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Dementia alters standing postural adaptation during a visual search task in older adult men

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Abstract

This study investigated the effects of dementia on standing postural adaptation during performance of a visual search task. We recruited 16 older adults with dementia and 15 without dementia. Postural sway was assessed by recording medial-lateral (ML) and anterior-posterior (AP) center-of-pressure when standing with and without a visual search task; i.e., counting target letter frequency within a block of displayed randomized letters. ML sway variability was significantly higher in those with dementia during visual search as compared to those without dementia and compared to both groups during the control condition. AP sway variability was significantly greater in those with dementia as compared to those without dementia, irrespective of task condition. In the ML direction, the absolute and percent change in sway variability between the control condition and visual search (i.e., postural adaptation) was greater in those with dementia as compared to those without. In contrast, postural adaptation to visual search was similar between groups in the AP direction. As compared to those without dementia, those with dementia identified fewer letters on the visual task. In the non-dementia group *only*, greater increases in postural adaptation in both the ML and AP direction, correlated with lower performance on the visual task. The observed relationship between postural adaptation during the visual search task and visual search task performance—in the non-dementia group only—suggests a critical link between perception and action. Dementia reduces the capacity to perform a visual-based task while standing and thus appears to disrupt this perception-action synergy.

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DISCLOSURES

Conflict of interest statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Keywords

postural adaptation; postural sway; visual search task; dual task; Alzheimer's disease; dementia

INTRODUCTION

In older adults, dementia is associated with decreased mobility and increased risk of falls [1,2]. The successful completion of many activities of daily living requires individuals to stand while concurrently interacting with their environment. For example, we must often stand while reading, talking and/or reaching for an object. A healthy postural control system adapts or adjusts to such dual tasking in order to optimize performance [3,4]. Intriguingly, however, optimal postural adaptation may be dependent upon the demands of the secondary task. For example, performance of tasks that require visual search may benefit from reduced postural sway, whereas other tasks (e.g. mental arithmetic) may not [5,6]. Among healthy adults, the kinematics of standing body sway changes with age [3,4,7,8,9]. Dementia may further disrupt balance and potentially increase the risk of falling [2,10], especially during situations in which individuals must simultaneously maintain their posture and perform additional cognitive tasks.

Existing research has focused on postural adaptation during performance of non-visual mental tasks [2,3,7,8,10]. Most studies report that performing this type of task increases postural sway in both healthy [8] and demented older adults [2,10]. On the other hand, both younger and older healthy adults *reduce* their postural sway when performing a standing visual search task as compared to looking at a blank board [9]. Visual search while standing is essential to many activities of daily life. It places restrictive constraints on the postural system such that a reduction in postural sway may stabilize the visual system and facilitate visual search performance [5,9]. The effect of dementia on the capacity to perform visual tasks while standing, however, is unknown. We hypothesized that in older adults, those with dementia would exhibit an impaired ability to reduce their postural motion during performance of a visual search task, relative to those without dementia. We further predicted that in general, postural adaptation during performance of a visual search task would correlate with visual search task performance.

MATERIALS AND METHODS

Subjects

Men and women aged 60-90 years were recruited from the VA Medical Center in Minneapolis, MN. Potential subjects were previously screened by a clinical team, consisting of a neurologist, gero-psychiatrist, internist, and neuropsychologist, for dementia within a 4 month period prior to study initiation. Included in the screening was the Mini-Mental State Exam (MMSE), which is both valid and reliable for initial dementia screening [11]. The research protocol was approved by the VA Medical Center and Institutional Review Board. Subjects or their guardians provided written informed consent prior to study involvement.

Inclusion criteria for the dementia group included a consensus diagnosis of Alzheimer's disease and a MMSE score of 12-23 [11,12]. Inclusion criteria for the non-dementia group included a MMSE score of 27-30 and a consensus by the clinical team as not having dementia [12]. Exclusion criteria included any other neurological or musculoskeletal disorder, physician-diagnosis of peripheral neuropathy, or significant visual impairment as defined by an inability to see presented letters within the visual search task (see Protocol subsection below).

