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Why does older adults' balance become less stable when walking and performing a secondary task? Examination of attentional switching abilities

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ABSTRACT

Previous research using dual-task paradigms indicates balance-impaired older adults (BIOAs) are less able to flexibly shift attentional focus between a cognitive and motor task than healthy older adults (HOA). Shifting attention is a component of executive function. Task switch tests assess executive attention function. This multivariate study asked if BIOAs demonstrate greater task switching deficits than HOAs. A group of 39 HOA (65–80 years) and BIOA (65–87 years) subjects performed a visuo-spatial task switch. A sub-group of subjects performed a dual-task obstacle avoidance paradigm. All participants completed the Berg Balance Scale (BBS) and Timed Up and Go (TUG). We assessed differences by group for: (1) visuo-spatial task switch reaction times (switch/no-switch), and performance on the BBS and TUG. Our balance groups differed significantly on BBS score ($p < .001$) and switch reaction time ($p = .032$), but not the TUG. This confirmed our hypothesis that neuromuscular and executive attention function differs between these two groups. For our BIOA sub-group, gait velocity correlated negatively with performance on the switch condition ($p = .036$). This suggests that BIOA efficiency of attentional allocation in dual task settings should be further explored.

1. Introduction

Dual-task paradigms are used to test if older adult gait may become unstable in complex environments due to difficulty flexibly shifting focus from a cognitive task to balance control when balance is threatened. Balance dysfunction has been correlated with an increase in the probability of falls in older adults. Such falls can result in inactivity [1], loss of independence, and death [2]. Research during the last 20 years has focused on investigating the cause of this increased probability of falls, with the goal of developing preventive and rehabilitation programs. Early studies hypothesized there would be a single cause of falls for each individual (e.g., vertigo, sensory neuropathy, postural hypotension) [3]. However, recent studies indicate falls result from multiple intrinsic and extrinsic (environmental) factors. Primary intrinsic factors include inactivity-induced weakness [1], delayed or reduced muscle activations, and inappropriately organized muscle responses to balance threats [4]. Another important intrinsic factor contributing to instability in BIOAs is impairment of attentional processing [5–11]. Stride time variability has been shown to be positively correlated with the Stroop task reaction time, a measure of executive attention function; more stable gait is associated with fast Stroop reaction times [5]. Additionally, recurrent falls have been correlated with degraded executive function as measured by Trail Making A and B, and the Digit Symbol and Block Design of the Adult Wechsler Adult Intelligence Scale [6–8]. Isolating specific aspects of executive function that are deficient in BIOAs is necessary for both clinical testing to predict fall probability and to skillfully target intervention training of older adults who are at risk for falls [12].

Evidence suggests that many falls in BIOAs occur when they are walking while simultaneously performing a secondary task [9]. It has been hypothesized that these falls are due to an inability to allocate attention between tasks during multi-task conditions [10,11], an aspect of executive attention [13]. Secondary tasks have included visual or auditory reaction time (RT), the Stroop [5], verbal memory, and simple math calculations, such as counting backwards by threes [12]. This evidence suggests that postural control is more attentionally demanding in older compared to young adults, with older adults demonstrating poorer performance on a secondary task performed during postural, balance or gait activities. In addition, a secondary task produces greater decrements in postural control in older compared to young adults [7,14]. Experiments also suggest the effect of a secondary task on postural

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control depends on many factors, including the complexity of the secondary task, the difficulty of the postural task, and the age and balance abilities of the participant [14–17].

Siu et al. [11] asked healthy young, HOA, and BIOA participants to simultaneously perform an obstacle crossing and an attentionally demanding auditory Stroop task. Young and healthy older adults were able to shift attention and improve performance on either the postural or cognitive task according to prioritization instructions. BIOAs demonstrated deficits in flexibly shifting their attention between the two tasks [11]. These results contribute to the literature that suggests BIOAs have deficits within the executive attention system.

