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Altered visual–spatial attention to task-irrelevant information is associated with falls risk in older adults

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ABSTRACT

Executive cognitive functions play a critical role in falls risk—a pressing health care issue in seniors. In particular, intact attentional processing is integral for safe mobility and navigation. However, the specific contribution of impaired visual–spatial attention in falls remains unclear. In this study, we examined the association between visual–spatial attention to task-irrelevant stimuli and falls risk in community-dwelling older adults. Participants completed a visual target discrimination task at fixation while task-irrelevant probes were presented in both visual fields. We assessed attention to left and right peripheral probes using event-related potentials (ERPs). Falls risk was determined using the valid and reliable Physiological Profile Assessment (PPA). We found a significantly positive association between reduced attentional facilitation, as measured by the N1 ERP component, and falls risk. This relationship was specific to probes presented in the left visual field and measured at ipsilateral electrode sites. Our results suggest that fallers exhibit reduced attention to the left side of visual space and provide evidence that impaired right hemispheric function and/or structure may contribute to falls.

1. Introduction

It is well known that executive cognitive functions, or higher-level processes including response inhibition, set-shifting, and working memory, play a critical role in mobility and balance (e.g., Lord, Sherrington, Menz, & Close, 2007). This relationship is illustrated in older adults who experience falls—a pressing health care issue for our aging society. Fallers have reduced global cognitive functioning (e.g., Tinetti, Speechley, & Ginter, 1988) and perform worse in laboratory tests of higher-level processing (for a review see Hsu, Nagamatsu, Davis, & Liu-Ambrose, 2012). One executive function that is essential for successful navigation through the environment is visual–spatial attention (e.g., Albert, Reinitz, Beusmans, & Gopal, 1999). For instance, visual–spatial attention during a volitional orienting task was previously found to be altered in older adults with a history of falls relative to those without such a history (Nagamatsu, Carolan, Liu-Ambrose, & Handy, 2009). Although differences in sensory processing afforded at an attended location – known as attentional facilitaton – were observed between fallers and non-fallers in the above study, it is currently unknown whether similar alterations in visual–spatial attention may exist for the implicit processing of task-irrelevant information.

Previous research has demonstrated that falls in older adults are associated with impaired attentional processing in multiple domains (Hausdorff et al., 2006; Holtzer et al., 2007; Springer et al., 2006). Why might we expect that visual–spatial attention to task-irrelevant information, specifically, would be associated with falls? First, the capacity to process external information depends on the availability of excess resources after the allocation of sufficient attention to the primary task. According to the capacity model of attention (e.g., Kahneman, 1973), we have a finite reserve of cognitive resources; the more resources a given task requires, the fewer that are available to distribute to a secondary task. This model is supported by previous studies that have demonstrated that early sensory processing of peripheral stimuli varies according to the perceptual difficulty of the task at fixation (e.g., Handy, Soltani, & Mangun, 2001). Specifically, the P1 event-related potential (ERP) component, which indexes early sensory processing and modulates as a function of attention, had reduced amplitude in response to task-irrelevant stimuli when perceptual load of the primary task was increased. Senior fallers have been proposed to possess reduced cognitive resources, as evidenced by their impaired ability to perform two tasks concurrently (i.e., dual-task)

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(e.g., Faulkner et al., 2007; Lundin-Olsson, Nyberg, & Gustafson, 1997; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Springer et al., 2006; Verghese et al., 2002). These findings suggest that fallers may not have adequate cognitive resources to dedicate to the sensory or cognitive processing of task-irrelevant information while attending to a central task.

Second, recent evidence suggests that fallers may have a “narrowed” focus of attention (Liu-Ambrose, Nagamatsu, Leghari, & Handy, 2008)—which may reduce their ability to process peripheral stimuli. Attention is often described as a spotlight, where information appearing within the spotlight is preferentially processed at a sensory (and subsequently cognitive) level, relative to information outside the spotlight (Posner, 1980). Evidence that fallers may have a narrowed spotlight of attention comes from a cross-sectional study, where fallers demonstrated superior behavioural performance compared with non-fallers on the Eriksen Flanker task (Liu-Ambrose et al., 2008), an executive task that assesses selective attention and conflict resolution (Eriksen & Eriksen, 1974). In this version of the Eriksen Flanker task, participants were required to indicate the direction that a central arrow was pointing while ignoring flanking arrows on either side of the target; trials were either congruent, with all arrows pointing in the same direction (e.g., <<<<<), or incongruent, with the central arrow pointing in the opposite direction as the distractor arrows (e.g., <<><<). Performance on this task relates to the extent to which one can ignore the task-irrelevant distractors surrounding the target. We reported that participants with a recent history of falls demonstrated less interference from incongruent trials relative to those without a history of falls (Liu-Ambrose et al., 2008). These counterintuitive results suggest that fallers may be better able to respond to central stimuli without interfering input from peripheral non-targets.

Taken together, the evidence provided above suggests that fallers may have reduced visual–spatial attention to task-irrelevant information. With approximately 30% of community dwelling seniors experiencing one or more falls per year, identifying the key cognitive contributors to falls risk will aid with the development of effective treatment and prevention strategies for reducing falls. Importantly, the neurocognitive risk factors for falls are not currently well understood. What is known, however, is that intact visual–spatial attention is critical for guiding motor functions (e.g., Handy et al., 2005). Also relevant to our present study is the notion that postural stability – the ability to maintain the position of the body within specific boundaries of space (Lord et al., 2007) – requires a complex interaction between musculoskeletal and sensory systems. Therefore, elucidating the exact visual–spatial impairments exhibited by fallers will advance our understanding of the potential underlying mechanisms that link cognitive functioning and falls. Hence, the primary aim of our current study was to examine whether visual–spatial attention to task-irrelevant stimuli is associated with falls risk in older adults.

