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Is Allocation of Attention Impaired in Fallers Compared to Non-Fallers? An Event-Related Potential Study

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Abstract

Approximately 30% of older adults experience one or more falls annually. The ability to properly allocate attention may be a risk factor falls. Our study examined whether older adults (aged 58-79) with a history of falls, allocated attention differently to auditory distractor stimuli compared to those without a history of falls, and whether such differences subsequently altered cognitive processing of visual target stimuli. We examined allocation of attention using event-related potentials (ERPs) as participants responded to visual targets while ignoring task-irrelevant auditory distractors. A posterior to anterior shift in electrical brain activity was exaggerated in the faller group compared to the non-faller group when cognitively processing the visual target stimuli. This suggests differences in the way stimuli are cognitively processed and classified between fallers and non-fallers.

Keywords: falls, attention, allocation, risk, EEG, ERP, cross-modal, older adults.

Co-Authorship

Work was conducted for this Master's Thesis by Phil Parrot-Migas under the supervision of Dr. Lindsay S. Nagamatsu. With guidance from Dr. Lindsay S. Nagamatsu, Phil designed the experiment, collected, analyzed, interpreted all the data and prepared the manuscript. Dr. Lindsay S. Nagamatsu helped with the revisions of this manuscript by providing helpful feedback. Phil Parrot-Migas is the first author and Dr. Lindsay S. Nagamatsu serves as a co-author.

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List of Abbreviations, Symbols and Nomenclature

ABC = Activities-Specific Balance Confidence Scale

EEG = Electroencephalography

ERP = Event Related Potential

FCI = Functional Comorbidity Index

FROP-Com = Falls Risk for Older People - Community Setting

GDS = Geriatric Depression Scale

IADL = Instrumental Activities of Daily Living

MMN = Mismatch Negativity

MMSE = Mini-Mental State Examination

MoCA = Montreal Cognitive Assessment

PASE = Physical Activities Scale for the Elderly

RON = Reorientation Negativity

SPPB = Short Physical Performance Battery

TMT = Trail Making Test; Test B – Test A

TUG = Timed Up and Go; Mean of Trial 1 & Trial 2

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Chapter 1

1 Introduction

Falls are a major health care concern, with approximately 30% of community-dwelling adults over the age of 65 experiencing one or more falls per year (Pearson et al., 2014). Substantial morbidity including decreased functioning and loss of independence are associated to non-fatal falls-related injuries (Sterling et al., 2001). In addition, falling causes more than 95% of hip fractures (Hayes et al., 1993), and over 70,000 Canadians are hospitalized each year due to fall-related injuries (Pearson et al., 2014). Therefore, identifying risk factors for falls is a health care priority.

Impaired cognitive functioning is a known risk factor for falls (Liu-Ambrose et al., 2008; Masdeu et al., 1989; Muir et al., 2012; Tinetti et al., 1988). One of the first studies to uncover the relationship between falls and cognitive function was a prospective study by Lundin-Olsson and colleagues (1997) who found that those who stopped walking when concurrently engaged in a conversation were more likely to fall during the six-month follow-up period, suggesting that they did not have the cognitive resources to simultaneously complete two activities at once. This relationship between falls and cognition has been widely studied using global measures of cognitive function, such as the Mini-Mental State Exam (MMSE) (Folstein et al., 1975). For example, individuals scoring in the impaired range (<24/30) on the MMSE are more likely to fall (Anstey et al., 2006; Deandrea et al., 2010). Furthermore, Gleason et al. (2009) found that in community-dwelling older adults, risk of falling increases for each point decrease on the MMSE.

While it has been acknowledged that impaired cognitive function is a risk factor for falls, a more specific domain of cognitive function that has gained recent interest is executive functioning. Executive functioning, which refers to higher-level cognitive skills, appears to play a major role in falls risk (Hsu et al., 2012). For example, Herman and colleagues (2010) examined the relationship between executive functioning and falls during a two-year prospective cohort study and found that those with lower executive functioning scores were three times more likely to fall per year than those with higher

executive functioning scores. Key areas of executive functioning that are related to falls risk are processing speed, set shifting, response inhibition, and attention (Anstey et al., 2006; Herman et al., 2010; Pijnappels et al., 2010; Watson et al. 2010). While looking at specific executive functions associated with falls, Lord and Fitzpatrick (2001) compared fallers to non-fallers and found that older adults with a history of falls performed significantly worse on the Trail Making B Test, demonstrating that the ability to go back and forth between multiple tasks is impaired in fallers compared to non-fallers. Furthermore, older adults with a history of falls perform significantly worse on the Stroop Color Word Test, indicating a reduced ability to suppress automatic responses (Hausdorff et al., 2006; Herman et al., 2010; Lord & Fitzpatrick, 2001).

In addition to the executive functions mentioned above, fallers also appear to have deficits in attention (Holtzer et al., 2007). Attention refers to the cognitive processes involved with orienting towards specific stimuli, the detection of stimuli for conscious processing, and the ability to maintain an alert or vigilant state (Kahneman 1973; Posner & Boies, 1971). Every day we are bombarded with a large number of stimuli from the environment and from within the body itself (e.g., stress, anxiety, proprioceptive cues, etc.), and attention governs which of the many stimuli we pay attention to (McDowd & Birren, 1990). Hausdorff et al. (2006) examined cognitive profiles of elderly fallers, and found that older adults with a history of falls experience significant cognitive changes, including impaired executive function and attention. In a prospective study interested in determining which specific cognitive processes are most strongly related to falls, the authors found the 15 Words test (15WT) to be an independent risk factor for falls (van Schoor et al., 2002). Notably, van Schoor and colleagues (2002) suggested that the ability to pay attention plays an important role when completing the 15WT and that a decrease in this ability may predict falls in older adults. Furthermore, in a study comparing fallers to non-fallers, Woolley et al. (1997) found that fallers experience lower selective attention abilities, indicated by performance decrements in a visual search task that required subjects to locate a target, focus attention on the target, and recognize the target. Combined, these results suggest that fallers have deficits in attention. However, the specific domains of attention that are impaired remain largely unknown.

While the relationship between attention and falls is now recognized, one specific area of attention that has not been examined in fallers thus far is allocation of attention. Allocation of attention refers to one's ability to collect information from the environment and from internal states, and then process this information to guide a directed behavior (Posner, 2011). Attention can be allocated exogenously and endogenously (Posner, 2011). The exogenous (reflexive) mode involves attention-attracting properties which causes a bottom-up involuntary shift of attention. In contrast, the endogenous (cognitively-driven) mode refers to top-down high level cognitive processes that determines where to shift attention accordingly (Pashler et al., 2001). An inability to properly allocate attention to different tasks may compromise gait control in older adults (Siu et al., 2008). Furthermore, the ability to distinguish relevant from irrelevant information is important for daily living and is a prerequisite for adaptive change in behavioural responses to changes in the external or internal environment (Correa-Jaraba et al., 2016). It may be important to be able to detect deviations in the sensory input (i.e., car honking) because it can indicate relevant changes in the environment that may be hazardous. Alternatively, this attention switch could trigger behavioural distraction (Berti, 2012). For example, if you are walking and you are paying attention to a bird flying while you should be focusing on the side-walk, this will increase the risk of tripping and falling because of behavioural distraction. Therefore, the inability to appropriately allocate attention to relevant stimuli in the environment may be a critical risk factor for falls. In particular, constant distraction caused by task-irrelevant noises in the environment may lead to an inadequate amount of attention being allocated to the task at hand (i.e., walking, navigating safely through the environment), thus leading to falls.

