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Attentional Mechanisms Contributing to Balance Constraints during Gait: The Effects of Balance Impairments

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Abstract

Background—Recent research has begun to explore the ability of older adults to perform balance tasks while simultaneously performing a secondary cognitive task; however, it has suffered from limitations regarding the mechanisms underlying the problems that cause dual-task deficits in older adults with balance impairments. Two possible attentional mechanisms (reduced general attentional capacity vs. a true dual-task performance deficit and inability to allocate attention between two tasks) contributing to balance constraints were examined.

Methods—Twelve healthy elderly adults and 12 elderly adults with balance impairments (BIOA) were asked to perform obstacle avoidance while walking, either alone or simultaneously with an auditory Stroop. Two experiments were designed to examine attentional mechanisms that may contribute to reduce performance in the dual-task situations for the BIOA.

Results—Experiment 1 determined whether for BIOA, single vs. dual-task performance conditions led to similar effects as a single-task difficulty (congruent vs. incongruent) manipulation. Results indicated that dual-task performance reduction did not exceed that of the difficult single task, suggesting that neither older adult group showed a true dual-task performance deficit, but rather BIOA showed a reduced attentional capacity. Experiment 2 showed that BIOA also showed deficits in flexibly focusing their attention between two tasks according to instructions.

Conclusion—Our study confirmed that the ability to allocate attention between a postural task and a secondary cognitive task was impaired in BIOA; it is suggested that inability to flexibly allocate attention could be one important factor among many factors that contribute to balance constraints during gait in fallers.

Keywords

Aging; gait; attention

1. Introduction

Falls are one of the most significant causes of accidental death among older adults in the United States (Rubenstein et al., 1997). Previous research has shown that stance balance control is reduced and falls increase in older adults when simultaneously performing a secondary cognitive task (Shumway-Cook et al., 1997; Brown et al., 1999; Shumway-Cook and Woollacott, 2000). These deficits in stance balance control under dual-task conditions are more prominent in older adults with balance impairments (Shumway-Cook et al., 1997a,b).

Early literature emphasized testing balance during quiet stance and concluded that older adults and balance-impaired elderly (BIOA) showed significantly higher levels of sway or center of pressure movement than young adults (Fernie et al., 1982; Toupet et al., 1992). Though this research provided information on age-related changes in stance balance control, the reality is that most falls in older adults occur while walking (Gabell et al., 1985; Nevitt et al., 1991).

Information about balance control during quiet stance is informative, but balance control requirements are increased during locomotion (Winter 1990). Consider the differences in task difficulty: (a) 80% of the gait cycle is spent in single limb support, (b) the center of mass is already in motion and has momentum that must be maintained or slowed, (c) because the body already possesses a quantity of motion (momentum), the strength required to manage the momentum changes becomes an even more critical consideration, and (d) when locomotor balance is threatened due to a slip, recovery of balance is significantly more difficult when compared to recovery from a similar threat during quiet stance.

These balance control requirements are even greater in BIOA, due to their neural or musculoskeletal limitations. Previous dual-task research in BIOA has suggested that the ability to recover stability is greatly decreased under dual-task conditions (Brauer et al., 2002). This may explain why inability to recover from slips and trips during gait accounts for the majority of falls in BIOA during single task situations (Gabell et al., 1985; Nevitt et al., 1991). Since many falls in older adults occur while simultaneously balancing or walking and performing a second task (such as engaging in conversation or carrying an object) (Connell and Wolf, 1997; Shumway-Cook and Woollacott, 2000; Verghese et al., 2002), the examination of how attentional demands of secondary tasks affect balance control in gait is a critical research area.

It has been hypothesized that an inability to produce an appropriate postural response due to the competition for attentional resources between the demands of the postural system and the cognitive task contributes to falls in older adults with poor balance (Shumway-Cook et al., 1997a,b). In particular, older adults with clinical balance impairments either stop (Lundin-Olsson et al., 1997) or take a longer time to complete a gait task when performed with an additional secondary task (Beauchet et al., 2005a,b). Furthermore, balance-impaired older adults are more likely to lose their balance under difficult sensory conditions in a dual-task context (Shumway-Cook and Woollacott, 2000).