Apparatus

Standing postural sway was assessed with a standard Wii Balance Board (Nintendo, Inc.). The Wii Board is a valid and reliable instrument to record postural motion [13,14]. The board utilizes four piezoelectric strain gauges to record center-of-pressure (COP) fluctuations in both the medial-lateral (ML) and anterior-posterior (AP) directions [13]. The board was connected to a laptop via Bluetooth capabilities. Data was recorded at 30Hz and stored on the laptop for later analysis.

Protocol

Target boards were placed 2.5 meters in front of the Wii Board at eye level. Subjects completed two 60-second trials in each of two conditions; control and visual search. The four trials were completed in random order.

In the control condition, subjects were instructed to maintain their gaze within the perimeter of a blank white target board (33.75 by 42.50 cm) [5,9]. In the visual search condition, subjects were instructed to count the frequency of a designated letter (i.e. M and T, one for each trial) in a panel of 156 randomized alphabet letters (serif typeface: Times New Roman; size: 32pt; standardized spacing) displayed on a white board of the same dimensions. The dispersion of the target letters was similar for each subject. Subjects were told to start back and "check their count" if they completed the text block before the end of the trial. At the end of each trial, the subject reported the total number of counted target letters. Of note, visual acuity was assessed prior to initiating the protocol by asking the subjects if the letters on the display were visually clear. Before each trial, subjects were instructed to remove their shoes and stand comfortably on the Wii Board with hands at their sides. No further posture-related instructions were given. The experimenter noted any instances of non-posture-related bodily movements (e.g. turning one's body or head to look at the experimenter or repositioning/folding one's arms). In order to minimize mental and physical fatigue, the first successfully completed trial (i.e. instructions were followed and non-posture related bodily movements were not observed) for each condition was used for analyses.

Data Analyses

Following Prado et al. [9], visual search task accuracy was calculated by dividing the number of reported target letters by the number of target letters within the amount of total reported letters scanned.

Postural sway variability was operationally defined as the standard deviation (SD) of COP position and was analyzed separately for the ML and AP directions. Normality of the data

was tested and as a result, the exclusion of measures that were $\pm 2SD$ outside the mean was implemented. Postural *adaptation* during performance of a visual search was quantified by calculating the absolute and percent change in both ML and AP sway variability between conditions. The percent change was calculated using the following formula:

$$\frac{\text{visual search sway variability} - \text{control sway variability}}{\text{control sway variability}} * 100$$

This calculation provided a combined measure of the ability to adapt postural sway during performance of a visual search task and also normalizes the data for subjects who may have relatively low or high postural sway variability in the control condition. In addition, this calculation allowed us to correlate postural activity with visual search task performance (See Statistical Analyses).

Statistical Analyses

Analyses were performed using JMP software (SAS Institute, Cary, NC). Descriptive statistics were used to summarize all variables. Outcomes have been expressed as mean $\pm$ SD or categorical (yes/no). Student's *t*-tests or Fisher's Exact tests were used to compare group characteristics and visual performance.

The effects of dementia on *postural adaptation* during performance of a visual search were examined using one-way ANCOVAs. Dependent variables were postural adaptations, in terms of the absolute or percent change in ML and AP sway variability between task conditions (i.e., control and visual search). The model effect was group. Models were adjusted for age, BMI and education. Significance level was set to $p=0.05$ for each outcome. Of note, for the ML axis, four subjects (2 dementia, 2 non-dementia) demonstrated sway variability measures that were greater than two SDs outside of the group mean within at least one condition and were therefore excluded from ML sway analysis. For the AP axis, one subject from the dementia group demonstrated sway variability that was greater than two SDs outside of the group mean within one condition and was therefore excluded from AP sway analysis.

