4-19-2020

Executive function as a mediating factor between visual acuity and postural stability in cognitively healthy adults and adults with Alzheimer's dementia

Susan W. Hunter

Alison Divine

Edward Madou

Humberto Omana

Keith D Hill

See next page for additional authors

Authors
Susan W. Hunter, Alison Divine, Edward Madou, Humberto Omana, Keith D Hill, Andrew M Johnson, Jeffrey D Holmes, and Walter Wittich

Executive function as a mediating factor between visual acuity and postural stability in cognitively healthy adults and adults with Alzheimer's dementia

Susan W Hunter[a,d], Alison Divine[b], Edward Madou[a], Humberto Omana[d], Keith D Hill[c], Andrew M Johnson[d], Jeffrey D Holmes[e], Walter Wittich[f]

a. School of Physical Therapy, University of Western Ontario, London, Ontario, Canada;

b. Faculty of Biological Sciences, University of Leeds, Leeds, England;

c. Rehabilitation, Ageing and Independent Living (RAIL) Research Centre, Monash University, Melbourne, Australia;

d. School of Health Studies, University of Western Ontario, London, Ontario, Canada;

e. School of Occupational Therapy, University of Western Ontario, London, Ontario, Canada.

f. École d'optométrie, Université de Montréal, Montreal, Quebec, Canada.

Corresponding Author:

Dr. Susan W. Hunter
University of Western Ontario
School of Physical Therapy
Room 1588, Elborn College
London, ON, Canada, N6G 1H1
Phone: 519-661-2111 ext 82754
Email: susan.hunter@uwo.ca

Executive function as a mediating factor between visual acuity and postural stability in cognitively healthy adults and adults with Alzheimer's dementia

ABSTRACT

Background: Falls in older adults, notably those with Alzheimer's dementia (AD), are prevalent. Vision and balance impairments are prominent falls risk factors in older adults. However, recent literature in the cognitively impaired suggests that executive function (EF) is important for falls risk assessments. The study objectives were to: 1) to compare balance among people with AD, healthy older adults (OA), and healthy young adults (YA) and 2) to quantify the interaction of visual acuity and EF on postural stability.

Methods: We recruited 165 individuals (51 YA, 48 OA, and 66 AD). Trail Making Tests (A and B) quantified EF and the Colenbrander mixed contrast chart measured high and low contrast visual acuity. Accelerometers recorded postural sway during the Modified Test for Sensory Integration. A two-way repeated measures ANOVA examined postural sway differences across groups. Mediation analysis quantified the association of EF in the relationship between contrast sensitivity and postural sway.

Results: Significant EF and visual acuity between-group differences were observed ($p<0.001$). For postural sway, a significant interaction existed between group and balance condition ($p<0.001$). In general, EF was a significant mediator between visual acuity and postural sway. Visual acuity, EF and postural sway was worse with increased age, particularly in the AD group.

Conclusions: Mediation analysis revealed that individuals with poorer visual acuity had poorer EF, and those with poorer executive function had poorer balance control. These results highlight the importance of assessing not only vision and balance but also EF, especially in older individuals living with AD.

Keywords: Cognition, Postural Balance, Vision, Adult, Dementia.

1.0 INTRODUCTION

Falls in older adults are a major public health problem, often leading to injury, hospitalization, and mortality.[1] Factors such as increasing age, reduced vision, balance impairment and cognition impairment are related to an increased falls risk. Specifically, 60% of cognitively-impaired older adults fall at least once each year, which is twice the number of cognitively-healthy older adults that suffer a fall.[2] The underlying mechanisms for this increased occurrence of falls among the cognitively impaired are not well understood.[3] Possible explanations for the greater falls risk include the magnitudes of association for risk factors that are shared with cognitively normal older adults is greater and that there may be unique risk factors that are not present in cognitively normal adults. What *is* known, however, is that the number of older adults living with dementia is expected to increase throughout the next decade.[4] Therefore, it is critical to understand the factors associated with the increased falls risk, as this may give healthcare professionals the knowledge required to prevent falls in this population.

Postural stability is a complex process requiring the integration of sensory information through higher order cognitive domains to yield appropriate responses.[5] Impaired postural stability, as measured by the amount of postural sway, is a prominent risk factor for falls among older adults[2,6] and particularly among those with cognitive impairment.[3,7,8] Postural stability requires the combined co-ordination of muscles in response to visual, vestibular and proprioceptive sensory inputs. Vision loss may lead to decreased postural balance control. [5,9] Additionally, better visual functioning in components such as contrast sensitivity and visual acuity may help maintain balance and stability in older adults, especially under more challenging conditions.[10,11] Interestingly, others have suggested that dependence on visual information is minimal for maintaining balance in both the cognitively unimpaired and in individuals with Alzheimer's dementia (AD).[12,13]

Alternatively, Reed-Jones et al. [14] have proposed that visual cognition, which includes elements of visual attention, processing and visual-spatial ability is a large contributor to balance control. Previous studies have indicated a variety of visual dysfunctions in the context of dementia [15]. Specifically, full-contrast visual acuity is quite robust and may only be affected in later stages of AD [16–19], while contrast sensitivity appears to be a more sensitive measure, being affected in earlier stages of cognitive decline. [19–21] Therefore, measuring vision at different levels of contrast may be ecologically important, given that several channels in the cortex are involved in its processing [22], and that many activities of daily living, such as face recognition, stair climbing, or cooking, require vision across several levels of contrast. [23]

Executive function (EF) refers to a collection of processes that include awareness, processing and evaluating, planning, task execution, and self-monitoring and regulation.[24] Individuals living with AD experience a deterioration in EF, affecting all of these processes.[25,26] Recent literature has begun exploring interactions among vision, balance, EF, and fall-risk in cognitively impaired older adults.[27,28] Taylor et al. [28] found that postural sway was a mediating factor in the relationship between EF and falls in older cognitively impaired adults. However, the role of executive function in the relationship between vision and postural stability has yet to be explored.

The objectives of this study were to evaluate: 1) balance performance as measured by postural sway among people with AD, cognitively healthy older adults (OA), and healthy young adults (YA) and 2) whether EF mediates the relationship between high and/or low contrast visual acuity and postural sway. We hypothesized that postural sway would be higher (indicating worse performance) among individuals living with AD, and would increase with increasing impairments in low contrast visual acuity compared to OA and YA. We also hypothesized that EF would be a mediating factor between visual acuity and postural sway.