There are several reasons to support the notion that allocation of attention may be impaired in fallers. First, allocation of attention requires executive processes (Baddeley, 1992) that are sensitive to aging (Holtzer, Stern, & Rakitin, 2005) and that are impaired in fallers (Herman et al., 2010). The ability to inhibit inappropriate responses and to selectively attend to relevant information are useful executive processes for successful information processing and decision making that are impaired in older adults with a history of falls (Hsu et al., 2012). For example, fallers perform worse on the Go-No-Go task (Herman et al., 2010) – a task used to test response inhibition, which involves

an individual's ability to inhibit a response that is deemed inappropriate (Georgiou & Essau, 2011). Therefore, the ability to inhibit incoming stimuli and selectively respond to a relevant stimulus are cognitive processes that are associated with falls risk (Liu-Ambrose et al., 2010), and that are likely needed for allocation of attention.

Second, allocation of attention is impaired in older adults compared to young adults (Andrés et al., 2006) and thus may be exacerbated in fallers. Within our auditory environment, unexpected changes can distract us, consequently capturing attention away from the primary task (Ljungberg et al., 2012). Importantly, novel stimuli are capable of automatically attracting attention (Grimm & Escera, 2012), which usually has a negative impact on behavioural measures such as prolonged response times or increased error rates (Escera et al., 2000). However, suppressing or inhibiting orientation of attention towards a novel sound reduces this negative impact (Andrés et al., 2006). Generally, novelty distraction is shown to be triggered by orientation of attention to and away from the novel stimuli, the immediate required selection of stimulus response and the reactivation of attention to subsequent stimuli (Parmentier & Andrés, 2010). Compared to younger adults, older adults are less efficient at ignoring irrelevant information (Hasher et al., 1991; McDowd & Oseas-Kreger, 1991). Previous studies using a cross-modal task found that when faced with a novel irrelevant sound, older adults are more distracted by this sound compared to younger adults (Andrés et al., 2006; Parmentier & Andrés, 2010). This distraction effect was measured by the difference in response times between novel and standard conditions (see Andrés et al., 2006 for more information). Furthermore, this age-related distraction may reduce the efficiency of executive and controlled behaviour (Andrés & Van der Linden, 2000), and thus influences how attention is allocated in older adults. Further evidence comes from the fact that those with neurodegenerative diseases, such as dementia and Alzheimer's disease (AD) who are at increased risk for falls (Nakamura et al., 1997; Puisieux et al., 2005) exhibit early deficits in the ability to filter out irrelevant stimuli (selective attention). More specifically, the ability to disengage and shift attention from one stimulus to another is impaired in AD patients. This may reflect impaired top-down processing, which is required for inhibition of competing stimuli (Perry & Hodges, 1999).

Third, there is preliminary evidence that fallers may not be able to allocate their attention appropriately (Persad et al., 1995), and that implementing the "posture first" strategy, which involves prioritizing the execution of motor tasks over execution of cognitive tasks during dual-tasking, reduces the risk of falling by maintaining balance (primary task) rather than focusing on a cognitively taxing secondary task (Bloem et al., 2006). The inability to appropriately prioritize tasks has been observed in cognitively impaired patients, thus suggesting that they may fall because of this hazardous behaviour (Bloem et al., 2001; Teasell et al., 2002). Poor performance on a dual-task test that combines walking and verbal fluency has shown to be a predictor for falls (Bootsma-van der Wiel et al., 2003), indicating that fallers have difficulty prioritizing and allocating attention to specific tasks. Further evidence that fallers may not allocate their attention appropriately comes from a study on mind-wandering in fallers. Using a sustained attention task, Nagamatsu et al. (2013) found that fallers spent a significantly greater amount of time mind-wandering, or engaging in task-irrelevant thoughts, providing support to our idea that fallers may not allocate their attention appropriately to the task at hand. In a separate study, Nagamatsu et al. (2011) examined risk of falling and the ability to judge when it was safe to cross the street under dual-task conditions. Using an immersive virtual reality environment, they found that at-risk of falling older adults had impaired mobility-related decision-making skills when crossing a busy street, but only in the most cognitively-taxing condition when they were concurrently engaged in a conversation on a cell phone – not when they were passively listening to music. This suggests that at-risk of falling older adults have a reduced ability to allocate attention when cognitively loaded in a physical environment.

Given the evidence presented above, the primary aim of our current study was to determine whether fallers allocate attention differently to auditory distractor stimuli compared to non-fallers, and whether such differences may subsequently alter cognitive processing of visual target stimuli. In our cross-sectional study, participants completed a cross-modal task (Andrés et al., 2006) where they were required to respond to visual targets while ignoring task-irrelevant auditory distractors (novel and standard sounds).

During performance of the cross-modal task, we recorded reaction times, accuracy, and event-related potentials (ERPs) between fallers and non-fallers.

ERPs are a measure of electrical brain activity that are evoked by a specific sensory or cognitive process. Critically, ERPs provide high temporal resolution information about sensory and/or cognitive processes, such as timing of mental processes and can determine which specific cognitive process is influenced by a given task (Luck, 2014). In our study specifically, ERPs allowed us to assess underlying neurocognitive differences in attention and cognitive processing between fallers versus non-fallers. ERPs are time-locked to the presentation of stimuli (auditory distractors and visual targets in our study) and after preprocessing and averaging many trials we are able to discern well-established ERP components of known amplitude, latency, and topography that modulate with sensory and/or cognitive processing. To determine whether fallers experience impaired allocation of attention, the ERP components that we focused on were the N100, Mismatch Negativity (MMN), P3a, and Reorientation Negativity (RON) time-locked to the auditory distractors (standard and novel sounds). The N100 ERP component is elicited by the detection of acoustic change (Näätänen & Picton, 1987) and increases in amplitude when greater attention is focused on a specific stimulus (Parasuraman, 1980). The MMN/P3a/RON complex provides a neurophysiological index of involuntary attention controls (Berti et al., 2004; Horváth et al., 2008). Specifically, the MMN elicits automatic infrequent change detection in a repetitive sound sequence and is related to reductions in amplitude with advancing age (Correa-Jaraba et al., 2016). The P3a is elicited by bottom-up attentional orientation of infrequent stimuli while the RON is elicited by reorientation of attention towards task-relevant stimuli following the processing of distractor stimuli (Berti et al., 2004; Horváth et al., 2008). To determine whether fallers experience altered cognitive processing as a result of the preceding auditory distractors, the P3b component was measured, time-locked to visual targets. The P3b reflects top-down cognitive processing (Polich, 2007), and is related to the amount of neural resources used to evaluate and categorize a target stimulus (Donchin & Coles, 1988; Nash & Fernandez, 1996). We hypothesized that fallers would be more distracted by novel sounds versus standard sounds compared to their non-faller counterparts. Specifically, we expected that they would allocate more attention to novel sounds

compared to standard sounds, indicated by larger N100, MNN, P3a amplitudes, which would result in reduced cognitive processing towards the visual target stimuli, indicated by decreased P3b amplitude and increased latency.