Executive attention function has been dissociated into three main components: shifting, inhibition, and updating [18]. Task switch tests isolate the shifting and inhibition functions of executive attention [19,20]. The assumption is that executive attention processes are activated during the switch trials but not the no-switch trials. Do BIOAs show longer reaction times than healthy older adults when switching tasks? Do switch trials take significantly longer than no-switch trials for BIOAs compared to HOAs (see Fig. 2b)? This would suggest that BIOA executive attention components of shifting and inhibition are degraded due to something other than normal aging [17–20]. Thus, this study compares HOA and BIOA performance on a visuo-spatial task switch test [18–20]. We hypothesized that if problems with visuo-spatial task-switching contribute to dual-task attention allocation deficits in BIOAs, they would show significantly slower RTs compared to HOAs. We further predicted that this decrement would correlate with poor balance performance as quantified by the Berg Balance Scale (BBS).

2. Materials and methods

2.1. Participants

We combined subjects from two previous studies in our lab with newly recruited subjects. Study 1 included 12 BIOAs and 12 HOAs and tested their ability to allocate attention during dual task obstacle avoidance [11]. Study 2 included 23 BIOAs. It evaluated the effects of 4 weeks of attention allocation training on attention function and standard posture and gait tasks [12]. These subjects also performed an obstacle avoidance task, and were tested with a visuo-spatial task switch. Seventeen of those BIOA subjects were included in this study. Five were excluded due to corrupt data files. We recruited Study 1 HOA and BIOA subjects with the goal of administering the same visuo-spatial task switch test used in Study 2. Unfortunately, only five and seven of these BIOAs and HOAs respectively were available for testing. We recruited 11 more HOAs to increase statistical power and balance the HOA and BIOA groups. One newly recruited HOA was excluded due to a BBS score below our cutoff of 52. We did not include this subject as a BIOA because he had no history of falls. Thus, BBS score, TUG speed, and visuo-spatial task switch and no-switch reaction times from 39 total subjects were compared by group (see Table 1). All subjects were $\geq$65 years of age (HOA 71.87 $\pm$ 1.32; BIOA 76.64 $\pm$ 1.12). All subjects were of similar height and weight: Study 1 HOA Ht 167 $\pm$ 9, Wt 71 $\pm$ 13; BIOA Ht 160 $\pm$ 6, Wt 69 $\pm$ 13. Study 2 BIOA Ht 162 $\pm$ 9, Wt 67 $\pm$ 11. Study 3 HOA Ht 166 $\pm$ 9, Wt 66 $\pm$ 10. In order to isolate executive attention function from known contributors to gait dysfunction, exclusion criteria for all subjects included no clinical or self-reported history of neurological or musculoskeletal diagnoses, including stroke or Parkinson's disease [11,12]. All BIOA subjects drawn from both previous studies had a self-reported history of one or more falls within the past year, scored <52 on the BBS, and scored >24 on the Mini-Mental State Examination (MMSE). The cutoff of <52 on the BBS indicates a 40% probability of falls [11,21]. All BIOAs were cleared by their physicians for participation. All HOAs scored >52 on the BBS and had no self-reported history of falls or balance impairment. Sixteen HOAs scored >24 on the MMSE. Nine newly recruited HOAs received the Telephone Mini-Mental State Examination [22]. One newly recruited HOA participant was unavailable for MMSE testing. All subjects were recruited from the Eugene and Springfield Oregon communities. Subject recruitment and experimental protocol was approved by the University of Oregon Institutional Review Board (UOIRB). Subjects were compensated for their participation and signed Informed Consent forms approved by the UOIRB.

2.2. Study design and procedure

2.2.1. Visuo-spatial task switching (VSTS) paradigm

The VSTS [20] we utilized required response rule switching [19]. Participants were trained in two different response rules (Rules 1 and 2) that indicated the spatial location of a randomly appearing dot within a fixation rectangle. For Rule 1, the button press response was compatible with the dot's location in space. For Rule 2 the button press was incompatible with the dot's location in space. For the Switch test (Rule 3) participants switched between Rule 1 and 2 on every other trial. Trials in which a switch of response rule was required were designated switch trials. Other trials were designated no-switch trials. Participants were not cued to switch rules; thus this test required working memory and the executive attention components of updating, shifting, and inhibition [18] (Fig. 1).