The effects of dementia on sway variability were further examined using 2 $\times$ 2 repeated-measures ANCOVAs. Dependent variables included sway variability in the ML or AP direction. Model effects were group (dementia, non-dementia), condition (control, visual search) and their interaction. Age, BMI and education were included as covariates to control for potential effects of variability within these outcomes. Post-hoc Least Square Means Student's *t*-test comparisons were used for significant tests. Significance level was set to $p=0.05$ for each outcome.

Linear regression analyses were used to determine whether performance on the visual search task correlated with 1) cognitive function, as measured by the MMSE, and 2) postural adaptation during visual search (i.e., the absolute and percent change in ML and AP sway variability between task conditions). Models were adjusted for education and/or age. Significance level was set to $p=0.05$ for each outcome.

RESULTS

Group Characteristics

Despite recruiting among both males and females, all subjects included in the analyses were male (mean age 78 ± 7 years). The dementia and non-dementia groups did not differ in age, BMI, education nor presence of type 2 diabetes mellitus, hypertension or hyperlipidemia (Table 1). Within the dementia group, five initial control trials and nine initial visual search trials were not successfully completed; that is, the subject talked, turned their head away from the visual search board, adjusted their arms, etc. Within the non-dementia group, one initial visual search trial was not successfully completed. In all cases, trials were completed successfully on the second attempt and data from this trial was subsequently used for analyses.

Visual Performance

The dementia group performed worse on the visual search task as compared to the non-dementia group ($p=0.03$) (Table 1).

Postural Sway

To examine the postural adaptation during performance of a visual search, we calculated the absolute and percent change in ML and AP sway variability between task conditions. Student's *t*-test indicated no group differences in absolute and percent change in ML ($p=0.12$ and $p=0.08$, respectively) or AP ($p=0.55$ and $p=0.49$, respectively) sway variability between task conditions. However, one-way ANCOVAs controlling for age, BMI and education revealed a group effect on the absolute ($F_{1,22}=6.09$, $p=0.02$) and percent ($F_{1,22}=5.0$, $p=0.04$) change in ML sway variability. The dementia group had higher ML absolute and percent change as compared to the non-dementia group (adjusted means: $+0.10 \pm 0.03\text{cm}$ vs. $-0.02 \pm 0.03\text{cm}$ and $+109 \pm 38\%$ vs. $-6 \pm 33\%$, respectively). On the other hand, one-way ANCOVAs controlling for age, BMI and education revealed no group differences in the absolute or percent change in AP sway variability ($F_{1,24} < 1.72$, $p > 0.2$) (Table 1).

A 2×2 repeated measures ANCOVA was also used to test the effects of dementia on sway variability as a function of task condition. In the ML direction, we found a significant interaction between subject groups and visual tasks ($F_{1,18}=6.09$, $p=0.02$) (See Figure 1A). This interaction was independent of age, BMI and education. Post hoc Student's *t*-test on adjusted means revealed that when looking at the blank board (i.e., control condition), ML sway variability did not differ between groups ($p=0.31$). The visual search task did not affect sway variability in the non-dementia group, but increased sway variability in the dementia group ($p=0.01$). In the AP direction, sway variability differed between groups ($F_{1,20}=7.35$, $p=0.01$) (Figure 1B), but was not influenced by task condition. Specifically, those with dementia exhibited greater sway variability than those without dementia, irrespective of task condition. This group effect was independent of age, BMI and education.

Linear Regression Analyses

Across groups, those with lower cognitive functioning, as measured by MMSE scores, performed worse on the visual search task ($r^2_{\text{adj}}=0.16$, $p=0.02$). This association remained significant after adjusting for age and education ($r^2_{\text{adj}}=0.20$, $p=0.02$).

Within the non-dementia group, a greater absolute ($r^2_{\text{adj}}=0.34$, $p=0.03$) or percent ($r^2_{\text{adj}}=0.46$, $p=0.01$) increase of ML sway variability between conditions, or greater absolute ($r^2_{\text{adj}}=0.44$, $p<0.01$) or percent ($r^2_{\text{adj}}=0.38$, $p=0.01$) increase of AP sway variability between conditions, correlated with worse performance on the visual search task, independent of education. In older adults with dementia, however, postural adaptation during visual search was not correlated with performance on the visual search task ($r^2_{\text{adj}}<0.01$, $p>0.68$) (Figure 2).