Chapter 2

2 Methods

2.1 Subjects

Participants were recruited from senior programs on campus at Western University in London, Ontario, Canada. Interested participants were screened over the phone to determine eligibility. We included participants who met the following criteria: 1) completed high school education, 2) able to read, write, and speak English fluently, 3) live in their own home, 4) able to walk independently, and 5) right handed. We excluded participants who met any of the following criteria: 1) diagnosed with visual impairments (e.g., glaucoma, cataracts, and blind/color-blind), 2) diagnosed with hearing impairments, 3) diagnosed with a neurodegenerative disease, including dementia or cognitive impairment (e.g., Alzheimer's disease, Parkinson's disease), 4) those who have had a stroke, 5) those who experience dizziness including vertigo which causes them to lose balance, 6) those who have been diagnosed with a psychiatric condition such as depression, 7) those who have sustained a concussion due to a fall in the last 12 months, or 8) women who are or have been on hormone replacement therapy in the last 24 months (possible cognitive effects; see LeBlanc et al., 2001 for more information). Ethics approval was obtained by the University of Western Ontario Research Ethics Board. All participants provided written informed consent.

Participants completed two testing sessions separated by one to two weeks, except for one participant who came in for the second session 84 days after their first session due to having to recover from an arm injury that they acquired on their own after completing Session One. During Session One, participants completed descriptive, executive function, and mobility measures (described in detail below). During Session Two, participants completed a cross-modal task while event-related potentials (ERPs) were recorded.

2.2 Fallers vs. Non-Fallers

Participants were grouped into faller and non-faller groups based on their self-reported falls history over the past 12 months. A fall was defined as "unintentionally

coming to the ground or some lower level other than as consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" (Kellogg & Work, 1987). Participants who reported one or more falls in the previous 12 months were grouped into the faller group, while participants who did not experience a fall in the previous 12 months were grouped into the non-faller group. Previous research has found that falls history is a significant predictor of future falls (Ruchinskas, 2003; American Geriatrics Society, 2011). For example, in a study by O'Loughlin and colleagues (1993), participants with a history of falls were more likely to sustain further falls at follow-up (48 weeks). Furthermore, an individual who has fallen at least once has a 2.77 times more likely chance to fall again within the next 12 months compared to an individual who has not fallen at all (Deandrea et al., 2010).

2.3 **Descriptive Measures**

Age, general heath, socioeconomic status, and falls and fracture history were obtained via questionnaires. The Functional Comorbidity Index (FCI) was used to estimate the degree of comorbidity associated with physical functioning (Groll et al., 2005). Global cognitive function was assessed using the Mini-Mental State Exam (MMSE) (Folstein et al., 1975), with a score below 24 suggesting cognitive impairment. Screening for possible mild cognitive impairment was also done using the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), with a cut-off score of 26 (score of 25 or below indicates impairment). Functional independence was determined using the Lawton and Brody Instrumental Activities of Daily Living (IADL) Scale, where participants were required to circle the scoring point for the statement that most closely corresponded to their current functional ability for specific tasks (lower scores indicate higher levels of dependence), (Lawton & Brody, 1970). Physical activity levels were assessed using the Physical Activities Scale for the Elderly (PASE), where participants recorded whether they performed specific activities and how many days and hours they spent performing these activities using a provided scale ranging from never to often and less than one hour to more than four hours (Washburn et al., 1993). The Activity-specific Balance Confidence (ABC) Scale was used to measure participant's level of confidence in doing each of 16 specific activities without losing balance or becoming unsteady, by choosing one of the percentage points on a scale from 0% (no confidence) to 100%

(completely confident), (Powell & Myers, 1995). The 15-item Geriatric Depression Scale (GDS) screened participants for depressive symptomatology (a score >11 indicates severe depression) (Sheikh & Yesavage, 1986). To further quantify falls risk, the Falls Risk for Older People – Community Setting (FROP-Com) questionnaire was administered. This questionnaire consists of 13 risk factors being rated, most on a 0-3 scale and demonstrates good intra-rater 0.93 (95% CI: 0.84-0.97) and inter-rater 0.81 (95% CI: 0.59-0.92) reliability and moderate capacity to predict falls (Russel et al., 2008). A score of 0-20 classifies participants as having mild to moderate falls risk, and a score of 21-60 classifies participants as having high falls risk.

2.4 **Executive Function Measures**

To assess executive cognitive functions, participants completed pen-and-paper versions of three separate but related tests. The ability to switch between different mental sets (set shifting) was assessed using the Trail Making Test Parts A and B (Corrigan & Hinkeldey, 1987). Part A requires participants to draw a line connecting the numbers 1 to 24 sequentially. Part B requires participants to draw a line connecting numbers and letters, alternating between the two (e.g., 1, A, 2, B, 3, C, etc.). Participants completed each test as quickly and accurately as possible. The amount of time required to complete each part was recorded in seconds. The ability to inhibit prepotent responses and select the appropriate response (selective attention) was assessed using the Stroop Color Word Test Parts A, B, and C (Jensen & Rohwer, 1966). The three parts of the Stroop Colour Word Test require participants to (A) read printed words in black ink, (B) name the ink colour of printed X symbols, and (C) name the ink colour of printed words (e.g., the word “BLUE” in red ink would require the answer “red”) as quickly and as accurately as possible. The time to complete each of the three tests was timed in seconds and number of self-corrected and uncorrected errors were recorded. Lastly, working memory (updating) was assessed using the Digits Forwards and Backwards Test. For both tests, participants were verbally presented with series of digits which they had to repeat back in the same order for the Forward Test and reverse order for the Backward Test (Hester et al., 2004). The Forward Test required participants to begin with a three-digit span and the Backward Test a two-digit span. If participants correctly responded to at least one of two digit spans, one more digit was added to the span length. Testing was stopped after two

consecutive failures of the same span length. The total number of correct responses indicated the scores obtained on each test. Smaller differences between the time to complete the Trail Making Test B and A and Stroop Colour Word Test C and B indicate better performance. Better performance is also indicated by a smaller difference in number of correct responses between the Digits Forward and Backward Tests.

2.5 Mobility Measures

Balance and functional mobility was assessed using the Timed Up and Go Test (TUG), the TUG with manual dual task (TUGman), and the TUG with cognitive dual task (TUGcog) (Shumway-Cook et al., 2000). For the TUG, participants begin seated in a standardized chair, stand up, walk three meters at their normal walking speed, turn 180 degrees, walk back to their chair, and sit back down (Podsiadlo & Richardson, 1991). For the TUGman, participants perform the TUG but after they stand up, they grasp a drinking glass filled with water (water surface one cm away from the edge of the glass) from a table 93 cm in height, carry it with them, and replace the glass on the table before they sit down (Hofheinz & Schusterschitz, 2010). For the TUGcog, participants perform the TUG while simultaneously counting backwards in threes from a randomly selected number of their choice between 20-100 (Shumway-Cook et al., 2000). The selected number cannot be repeated for the second trial of the TUGcog. For each TUG test, participants performed two trials and were timed in seconds to nearest 100^{th}. The average of the two trials for each TUG test were recorded, with faster times indicating better performance. Lastly, to measure balance and gait, the Short Physical Performance Battery (SPPB), was administered (Guralnik et al., 1994). The SPPB examines one's ability to stand with their feet together side by side, in semi tandem, and tandem positions, time to walk four feet at their usual walking pace, and time to rise from a chair and return to their seated position five times as quickly as possible. An overall performance scale is used by summing the category scores for balance, walking, and chair stand for a maximum of 12 points (Guralnik et al., 1994).