2.0 METHODS

2.1 Study Participants

Younger adults (YA), cognitively healthy older adults (OA), and adults with Alzheimer's dementia (AD) were recruited to participate in this study. Younger and older adults were recruited through e-newsletter postings and from a community fitness program, respectively. Participants with AD were recruited from a specialty day program for adults with dementia. Inclusion criteria for all participants were: able to walk independently for 30 meters without the use of a mobility aid or the assistance from another person, between the ages of 18-35 for YA and above the age of 50 for OA and AD. An added inclusion criterion for AD participants was a physician confirmed diagnosis of Alzheimer's dementia. Exclusion criteria for all groups were: not able to understand instructions in English, and any neurological or musculoskeletal disorder that impacted walking mobility. Participants provided informed consent. Where a participant with AD required a substitute decision maker, the decision maker provided informed consent and the participant provided assent to participate in the study. This study was approved by the University of Western Ontario Research Ethics Board for Health Sciences Research involving Human Subjects (HSREB#108430).

2.2 Data Collection

Participants or the substitute decision maker completed socio-demographic and physical functioning questionnaires to obtain age, sex, Body Mass Index, level of education, physical activity level (sedentary, engages in physical activity less than three times a week; moderate, engages in physical activity at least three times per week; vigorous, engages in structured exercise programs for 30 minutes at least three times a week), comorbidities, and activities of daily living using Lawton-Brody Basic Activities of Daily Living (BADL) and Instrumental Activities of Daily Living (IADL) scales, in which higher scores represent better functioning.[29]

Visual cognition and EF were measured using the Trail Making Test A (TMTA) and B (TMTB).[30] TMTA consists of identifying and connecting numbers in sequence and represents visual attention. TMTB requires participants to switch between sequencing numbers and associated letters evaluating visual attention, cognitive process and mental flexibility. Both tests are timed using a stopwatch and longer times to complete the tests are associated with poorer executive functioning. [30]

Visual acuity was assessed using the Colenbrander Mixed Contrast Visual Acuity chart (Precision Vision, Woodstock, IL). Visual acuity is a measure of the highest spatial frequency (smallest letters) that can be resolved and correctly identified at full contrast (black on white) or at low contrast (grey on white) at a 40 cm viewing distance. Measuring vision at different levels of contrast is ecologically important because it is an indicator of functional abilities such as recognizing objects, detecting edges and identifying obstacles.[31] Values are based on the participant's ability to correctly identify a series of letters at decreasing size, at two levels of contrast (100% and 10%). Scores are presented in the logarithm of the minimum angle of resolution (logMAR), whereby higher values indicate poorer performance (e.g., logMAR = 0 equals normal acuity of 20/20, logMAR = 1 equates to acuity of 20/200 or legal blindness) .

Postural sway was quantified as total sway area (cm^2), proxy for the magnitude of movement of the center of mass, in the medial-lateral and anterior-posterior direction using body worn accelerometers (BioSensics™, Cambridge, MA). The accelerometers use a gyroscope (+2000 degrees) with a sample frequency of 100Hz to assess postural sway. Assessment was completed with two sensors, one on the lower leg in the frontal plane, and one around the waist centered on the lower back. Participants completed the Modified Clinical Test of Sensory Integration in Balance Test (mCTSIB).[32,33] The mCTSIB is comprised of four test conditions: 1) standing on a rigid surface with eyes open (RSEO), 2) standing on a rigid surface with eyes closed (RSEC), 3) standing on a foam (compliant) surface with eyes open (CSEO), and 4) standing on a foam (compliant) surface with eyes closed (CSEC). Participants were instructed to complete each test standing upright in a comfortable position for thirty seconds. For the compliant surface trials, a 6cm foam pad (Airex AG, Sins, Switzerland) was used.

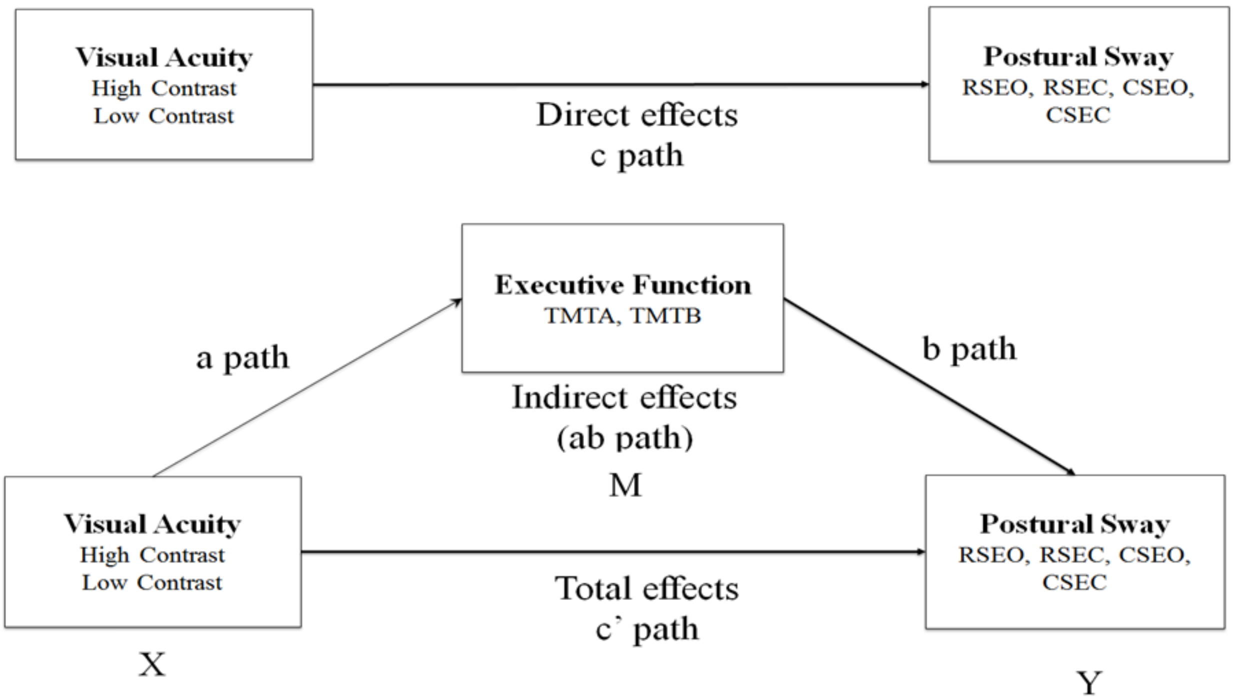
2.3 Data Analysis

Participant characteristics are summarized in table 1. One-way analysis of variance (ANOVA) and chi-square tests were used where applicable to determine between-group differences in demographic characteristics between YA, OA, and AD. Comparison of the values for high and low contrast sensitivity, Trail Making Test A and Trail Making Test B between groups was also completed using a one-way ANOVA. Post-hoc testing using Tukey HSD was conducted to determine significant pair-wise differences between groups. Effect sizes (Cohens d) were calculated to highlight the magnitude of any observed differences. Small, medium and large effect sizes are represented by values of 0.2, 0.5 and 0.8, respectively. [34]

