance task reflected a significant finding for the effects of instructional sets involving prioritized focus. As is seen in Figure 2a, with both healthy young and older groups were asked to focus on the Stroop task (FS), they both reduced their reaction time (VRT); however, the older groups showed a smaller allocation effect; that is, the older group did not reduce their VRT as much as the young group. In contrast, as was seen in Figure 2b, when asked to focus on the obstacle (FO), both groups increased their GV; however, the older group again showed a smaller allocation effect, increasing GV a smaller amount. The disproportionate reduction in VRT may have been caused by the age and scaling differences, and the use of the AAI could account for these differences by using the condition of both tasks equally attended to resolve the disproportionate effects.

Consistent with our expectations, there was a tendency toward a reduced ability to allocate attention according to instructional set regarding priority of focus that might have reached statistical significance with greater statistical power. However, we also found that the general ability to switch attention flexibly was predictive of the ability to adhere to the instructional set. Furthermore, there is evidence that the combination of older age and slow flexible switching with small AAI values constitutes a vulnerability factor for a reduced ability to negotiate attention between gait control and a secondary cognitive task.

Several studies have suggested that falls in older adults occurring under dual-task situations may be caused by the reduced ability to flexibly allocate attention between two tasks to give postural stability a top priority (11,14,15). Recently, a review from Yogev-Seligmann and colleagues (38) also suggested that an unconscious “posture first” strategy could be a key to avoiding hazards and reducing falls during walking in healthy elderly persons. Giving instructions to prioritize the gait task under dual-task conditions may facilitate the focus of attention on gait and thus help individuals avoid instability (39). Inappropriately low prioritization of gait may cause instability and gait disorders, such as seen in patients with Parkinson’s disease (40).

In this study, we limited our investigation to whether healthy older adults could flexibly allocate attention according to priority instructions. Our results supported the hypothesis that healthy older adults did have less capability in the allocation of attention between two tasks. However, our study was not designed to answer the question of whether older adults simply have a strong preference to focus more attention on the task with a higher safety threat. We used an AAI to determine attentional focus abilities and found that both young and older participants were able focus their attention on either the obstacle or Stroop task under different instructional sets involving priority of focus. However, there was a tendency for this ability to be reduced with smaller AAI values in the older adults. In addition, the general ability to switch attention flexibly was predictive of the ability to adhere to instructional set. Thus, the combination of older age and limitations in attentional switching appears to create vulnerability toward a reduced ability to switch attention between gait control and a secondary cognitive task. This pattern of findings suggests that the ability to flexibly allocate attention to different tasks is an additional factor that may compromise gait control in healthy older adults.

**ACKNOWLEDGMENT**

This study was support by the National Institutes of Health, Aging Grant AG-021598 (M. Woollacott, PI).

**CORRESPONDENCE**

Address correspondence to Ka-Chun Siu, PhD, Nebraska Biomechanics Core Facility, 6001 Dodge Street, University of Nebraska at Omaha, Omaha, NE 68182. E-mail: ksu@mail.unomaha.edu

**REFERENCES**


13. Tideiksaar R.