DISCUSSION

Our results suggest that dementia influenced overall standing postural sway, as well as the participants' ability to reduce postural sway during performance of a visual search task. Older adults with dementia exhibited greater sway variability (in the AP direction) when looking at a blank white board (i.e., control condition). As compared to their non-demented counterparts, the dementia group demonstrated greater absolute and percent increase in ML sway variability between task conditions, suggesting impaired postural adaptation. Intriguingly, the non-dementia participants who performed worse on the visual search tended to demonstrate greater increases in ML and AP postural adaptations during the visual search. This relationship was not observed, however, within the dementia group. These findings together suggest that the constraints of the visual search task alter postural sway, and that dementia may disrupt this functional relationship.

Performance of activities of daily living may or may not benefit from a reduction in postural sway magnitude and can vary in the degree of postural stability required for performance [15,16]. Within the non-dementia group, participants who performed worse on the visual search task tended to exhibit greater increases in ML and AP sway variability when performing the visual search (as compared to looking at a blank board). Of note, two non-dementia participants had 100% visual search accuracy despite increasing sway variability in one or both planes (Figure 2). This could be due to a ceiling effect in which the task may have been too simple for these individuals. Nevertheless, these results support the hypothesis that postural sway was modulated to facilitate visual performance [15]. Furthermore, our results support the notion that the postural control system functions not as an autonomous system, but as part of a "perception-action synergy," i.e., a functional integration of perception, cognition and motor function in which cognitive processes are deeply rooted in the body's interactions with the world [17,18]. The fact that the relationship between postural adaptation and performance on the visual search task was not present in those with dementia suggests that cognitive impairment may disrupt integration between perception and action.

Considerable evidence indicates that cognitive impairment disrupts dual task capacity. Specifically, when asked to perform a non-visual mental task while standing [2,10] or

walking [19,20,21], older adults with dementia exhibit greater increases in standing postural sway area and path length; and an increase in gait stride time variability and slowed walking speed. Our results revealed that when performing a visual search task older adults with dementia displayed an increase in postural sway (in the ML direction), rather than a decrease typically displayed in those without dementia [9]. This finding suggests that dementia diminished participants' ability to adapt postural sway to a visual search task. Dementia therefore appears to disrupt the functional connections between postural control and cognitive activity. In this sense our results may provide insight as to why cognitive impairment is an independent risk factor for falls.

We observed that the effects of visual tasks on postural sway differed as a function of sway axes. Sway in the ML direction varied as a function of visual task condition (blank target vs. visual search). In the AP direction, sway differed between groups (sway was greater for the dementia group than for the non-dementia group), but did not differ between visual tasks. The pattern of effects in the AP and ML directions differed from some previous studies. Stoffregen et al. [6] and Prado et al. [9] found that variations in the difficulty of visual tasks affected postural sway in the AP direction but not in the ML direction in healthy young [6] and older adults [9]. The present study differed from Prado et al. [9] by the stimuli used in the visual search tasks and group characteristics. In the Prado et al. [9] study, subjects searched for target letters within a block of text, whereas the present study's target letters were embedded in a matrix of individual letters. The ages of the subjects in the Prado et al. [9] study varied from 65-75 years and were healthy and active individuals, whereas in the present study the mean age was 78 years and subjects presented with co-morbidities (e.g. type 2 diabetes, hypertension, and hyperlipidemia). Furthermore, postural control was assessed during trials of standing for 60 seconds. While adequate rest was provided and trial duration was consistent with Prado et al. [9], the present results may have nevertheless arisen from group differences in physical conditioning and ease of fatigue. Any of these reasons might account for the differences in results between studies and have mitigated the expected standing postural adaptation during performance of the visual search.