Though recent research has begun to explore balance impairment-related changes in the ability of older adults to perform balance tasks in a dual-task context, there is still limited understanding of the mechanisms underlying these changes. Although this literature is complex, one dominant finding is that age effects are larger when two tasks need to be performed in conjunction rather than alone (Kramer et al., 1995). Two possible explanations for this balance impairment-related difference in dual-task performance are:

1. Dual-task situations depend more on a general attentional resource that is reduced with balance impairments. Based on this hypothesis one would predict that dual-task situations behave like complex single-task situations. Some data on dual-task age differences can be accounted for by such a model; however, there are studies in which age differences do not fully account for the changes in dual-task performance. In this case, there appears to be a true deficit related to dual-task performance itself (Madden, 1987; Park et al., 1989).
2. Dual-task situations require the flexible allocation of attention and maintenance of instructional set. For example, the instructional set in posture-control dual-task research often directs participants to "maintain balance and perform the secondary task as quickly and accurately as possible", and thus to attend to both tasks. It is possible that old adults have a deficit with the "executive control" involved in implementing such instructional sets (Mayr, 2001; Mayr and Liebscher 2001) or involved in gait (Coppin et al., 2006; Springer et al., 2006; Delval et al., 2008; Yogev-Seligmann et al., 2008), and therefore they are impaired in terms of allocating attentional resources between two tasks. This is supported by Persad et al (1995), showing that neuropsychological measures including executive functions predict poor performance in obstacle avoidance during gait.

Thus, two experiments were designed (1) to determine if healthy older adults (HOA) and BIOA perform differently in attentionally-demanding single tasks which vary in complexity (a test of the general attentional resource hypothesis vs. a true deficit in dual-task performance) and (2) to assess the ability of healthy older adults vs. BIOA to simultaneously perform a postural task and a cognitive task under two instructional conditions: focus primarily on the postural task vs. the cognitive task (a test of the attentional-allocation hypothesis).

2. Experiment 1

2.1. Introduction

The aim of this experiment was to determine 1) if differences between HOA and BIOA in Stroop performance in single vs. dual-task situations were qualitatively different and 2) whether balance impairment-related difference in dual-task performance was due to the general reduction of attention resource or a true dual-task deficit. The hypothesis was tested by primarily comparing three tasks: 1) congruent Stroop task while sitting (simple single task), 2) incongruent Stroop task while sitting (difficult single task) and 3) congruent Stroop task while level walking (simple dual-task) in both HOA and BIOA. If performance of the difficult single task condition led to similar results as for the simple dual-task conditions, this finding would be consistent with the general attentional resource hypothesis suggesting that the dual-task impairment found in BIOA could simply be due to the general reduction of attention resources. Alternatively, the dual-task situations could lead to greater costs than the difficult single task condition. This result would suggest that additional mechanisms beyond a reduction of general attentional resources account for balance impairment-related decrements when gait control occurred in a dual-task context. In this experiment, all participants also performed three more dual-task conditions (level walking with the incongruent Stroop task, and obstacle avoidance with both congruent and incongruent Stroop task) for further data comparison.

2.2. Results

Both HOA and BIOA showed a significant reduction in gait velocity and increase in stride time ($p < .05$) with no differences in stride length and step width when comparing level walking with obstacle crossing without the Stroop task. This suggested that obstacle

crossing did not provide additional physical difficulty for BIOA. A comparison between single and dual-task conditions found no significant differences in gait parameters ($p > .05$). This indicates that performing the auditory Stroop task did not affect gait stability in older adults. In contrast, when comparing the verbal reaction time (VRT) performance in the simple dual-task (level walking and congruent Stroop task) condition with the difficult single task (incongruent Stroop task while sitting) condition, both HOA and BIOA responded significantly faster in the simple dual-task than in the difficult single task ($p < .05$). Fig. 1 showed not only the simple dual-task, but also another three dual-task conditions (level walking with the incongruent Stroop task, obstacle avoidance with both congruent and incongruent Stroop task). For the HOA, the VRT performance in the dual-task condition was never beyond the difficult single task performance. Interestingly in BIOA, the difference in VRT between the dual-task (obstacle avoidance with incongruent Stroop task) and difficult single task conditions was significant ($p = .050$). Fig. 2 demonstrates the point in obstacle crossing where a HOA and a BIOA actually responded to an incongruent Stroop task. It is clear that the BIOA increased her stride time on the first force plate and responded to the Stroop task when she started a double-stance period.