Objective 1: The first objective comparing postural sway across mCTSIB test conditions between the three groups was evaluated using a two-way repeated measures ANOVA. The main factors were group (YA, OA, AD) as the between groups variable and balance condition (the four conditions of the mCTSIB) as the within-group variable. Post-hoc pairwise comparisons were conducted using a Bonferroni post hoc analysis where appropriate.

Objective 2: Initial analysis used a one-way ANOVA to evaluate differences across the three groups on low contrast sensitivity, high contrast sensitivity and cognition (Trail Making Tests A and B). Pairwise comparisons were then completed with a post hoc Tukey HSD analysis. Next a mediation analysis was performed to evaluate how high and low contrast visual acuity exert an effect on the outcome variable (postural sway) through our proposed causally linked mediator intervening variable of executive function.[35] Separate mediation analyses were conducted for both high and low contrast acuity and for each balance condition and measure of executive function – for a total of 16 models. High and low contrast acuity were the independent variables, total sway area in each balance condition were the dependent variables and cognitive function (TMTA and TMTB) were the mediators. The analysis was performed using the command "PROCESS"[35] with 5,000 bootstraps. PROCESS, an ordinary least squares and logistic regression path analysis modeling tool, employs bootstrapping to estimate the size of direct and indirect effects using adjusted percentile (asymmetrical) confidence intervals.[35] The total effect (c) quantifies the effect of acuity on postural sway. The indirect effect (ab) is the mediation effect, which is the effect of acuity on postural sway through executive function. The direct effect (c') is the effect of acuity on postural sway independent of the mediator executive function. The mediation model is presented in Figure 1. Significance of the indirect effect was tested using a bias –corrected bootstrap confidence interval based on 1,000 bootstrap samples in which the mediation effect is considered significant if the confidence interval does not cross zero. All statistical analyses were performed using SPSS (version 25.0; IBM Corporation, Armonk, NY).

Figure 1: Mediation regression model for assessment of cognition as a mediator in the relationship between visual acuity and postural sway.



Note. TMTA, Trail Making Test A; TMTB, Trail Making Test B; direct effects (path c), the relationship between visual acuity and postural sway; indirect effects (path ab), the effects of visual acuity on postural sway through the mediator (executive function); direct effects (path c'), the remaining effect of visual acuity on postural sway after taking into account executive function as the mediator.

3.0 RESULTS

A total of 165 participants- 51 YA (Age: 25.65 ± 6.59, n=40 female), 48 OA (69.23 ± 12.13, n=38 female), and 66 AD (82.27 ± 8.30, n= 28 female) were recruited. Overall analysis revealed significant differences for each variable between each group. (Table 1). Participants with AD were older and scored lower on IADL and BADL compared to OA and YA (OA d=4.47, 0.89 YA d=5.39, 0.92), which is consistent with factors that define a dementia diagnosis. Additionally, individuals with AD had less education (YA d=1.94, OA d=1.15) and were less physically active than YA. OA in comparison to YA tended to have a larger BMI (d= -1.21), were less educated (d=0.41), score lower on IADL (d=0.21) and BADL (d=0.21), and be less active.

All one-way ANOVA analyses comparing contrast acuity and Trail Making Test scores were statistically significant ($p<0.001$) and post-hoc pairwise comparisons were completed for each variable. For high contrast acuity, the AD group had poorer scores (0.31±24 logMAR) compared to YA (0.00±0.05 logMAR, $p=0.009$) and OA (0.14±0.12 logMAR, $p<0.001$) groups; however, there was no significant difference between YA and OA groups ($p=0.844$). For low contrast acuity, pairwise comparisons showed the AD group had poorer scores (0.55±0.28 logMAR) compared to YA (0.07±0.09 logMAR, $p<0.001$) and OA (0.34±0.17 logMAR, $p<0.001$) groups, and OA had poorer scores than YA ($p<0.001$). YA performed better on the TMTA (26.95±8.38 sec) to OA (45.57±23.00 sec) and AD (154.37±99.50 sec), while OA performed better than AD ($p<0.001$). The same pattern was observed for the TMTB, YA performed better (54.54±20.03 sec) than OA (87.59±52.15 sec) and AD (261.13±58.15 sec), and OA performed better than AD ($p<0.001$).

Postural sway was higher in those with Alzheimer's dementia, and increased across groups with increasing difficulty of the balance task. In the two-way repeated measures ANOVA, there was a significant overall interaction between the main factors of group and balance condition ($F_{3, 6} = 5.01$, $p<0.001$) which can be seen in Figure 2 and Supplementary Table 1.

The results of the mediation analysis for objective 2 with high contrast acuity are presented in Table 2. The mediation analysis for high contrast acuity demonstrated significant total effect values for TMTA and TMTB under each balance condition. This indicates that high contrast acuity does exert an effect on the amount of postural sway. Specifically, poorer scoring in high contrast acuity is associated with increased postural sway. Significant indirect effects, and non-significant direct effects were also observed for each condition except TMTA in the CSEC condition. This indicates that high contrast acuity performance alone was a poor predictor of postural sway, but affected postural sway through the mediation of Trail Making Tests A and B in all but the TMTA-CSEC condition in which high contrast sensitivity alone was a predictor of postural sway.

The mediation analysis for low contrast acuity demonstrated similar results. (Table 2) Overall, significant total effect values were observed for TMTA and TMTB under each balance condition. Significant indirect effects were observed for TMTA and TMTB under each balance condition except TMTA-CSEC. Significant direct effects were only observed for TMTA and TMTB in the CSEC condition. These results suggest that TMTA is a mediating factor of low contrast acuity on all balance conditions except CSEC and TMTB is a mediating factor of low contrast acuity on all balance conditions. Figure 3 shows a 3-D scatter plot highlighting the mediating relationship between vision, EF and balance for each group and under each balance condition.