The secondary aim of our study was to evaluate whether visual field asymmetries are associated with falls risk. We previously found that older adults with a history of falls exhibited reduced attentional facilitation during an orienting task—but that this effect was specific to the left visual field (Nagamatsu et al., 2009). Given the contralateral nature of visual processing, impaired visual–spatial attention exclusively on the left side of visual space is indicative of problems with function and/or structure of the right hemisphere. To the point, research on split-brain patients has revealed that the right hemisphere orients attention to both visual fields, whereas the left hemisphere only orients to the right side of space (e.g., Mangun et al., 1994). Hence, reduced function in the right hemisphere would result in a lack of attention to the left side of space, without adequate compensation from the left hemisphere. Thus, comparing the level of visual–spatial attention between the two visual hemifields may provide insight into the underlying neurocognitive link between attention and falls risk.

Towards addressing our specific study aims, we conducted a cross-sectional study of older adults, examining the relationship between visual–spatial attention and falls risk. Participants completed a visual target discrimination task at fixation while task-irrelevant probes were presented in the left and right periphery. Task complexity was manipulated by varying difficulty of the primary task at fixation. To ascertain the relationship between visual–spatial attention to task-irrelevant probes and falls risk, we measured ERPs during task performance. Accordingly, the ERP components of interest in our study included the P1 and N1, both of which index early sensory processing—and consequently, attentional facilitation (e.g., Mangun, Hillyard, & Luck, 1993). Key to examining visual–spatial attention in this study, these components have increased amplitudes to stimuli appearing at an attended location relative to those in an unattended location (e.g., Mangun et al., 1993). This modulation in amplitude provides us with the opportunity to infer where in visual space participants are attending at any given time. Importantly, the P1 and N1 components are functionally dissociable; whereas the P1 represents facilitation of early sensory processing, the N1 has specifically been implicated in discriminative processing (e.g., Vogel & Luck, 2000). Additionally we examined performance on the target discrimination task via reaction times, accuracy, and the P300 component. Briefly, the P300 component represents cognitive evaluation of the stimuli and is required for the maintenance of working memory (e.g., Polich, 1996). Falls risk was determined using the Physiological Profile Assessment (PPA)—a widely used measure that accounts for multiple physiological risk factors for falls (Lord, Menz, & Tiedemann, 2003). Based on our previous findings (Liu-Ambrose et al., 2008; Nagamatsu et al., 2009), we hypothesized that falls risk would be associated with reduced attentional processing to peripheral probes, and that this effect would be further characterized by hemispheric asymmetries.

2. Methods

2.1. Participants

Our study included thirty-one participants (20 female). The mean age was 75.23 ($SD = 3.43$) years. All participants had normal or corrected-to-normal vision and 27 participants were right-handed. Participants had intact cognitive functioning, as indicated by a mean MMSE score of 28.39 ($SD = 1.58$). Participants in our study were part of a large-scale cross-sectional study (CogMob) comparing cognitive profiles of senior fallers and non-fallers using functional magnetic resonance imaging (fMRI). They were recruited via advertisements in local newspapers. Upon consenting to participation in the larger study, participants were individually asked if they would be interested in completing a second, independent, sub-study. Those that agreed to be contacted were then scheduled to participate in this secondary study.

2.2. Falls risk

We assessed physiological falls risk using the Physiological Profile Assessment (PPA), which is a valid and reliable measure of falls risk (Lord et al., 2003) (Prince of Wales Medical Research Institute, AUS). The PPA is a z-score based on five separate physiological measures (hand reaction time, contrast sensitivity, proprioception, leg extension strength, and sway) to indicate relative risk of falls (Lord et al., 2003). A PPA z-score of 0–1 indicates mild risk of falls, 1–2 indicates moderate risk, 2–3 indicates high risk, and 3 and above indicates marked risk (Lord et al., 2003). The PPA has been shown to have 75% predictive accuracy for falls in older adults (Lord et al., 2003).

2.3. Descriptive measures

Descriptive measures were collected from all participants during the CogMob study. Demographic information was ascertained via questionnaire. Falls history over the past 12 months was reported based on subjective recall and corroborated by an immediate family memory or close friend. General cognitive functioning was assessed using the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). We assessed depression using the geriatric depression scale (GDS) (Yesavage, 1988) and number of comorbidities using the Functional Comorbidity Index (FCI) (Groll, To, Bombardier, 2005). Balance confidence was assessed using the activities-specific balance confidence scale (ABC) (Powell & Myers, 1995). The timed up and go test (TUG) (Podsiadlo & Richardson, 1991) was used to assess general balance and mobility. For this task, participants start from a seated position and are instructed to stand up, walk 3 m, return to their chair, and sit back down. The average time to complete the TUG on two separate trials was recorded, with faster times indicating better performance.

2.4. Procedure

Trial sequence and timing are provided in Fig. 1. Stimuli were presented on an 18 in. colour monitor approximately 100 cm from each participant. In this experiment, participants completed a visual target discrimination task at central fixation under each of two conditions: low load and high load. Each trial began with a fixation cross in the centre of the screen for 500–700 ms. Next, one of six possible stimuli appeared, with equiprobability. Targets/non-targets were presented at the centre of the screen and consisted of a bar that randomly varied by colour (purple or green) and orientation (horizontal or vertical); each configuration of the bars occurred an equal number of times within each block. Task-irrelevant probes included three by three black and white checkerboards presented on either the left or right side of the screen. Blocks consisted of 96 trials, with 16 of each trial types occurring within each block. Participants were instructed to make a manual response on a game pad (using either their left or right index finger, counterbalanced between participants) as quickly and accurately as possible if the bar at fixation matched the criteria provided to them at the beginning of the session. For the low load condition, participants were instructed to respond if the bar was a pre-specified colour (e.g., green; counterbalanced between participants), regardless of bar orientation. For the high load condition, participants were told to respond if the bar matched one of two particular colour and orientation combinations (e.g., either green and vertical or purple and horizontal; counterbalanced between participants). Participants were asked to ignore the checkerboards on the left and right side of the screen because they were tangential to the task. All participants completed eight consecutive blocks of each condition (i.e., low and high load); the order that the conditions were completed was counterbalanced between participants.