2.3. Discussion

Our results showed that dual-task performance in most conditions for both HOA and BIOA was never any worse than the difficult single task, suggesting that this dual-task situation basically behaved like the complex single-task situation. However, when the dual-task situation become more challenging, such as obstacle avoidance with incongruent Stroop task, the dual-task performance was worse than that in the difficult single task in BIOA. This suggests that there may be some deficit beyond the general attentional resource reduction in BIOA under complex dual-task situations. It is possible that BIOA are unable to allocate their attention when performing two tasks simultaneously or to prioritize their focus on one task in a dual-task environment. BIOA might modulate their responses by delaying the response until they begin a double-stance support phase which is a more stable situation. (Fig. 2)

3. Experiment 2

3.1. Introduction

This experiment was designed to determine the ability to flexibly allocate attention between a postural and a cognitive task in HOA and BIOA under three instructional conditions: 1) focus primarily on the postural task, 2) focus primarily on the cognitive task and 3) perform both tasks with equal focus. It was hypothesized that HOA would have no difficulty in flexibly allocating attention according to the instructional sets. Conversely, BIOA would show a reduced or no ability to allocate attention between two tasks and reduced or no differences in performance would be found among any instructional sets.

3.2. Results

Both HOA and BIOA were asked to perform three instructional dual-task conditions in random order: 1) participants were instructed to focus on the obstacle without hitting it while responding to the Stroop task, 2) participants were instructed to focus on the Stroop task and respond as accurately and quickly as possible while obstacle crossing and 3) participants were instructed to perform both tasks with equal focus. When comparing the three instructional conditions between HOA and BIOA, a group * condition interaction in the VRT was found ($F_{5, 43} = 11.91$, $p < .001$) and post-hoc analyses revealed that only HOA significantly reduced their verbal responses when they were instructed to focus on the Stroop task compared with instructions to focus on the obstacle task (Fig. 3a). Two-way interactions (group*conditions) were also found in gait velocity ($F_{5, 43} = 33.62$, $p < .001$), the

trailing toe-obstacle clearance (TTOC) ($F_{5, 43} = 15.89$, $p < .001$) and the horizontal heel-obstacle distance (HHOD) ($F_{5, 43} = 4.66$, $p < .05$). Only HOA significantly reduced their gait velocity (Fig. 3b), increased obstacle clearance in trailing limb (Fig. 3c), and decreased heel-obstacle distance in the leading limb (Fig. 3d) when they were instructed to focus on obstacle avoidance. In contrast, BIOA showed no differences regardless of the instructions.

The value of the Attentional Allocation Index (AAI) is shown for individual subjects in Fig. 4a. Ten out of 12 HOA showed significant shifts in the allocation of their attention in the VRT performance (positive value of the AAI_{VRT}) and in gait performance (negative value of the AAI_{gvt}) ($\chi^2 = 5.33$, $p < .05$). In contrast, only 7 BIOA showed a slight ability to allocate their attention, with a relative small value of AAI ($\chi^2 = .33$, $p > .05$). Moreover, half of BIOA did not show an observable attentional allocation effect, showing a small or even 0 value for AAI in gait performance. In order to test to what degree the attentional allocation deficit in BIOA participants is due to a general executive control deficit, we also looked at AAI scores ($AAI_{VRT} - AAI_{gvt}$) as a function of a neuropsychological switch measure (i.e., TMT Score = Trail Making Test B - Trail Making Test A; Fig. 4b). In a linear regression with AAI scores as dependent variable, we first entered the switch score as the predictor, which explained a significant portion of the variance ($R^2 = .17$, $F(1,21) = 4.42$, $p < .05$). The group variable entered in a second step explained additional variance ($R^2 = .18$, $F(1,21) = 5.43$, $p < .05$); however the interaction between the TMT switch score and the group variable was not reliable ($R^2 = .01$, $F(1,21) = .40$, $p > .5$). This suggests that while switching efficiency on the TMT test is generally related to the ability to allocate attention between the Stroop task and gait performance, it does not explain the specific allocation deficit observed in balanced impaired subjects.