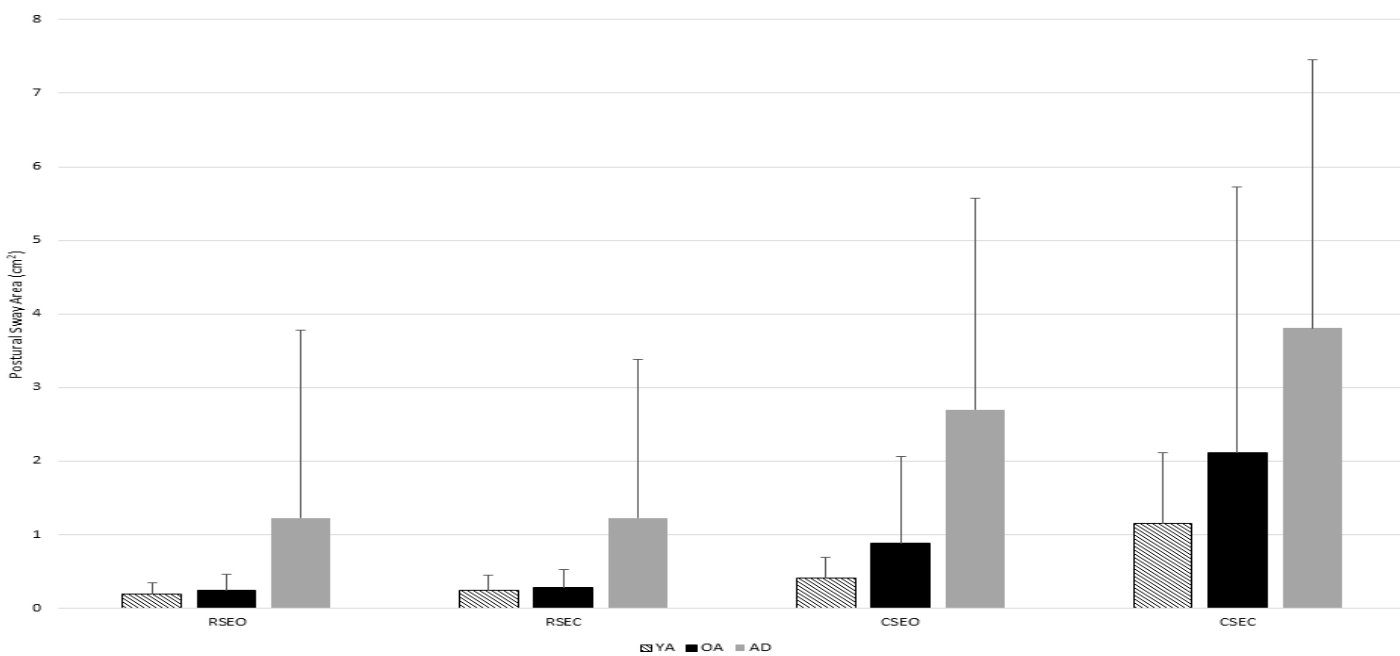
Table 1: Demographic characteristics for sample composed of three groups - young adults (YA), older adults (OA) and adults with Alzheimer's dementia (AD).

	Sample stratified by group			
Participant Characteristics	**Means ± SD or Frequency (%)**			
	YA (N=51)	**OA (N=48)**	**AD (N=66)**	**p-value***
Age (years) [A, B, C]	25.65 ± 6.59 (Min: 19.0, Max: 35.0)	69.23 ± 12.13 (Min: 50.0, Max: 91.0)	82.27 ± 8.30 (Min: 56.0, Max: 97.0)	**<.001**
Sex (female) [A, B]	40 (78%)	38 (76%)	28 (42.4%)	**<.001**
Body Mass Index(kg/m^2) [B,C]	22.72 ± 3.90	28.46 ± 5.45	26.82 ± 5.12	**<.001**
Years of Education [A,B]	17.40 ± 2.03	16.26 ± 3.77	12.24 ± 3.17	**<.001**
IADL [A, B]	8.00 ± .00	7.85 ± 1.01	1.79 ± 1.63	**<.001**
BADL [A, B]	6.00 ± .00	5.98 ± .14	5.21 ± 1.22	**<.001**

Physical activity				**<.001**
Sedentary	0 (0%)	2 (4.2%)	25 (47.9%)	
Moderate	8 (16%)	13 (27%)	30 (45.5%)	
Vigorous	43 (84%)	33 (68.8%)	11 (16.7%)	
Comorbidities				
Hypertension	0 (0%)	13 (27.1%)	18 (27.3%)	**<.001**
Osteoarthritis	0 (0%)	16 (33.3%)	19 (28.8%)	**<.001**
Hearing Problems	2 (3.9%)	11 (22.9%)	30 (45.5%)	**<.001**
Cataracts/Cataract	1 (2%)	25 (52.1%)	39 (59.1%)	**<.001**
Surgery	26 (51%)	43 (89.6%)	56 (84.8%)	**<.001**
Glasses				

Note. IADL, instrument activities of daily living; BADL, basic activities of daily living; *, Statistical analysis involved one-way ANOVA for continuous values and Chi-square test for frequencies. Post hoc Bonferroni analysis was performed for statistically significant one-way ANOVA to evaluate pair-wise relationships. Superscript letters refer to statistically significant post-hoc pair-wise comparisons: A=Sig. between AD and OA, B=Sig. between AD and YA, C=Sig. between OA and YA. Statistical significance was set at $p<0.001$ to adjust for multiple comparisons.

Figure 2: Mean postural sway (cm2) for individuals with Alzheimer's dementia (AD), older adults (OA), and younger adults (YA) under each test condition in the Modified Clinical Test for Sensory Integration in Balance.



Note. RSEO: Rigid Surface Eyes Open, RSEC: Rigid Surface Eyes Closed, CSEO: Compliant Surface Eyes Open, CSEC: Compliant Surface Eyes Closed. YA: Young Adult, OA: Older Adult, AD: Individual with Alzheimer's Dementia.

Table 2: Results of mediation analysis for Trail Making Test A (TMTA) and B (TMTB) mediating the association between high contrast visual acuity on balance in the Modified Clinical Test for Sensory Integration in Balance.