2.5. Electrophysiological recording and analysis

During task performance, electroencephalograms (EEGs) were recorded from 32 active electrodes (Bio-Semi Active 2 system) evenly distributed over the head. All EEG activity was recorded relative to two scalp electrodes located over medial-frontal cortex (CMS/DRL), which served as the ground, and the average of the two mastoids (left/right), which served as the reference. Data was recorded using a second order low pass filter of 0.05 Hz, with a gain of 0.5, and digitized on-line at a sampling rate of 256 samples-per-second. To ensure proper eye fixation and allow for the correction and/or removal of events associated with eye movement artifacts, vertical and horizontal electro-oculograms (EOGs) were also recorded, the vertical EOG from an electrode inferior to the right eye, and the horizontal EOG from an electrode on the right outer canthus.

Electrophysiological analysis was performed using ERPlab (http://erpinfo.org/erplab/), a Matlab package used in conjunction with EEGLAB (Delorme & Makeig, 2004). Continuous data was first separated into −1500 to 1500 ms epochs time-locked to stimulus presentation, then grouped into bins according to trial type.

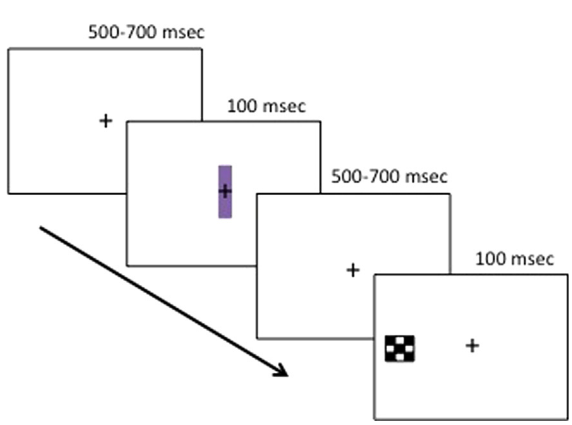

Fig. 1. Stimulus presentation and timing for the target discrimination task at fixation, with task-irrelevant probes presented in the left and right periphery.

Artifact rejection was used to eliminate epochs during which detectable eye movements, blinks, or muscle potentials occurred. For artifact rejection, the moving windows peak-to-peak option within ERPlab was implemented, with thresholds customized for each participant. Data was then low- and high-pass filtered using the IIR Buttersworth option in ERPlab, at 30 and 0.1 Hz, respectively. Statistical quantification of ERP data was based on mean amplitude measures relative to a −200 to 0 pre-stimulus baseline. Electrode sites and time windows for our ERP analyses were chosen based on the extant literature for these well-studied components (see below).

2.6. Data analysis

Behavioural performance measures comprised of accuracy and reaction times. Accuracy was assessed using *d*-prime, a measure of signal detection that corrects for response bias. Larger *d*-prime values represent better performance. Reaction times were measured for correct trials only. Faster reaction times represent better performance. Behavioural data was analyzed using paired *t*-tests to compare performance during high versus low load blocks. Our electrophysiological data was analyzed using repeated-measures ANOVAs to compare mean amplitudes of the ERP components as a function of load (high vs. low), trial type (left vs. right visual field for the P1 and N1; target vs. non-target for the P300), and electrode location. Correlations between key variables of interest were computed using Pearson's product-moment coefficient. All data was analyzed using SPSS (Version 20 for MAC), with alpha set at $p<0.05$.

3. Results

3.1. Descriptive measures and falls risk

Descriptive data are reported in Table 1. The mean PPA score was 0.45 ($SD=0.95$), indicating an overall mild risk of falls. Falls risk ranged from low risk to high risk, as exhibited by the range for PPA scores from −1.29 to 2.80. PPA scores were significantly correlated with number of falls over the past 12 months, $r(31)=0.51$, $p=0.003$, balance confidence (ABC score), $r(31)=-0.42$, $p=0.02$, and timed up and go time, $r(31)=0.47$, $p=0.008$. Correlations between PPA score and other descriptive measures were non-significant (all p's >0.05).

3.2. Behaviour

Behavioural results are presented in Table 2. One participant did not complete both experimental conditions, and was therefore excluded from analyses with "low load" as a factor. Overall, participants were faster to respond and had higher accuracy during low load blocks relative to high load. This was revealed via significant differences in performance between block types, $t(29)=13.55$, $p<0.001$ and $t(29)=4.85$, $p<0.001$, for reaction times and *d*-prime respectively.

Examining the correlations between our behavioural measures and falls risk (PPA score), we found that both reaction time and accuracy were significantly associated with falls risk—but only in the high load condition. Specifically, in high load conditions, better performance (i.e., faster reaction times and higher accuracy) was correlated with lower falls risk. The correlation between reaction time and PPA in high load condition was $r(31)=-0.37$, $p=0.04$. The correlation between *d*-prime and PPA in the high load condition was $r(31)=-0.47$, $p<0.01$. In contrast, the correlations between behavioural performance during the low load blocks and falls risk were not significant, $p=0.63$ for reaction time and $p=0.73$ for *d*-prime.

3.3. Electrophysiology

Six participants were excluded from the electrophysiological analysis due to excessive noise in their data (i.e., large pre-stimulus baseline amplitudes or high artifact rejection rates).

3.3.1. P1 ERP component

We measured the P1 ERP component time-locked to peripheral probes to assess attentional facilitation to task-irrelevant stimuli. Grand-averaged waveforms for the P1 component are presented in Fig. 2 and mean amplitudes are provided in Table 3. In our analysis, the electrode sites we used were OL+ and OR+, which are the average of lateral occipital–parietal sites (P3, P7, PO3, and O1 for OL+; P4, P8, PO4, and O2 for OR+) (e.g., Mangun et al., 1993). To accurately capture the P1 component, for each electrode site and condition, the time windows of analysis were centered on the peak amplitudes of the component in the grand-averaged waveform. For the P1, the windows were 130–170 ms post-stimulus for ipsilateral sites and 110–150 ms for contralateral sites.