2.6 Auditory Acuity Test

Participants were screened for normal hearing acuity using an auditory test which required them to categorize sounds as standard or novel. The standard sound was a

600Hz sinewave tone and the novel sounds were environmental sounds such as those produced by a drill, hammer, rain, door, telephone ringing, etc. (adapted from Escera et al., 1998, 2003; Andrés et al., 2006). Novel sounds were selected from a database of 120 novel sounds that participants ranked as identifiable and non-identifiable in a previous study done by Escera and colleagues (2003). More familiar/identifiable tones or sounds yield larger involuntary attentional orientation; therefore, of the 120 novel sounds, the 50 most identifiable sounds were used (Escera et al., 2003). Before beginning the auditory acuity test, participants heard the standard sound three times and were told that any other sound is considered a novel sound. Participants manually indicated their response on a gamepad by pressing a button with their index finger on their right hand for a standard sound and left hand for a novel sound. The sounds were presented in a random order with 80% of the trials consisting of standard sounds and 20% consisting of novel sounds. Participants completed four blocks of 20 trials each. Participants who correctly classified ≥60 out of 80 sounds were considered as having normal hearing acuity and therefore were included in our study.

2.7 Cross-Modal Task

2.7.1 Apparatus and Stimuli

The trial sequence for the cross-modal task is provided in Figure 1. Each auditory stimulus (standard and novel sounds) was presented for 200ms binaurally via Logitech LS11 Multimedia Speakers that were placed on a table at shoulder height, 30cm behind the participant. Visual stimuli were presented on a 24-inch colour monitor placed approximately 120cm from the subject. Each visual stimulus (digits 1-8) was presented at the center of the screen for 200ms in white above a fixation cross on a black screen.

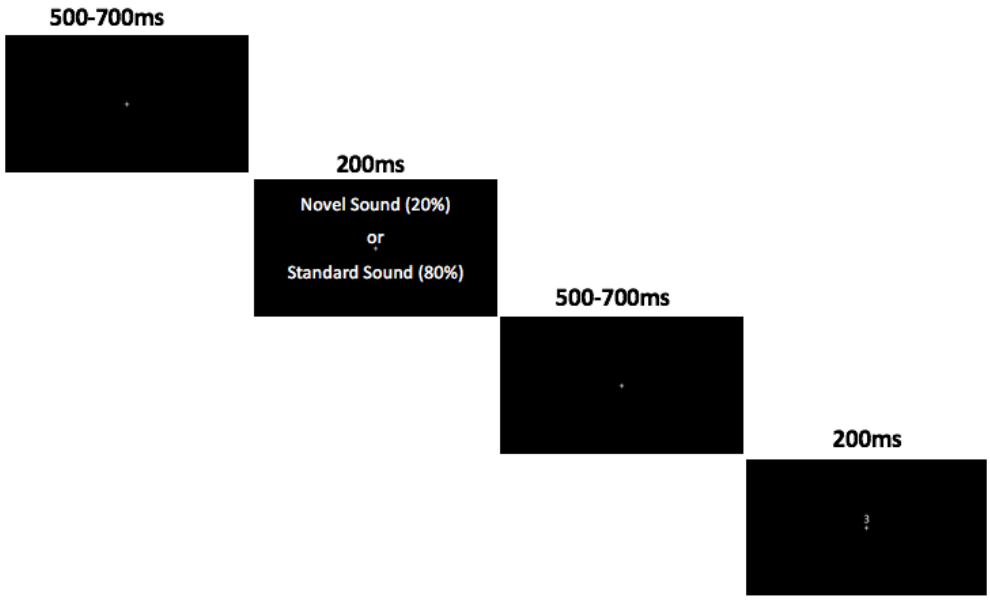

Figure 1: Cross-Modal Task
Auditory and visual stimulus timing and displays presented to participants during each trial. Novel sounds appeared in 20% of trials and standard sounds appeared in 80% of trials. Digits 1-8 were randomly presented with equal chance of appearing, and always appeared in the center of the screen above a fixation cross.

2.7.2 Procedure

Participants were presented with visual stimuli presented individually (digits 1-8) that they had to categorize as odd or even as quickly and accurately as possible using the index finger on their left hand for odd numbers and right hand for even numbers[1]. The order that the digits were presented was randomized. Before each visual stimulus, a task irrelevant sound was presented. Participants were instructed to ignore the sounds. The auditory stimuli were the same sounds as the ones used in the auditory acuity test. Each auditory stimulus was either a standard sound (80% of trials), or a novel sound (20% of trials). Participants completed 18 blocks of 50 trials each.

2.8 Electrophysiological recording and analysis

During the cross-modal task, electroencephalograms (EEGs) were recorded from 64 active scalp electrodes (Brain Vision ActiCHamp) using Brain Vision PyCorder (http://www.brainvision.com/pycorder.html). The electrodes were mounted in a fitted cap with a standard 10-20 layout. All EEG activity was recorded relative to a scalp electrode

[1] Except for three participants who responded using their thumbs to increase comfort.

located over the anterior frontal cortex (AFz). Vertical and horizontal electrooculograms (VEOGs and HEOGs) were recorded from electrodes placed below and on the outer canthi of both eyes to monitor eye movements. Electrode impedance was kept below 20 kΩ. EEG signals were filtered at 0.01 Hz low cutoff and 100 Hz high cutoff and digitized at a rate of 500 Hz. The data was imported into EEGLAB (v13.5.4b) and was re-referenced to the average of all scalp electrode sites. Next, ERPLAB (v5.0.0.0) was used to preprocess the data. Only correct responses to the visual stimuli during the cross-modal task were examined. Data was filtered using a 0.1 Hz high pass and a 30 Hz low pass filter. Continuous EEG data was segmented into epochs from -200ms to 800ms. Artifact detection was performed on the epoched data using moving window peak-to-peak thresholds (moving windows full width = 200ms, window step = 100ms). Next, epochs assigned to each bin were averaged together for each participant, and grand averages were created to compare the non-faller and faller groups. Relevant amplitudes and latencies of the ERP components of interest were extracted and imported as detailed below.

2.9 **Data Analysis**

All data were recorded and then imported into IBM SPSS Statistics (Version 24 for Mac) for statistical analysis, to determine whether group differences existed across our sample. Descriptive data, executive function measures, and mobility measures were analyzed using independent sample t-tests. Behavioural data was analyzed using repeated measures ANOVA with a between subject factor of group (non-faller vs. faller) and a within subject factor of sound type (Novel vs. Standard) that preceded the visual stimuli. The mean amplitudes of auditory ERP components (N100, P3a, and RON) were analyzed using repeated measures ANOVA with a between-subject factor of group (non-faller vs. faller) and a within subject factor of sound type (Novel vs. Standard). MMN mean amplitude was examined between non-fallers and fallers using a one-way ANOVA. The mean amplitudes and peak latencies of the visual ERP component (P3b) were both examined using repeated measures ANOVA with a between-subject factor of group (non-faller vs. faller) and within subject factors of sound type (Novel vs. Standard) and electrode site (Fz, FCz, Cz, CPz, Pz).