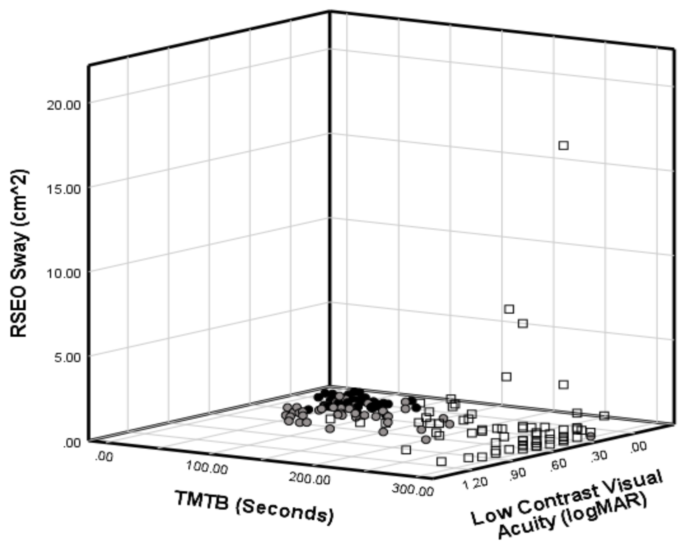
A. High Contrast Visual Acuity					
Mediator	**R^2**	**Total effects**	**Indirect effects**	**Indirect Effects CI**	**Direct effects**
Rigid surface eyes open					
TMTA	0.17**	1.57 ± .61*	2.63 ± 1.42	0.53, 5.88†	-1.06 ± .76
TMTB	0.10**	1.57 ± .61*	1.74 ± .88	0.52, 3.87†	-0.16 ± .78
Rigid surface eyes closed					
TMTA	0.15**	1.30 ± .52*	2.08 ± 1.00	0.47, 4.38†	-0.79 ± .66
TMTB	0.13**	1.30 ± .52*	1.80 ± .72	0.63, 3.38†	-0.50 ± .65
Compliant surface eyes open					
TMTA	0.19**	5.42 ± 1.05**	3.05 ± .99	1.39, 5.21†	2.37 ± 1.38
TMTB	0.20**	5.42 ± 1.05**	3.16 ± 1.23	1.22, 6.13†	2.26 ± 1.36
Compliant surface eyes closed					
TMTA	0.13 **	5.46 ± 1.14**	1.44 ± 1.56	-1.56, 4.67	4.02 ± 1.54*
TMTB	0.16**	5.46 ± 1.14**	2.62 ± 1.08	0.67, 4.97†	2.83 ± 1.48
B. Low Contrast Visual Acuity					

Mediator	R^2	Total effects	Indirect effects	Indirect Effects CI	Direct effects
Rigid surface eyes open					
TMTA	0.16**	1.31 ± 0.43*	1.49 ± 0.86	0.26, 3.56†	-0.18 ± 0.52
TMTB	0.10**	1.31 ± 0.44*	1.18 ± 0.61	0.35, 2.64†	0.13 ± 0.58
Rigid surface eyes closed					
TMTA	0.14**	1.28 ± 0.37**	1.06 ± 0.54	0.22, 2.30†	0.22 ± 0.45
TMTB	0.12**	1.28 ± 0.37*	1.09 ± 0.46	0.32, 2.11†	0.19 ± 0.49
Compliant surface eyes open					
TMTA	0.19**	3.56 ± 0.78**	2.22 ± .70	1.04, 3.83†	1.34 ± 0.94
TMTB	0.19**	3.56 ± 0.78**	2.67 ± 1.02	1.14, 5.04†	0.89 ± 1.01
Compliant surface eyes closed					
TMTA	0.16 **	4.39 ± 0.82**	0.82 ± 0.78	-.053, 2.56	3.56 ± 1.03**
TMTB	0.17**	4.39 ± 0.82**	1.62 ± .57	0.58, 2.80†	2.77 ± 1.09*

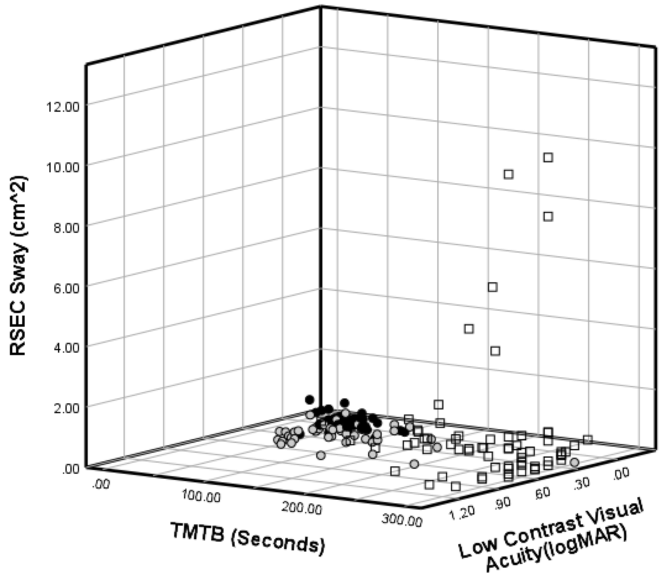
Note. *, $p<0.05$; **, $p<0.001$; †, significant confidence interval (CI).

Figure 3: 3-Dimensional scatter plot examining the relationship between visual acuity, executive function as measured by Trail Making Test B (TMTB) and postural sway in the four test conditions of the Modified Clinical Test for Sensory Integration in Balance among individuals with Alzheimer's dementia (AD, □), older adults (OA, ●), and younger adults (YA, ●).