3.3. Discussion

Our results demonstrated that HOA have no difficulty in focusing on either the obstacle avoidance task or auditory Stroop task under different instructional sets. However, balance-impaired older adults showed no differences in either VRT or gait performance across the three instructional conditions. This indicates that dual-task deficits in BIOA may be due to the inability to flexibly allocate attention between the cognitive task and gait control. However, our analysis relating attentional allocation to a neuropsychological measure of executive switching efficiency showed that the allocation deficit of the BIOA participants could not be explained in terms of a generalized executive control deficit. Rather, the deficit seems specific to the domain of balance control.

4. General discussion

This study aimed to determine the relative contributions of attentional mechanisms to the balance impairment-related reduction in dual-task performance during gait. These included a balance impairment-related reduction: 1) in general attentional capacity vs. a true dual-task deficit, and 2) in the ability to allocate attentional resources between two tasks. Healthy older adults (HOA) and balance-impaired older adults (BIOA) performed an auditory Stroop task and an obstacle avoidance task either alone or simultaneously under different conditions in order to examine contributions of the above mechanisms to dual-task interference.

Experiment one aimed to determine if there were qualitative differences between HOA and BIOA in their dual-task performance versus their performance during a single task that varied in complexity. Our results indicated that the simple dual-task performance in HOA and BIOA did not increase beyond that of the difficult single task, supporting the reduced general attentional resource hypothesis that the dual-task situation basically behaved like a complex single-task situation. However, the hypothesis is only supported when both HOA and BIOA performed a simple dual-task. As the context of the dual-task became more

complex or challenging, such as during obstacle avoidance with incongruent auditory Stroop task, surprisingly, BIOA showed a dual-task deficit, with increased VRT when they performed the more difficult dual-task. It is suggested that additional mechanisms beyond a reduction of general attentional resources account for specific decrements when gait control occurs in the context of complex dual-task situations.

It is important to note that dual-task deficits only became apparent in BIOA when the dual-task became more difficult. This indicates that the deficit may be driven by the complexity of the dual-task. Previous studies have revealed that only secondary tasks related to executive functions, such as arithmetic tasks, but not verbal fluency tasks as well as lateral gait stability (Beauchet et al., 2005a,b) or stride time variability (Beauchet et al., 2005a,b) showed performance decreases under dual-task conditions in transitionally frail older adults. The incongruent auditory Stroop task requires the subject to inhibit a prepotent response and substitute a less automatic response. It would thus require executive attentional resources and thus more interference with postural control than the congruent version, and lead to more prominent dual-task interference in BIOA.

Several studies have suggested that falls in older adults that occur under dual-task situations may be due to the reduced ability to flexibly allocate attention between the two tasks, in order to give postural stability attentional priority, that is, to utilize a “posture first strategy” to stabilize balance while performing other tasks (Lajoie et al., 1993; Shumway-Cook et al., 1997; Shumway-Cook and Woollacott, 2000; Verghese et al., 2007). Our data confirm that the ability to flexibly allocate attention between a postural task and a secondary cognitive task was reduced in older adults with a history of falls. When instructed to focus their attention on the obstacle, rather than on the secondary Stroop task, only HOA significantly reduced their gait velocity, increased toe obstacle clearance, and decreased horizontal heel obstacle distance. In contrast, no difference was found in BIOA regardless of instructions. Our data also suggest that our BIOA not only had an impairment of balance control, but also had a reduction of ability to flexibly allocate attention. However, it should be noted that our two groups of subjects showed slight differences in age, and thus age may also contribute to decrements in flexible allocation of attention. Figure 4b shows a significant finding of poorer TMT performance and poorer values of AAI with age. In addition, for older adults with a history of falls, the ability to selectively allocate attention in gait could be further affected beyond that seen for non-balance-impaired elderly.