Chapter 3

3 Results

3.1 Descriptive, Executive Function, and Mobility Measures

The results for the descriptive measures are presented in Table 1 and executive function and mobility measures are presented in Table 2. Twenty-five community-dwelling older adults between the ages of 58 and 79 years (M = 67.72, S.D. = 5.09, 17 females) were included in the study. Twenty-six participants were recruited, but one participant was excluded for having a MoCA score below 24. For the auditory acuity test, all participants correctly classified ≥60 out of 80 sounds, and were therefore included in our study. Compared to the non-faller group, the faller group had significantly more comorbidities, as indicated by higher mean FCI scores, $t(23) = 2.583$, $p = 0.017$, and significantly higher falls risk scores, as indicated by the FROP-com questionnaire, $t(23) = 4.781$, $p < 0.001$. There were no significant differences between groups for age, MMSE, MoCA, depression level, physical activity level, executive function, mobility, balance and gait, all p values > 0.05.

Table 1: Descriptive Measures for Non-Faller and Faller Groups

Measures [a]	**Non-Fallers n= 16**	**Fallers n= 9**	**All Subjects N=25**
Age, years	66.56 (3.98)	69.50 (6.36)	67.72 (5.09)
Sex, No. (%)			
Female	11 (68.75)	6 (66.66)	17 (68.00)
Number of Falls (12 months)	0 (0)	1.30 (0.67) **	0.48 (0.77)
FROP-Com [b]	3.81 (1.91)	8.89 (3.44) **	5.64 (3.52)
Education, No. (%)			
- High School graduate, diploma or equivalent	0 (0.0)	2 (22.2)	2 (8.0)
- Some college, no degree	2 (12.50)	0 (0.0)	2 (8.0)
- Trade/technical/vocational training	1 (6.25)	0 (0.0)	1 (4.0)
- Bachelor's Degree	9 (56.25)	7 (77.8)	16 (64.0)
- Graduate Degree	4 (25)	0 (0.0)	4 (16.0)
FCI [c]	0.44 (0.81)	1.33 (0.86) *	0.76 (0.93)
MMSE [d]	28.31 (1.49)	28.56 (1.51)	28.40 (1.47)
MoCA [e]	25.94 (1.57)	26.89 (1.76)	26.28 (1.67)
GDS [f]	0.19 (0.54)	0.67 (1.32)	0.36 (0.91)
PASE [g]	174.33 (64.82)	153.20 (53.97)	166.72 (60.65)
ABC Scale [h]	97.01 (3.87)	95.28 (4.20)	96.38 (3.99)
IADL [i]	8 (0)	8 (0)	8 (0)

[a] Data presented as mean (SD), unless otherwise indicated as No. (%)
[b] FROP-Com =Falls Risk for Older People – Community Setting; Mild to moderate falls risk (Score = 0-20)
[c] FCI = Functional Comorbidity Index
[d] MMSE = Mini-Mental Status Examination; maximum 30 points
[e] MoCA = Montreal Cognitive Assessment; maximum 30 points
[f] GDS = Geriatric Depression Scale; maximum 15 points
[g] PASE = Physical Activities Scale for the Elderly
[h] ABC = Activities-specific balance confidence scale; maximum 100 points
[I] IADL = Instrumental Activities of Daily Living; maximum 8 points
** P-value significant at 0.01 level (2-tailed)
* P-value significant at 0.05 level (2-tailed)

Table 2: Executive Function and Mobility Measures for Non-Faller and Faller Groups

Measures [a]	**Non-Fallers n= 16**	**Fallers n= 9**	**All Subjects N=25**
Digit Span (F-B)	2.38 (2.42)	2.56 (1.74)	2.44 (2.16)
Trail making Test (B-A) [b]	41.00 (30.77)	33.01 (14.04)	38.13 (25.94)
Stroop C-B (sec.)	44.49 (15.49)	44.90 (10.48)	44.63 (13.66)
TUG (sec) [c]	9.47 (0.69)	9.50 (1.46)	9.48 (1.00)
TUGman (sec.)	10.94 (0.76)	11.01 (1.99)	10.97 (1.30)
TUGcog (sec.)	11.36(1.52)	12.21 (3.50)	11.67 (2.31)
SPPB [d]	10.73 (1.10)	10.89 (0.78)	10.79 (0.98)

[a] Data presented as mean (SD)
[b] TMT = Trail Making Test; Test B – Test A
[c] TUG = Time up and Go; Mean of Trial 1 & Trial 2
[d] SPPB = Short Physical Performance Battery; maximum 12 points
** P-value significant at 0.01 level (2-tailed)
* P-value significant at 0.05 level (2-tailed)

3.2 Behavioural Results for Cross-Modal Task

Reaction times and accuracy scores are presented in Table 3 as a function of group (non-faller vs. faller) and auditory-visual condition (visual stimuli preceded by novel sound vs. visual stimuli preceded by standard sound). As a group, a trend towards faster reaction times to the visual target stimuli following a standard sound compared to a novel sound was found. This was indicated by a main effect of sound type approaching significance, $F(1,23) = 4.04$, $p = 0.056$. Participants made more correct responses when a novel sound preceded the visual target stimuli compared to a when a standard sound preceded the visual target stimuli, as indicated by a significant main effect of sound type, $F(1,23) = 5.77$, $p = 0.025$. In addition, as a group more incorrect responses were recorded when a standard sound preceded the visual target stimuli, as indicated by a

significant main effect of sound type, $F(1,23) = 18.15$, $p < 0.001$, whereas participants did not significantly differ in number of trials missed (i.e., no behavioural response recorded), $F(1,23) = 1.82$, $p = 0.190$. In both auditory-visual conditions, there were no significant between-group differences in reaction times or accuracy scores for non-fallers vs. fallers, all p values > 0.05.

Table 3: Behavioral Results for Non-Faller and Faller Groups

BEHAVIOURAL RESULTS	Non-Fallers n= 16	Fallers n= 9
Reaction Time (ms) [a]		
Novel Sound [b]	604.85 (0.05)	612.31 (0.05)
Standard Sound [c]	600.86 (0.05)	602.16 (0.05)
Accuracy [d]		
Correct		
Novel Sound	97.84 (1.77)	96.39 (3.10)
Standard Sound	95.93 (4.01)	95.67 (3.33)
Incorrect		
Novel Sound	0.72 (1.01)	1.22 (1.37)
Standard Sound	2.16 (1.90)	2.10 (1.70)
Missed		
Novel Sound	1.27 (1.54)	2.16 (2.24)
Standard Sound	2.01 (2.07)	2.24 (3.06)

[a] Data presented as mean (SD)
[b] Reaction time to visual stimuli when preceded by a novel sound
[c] Reaction time to visual stimuli when preceded by a standard sound
[d] Data presented in percentage (percent SD) unless otherwise indicated
** P-value significant at 0.01 level (2-tailed)
* P-value significant at 0.05 level (2-tailed)

3.3 Electrophysiology

Allocation of attention to auditory distractor stimuli (novel and standard sounds) and cognitive processing of visual target stimuli when preceded by either novel or standard sounds were assessed using time-locked ERPs to each stimulus respectively. The ERP components measured for assessing allocation of attention to the distractor were N100, P3a, RON, and MMN, which are used for measuring distraction triggered by unexpected stimuli and orientation of attention (Correa-Jaraba et al., 2016). To evaluate cognitive processing of the visual stimuli, the ERP component P3b was analyzed. P3b is related to the amount of neural resources used to categorize a target stimulus (Donchin & Coles, 1988).