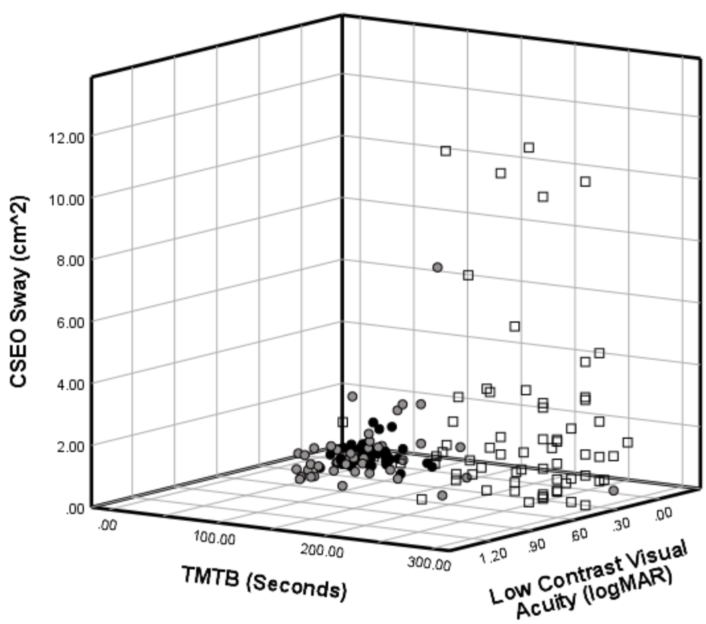
a) Rigid surface with eyes open (RSEO)



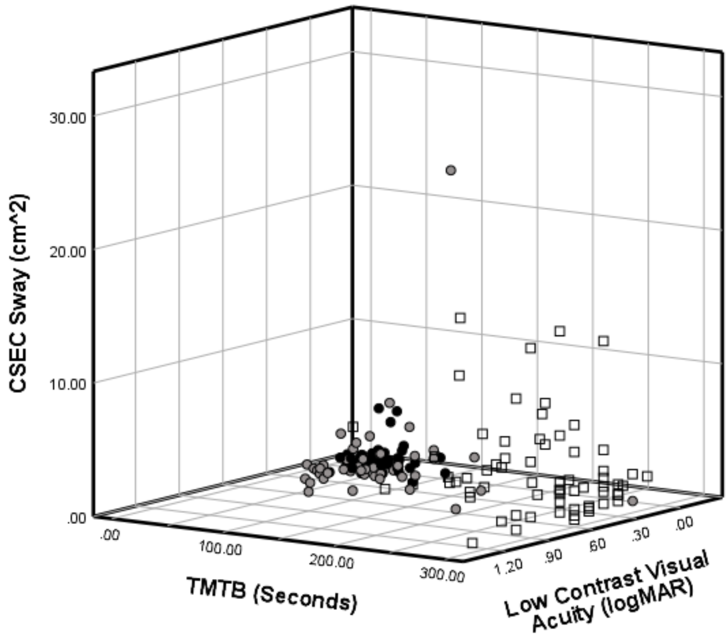
b) Rigid surface with eyes closed (RSEC)



c) Compliant surface with eyes open (CSEO)



d) Compliant surface with eyes closed (CSEC)



4.0 DISCUSSION

The first objective of this study was to compare balance performance among people with AD, cognitively healthy older adults, and healthy young adults. We observed that increasing balance task difficulty, through the progressive removal of sensory input in each of the mCTSIB test conditions, as well as increased age and cognitive impairment resulted in increased postural sway. Our second objective was to quantify the mediation of EF on the association between visual acuity and postural sway. Our results suggest that EF is a significant mediating factor of the relationship between visual acuity and postural sway under most test conditions.

The results of our mediation analysis revealed significant total effects. These results suggest a relationship between an individual's visual acuity, under different levels of contrast, and their static balance performance. However, very few direct effects were observed suggesting that acuity at high and low contrast alone may not account for changes in postural balance. Additionally, significant indirect effects were observed under all but two conditions for TMTA and all conditions for TMTB. A significant indirect effect signifies that the dependent variable of postural sway was affected by the mediator of cognition, TMTA and B. In summary, an individual's visual acuity at both high and low contrast is related to changes in postural sway but only when an individual's EF is taken into account. It may seem counter-intuitive that under closed eyes conditions visual acuity is a better predictor than TMTA; however, previous literature has reported that in those with cognitive impairment, more visual feedback can actually hinder performance on a balance task. [36] Therefore, in closed eyes conditions with no visual feedback, visual cognition as measured by TMTA, may be less significant. Our results also expand on the literature exploring the relationship between balance, EF and falls risk in older adults [28,37] by observing that an individual's visual performance as well as EF are important for determining balance impairments. Further, our results may help explain some of the contrasting literature regarding the impact of vision on balance. The results of this analysis indicate that assessing both visual and executive function performance may be essential in evaluating balance and falls risk, especially in older adults and sub-populations more susceptible to falls (i.e., those diagnosed with AD).

The results of this study are also consistent with existing literature in highlighting that increases in postural sway are associated with increased age and with AD.[38–41] Additionally, as expected, increased age and AD resulted in poorer high and low contrast acuity and EF performance. Balance and vision impairments are commonly linked to falls risk in older adults with and without cognitive impairment.[1,3,10,39,42] Recent studies have begun examining the role of EF and have highlighted that it may be an important factor in assessing falls risk.[28,37,43] The current study has expanded on previous literature by observing a mediating effect of EF between visual ability and balance performance. In most test conditions of the mCTSIB, individuals with poorer visual acuity have poorer executive function, and those with poorer executive function have worse postural control. Therefore, when assessing future falls risk, as suggested by Muir-Hunter et al. [37] EF should be an additional evaluation along with visual and balance outcomes.

This study had several limitations that should be considered in the interpretation of the findings. The people with AD were recruited from a specialty day program and therefore are not representative of all people with AD due to variations in disease severity and common comorbidities that excluded individuals from participation thus limiting generalizability. Similarly, the YA group was recruited from a local university and the OA group from a local fitness program. Thus, participants were more likely to be healthier than the general population, which may have increased the strength of the relationship between vision, executive function and balance. Healthy older adults and individuals with AD were not age or sex matched, therefore the influence of increased age or sex effects in AD participants cannot be ruled out. Additionally, we only examined static postural balance control which was depicted using one parameter of postural sway. Dynamic stability during gait or obstacle avoidance may result in different levels of contribution from vision and EF.[44,45] However, static balance was chosen as it has been shown to be a clinically viable measure of postural balance control and falls-risk.[3,39] Finally, we only measured visual acuity for two levels of contrast; it is possible that an assessment of contrast sensitivity across multiple spatial frequencies might render more informative results.[23] We suggest additional research to further refine and expand our understanding of balance and its inter-relationship with executive function and vision in this patient population, such as the examination of gender effects. There are several strengths to this study we would like to highlight. Our mediation analysis was not focused on one particular group but included the range of participants from young adults to older adults with AD with a large sample size. Therefore, these results should be generalizable to a large population. Additionally, to our knowledge this is the first study attempting to directly quantify the interaction between EF, visual acuity and balance.