Stimuli were displayed on a computer monitor located ~60 cm in front of the participant. Participants responded to target appearance using the number pad of a keyboard. For Rule 3 participants were provided with visual feedback in the case of erroneous responses. They corrected their error and continued the trial block. A criterion of 85% accuracy was set as a lower limit. In practice, most subjects performed at >90% accuracy during their practice blocks. The goal was to make sure that subjects understood and could confidently execute the test. Rules 1 and 2 consisted of 48 trials in two blocks. Rule 3 (the actual task switch) consisted of four blocks of 48 trials. All tests were administered from the same instruction script on a Macintosh computer (350 MHz iMac G3).

Table 1
Participants by Study.

Study	Group	
	BIOA	HOA
1 (11)	5 (all female)	7 (4 female)
2 (12)	7 (15 female)	
New HOAs		10 (8 female)
Total subjects	22	17

BIOA, Balance impaired older adult; HOA, Healthy older adult.
All subjects completed the Mayr Visuo-spatial task switch test, Mini-Mental State Examination, Berg Balance Scale, and Timed Up and Go. One newly recruited, independently living HOA was unavailable for the Telephone MMSE.

2.2.2. Balance and gait tests

Two clinical tests of balance control, the Berg Balance Scale (BBS) [21] and the Timed Up and Go (TUG) [22] were administered from the same scripts for all participants. The BBS evaluates simple neuromotor control in 14 basic postures and simple postural tasks [23]. The Timed Up and Go evaluates moving from sitting to standing, turning and walking. It is a good predictor of hip and knee functionality [24]. A subset of subjects also performed an obstacle avoidance paradigm [12].

2.2.3. Dual task gait test

Study 2 BIOAs walked at a self-selected pace 3 m, crossed an obstacle 10% of their height, and walked another 3 m. An eight camera system with 29 reflective markers (Motion Analysis Corporation, Santa Rosa, CA) captured whole body motion. Markers were placed bilaterally on bony landmarks [11,12]. Three-dimensional marker data were collected at 60 Hz. 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 [25]. Subjects completed obstacle crossing while responding to an auditory Stroop task. Subjects completed five crossings per condition (high or low pitch either congruent or incongruent with the word high or low). Trial types were randomized. Subjects reported the pitch of the voice not the meaning of the word. Average frontal plane center of mass position and ankle joint center (AJC) inclination angle were the primary kinematic observations. Accuracy, reaction time and these kinematic measures assessed gait stability and attentional allocation efficiency. These results are reported elsewhere [12].

2.3. Statistical analyses

A multivariate analysis of variance was used to test our hypothesis [26]. Age was a covariate. Dependent variables were the two conditions of Rule 3 of the VSTS: (1) switch and (2) no switch, and the (3) TUG and (4) BBS. All task switch trials were collapsed onto means for the two VSTS conditions. Often error trials are excluded from task switch studies [20]. Evidence has shown that errors are associated with longer RTs [27]. Because longer RTs when switching between motor and/or cognitive tasks during gait perturbations (avoidance or saving strategies) may exacerbate gait instability [28], we included error RTs in our data analysis. If balance impairment correlates with deficits in executive attention function, the multivariate procedure (MANOVA), which assigns multiple dependent variables weights corresponding to the amount of variance that each explains in our outcome [26], would pinpoint any differences between our two groups. *T*-tests were performed on the standard deviations seen on the switch and no-switch RTs in order to evaluate the magnitude of variability between groups. To explore the relationship between gait and switch RT, a correlation controlling for age was done for those included subjects from Study 2 [11,12]. Significance level for all tests was set at *alpha* = .05.