For the P1 ERP component, there were no significant effects of load, visual field, or laterality, as revealed by the repeated measures ANOVA (all p's > 0.12). We examined the association between attentional facilitation and falls risk by calculating the correlations between mean amplitudes of the P1 component and PPA scores. Because there were no significant modulations of load in the repeated measures ANOVAs, we collapsed high and low load conditions. Therefore, we had four measures of interest for each component: Left and right visual probes, each measured at ipsilateral and contralateral electrode sites. There were no significant associations between P1 amplitude and PPA (all p's > 0.22).

Table 1
Descriptive information.

Variables[a]	n=31
Age, years	75.23 (3.43)
Falls history, No.	2.42 (3.60)
Education, No. (%):	
Less than grade 9	1 (3.2)
Grade 9–13 without certificate/diploma	2 (6.5)
High school certificate/diploma	0 (0.0)
Trades or professional certificate/diploma	7 (22.6)
Some University without certificate/diploma	2 (6.5)
University certificate/diploma	4 (12.9)
University degree	15 (48.4)
MoCA[b]	24.77 (2.97)
MMSE[c]	28.39 (1.58)
Timed up and go (TUG)	8.63 (3.58)
Geriatric depression scale (GDS)	0.57 (1.01)
Physiological falls risk (PPA)	0.45 (0.95)
Comorbidities	3.06 (2.10)
ABC[d]	84.68 (16.50)

[a] Data presented as mean (*SD*), unless otherwise indicated.
[b] MoCA = Montreal Cognitive Assessment; maximum 30 points.
[c] MMSE = Mini-Mental State Examination; maximum 30 points.
[d] ABC = activites-specific balance confidence scale; maximum 100 points.

Table 2
Behavioural results.

	High load (n=31)	Low load (n=30)
Reaction time (ms)	550.50 (79.80)	403.20 (59.80)**
Accuracy (d')	2.98 (0.96)	4.19 (0.79)**

** $p < 0.001$.

3.3.2. N1 ERP component

The N1 ERP component was measured time-locked to peripheral probes to assess attentional facilitation to task-irrelevant stimuli. Grand-averaged waveforms for the N1 component are presented in Fig. 2 and mean amplitudes are provided in Table 3. The same lateral occipital–parietal electrode sites were used as for the P1: OL+ and OR+. The time windows of analysis were centered on the peak amplitudes of the component in the grand-averaged waveform. For the N1, the windows were 180–220 ms for ipsilateral sites and 160–200 ms for contralateral sites.

For the N1 ERP component, amplitudes measured at electrode sites contralateral to peripheral probes were larger than at ipsilateral sites, as demonstrated via a significant main effect of laterality, $F(1,24)=34.86$, $p < 0.001$. The main effects of load and visual field were non-significant (p's > 0.24). The same method for the P1 was applied to the N1 for our correlation calculations, where the factor of load was collapsed. As can be observed in Fig. 3a, we found that a larger N1 amplitude (i.e., more negative) was associated with lower falls risk. This was confirmed via a significant correlation between falls risk and mean amplitude of the N1 for peripheral probes presented in the left visual field, measured at ipsilateral electrode sites, $r(25)=0.44$, $p < 0.03$.

3.3.3. P300 ERP component

We assessed cognitive processing to task-relevant stimuli via the P300 ERP component time-locked to central targets and non-targets. Grand-averaged waveforms for the P300 ERP component are presented in Fig. 4 and mean amplitudes are provided in Table 4. In our analysis, we used midline electrode sites (CZ, PZ, OZ) at a time window of 430–530 ms post-stimulus, centered around the peak of the P300 in the grandaveraged waveform (e.g., Eimer, 1996, 1998). Trials were separated into those with "Go" targets and those with "NoGo" non-targets. Our analysis only included those trials with correct responses.

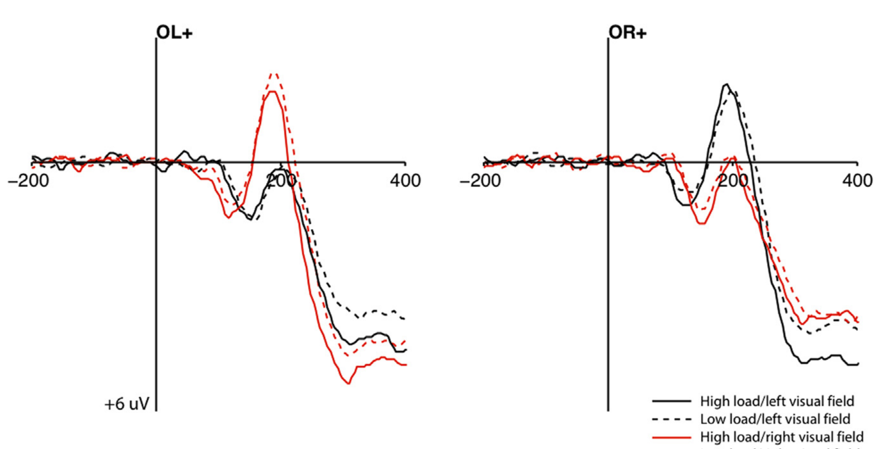

Fig. 2. ERP waveforms for the P1 and N1 components, time-locked to task-irrelevant probes, as a function of load (high versus low) and visual field presentation (left versus right). Larger N1 amplitude (i.e., more negative) was significantly associated with lower falls risk for left visual field probes measured at OL+.

Table 3
Mean amplitudes for P1 and N1 ERP components time-locked to task-irrelevant probes.