5.0 CONCLUSION

Falling is a major concern to clinicians working with community-dwelling older adults and cognitively impaired individuals. Falls-risk has been associated with impairments in vision and balance. However, executive function may be another important factor to consider when assessing falls-risk. The current study observed that visual acuity at two levels of contrast (full and 10%), executive function and postural balance control all deteriorate with increasing age and with the onset of AD. Furthermore, a mediating effect was observed for EF between visual acuity and postural sway, highlighting that under most conditions individuals with poorer visual acuity had poorer EF, and those with poorer EF had poorer postural balance. Therefore, visual acuity, EF, and balance should all be considered when assessing falls-risk. Future research should attempt to examine the effect of EF training on this relationship as a possible fall prevention strategy.

DECLARATIONS OF INTEREST: none

FUNDING

This work was supported by the Alzheimer's Association (AARG-16-440671) and was not involved in the conduct of the study.

ACKNOWLEGEMENTS

The authors thank Karen Johnson, Director of McCormick Dementia Services; Steve Crawford, CEO, McCormick Care Group, Catherine Blake of McCormick Dementia Research and the staff and clients at the McCormick Dementia Services day program for their hospitality, assistance in organizing this project and participation in the data collection process.

REFERENCES

1. Stinchcombe A, Kuran N, Powell S. Seniors' falls in Canada: Second report: Key highlights. *Chronic Dis Inj Can*. 2014;34(2-3):171-174.

2. Panel for Prevention of Falls in Older Adults, American Geriatrics Society, Society BG. Summary of the Updated American Geriatrics Society/British Geriatrics Society Clinical Practice Guideline for Prevention of Falls in Older Persons. *J Am Geriatr Soc*. 2011;59(1):148-157. doi: 10.1111/j.1532-5415.2010.03234.x

3. Fernando E, Fraser M, Hendriksen J, Kim CH, Muir-Hunter SW. Risk factors associated with falls in older adults with dementia: A systematic review. *Physiother Canada*. 2017;69(2):161-170. doi: 10.3138/ptc.2016-14

4. Fernando E, Fraser M, Hendriksen J, Kim C, Hunter S. Risk factors for falls in peole with dementia: a systematic review. *Physiother Canada*. 2016;69(2):161-170. doi: 10.3138/ptc.2016-14

5. Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research into Clinical Practice*. Fifth. Wolters Kluwer India Pvt Ltd; 2016. ISBN: 9781496302632.

6. Muir SW, Berg K, Chesworth B, Klar N, Speechley M. Quantifying the magnitude of risk for balance impairment on falls in community-dwelling older adults: a systematic review and meta-analysis. *J Clin Epidemiol*. 2010;63(4):389-406. doi: 10.1016/j.jclinepi.2009.06.010

7. Hauer K, Pfisterer M, Weber C, Wezler N, Kliegel M, Oster P. Cognitive Impairment Decreases Postural Control during Dual Tasks in Geriatric Patients with a History of Severe Falls. *J Am Geriatr Soc*. 2003;51(11):1638-1644. doi: 10.1046/j.1532-

5415.2003.51517.x.

8. Mesbah N, Perry M, Hill KD, Kaur M, Hale L. Postural Stability in Older Adults With Alzheimer Disease. *Phys Ther*. 2017;97(3):290-309. doi: 10.2522/ptj.20160115

9. Gopinath B, Mcmahon CM, Burlutsky G, Mitchell P. Hearing and vision impairment and the 5-Year incidence of falls in older adults. *Age Ageing*. 2016;45(3):353-358. doi: 10.1093/ageing/afw022

10. Dhital A, Pey T, Stanford MR. Visual loss and falls: A review. *Eye*. 2010;24(9):1437-1446. doi: 10.1038/eye.2010.60

11. Lord SR, Menz HB. Visual contributions to postural stability in older adults. *Gerontology*. 2000;46(6):306-310. doi: 10.1159/000022182

12. Chong RKY, Horak FB, Frank J, Kaye J. Sensory organization for balance: Specific deficits in Alzheimer's but not in Parkinson's disease. *Journals Gerontol - Ser A Biol Sci Med Sci*. 1999;54(3). doi: 10.1093/gerona/54.3.M122

13. Kunimune S, Okada S. Contribution of vision and its age-related changes to postural stability in obstacle crossing during locomotion. *Gait Posture*. 2019;70(March):284-288. doi: 10.1016/j.gaitpost.2019.03.012

14. Reed-Jones RJ, Solis GR, Lawson KA, Loya AM, Cude-Islas D, Berger CS. Vision and falls: A multidisciplinary review of the contributions of visual impairment to falls among older adults. *Maturitas*. 2013;75(1):22-28. doi: 10.1016/j.maturitas.2013.01.019

15. Armstrong R, Kergoat H. Oculo-visual changes and clinical considerations affecting older patients with dementia. *Ophthalmic Physiol Opt*. 2015;35(4):352-376. doi:

10.1111/opo.12220

16. Uhlmann RF, Larson EB, Koepsell TD, Rees TS, Duckert LG. Visual impairment and cognitive dysfunction in Alzheimer's disease. *J Gen Intern Med*. 6(2):126-132. doi: 10.1007/bf02598307

17. Friedman DS, Munoz B, Massof RW, Bandeen-Roche K, West SK. Grating visual acuity using the preferential-looking method in elderly nursing home residents. *Investig Ophthalmol Vis Sci*. 2002;43(8):2572-2578. ISSN: 01460404

18. Ciocler Froiman P, Dantas PEC. Assessment of Visual Acuity in Patients with Dementia using Teller Acuity Cards. *Strabismus*. 2013;21(2):93-97. doi: 10.3109/09273972.2013.787634

19. Lakshminarayanan V, Lagrave J, Louise Kean M, Dick M, Shankle R. Vision in dementia: Contrast effects. *Neurol Res*. 1996;18(1):9-15. doi: 10.1080/01616412.1996.11740369

20. Crow RW, Levin LB, LaBree L, Rubin R, Feldon SE. Sweep Visual Evoked Potential Evaluation of Contrast Sensitivity in Alzheimer's Dementia. *Investig Opthalmology Vis Sci*. 2003;44(2):875. doi: 10.1167/iovs.01-1101

21. Neargarder SA, Stone ER, Cronin-Golomb A, Oross S. The impact of acuity on performance of four clinical measures of contrast sensitivity in Alzheimer's disease. *Journals Gerontol - Ser B Psychol Sci Soc Sci*. 2003;58(1):54-62. doi: 10.1093/geronb/58.1.P54

22. Campbell FW, Robson JG. Application of Fourier analysis to the visibility of gratings. *J Physiol*. 1968;197(3):551-566. doi: 10.1113/jphysiol.1968.sp008574

23. Pelli DG, Bex P. Measuring contrast sensitivity. *Vision Res*. 2013;90:10-14. doi: 10.1016/J.VISRES.2013.04.015

24. Purdy MH. Executive Functions: Theory, Assessment, and Treatment. In: *Cognitive Communication Disorders*. 2011:77-85.