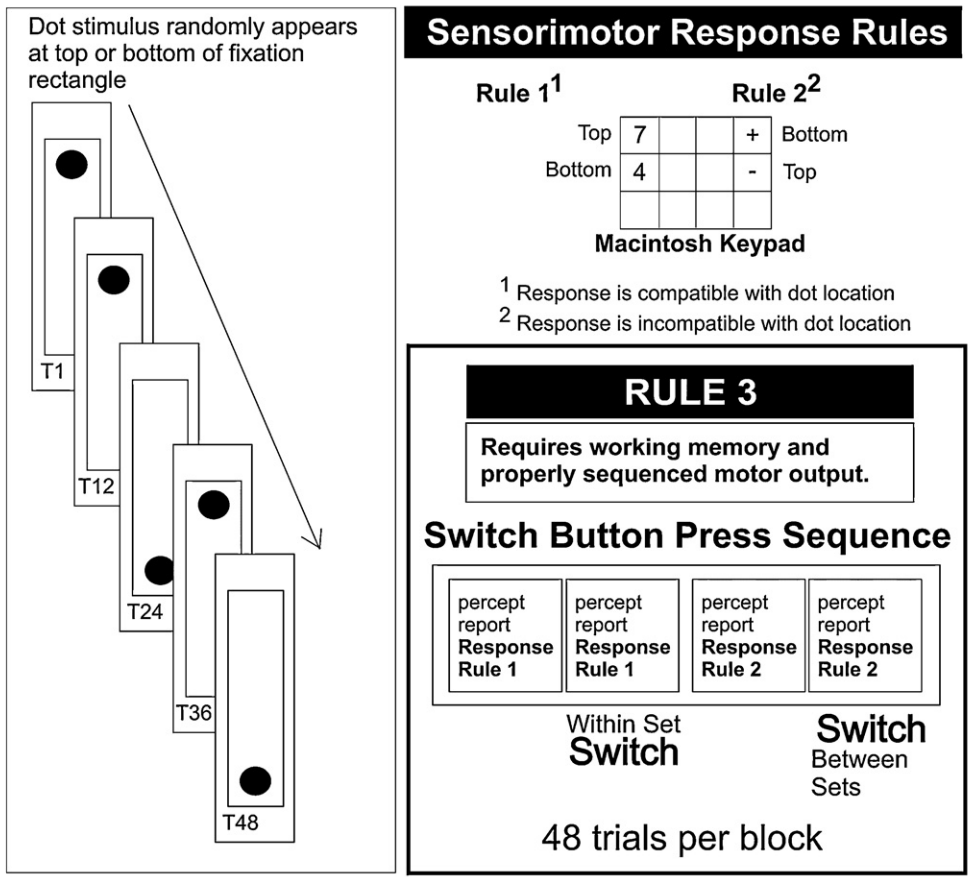


Fig. 1. A representation of the sequential steps involved in each trial of the task switch paradigm.
Response Rule 1: Subjects pressed the seven to indicate the dot had appeared at the top of the rectangle or the four to indicate the dot had appeared at the bottom of the rectangle for 2 × 48 trials.
Response Rule 2: Subjects pressed the + to indicate the dot had appeared at the bottom of the rectangle or − to indicate the dot had appeared at the top of the rectangle for 2 × 48 trials.
Switch trials: Subjects performed:•. 2 Response Rule 1RULE **SWITCH**•. 2 Response Rule 2RULE **SWITCH**
to randomly appearing dot stimuli for 4 blocks × 48 trials.

IBM SPSS Statistics version 19 (IBM Corp., Armonk, NY) was used for statistical analyses. Data met multivariate normalcy criteria for independence of observations [26].

3. Results

Means and standard deviations for clinical examination and task switch scores as well as percent variance explained by each of our key measures are reported in Table 2. In comparison to HOAs, BIOAs were significantly older ($p < .007$) and demonstrated significantly slower scores on the switch portion of the task switch test ($p = .032$).