	High load (n=25)	Low load (n=25)
P1[a]		
Left ipsilateral (OL+)	1.17 (0.94)	1.19 (1.13)
Left contralateral (OR+)	0.93 (0.99)	0.67 (1.42)
Right ipsilateral (OR+)	1.24 (1.34)	0.93 (1.22)
Right contralateral (OL+)	1.11 (1.32)	0.83 (0.97)
N1		
Left ipsilateral (OL+)	0.33 (1.87)	0.35 (1.72)
Left contralateral (OR+)	−1.17 (2.00)	−0.89 (2.19)
Right ipsilateral (OR+)	0.24 (1.93)	0.04 (2.22)
Right contralateral (OL+)	−1.29 (2.36)	−1.57 (2.49)

[a] Mean amplitudes measured in uV.

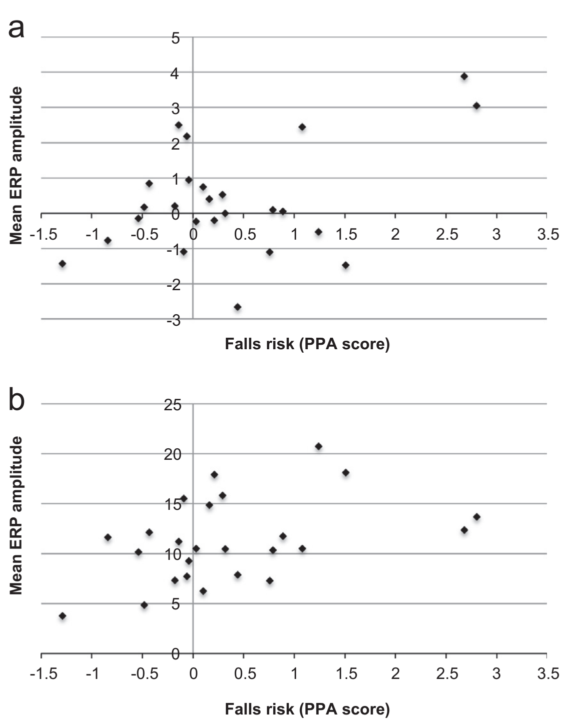

Fig. 3. Significant correlations between mean ERP amplitudes (uV) and falls risk for (a) the N1 for stimuli presented in the left visual field, measured at ipsilateral sites (OL+) and (b) for the P300 for targets presented at fixation during low load blocks.

Based on our Fig. 4, the P300 amplitude was largest at the PZ electrode site, and larger during low load blocks compared to high load, and for targets relative to non-targets. Indeed, this is what we found with main effects of load $F(1,24)=16.33$, $p<0.001$, target type $F(1,24)=15.14$, $p=0.001$, and electrode location $F(2,48)=33.08$, $p<0.001$. Furthermore, there was a significant load x target type x electrode interaction $F(2,48)=4.94$, $p=0.01$. For our correlational analysis, larger positive deflections in P300 amplitude during low load blocks were associated with higher risk of falling (see Fig. 3b). In particular, there was a significant correlation between the P300 amplitude measured at electrode site PZ and PPA score, $r(25)=0.43$, $p=0.03$. All other correlations were non-significant (p's>0.07).

3.3.4. Control analyses

To ensure that our significant correlations presented above were not caused by extreme outliers, we converted scores on the three relevant variables (PPA, N1 amplitude to left probes measured at ipsilateral sites, and P300 amplitude to targets during low load blocks) to z-scores. This revealed that there were no extreme scores (all z-scores <2.5). Furthermore, our variables were normally distributed, as indicated by both skewness and kurtosis values <1.5 for all three variables.

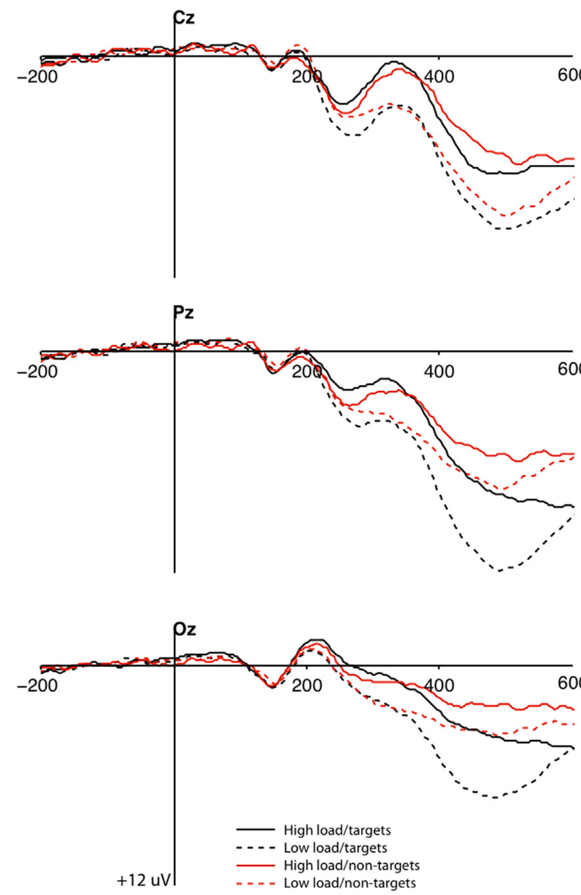

Fig. 4. ERP waveforms for the P300 component, time-locked to central targets and non-targets, as a function of load (high versus low) and trial type (targets versus non-targets). P300 amplitude was largest measured at the PZ electrode site, and for targets appearing in low load blocks.

Table 4
Mean amplitudes for P300 ERP component time-locked to central stimuli.

	High load (n=25)	Low load (n=25)
Targets[a]		
CZ	6.14 (4.96)	8.80 (5.20)**
PZ	7.50 (5.09)	11.28 (4.22)**
OZ	3.85 (4.22)	6.96 (3.75)**
Non-targets		
CZ	5.09 (4.20)	7.96 (4.30)*
PZ	5.54 (4.14)	7.04 (3.58)
OZ	2.25 (3.40)	3.64 (3.32)

[a] Mean amplitudes measured in uV.
* $p<0.05$.
** $p<0.01$.