One limitation of our study was that while the regression between the AAI score and TMT score explained a significant (20%) portion of variance, it did not explain the majority of the variance. This may be due to the limited number of elderly subjects recruited in this study. It is also possible that the tasks used in the study, including obstacle negotiation and the auditory Stroop task were limited in their ability to differentiate attention mechanisms contributing to balance constraints during gait in these two groups of older adults. For example, the BIOA may have always used a posture first strategy (Shumway-Cook et al., 1997a,b), by stabilizing performance and decreasing the degrees of freedom needed for stability. This would explain the decreased gait velocity in this group and the lack of change when asked to shift the prioritization of the two tasks. But interestingly, within a sample of healthy old adults we found that general attentional control as assessed via the TMT did capture which older adults had potential problems allocating attention flexibly between walking and cognition. Thus, apparently the processes that lead to dual-task deficits may be different for healthy older adults and the balanced-impaired elderly.

Taken together, the above results suggest that the flexible allocation of attention is a key and inevitable component to successfully performing two tasks simultaneously in older adults. Training the ability to switch attention under dual-task situations should be an area of focus

in designing rehabilitation programs for balance-impaired elderly to reduce the incidence of falling and enhance the quality of their lives. A recent set of studies (Silsupadol et al., 2006; Silsupadol et al., in press) involving balance training under dual-task conditions suggested that only dual-task training with varied instructional set improved balance performance in BIOA under dual-task situations. Traditional single-task training did not show training benefits in the dual-task environment. Dual-task balance training with varied-priority instructional sets may enhance the capacity of BIOA to perform two tasks simultaneously and reduce dual-task deficits.

4.1. Conclusion

Two attentional mechanisms (reduction in general attentional capacity and reduced ability to flexibly allocate attention) were tested in this study of dual-task interference in healthy older adults and balance-impaired older adults. Results support the conclusion that the dual-task deficits in BIOA when performing a postural task and a secondary task may be due to a reduction in attentional capacity. As the dual-task became more complex, there was an additional deficit beyond a reduction of general attentional resources that led to specific decrements in the dual task performance of BIOA. Data in experiment 2 suggested that inability to flexibly allocate attention between the two tasks could be one of the potential factors contributing to balance constraints during gait in older adults with balance problems.

5. Experimental Procedures

5.1. Participants

Approval for the use of human subjects was granted prior to testing by the University of Oregon Institutional Review Board. Written consent was obtained from each participant prior to testing. Twelve healthy older adults (HOA) and 12 BIOA were recruited for this study. All the BIOA subjects were greater than 65 years of age, lived independently in the community, had confirmed balance control complications as indicated by poor performance (score <52, out of a total of 56) on the Berg Balance Scale (BBS) (Berg et al., 1992), and a self-report of one or more falls in the previous 12 months.

The BBS is a 14-item test that quantifies performance on tasks such as standing up, standing with eyes open or closed, and standing with feet together, on a 4 point ordinal scale. Scores range from 0 to 56, with high scores suggesting better balance. Research has demonstrated a strong relationship between the BBS scores and fall risk in older adults. A score of <52 has been shown to predict a 40% probability for falls (Shumway-Cook et al., 1997a,b).

Prior to experimental testing, each participant was screened for motor deficits using the BBS, the Timed-Up and Go Test (Podsiadlo and Richardson 1991) and an Activities-specific Balance Confidence Scale (Powell and Myers 1995). Neuropsychological deficits were screened using the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) and the Trail Making Test (TMT) (Spree and Strauss, 1998). Participants were excluded when their MMSE was lower than 25 (out of a total of 30) or when they were unable to complete the TMT test. All participants both self-reported and received medical clearance from their personal physician stating that they had no history of neurological or musculoskeletal deficits that might contribute to instability and falls, including cerebral vascular accident and Parkinson's disease. Demographics for the two groups of subjects are summarized in Table 1.