3.3.1 Attention to the Auditory Distractor Stimuli

N100, P3a, RON, and MMN Mean Amplitude. Grand-averaged ERP waveforms for the N100, P3a, RON, and MMN components for non-fallers and fallers are presented in Figure 2 and mean amplitudes are provided in Table 4. The N100, P3a, and RON components were analyzed using the frontal midline electrode site Fz. The time window used for measuring mean amplitude was based on the peak latency of the grand averaged waveforms for novel and standard sounds within each group (i.e., non-faller and faller) separately. MMN is typically maximal at frontal-central electrode sites (Correa-Jaraba et al., 2016), but for our data set, MMN was maximal at the midline parietal electrode site Pz. MMN was derived by subtracting the ERP waveform produced from the novel auditory stimuli from the waveform produced from the standard auditory stimuli. The time window used for measuring mean MMN amplitude was based on the peak latency of the grand averaged waveform for the derived MMN within each group (i.e., non-faller vs. faller).

As a group, more attention was dedicated to standard sounds compared to novel sounds, as indicated by the amplitude of the N100 ERP component having a significant main effect of sound type, $F(1,21) = 23.18$, $p < 0.001$. There was no difference in allocation of attention to task-irrelevant auditory distractors between non-fallers and fallers. Specifically, there was no significant difference in mean amplitude between the non-faller and faller groups for the N100, P3a, RON, and MMN, all p values > 0.05.

3.3.2 Cognitive Processing of the Visual Target Stimuli

P3b Mean Amplitude. Grand-average ERP waveforms for the P3b component are presented in Figure 3 and mean amplitudes are provided in Table 4. Two participants total (one from each group, non-faller and faller) were excluded for excessive noise in auditory-visual ERP data as determined via visual inspection. The P3b ERP component is typically measured at the midline parietal (Pz) electrode site, but with age, the P3b shows a posterior to anterior shift in scalp distribution (Friedman et al., 1997). Therefore, to examine this potential shift in distribution of electrical activity, we analyzed the P3b at Fz, CFz, Cz, CPz, and Pz electrode sites. The time window used for measuring mean P3b

amplitude was based on the peak latency of the grand averaged waveforms for visual target stimuli preceded by novel sounds and visual target stimuli preceded by standard sounds within each group (i.e., non-faller vs. faller).

As a group, more cognitive resources were dedicated to visual stimuli presented after a standard sound compared to after a novel sound, as indicated by a significant main effect of sound type, $F(1,21) = 7.316$, $p = 0.01$. There were no differences in the cognitive processing of the visual target stimuli between non-fallers and fallers. Specifically, P3b mean amplitude was not significantly different between the two groups, $p > 0.05$. Notably, there was a posterior to anterior shift in the distribution of the P3b as a group, indicated by a significant main effect of electrode site, $F(1,21) = 10.187$, $p < 0.001$. Interestingly, this anterior-directed shift of electrical activity appears to be exaggerated in the faller group compared to the non-faller group, as indicated by a trend towards a group by electrode site interaction, $F(1,21) = 2.1$, $p = 0.08$. This interaction can be seen in Figure 4.

P3b Peak Latency. P3b peak latencies to the visual stimuli are provided in Table 5. The same time windows, electrodes sites (Fz, FCz, Cz, CPz, Pz), and number of participants that were used for measuring P3b mean amplitude were used for the analysis of P3b peak latency.

As a group, the time needed to classify the visual target stimuli was larger from parietal to frontal electrode sites, as indicated by a significant main effect of electrode site $F(1,21) = 29.569$, $p < 0.001$. Notably, the time spent classifying the visual target stimuli was larger for the fallers from parietal to frontal electrode sites compared to the non-fallers, as indicated by a significant interaction between electrode site and group $F(1,21) = 12.024$, $p < 0.001$.

Table 4: ERP Component Mean Amplitude for Non-Faller and Faller Groups

ERP COMPONENT & EVENT [a]	Non-Fallers [b]	Fallers [c]
Auditory Stimuli		
N100 at Fz	(88-128ms) [d]	(88-128ms)
Novel Sound	-0.92 (0.77)	-0.75 (0.84)
Standard Sound	-1.48 (1.25)	-1.61 (1.11)
P3a at Fz	(280-360ms)	(280-360ms)
Novel Sound	1.23 (1.65)	1.05 (0.94)
MMN at Pz	(190-360ms)	(190-360ms)
Novel Sound - Standard Sound	-0.57 (0.83)	-0.77 (0.95)
RON at Fz	(480-680ms)	(480-680ms)
Novel Sound	-0.93 (0.72)	-1.01 (0.80)
Standard Sound	-0.86 (0.67)	-1.06 (0.65)
Visual Stimuli		
P3b at Fz	(450-580ms)	(480-610ms)
Novel Sound [e]	1.94 (2.12)	2.58 (2.71)
Standard Sound [f]	2.02 (2.51)	2.70 (2.61)
P3b at FCz	(456-580ms)	(480-610ms)
Novel Sound	1.60 (1.78)	1.99 (2.89)
Standard Sound	1.75 (2.09)	2.45 (2.47)
P3b at Cz	(418-554ms)	(388-532ms)
Novel Sound	1.17 (2.26)	0.24 (1.82)
Standard Sound	1.42 (2.54)	0.80 (1.44)
P3b at CPz	(418-628ms)	(354-486ms)
Novel Sound	1.03 (1.83)	-0.17 (1.65)
Standard Sound	1.14 (1.84)	0.39 (1.81)
P3b at Pz	(330-615ms)	(290-450ms)
Novel Sound	0.56 (1.26)	-0.52 (0.86)
Standard Sound	0.73 (1.36)	-0.01 (1.28)

[a] Data presented as mean (SD)
[b] n = 16 for auditory event, n = 15 for auditory-visual event
[c] n = 8 for both events
[d] Time window used for measuring mean amplitude
[e] Visual Stimuli preceded by novel sound
[f] Visual Stimuli preceded by standard sound
** P-value significant at 0.01 level (2-tailed)
* P-value significant at 0.05 level (2-tailed)