4. Discussion

Our present study was aimed at examining the association between visual–spatial attention to task-irrelevant stimuli and falls risk in older adults. To that end, we report two main results.

The first is that falls risk was associated with reduced attentional facilitation to task-irrelevant stimuli presented in the left visual field—but this relationship was only evident in the N1 component measured at ipsilateral electrode sites.

The second result pertains to performance and processing of the task-relevant information. Specifically, increased falls risk was significantly related to poorer behavioural performance during the visual discrimination task under high load conditions. Moreover, increased falls risk was also associated with an increased level of cognitive processing for targets during low load conditions. Our results support current prevailing theories on the relationship between executive cognitive functions and falls risk, and provide insight into the specific impairments that may contribute to falls.

4.1. Primary finding

Our primary result regarding the relationship between falls risk and attentional facilitation corroborates and extends our previous finding that older adults with a history of falls have altered visual–spatial attention to the left hemifield (Nagamatsu et al., 2009). Based on the notion that the right hemisphere is exclusively responsible for orienting attention to the left side of visual space (e.g., Mangun et al., 1994), this pattern of results is consistent with what is observed in patients with left visual neglect following right hemisphere damage (e.g., Bublak, Redel, & Finke, 2006; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). Hence, our results suggest that the cognitive profile of older adults at-risk for falls resembles that of patients with visual neglect. Importantly, neglect to the left side of visual space could potentially directly lead to falls; indeed, ignoring pertinent hazards or obstacles in the environment (e.g., steps or curbs), or conversely, failing to notice useful safety tools (e.g., handrails) could impair mobility. While our current data does not allow us to make causal conclusions, the possibility that falling may stem from a mild form of visual neglect should be explored in future research.

Given that reduced attentional facilitation was specifically observed at ipsilateral electrode sites, there are at least two potential underlying factors. First it is possible that falls risk may be associated with impaired inter-hemispheric transfer of visual information across the corpus callosum. The corpus callosum is a dense bundle of neural fibres that connects the two cerebral hemispheres of the brain. Previous studies have reported a critical link between white matter integrity in the corpus callosum and both cognitive and mobility measures (e.g., Bhadelia et al., 2009; Frederiksen et al., 2011; Moscufo et al., 2011, 2012; Ryberg et al., 2011, 2007). Of particular relevance, atrophy in the splenium – a posterior region of the corpus callosum – appears to be most associated with reduced general mobility (e.g., Frederiksen et al., 2011; Moscufo et al., 2011, 2012) as measured by the Short Physical Performance Battery (SPPB) (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). Importantly, the splenium is implicated in inter-hemispheric transfer of visual and somatosensory information from occipital and posterior–inferior parietal cortices (e.g., Park et al., 2008); this information is fundamental for the integration of visual and spatial inputs to motor responses (e.g., Moscufo et al., 2011). Within this context, our data suggests that reduced attentional facilitation may be a functional consequence of atrophy in the posterior corpus callosum in those at-risk for falls.

The second potential interpretation for the observed reduction in attentional facilitation at ipsilateral electrode sites in our study is that the posterior right hemisphere may have problems with generating a signal to transfer visual information to the left hemisphere. For example, unilateral neglect is most often the result of damage to the right posterior parietal lobe—and more specifically, the inferior parietal lobule or the temporo-parietal junction (e.g., Halligan, Fink, Marshall, & Vallar, 2003). This anatomical identification of the neural basis of neglect has been corroborated by transcranial magnetic stimulation (TMS) studies (e.g., Halligan et al., 2003). Regardless of the underlying mechanism responsible for the pattern of results we have obtained, our data fits with a neglect model of hemispheric differences in attention to visual space. We note that these two possible explanations are not mutually exclusive and remain speculative; however, elucidating the role of functional and/or structural neural correlates in the relationship between visual–spatial attention and falls risk is required in future research.

4.2. Secondary finding

Our secondary result that superior behavioural performance on our visual target detection task was positively associated with lower falls risk concurs with the widely accepted cognitive profile of senior fallers. Evidence has consistently implicated cognitive impairment – and more specifically, reduced executive functioning – in falls and falls risk (e.g., Hsu et al., 2012). In our study, task performance and falls risk were only significantly correlated during the more cognitively challenging condition (i.e., high load). This is consistent with previous reports that have demonstrated that fallers have impaired performance on complex, higher-level tasks requiring response inhibition and selective attention (e.g., Liu-Ambrose et al., 2008; Lord & Fitzpatrick, 2001) In contrast, impaired performance on perceptually easy tasks – akin to our low load condition – is not characteristic of senior fallers (e.g., Woolley, Czaja, & Drury, 1997). Hence, our study lends further support to the notion that falls risk accompanies impaired executive cognitive functioning rather than a more generalized cognitive slowing.

For our electrophysiological results, we reported that an enhanced P300 mean amplitude to targets during the low load condition was associated with falls risk. Previous studies have found that the P300 modulates as a function of task difficulty, with a larger positive deflection during easy – or low load – tasks, relative to more difficult tasks (e.g., Kok, 2001; Polich, 1987). Predicated on the idea that the P300 has been proposed to index attentional resource allocation when memory updating is engaged (e.g., Polich, 1996), those at higher risk of falls may be more immersed in the primary task and less able to distribute attention. This idea certainly fits with the preexisting body of knowledge that has reported poor dual-task performance among fallers (e.g., Hsu et al., 2012). Most notably, these results apply to the low load condition, suggesting that falls risk may be associated with difficulty performing two tasks concurrently, even when the attentional demands of the primary task are low.