5.2. Experimental apparatus

Three-dimensional marker trajectories in space were collected by an eight-camera motion analysis system (Motion Analysis, Santa Rosa, CA) with 60Hz sampling rates as subjects

walked down a walkway. Twenty-nine retro-reflective markers were placed bilaterally on bony landmarks of the body (Hahn and Chou, 2004). Ground reaction forces and moments were collected by two force plates (Advanced Mechanical Technologies Inc. Watertown, MA) located in the center of the walkway (Figure 5). A PVC pipe crossbar (1/2 in. 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 (Cohen and Martin 1975) was implemented by SuperLab Pro (Cedrus, San Pedro, CA). The Stroop task consisted of the presentation of the words “high” or “low” spoken with a high or low pitch. Congruency between pitch and the word spoken was randomized. 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 at either heel strike or during swing phase of the gait cycle during obstacle crossing.

5.3. Data Processing

Analog signals from the two force plates, Stroop stimulus and microphone recordings were collected at 960Hz for 6 s per trial. EVaRT 4.4 (MotionAnalysis, Santa Rosa, CA) was used to track the markers in space. They were then filtered with a low-pass, fourth order Butterworth filter at a cutoff frequency of 8 Hz. Virtual markers were created at joint centers and combined with anthropometric data to determine center of mass (COM) location (Winter, 1990). Gait velocity, stride length, average step width, and stride time were also calculated from the position change of the body COM and time change during a complete stride.

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 distances (HTOD and HHOD, respectively) were calculated. Verbal reaction times (VRT) during Stroop tasks were calculated and only trials with correct verbal responses were included for statistical analysis. In sum, 6.97% (44 trials for HOA and 63 trials for BIOA) and 6.16% (27 trials for HOA and 44 trials for BIOA) of the total trials were excluded respectively in experimental 1 and 2 for data analysis. Although the number of excluded trials was not substantial, it could be a potential confounder in this study.

5.4. Experiment 1

5.4.1. Experimental protocol—First, participants performed three different single tasks including level walking, obstacle crossing and the Stroop task while seated. The auditory Stroop task was presented in a simple (congruent) and a difficult (incongruent) version. Second, participants completed 4 randomized trials of each version of the Stroop task while seated, then 8 trials of each of these conditions in random order: 1) level walking, 2) level walking and congruent Stroop task (dual/simple task), 3) obstacle avoidance, and 4) obstacle avoidance and Stroop task with both congruent and incongruent versions. Vision of the walkway was occluded prior to walking trials so participants could not preprocess walking condition information. Finally, participants performed 4 trials of the seated Stroop task at the end of experiment.

5.4.2. Data Analysis—In order to determine if there was a “true” dual-task deficit related to balance impairments, the following sets of analyses were performed. Gait performance in the postural task and verbal response time in the auditory Stroop task were included as the dependent variables. All gait parameters were analyzed during a crossing stride, which was defined from the heel strike of the trailing limb before the obstacle to the heel strike of the same limb after crossing the obstacle. Data in level walking trials were analyzed from the

heel strike of the trailing limb on the first force plate (Fig. 5) to the heel strike of the same limb on the floor. A mixed ANOVA factorial design was used, including one within subjects factor (conditions: single/simple, single/difficult and dual/simple) and one between subjects factor (age group: HOA and BIOA). Significance level was set at $p \leq .05$.

5.5. Experiment 2

5.5.1. Experimental protocol—All participants started with the walking task to establish a comfortable self-selected walking pace. Then participants completed eight randomized trial blocks of each of the following conditions: 1) Stroop task and obstacle task with fixed priority instructional set (both tasks equally important); 2) Stroop task and obstacle task with instructions to focus on the obstacle task (variable priority-obstacle) and 3) Stroop task and obstacle task with instructions to focus on the Stroop task (variable priority-Stroop). For blocks that involved primary focus on the obstacle clearance task, participants were instructed to keep their balance during stepping over the obstacle as safe and stable as possible and to make this their primary focus. For blocks that involved primary focus on the auditory Stroop task, participants were told to respond as quickly and accurately as possible to the auditory Stroop task and to make this their primary focus.