25. McGuinness B, Barrett SL, Craig D, Lawson J, Passmore AP. Executive functioning in Alzheimer's disease and vascular dementia. *Int J Geriatr Psychiatry*. 2010;25(6):562-568. doi: 10.1002/gps.2375

26. Kirova A-M, Bays RB, Lagalwar S. Working Memory and Executive Function Decline across Normal Aging, Mild Cognitive Impairment, and Alzheimer's Disease. *Biomed Res Int*. 2015;2015. doi: 10.1155/2015/748212

27. Szczepańska-Gieracha J, Cieślik B, Chamela-Bilińska D, Kuczyński M. Postural Stability of Elderly People with Cognitive Impairments. *Am J Alzheimers Dis Other Demen*. 2016;31(3):241-246. doi: 10.1177/1533317515602547

28. Taylor ME, Lord SR, Delbaere K, Kurrle SE, Mikolaizak AS, Close JCT. Reaction Time and Postural Sway Modify the Effect of Executive Function on Risk of Falls in Older People with Mild to Moderate Cognitive Impairment. *Am J Geriatr Psychiatry*. 2017;25(4):397-406. doi: 10.1016/j.jagp.2016.10.010

29. Lawton MP, Brody EM. Assessment of Older People: Self-Maintaining and Instrumental Activities of Daily Living. *Gerontologist*. 1949;9(3):179–186. doi: 10.1001/jama.1949.02900240052023

30. Tombaugh TN. Trail Making Test A and B: Normative data stratified by age and

education. *Arch Clin Neuropsychol*. 2004;19(2):203-214. doi: 10.1016/S0887-6177(03)00039-8

31. Duggan E, Donoghue O, Kenny RA, Cronin H, Loughman J, Finucane C. Time to Refocus Assessment of Vision in Older Adults? Contrast Sensitivity but Not Visual Acuity Is Associated With Gait in Older Adults. *J Gerontol A Biol Sci Med Sci*. 2017;72(12):1663-1668. doi: 10.1093/gerona/glx021

32. Cohen H, Blatchly CA, Gombash LL. A Study of the Clinical Test of Sensory Interaction and Balance. *Phys Ther*. 1993;73(6):346-351. doi: 10.1093/ptj/73.6.346

33. Shumway-Cook A, Horak FB. Assessing the Influence of Sensory Interaction on Balance. *Phys Ther*. 1986;66(10):1548-1550. doi: 10.1093/ptj/66.10.1548

34. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Second. (Lawrence Erlbaum Associates, ed.). New York, NY; 1988.

35. Hayes AF. *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. Second Edi. New York, NY: The Guilford Press; 2018. ISBN: 9781462534654

36. Szczepańska-Gieracha J, Chamela-Bilińska D, Kuczyński M. Altered postural control in persons with cognitive impairment during visual feedback tasks. *Gait Posture*. 2012;35(2):312-315. doi: 10.1016/j.gaitpost.2011.10.001

37. Muir SW, Gopaul K, Montero Odasso MM. The role of cognitive impairment in fall risk among older adults: A systematic review and meta-analysis. *Age Ageing*. 2012;41(3):299-308. doi: 10.1093/ageing/afs012

38. Laughton CA, Slavin M, Katdare K, et al. Aging, muscle activity, and balance control: Physiologic changes associated with balance impairment. *Gait Posture*. 2003;18(2):101-108. doi: 10.1016/S0966-6362(02)00200-X

39. Suttanon P, Hill KD, Said CM, Dodd KJ. A longitudinal study of change in falls risk and balance and mobility in healthy older people and people with alzheimer disease. *Am J Phys Med Rehabil*. 2013;92(8):676-685. doi: 10.1097/PHM.0b013e318278dcb3

40. Liaw M-Y, Chen C-L, Pei Y-C, Leong C-P, Lau Y-C. Comparison of the static and dynamic balance performance in young, middle-aged, and elderly healthy people. *Chang Gung Med J*. 2009;32(3):297-304. ISSN: 2072-0939

41. Roman-Liu D. Age-related changes in the range and velocity of postural sway. *Arch Gerontol Geriatr*. 2018;77(September 2017):68-80. doi: 10.1016/j.archger.2018.04.007

42. Lord SR, Dayhew J. Visual risk factors for falls in older people. *J Am Geriatr Soc*. 2001;49(5):508-515. doi: 10.1046/j.1532-5415.2001.49107.x

43. Mirelman A, Herman T, Brozgol M, et al. Executive function and falls in older adults: New findings from a five-year prospective study link fall risk to cognition. *PLoS One*. 2012;7(6):1-8. doi: 10.1371/journal.pone.0040297

44. Hallemans A, Ortibus E, Meire F, Aerts P. Low vision affects dynamic stability of gait. *Gait Posture*. 2010;32(4):547-551. doi: 10.1016/j.gaitpost.2010.07.018

45. IJmker T, Lamoth CJC. Gait and cognition: The relationship between gait stability and variability with executive function in persons with and without dementia. *Gait Posture*. 2012;35(1):126-130. doi: 10.1016/j.gaitpost.2011.08.02

SUPPLEMENTARY MATERIAL

Table 1: Mean postural sway ± SD (cm^2) for individuals with Alzheimer's dementia (AD), older adults (OA), and younger adults (YA) under each test condition in the Modified Clinical Test for Sensory Integration in Balance.

Total Sway Area (cm^2)				
Group	**Rigid Surface Eyes Open (RSEO)**	**Rigid Surface Eyes Closed (RSEC)**	**Compliant Surface Eyes Open (CSEO)**	**Compliant Surface Eyes Closed (CSEC)**
Young Adults (YA)	0.19 ± 0.16	0.24 ± .21	0.41 ± 0.28	1.16 ± 0.96
Older Adults (OA)	0.25 ± 0.21	0.28 ± .24	0.89 ± 1.17	2.11 ± 3.62
Alzheimer's Dementia (AD)	1.23 ± 2.55	1.23 ± 2.15	2.70 ± 2.87	3.81 ± 3.65