4.3. Additional issues

An important question worth discussing is why we failed to observe modulations in attentional facilitation to peripheral probes as a function of load on the visual target detection task. Previous studies have reported increased visual–spatial attention – as indexed by the P1 and N1 ERP components – to peripheral stimuli during low load conditions relative to high load (e.g., Handy et al., 2001). We highlight that our behavioural and electrophysiological data for the visual target detection task provide evidence that our paradigm manipulation was effective. Specifically, participants performed worse during the high load condition and P300 mean amplitude was significantly larger for low load blocks, consistent with what our expectations (e.g., Dark, Johnston, Myles-Worsley, & Farah, 1985; Kok, 2001; Polich, 1987; Yantis & Johnston, 1990). Given that the capacity and distribution of attention resources are known to change with age (e.g., Craik &

Byrd, 1982), future work regarding how attention is allocated to task-irrelevant peripheral probes in older adults is warranted.

We acknowledge the strengths and limitations of our study. First, we examined *falls risk* as a continuous variable, rather than categorizing participants as fallers versus non-fallers based on falls history. This is because memory for previous falls is subject to retrospective bias (Lachenbruch, Reinsch, MacRae, & Tobis, 1991) and dividing participants into separate groups would be prone to misclassification. Importantly, our falls risk assessment using PPA scores was reliable, given that PPA was significantly correlated with number of falls over the past 12 months, balance confidence, and timed up and go time—all of which discriminate fallers from non-fallers (e.g., Powell & Myers, 1995; Shumway-Cook, Brauer, & Woollacott, 2000). Second, while we recognize that we had a relatively small sample size in this study, we highlight that our results cannot be attributed to outliers and that our high correlations indicate a strong relationship between visual–spatial attention to task-irrelevant information and falls risk. We also had a large range of falls risk within our sample, ranging from low risk to high risk—a strength of our study, given that this allowed us to examine visual–spatial attention within the entire range of falls risk scores. Lastly, the cross-sectional nature of our study does not allow us to infer a causal relationship between visual–spatial attention and falls risk. Thus, future intervention studies with large sample sizes are required to further elucidate the potential contribution of impaired visual–spatial attention to falls risk.

4.4. Conclusion

In conclusion, our study is the first to our knowledge to provide evidence that reduced visual–spatial attention to task-irrelevant stimuli in the left visual field is associated with falls risk in older adults. It is well known that intact brain structure and function are essential for physical functioning. Surmounting evidence is implicating cognitive function as an arbiter between the brain and mobility. Importantly, impaired mobility represents a major source of disability and loss of independence among older adults. With our rapidly aging population, identifying key contributors to falls risk is becoming an increasing health care priority. While the role of cognitive functions in falls risk is now being recognized more than ever, future research should focus on determining the exact nature of the relationship between visual–spatial attention, brain structure, and falls risk.

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References

Albert, W. S., Reinitz, M. T., Beusmans, J. M., & Gopal, S. (1999). The role of attention in spatial learning during simulated route navigation. *Environment and Planning A*, *31*, 1459–1472.

Bhadelia, R. A., Price, L. L., Tedesco, K. L., Scott, T., Qiu, W. Q., Patz, S., et al. (2009). Diffusion tensor imaging, white matter lesions, the corpus callosum, and gait in the elderly. *Stroke*, *40*, 3816–3920.

Bublak, P., Redel, P., & Finke, K. (2006). Spatial and non-spatial attention deficits in neurodegenerative diseases: Assessment based on Bundesen's theory of visual attention (TVA). *Restorative Neurology and Neuroscience*, *24*, 287–301.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In: F. I.M. Craik, & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum.

Dark, V. J., Johnston, W. A., Myles-Worsley, M., & Farah, M. J. (1985). Levels of selection and capacity limits. *Journal of Experimental Psychology: General*, *114*, 472–497.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics. *Journal of Neuroscience Methods*, *134*, 9–21.

Eimer, M. (1996). ERP modulations indicate the selective processing of visual stimuli as a result of transient and sustained spatial attention. *Psychophysiology*, *33*, 13–21.

Eimer, M. (1998). Mechanisms of visuospatial attention: Evidence from event-related brain potentials. *Visual Cognition*, *5*, 257–286.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception and Psychophysics*, *16*, 143–149.

Faulkner, K. A., Redfern, M. S., Cauley, J. A., Landsittel, D. F., Studenski, S. A., Rosano, C., et al. (2007). Body Composition S. t. u. d., et al. (2007). Multitasking: Association between poorer performance and a history of recurrent falls. *Journal of the American Geriatrics Society*, *55*(4), 570–576, http://dx.doi.org/10.1111/J.1532-5415.2007.01147.X.

Frederiksen, K. S., Garde, E., Skimminge, A., Barkhof, F., Scheltens, P., van Straaten, E. C. W., et al. (2011). Corpus callosum tissue loss and development of motor and global cognitive impairment: The LADIS study. *Dementia and Geriatric Cognitive Disorders*, *32*, 279–286.

Groll, D. L., To, T., Bombardier, C., et al. (2005). The development of a comorbidity index with physical function as the outcome. *Journal of Clinical Epidemiology*, *58* (6), 595–602.

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New England Journal of Medicine*, *332*(9), 556–562.

Halligan, P. W., Fink, G. R., Marshall, J. C., & Vallar, G. (2003). Spatial cognition: Evidence from visual neglect. *Trends in Cognitive Sciences*, *7*(3), 125–133.

Handy, T. C., Schaich Borg, J., Turk, D. J., Tipper, C., Grafton, S. T., & Gazzaniga, M. S. (2005). Placing a tool in the spotlight: Spatial attention modulates visuomotor responses in cortex. *NeuroImage*, *26*, 266–276.

Handy, T. C., Soltani, M., & Mangun, G. R. (2001). Perceptual load and visuocortical processing: Event-related potentials reveal sensory-level selection. *Psychological Science*, *12*(3), 213–218.

Hausdorff, J. M., Doniger, G. M., Springer, S., Yogev, G., Giladi, N., & Simon, E. S. (2006). A common cognitive profile in elderly fallers and in patients with Parkinson's disease: The prominence of impaired executive function and attention. *Experimental Aging Research*, *32*(4), 411–429.