5.5.2. Data Analysis—The dependent variables VRT, gait velocity, trailing toe-obstacle clearance (TTOC) and horizontal heel-obstacle distance (HHOD) were analyzed. The statistical analysis was performed by a mixed ANOVA factorial design which included one within-subjects factor (three instructional conditions) and one between-subjects factor (age groups: HOA and BIOA).

In order to assess variability in participants' dual-task performance as a function of varied attention instructional sets, the attentional allocation index (AAI) (Siu and Woollacott, 2006) was calculated. The AAI was derived from the equation: $AAI = (O - S) / N$, where O represents the dependent variable (e.g. gait velocity) 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. AAI scores will have a value between 1 and -1. An AAI value of -1 in the gait velocity signals a complete shift of attentional resources and subsequent performance towards the prioritized task. Conversely, a value of 1 indicates a complete shift away from the prioritized task. Similarly an AAI value of -1 in the VRT measure indicates a complete shift of performance and attentional resources away from the prioritized task, while a value of 1 signals a complete shift towards the prioritized task. An AAI value of 0 represents no observable shift in performance across conditions of varied attentional focus. A Chi-Square analysis was performed to examine the number of participants who showed the capability to allocate attention between two tasks. A Pearson correlation was performed to examine the correlation between the AAI score and clinical testing across HOA and BIOA participants in this study. If the results in any clinical testing were larger than the group mean plus three standard deviations, those data were treated as outliers and excluded from statistical analysis.

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Figure 1.

Verbal response times (VRT) for the two subject groups ($\# p = 0.050$) in two versions of the Stroop task while seated (single/simple and single/difficult), during level walking with the Stroop task (dual/simple) and during obstacle avoidance with the Stroop task.

Figure 2.

Force profile from two force plates with verbal response time for (a) a HOA and (b) a BIOA. The Solid lines represent the force profile from the first force plate before the obstacle and the dotted line represents the second force plate after obstacle crossing. Verbal response times for both participants are shown as a grey dotted line.

Figure 3. Performance in (a) verbal response time, (b) gait velocity, (c) toe-obstacle clearance in the trailing limb (TTOC), and (d) horizontal heel-obstacle distance in the leading limb (HHOD) between HOA and BIOA in three instructional conditions: No priority focus (NF), variable priority focus on the obstacle (FO), variable priority focus on the Stroop task (FS).

Figure 4.

(a) The attentional allocation index (AAI) and (b) the correlation between the AAI in gait velocity performance and the Trail Making Test (TMT) Score. Black circles and the solid line represent healthy older adults, and the open circles and dotted line represent balance-impaired older adults.

Figure 5.
Experimental setting.

Table 1

Characteristic of Subjects and Clinical Measurements

	Healthy Older Adults	Balance-Impaired Older Adults
N	12	12
Age (year) *	74.1 ± 5.0	81.0 ± 4.5
Gender (% women)	75.0	66.7
One or more falls in past year (%)	0	83.3
Report imbalance (%)	8.3	100
Berg Balance Scale * (Range 0–56)	55.6 ± 0.7	47.9 ± 1.8
Dynamic Gait Index * (Range 0–24)	23.4 ± 0.8	19.0 ± 1.7
Timed Up and Go (s) *	9.0 ± 1.9	13.3 ± 2.5
Trail Making Test A (s)	29.4 ± 10.2	36.0 ± 14.4
Trail Making Test B (s)	83.5 ± 32.2	99.1 ± 57.6
Activities Balance Confidence Scale (%)	92.6 ± 11.2	84.9 ± 12.9
Average Gait Velocity (m/s) *	1.27 ± 0.18	0.97 ± 0.14

*
 $p < .05$