Future research

The results of the present study raise several questions that require future research. Our study was limited to standing posture. As standing postural control may be fundamentally different than sitting postural control [22], the effects of dual tasking may also differ between these conditions [3]. Existing studies have compared performance on visual and cognitive tasks during sitting and standing, but have not reported on postural sway. Thus, a full understanding of relations between sitting, standing and visual task performance requires new research in which both visual performance and postural kinematics are investigated.

Previous studies have identified a relationship between cerebrovascular mechanisms and postural control [23]. New research is needed to assess the impact of cerebrovascular co-morbidities (e.g. Type 2 diabetes mellitus and hypertension) on postural adaptation to visual search in older adults. Moreover, prospective studies are needed to determine the clinical meaningfulness of sway outcomes in order to improve the prediction of the onset of

dementia and other important outcomes such as executive dysfunction, falls and loss of independence. Finally, as our sample comprised only men, future research should determine whether similar effects are present in women.

Our results suggest that dementia alters standing postural adaptation during performance of a visual search task. This finding supports the notion that the postural control system is not autonomous, but is linked to perceptual task demand. In healthy aging, perceptual demand appears to limit postural motion specifically during a visual task while standing so as to facilitate performance on the task. The perception-action synergy with respect to postural control and visual tasks may serve as a novel assessment for dementia.

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Highlights

□ □ We examine the effects of dementia on postural adaptation during visual search. □
Dementia influences overall standing postural sway. □ Postural adaptation correlates
with task performance *only* in those non-demented. □ Dementia alters the ability to adapt
one's posture to a visual search task. □ The perception-action synergy may serve as a
novel assessment for dementia.

Figure 1. The effects of dementia on medial-lateral (ML) (A) and anterior-posterior (AP) (B) postural sway variability with and without performance of a visual search task

Figure 1A illustrates the observed interaction ($*p < 0.05$) for ML sway variability. Standing under the control task, groups had similar ML sway variability. In the dementia group, performing the visual search resulted in higher ML sway variability while the non-dementia group remained stable. Figure 1B illustrates greater AP sway variability, irrespective of task conditions. Error bars indicate standard error of the mean.

Figure 2. The relationship between visual search task accuracy (% correct) and postural adaptation during visual search in the dementia and non-dementia group

The relationship between accuracy and absolute (2A) and percent (2C) change in ML sway variability. The relationship between accuracy and absolute (2B) and percent (2D) change in AP sway variability. In the non-dementia group, those who performed worse on the visual search task tended to demonstrate greater increases in postural adaptation during visual search. This association was not present in the dementia group.

Table 1

Group characteristics and diagnostic scores

	Dementia [†] n=16	Non-Dementia [†] n=15	p
Age (yrs.)	78.5±9.1	78.2±3.9	0.91
BMI (kg/m ²)	25.1±3.6	27.2±3.2	0.14
Education (yrs.)	12.4±2.3	13.3±1.5	0.25
MMSE	18.6±2.8	28.8±0.7	<0.01*
Experimental Range	12-23	27-30	
Type 2 Diabetes Mellitus (yes/no)	2/14	5/10	0.22
Hypertension (yes/no)	10/6	9/6	0.99
Hyperlipidemia (yes/no)	12/4	11/4	0.99
Accuracy (% correct)	80.0±17.6	92.2±10.0	0.03*
Range	28.6–100.0	72.7–100.0	
Postural Adaptation			
Absolute Change (cm)			
Medial-lateral	0.05±0.15	−0.02±0.06	0.02 _x ^{†*}
Anterior-posterior	−0.05±0.29	−0.11±0.25	0.55 _x [†]
Percent Change (%)			
Medial-lateral	74.1±148.4	−3.8±38.8	0.04 _x ^{†*}
Anterior-posterior	0.1±29.3	−7.5±31.2	0.49 _x [†]

MMSE = Mini-Mental State Examination.

[†] Values reflect group unadjusted means ± SD^{*} Group characteristics and Accuracy group difference p-values result from Student's *t*-test or for categorical (yes/no) Fisher's Exact test; Postural Adaptation group difference p-values are based on one-way ANCOVAs adjusted for age, BMI and education