3.1. Differences between HOA and BIOA on the task switch test, BBS and TUG

The Wilk's lambda (Λ) statistic for our whole model was significant ($F(6, 31) = 23.697$, $p < .001$) indicating that the weighted linear combination of our outcome measures was significantly different between groups. Age covariate was significant ($F(6, 31) = 3.642$, $p = .007$) (see Fig. 2a). On the balance grouping variable, the Wilk's lambda (Λ) statistic was significant ($F(6, 31) = 4.572$, $p = .002$). The *partial eta square* of our whole model was .821, indicating the weighted linear combination of our outcome variables explains 82% of the variance in our outcome.

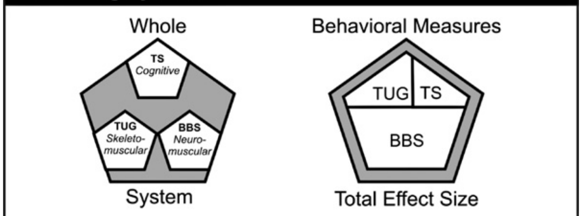
By balance group, BIOAs and HOAs differed significantly on the BBS ($F(1, 36) = 23.643$, $p < .001$) and the switch condition ($F(1, 36) = 4.974$, $p = .032$) (see Table 2). Importantly, age alone did not contribute significantly to the difference between our groups on the key switch variable ($F(1, 36) = 1.072$, $p = 307$). This confirms that when controlling for age these BIOAs performed significantly less well on the switch condition (Rule 3) than these HOAs (see Fig. 2b). BIOAs appear more variable on the task switch measures. *T*-tests comparing the standard deviations for the switch and no-switch conditions revealed BIOA and HOA variability was not statistically different ($p = .135$ and $p = .169$ respectively).

3.2. Correlations between gait velocity and task switching

For Study 2 BIOA subjects who were tested with dual-task obstacle crossing, switch RT correlated negatively with gait velocity ($r^2 = .277$, $p = .036$) (see Fig. 3).

Table 2
Variance explained, means, and standard deviations.

Interacting Systems



Total Variance explained (Partial Eta Squared) = 82%
Variance explained by Balance Group and Age Covariate

Balance	*p* = .002	*ES* = 46.9 %	Age	*p* = .007	*ES* = 41.3%
Switch	*p* = .032	*ES* = 13.5 %	Switch	*p* = .307	*ES* = 3%
No-switch	*p* = .064	*ES* = < 1%	No-switch	*p* = .562	*ES* < 1%
BBS	*p* < .001	*ES* = 47.5 %	BBS	*p* = .003	*ES* = 22%
TUG	*p* = .997	*ES* = < 1%	TUG	*p* = .003	*ES* = 21.7%

Notes
% Variance Explained = 82. %
Unexplained Variance = 18 %
ES = Effect size is *partial eta squared*.
TS = Task Switch.
Switch = TS Rule 3.
Reaction time in msec.
No-switch = TS Rule 3.
Reaction time in msec.
BBS = Berg Balance Scale (1-56)
TUG = Timed Up and Go (seconds).
BIOAs appear more variable on the TS measures. *T*-tests comparing the standard deviations for the switch and no-switch conditions revealed they were not statistically different (*p* =.135 and *p* = .169 respectively).

	M	*SD*
Switch		
BIOA	1954.18	673.80
HOA	1437.84	435.17
No-switch		
BIOA	1248.29	513.36
HOA	973.24	293.86
BBS		
BIOA	48.18	3.58
HOA	55.06	2.18
TUG		
BIOA	8.77	3.58
HOA	7.73	1.78