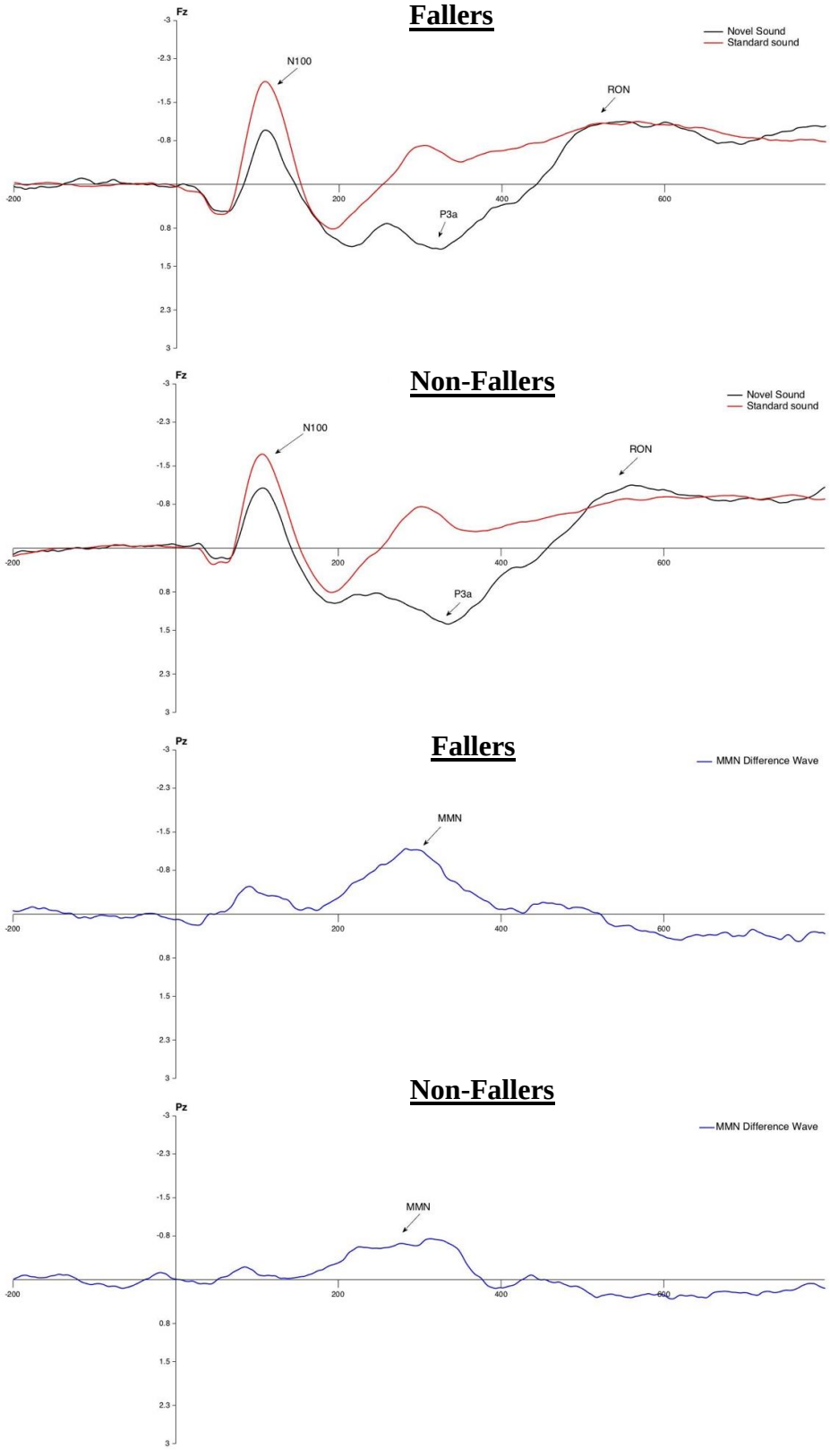

Figure 2: ERP waveforms time-locked to auditory stimuli.

Grand averaged ERP waveforms to the auditory stimuli for the N100, P3a, RON and MNN components in fallers and non-fallers as a function of novel and standard sounds. The time window is from – 200ms pre-stimulus (baseline) to 800ms post-stimulus. Amplitudes are measured in μV. There were no significant amplitude differences between fallers and non-fallers for the N100, P3a, RON, and MNN components. As a group, N100 component was significantly higher in amplitude.

Table 5: P3b Component Peak Latency for Non-Faller and Faller Groups

ERP COMPONENT & EVENT [a]	Non-Fallers n= 15	Fallers n= 8
Visual Stimuli		
P3b at Fz		
Novel Sound [b]	492 (25.82)	544 (35.41)
Standard Sound [c]	546 (36.23)	530 (34.07)
P3b at FCz		
Novel Sound	530 (28.24)	540 (38.98)
Standard Sound	548 (34.18)	550 (36.61)
P3b at Cz		
Novel Sound	532 (38.32)	482 (47.94)
Standard Sound	472 (46.31)	436 (52.76)
P3b at CPz		
Novel Sound	586 (63.81)	424 (32.22)
Standard Sound	476 (64.99)	422 (45.20)
P3b at Pz		
Novel Sound	434 (75.70)	414 (61.38)
Standard Sound	436 (76.07)	374 (51.81)

[a] Data presented as mean (SD)
[b] Visual Stimuli preceded by novel sound
[c] Visual Stimuli preceded by standard sound
** P-value significant at 0.01 level (2-tailed)
* P-value significant at 0.05 level (2-tailed)

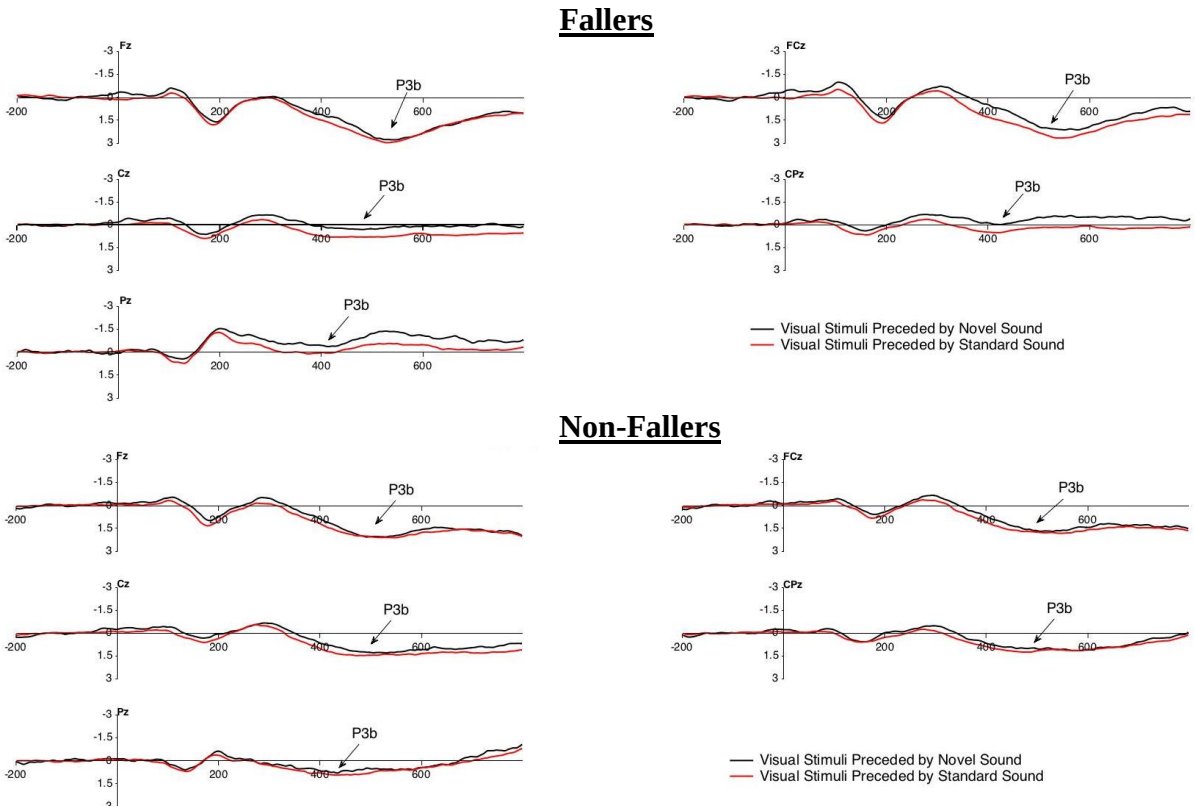

Figure 3: ERP waveforms time-locked to visual stimuli.