Holtzer, R., Friedman, R., Lipton, R. B., Katz, M., Xue, X., & Verghese, J. (2007). The relationship between specific cognitive functions and falls in aging. [Article]. *Neuropsychology*, *21*(5), 540–548.

Hsu, C. L., Nagamatsu, L. S., Davis, J. C., & Liu-Ambrose, T. (2012). Examining the relationship between specific cognitive processes and falls risk in older adults: A systematic review. *Osteoporosis International*, http://dx.doi.org/10.1007/s00198-012-1992-z.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, New Jersey: Prentice Hall.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*, 557–577.

Lachenbruch, P. A., Reinsch, S., MacRae, P. G., & Tobis, J. S. (1991). Adjusting for recall bias with the proportional hazards model. *Methods of Information in Medicine*, *30*(2), 108–110.

Liu-Ambrose, T., Donaldson, M. G., Ahamed, Y., Graf, P., Cook, W. L., Close, J., et al. (2008). Otago home-based strength and balance retraining improves executive functioning in older fallers: A randomized controlled trial. *Journal of the American Geriatrics Society*, *56*(10), 1821–1830.

Liu-Ambrose, T., Nagamatsu, L. S., Leghari, A., & Handy, T. C. (2008). Does impaired cerebellar function contribute to risk of falls in seniors? A pilot study using functional magnetic resonance imaging. *Journal of American Geriatric Society*, *56* (11), 2153–2155.

Lord, S., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls-risk assessment and prevention. *Physical Therapy*, *83*(3), 237–252.

Lord, S., Sherrington, C., Menz, H., & Close, J. (2007). *Falls in older people*. Cambridge: Cambridge University Press.

Lord, S. R., & Fitzpatrick, R. C. (2001). Choice stepping reaction time: A composite measure of falls risk in older people. *Journals of Gerontology Series a-Biological Sciences and Medical Sciences*, *56*(10), M627–M632.

Lundin-Olsson, L., Nyberg, L., & Gustafson, Y. (1997). "Stops walking when talking" as a predictor of falls in elderly people. *The Lancet*, *349*, 617.

Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. *Attention and Performance*, *14*(14), 219–243.

Mangun, G. R., Luck, S. J., Plager, R., Loftus, W., Hillyard, S. A., Handy, T., et al. (1994). Monitoring the visual world: Hemispheric asymmetries and subcortical processes in attention. *Journal of Cognitive Neuroscience*, *6*, 265–273.

Moscufo, N., Guttmann, C. R. G., Meier, D., Csapo, I., Hildenbrand, P. G., Healy, B. C., et al. (2011). Brain regional lesion burden and impaired mobility in the elderly. *Neurobiology of Aging*, *32*, 646–654.

Moscufo, N., Wolfson, L., Meier, D., Liguori, M., Hildenbrand, P. G., Wakefield, D., et al. (2012). Mobility decline in the elderly relates to lesion accrual in the splenium of the corpus callosum. *Age*, *34*, 405–414.

Nagamatsu, L. S., Carolan, P., Liu-Ambrose, T., & Handy, T. C. (2009). Are impairments in visual–spatial attention a critical factor for increased falls risk in seniors? An event-related potential study. *Neuropsychologia*, *47*, 2749–2755.

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., et al. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53* (4), 695–699.

Park, H.-J., Kim, J. J., Lee, S.-K., Seok, J. H., Chun, J., Kim, D. I., et al. (2008). Corpus callosal connection mapping using cortical gray matter parcellation and DT-MRI. *Human Brain Mapping*, *29*, 503–516.

Podsiadlo, D., & Richardson, S. (1991). The timed "up and go": A test of basic functional mobility for frail elderly persons. *Journal of American Geriatric Society*, *39*(2), 142–148.

Polich, J. (1987). Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *68*, 311–320.

Polich, J. (1996). Meta-analysis of P300 normative aging studies. *Psychophysiology*, *33*, 334–353.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.

Powell, L., & Myers, A. (1995). The activities-specific confidence (ABC) scale. *Journal of Gerontology*, *50A*(1), M28–M34.

Reuter-Lorenz, P. A., Kinsbourne, M., & Moscovitch, M. (1990). Hemispheric control of spatial attention. *Brain and Cognition*, *12*(2), 240–266.

Ryberg, C., Rostrup, E., Paulson, O. B., Barkhof, F., Scheltens, P., van Straaten, E. C. W., et al. (2011). Corpus callosum atrophy as a predictor of age-related cognitive and motor impairment: A 3-year follow-up of the LADIS study cohort. *Journal of the Neurological Sciences*, *307*, 100–105.

Ryberg, C., Rostrup, E., Stegmann, M. B., Barkhof, F., Scheltens, P., van Straaten, E. C. W., et al. (2007). Clinical significance of corpus callosum atrophy in a mixed elderly population. *Neurobiology of Aging*, *28*, 955–963.

Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the timed up and go test. *Physical Therapy*, *80*(9), 896–903.

Shumway-Cook, A., Woollacott, M., Kerns, K. A., & Baldwin, M. (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *Journal of Gerontology: Medical Sciences*, *52A*(4), M232–M240.

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E. S., & Hausdorff, J. M. (2006). Dual-tasking effects on gait variability: The role of aging, falls, and executive function. *Movement Disorders*, *21*(7), 950–957.

Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *New England Journal of Medicine*, *319* (26), 1701–1707.

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., et al. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society*, *50*(9), 1572–1576.

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, *37*, 190–203.

Woolley, S. M., Czaja, S. J., & Drury, C. G. (1997). An assessment of falls in elderly men and women. *Journal of Gerontology: Medical Sciences*, *52A*(2), M80–M87.

Yantis, S., & Johnston, J. (1990). On the locus of visual selection: Evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 135–149.

Yesavage, J. A. (1988). Geriatric depression scale. *Psychopharmacology Bulletin*, *24* (4), 709–711.