4. Discussion

4.1. Summary

Deficits in executive attention function have been correlated with falls in elderly subjects [5,8]. Attention allocation deficits have been shown in balance-impaired vs. healthy elders [11]. Our MANOVA confirmed that age does not account for the differences in switch or no-switch RT between our balance groups. Age and balance impairment do contribute to the differences between our groups on the BBS (22% and 47.5% of explained variance respectively, see Table 2). This suggests neuromuscular and executive attention switching deficits may interact to exacerbate gait instability in BIOAs. Evidence shows the average time to impact following a sideways slip is 626 ms [28]. If fallers are able to mitigate a fall, impact velocity and force are reduced [28]. Longer switch times interacting with an impaired neuromuscular system could increase the probability of gait instability and an inability to make timely postural adjustments to mitigate falls. To further explore this finding we conducted a correlation between gait velocity during dual task conditions and task switching performance. We hypothesized that longer switch times would correlate with slowed gait velocity. We confirmed this. There was a negative correlation between gait velocity in dual task conditions and switch RT (see Fig. 3). These BIOAs demonstrated both a slowed gait and slow attentional shifts. We also compared the scores of the subject we excluded to our group means. Recall, he did not meet either of our groups' inclusion criteria. He presented as a healthy 85 year-old adult non-faller. However, his BBS was 47 (our cutoff was 52 for inclusion in the HOA group). This score is also lower

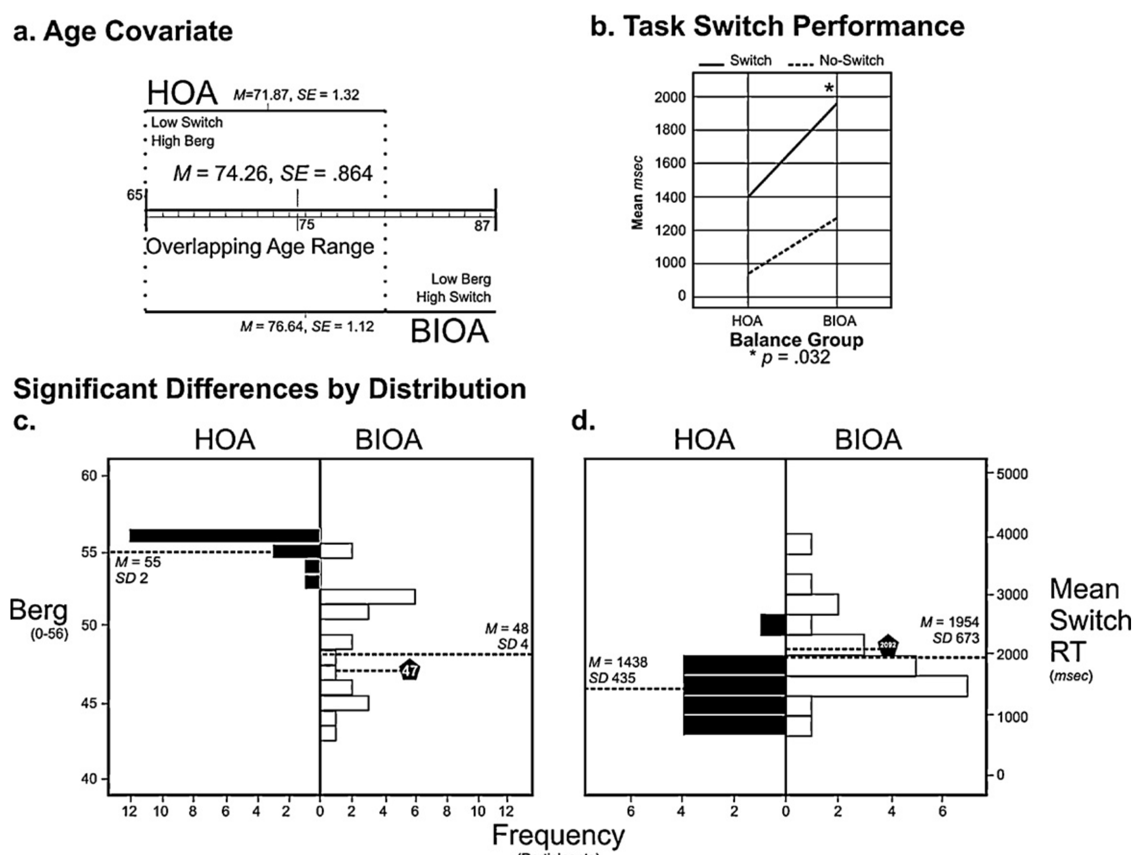


Fig. 2. (a) Overlapping age ranges for BIOAs (in black) and HOAs (in grey). HOA Age: *M* = 71.8, SE = 1.12. BIOA age: *M* = 76.64, SE = 1.12. HOA Berg range (56 is a perfect score): 52–56. BIOA Berg range: 35–55. HOA switch range: 821.60–2349.50 ms. BIOA switch range: 713.04–3670.96 ms. HOA no-switch range: 524.76–1461.81 ms. BIOA no-switch range: 565.81–2763.41 ms. (b) Comparison of HOA and BIOA performance in ms in the two key conditions of the spatial task switch paradigm: switch and no-switch trials. (c) Distribution of BBS scores by balance group. (d) Distribution of switch reaction time by balance.

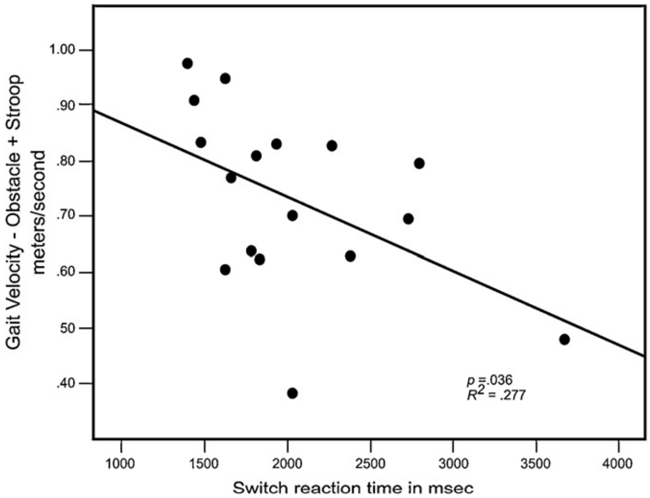


Fig. 3. Scatterplot of correlation between switch speed and gait velocity for balance impaired elder adults.

than the BIOA mean (Fig. 2c). His switch RT (2092.54 ms) was also slower than the mean BIOA switch RT (Fig. 2d). Is this person transitioning to impairment? If so, would he benefit from training found to positively affect neuromuscular functionality in the elderly [29]? Certainly balance training such as that obtained through Tai Chi classes has been shown to improve neuromuscular [29] and as well as executive attention function [30] in normally aging and impaired adults.

These results suggest slower attentional switching between a cognitive and motor task in the presence of neuromuscular deficits (lower BBS scores) may be a strong contributor to less efficient BIOA allocation of system-wide motor and attention responses during gait or balance perturbations.

4.2. Limitations

BIOAs were older than HOAs (mean age of 77 years vs. 72 years). Are age effects responsible for the switch performance seen in our BIOA subjects [20] as well as their lower BBS scores? The age covariate suggests otherwise. Age had a significant impact on the TUG ($p = .003$) and BBS ($p = .003$), but not on the switch ($p = .307$) or no-switch ($p = .562$) reaction times.

All subjects were volunteers. Our results may not generalize to non-volunteers [26]. Most of the subjects were female (33/38). Differences in bone mass, hip structure, muscle mass, and strength could affect cognitive interaction with gait differently for females than males [25].

5. Conclusions

BIOA ability to switch attention between tasks showed greater than normal aging decrements. This slower switch speed was negatively correlated with gait velocity. Since allocating attention appropriately between postural and secondary cognitive tasks when navigating in complex task environments is critical to gait stability and avoiding or mitigating falls, further studies confirming these findings are warranted. If these results are confirmed, this combination of tests may help identify patients who are likely to fall in complex environments, as well as suggest specific rehabilitation or preventive training regimens.

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Conflict of interest

No conflicts of interest exist.

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