Grand averaged ERP waveforms to the visual stimuli at electrode sites Fz, FCz, Cz, CPz, and Pz for the P3b component in fallers and non-fallers as a function of visual stimuli preceded by novel sound and visual stimuli preceded by standard sound. The time window is from – 200ms pre-stimulus (baseline) to 800ms post-stimulus. Amplitude was measured in μV and latency was measured in milliseconds (ms.). There were no significant amplitude differences between fallers and non-fallers for the P3b component. As a group, the P3b component was significantly higher in amplitude when the standard sound preceded the visual stimuli. Towards frontal electrode sites, as a group, the P3b component was significantly higher in amplitude and longer in latency for both auditory visual conditions, and further exaggerated in fallers.

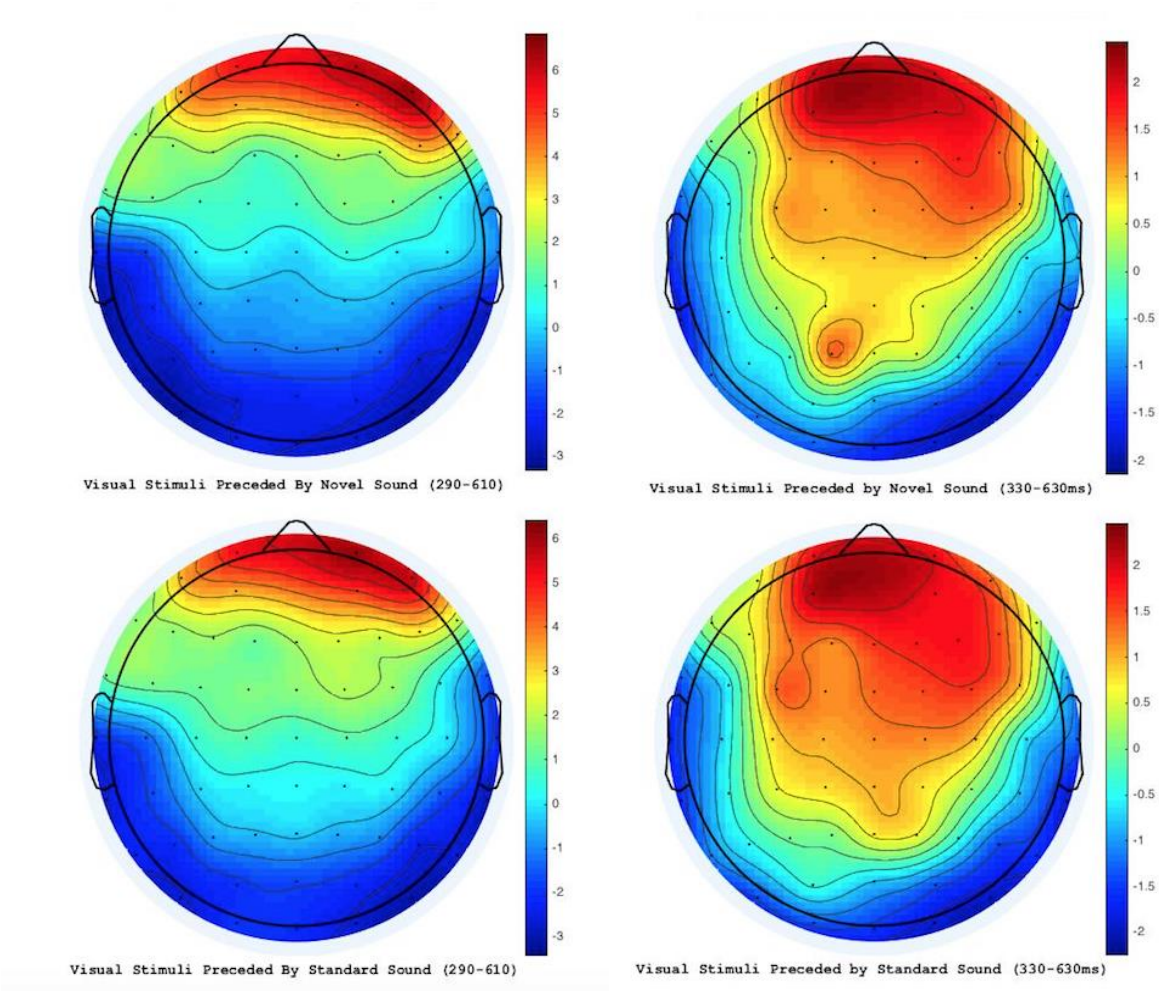

Figure 4: P3b Mean Amplitude Scalp Distribution

P3b component mean amplitude scalp distribution in fallers and non-fallers as a function of visual stimuli preceded by novel sound and visual stimuli preceded by standard sound. As a group, P3b mean amplitude was significantly larger towards frontal electrodes sites, indicated by warmer colours in these regions. P3b mean amplitude was more frontally oriented in fallers compared to the non-fallers.

Chapter 4

4 Discussion, Limitations, and Conclusion

4.1 Discussion

Our study examined whether fallers allocate attention differently to auditory distractor stimuli compared to non-fallers and whether such differences may subsequently alter cognitive processing of visual target stimuli. In this regard, we found no significant differences in the allocation of attention to auditory distractors or cognitive processing of visual targets between fallers and non-fallers. However, as a group, more cognitive resources were dedicated to visual stimuli presented after a standard sound compared to after a novel sound. Notably, a posterior to anterior shift in the distribution of the P3b mean amplitude as a group, was found. However, in the fallers, this shift seems to be amplified, suggesting differences in the way stimuli are cognitively processed and classified between faller groups. Our current findings expand our understanding of the way stimuli are cognitively processed and classified between faller and non-faller groups. Given our results, several noteworthy points of discussion follow.

First, in regard to our finding that there were no significant differences between non-fallers and fallers in terms of allocation of attention to auditory distractors and cognitive processing of visual targets, there are several possible explanations. One potential reason for our lack of significant results is that we may not have accurately classified participants as fallers and non-fallers. We classified participants into their respective groups based on their self-reported falls history over the past 12 months. Importantly, self-reports are subject to bias and rely on accurate retrospective memory – which is known to decline with age (Short et al., 2009). Furthermore, there is a debate in the literature as to whether a single fall classifies someone as a "faller". Specifically, a single fall can be a "fluke" accident, whereas recurrent falls are more likely caused by chronic intrinsic factors such as impaired cognitive function (Tromp et al., 2001). For example, Holtzer et al. (2007) found that recurrent fallers experience impairments in more cognitive domains and are more likely to be diagnosed with neuropathological disorders compared to single fallers. Previous research has also found that older adults reporting *recurrent* falls in the previous year perform worse on measures of processing

speed and executive functioning compared to non-fallers (Anstey et al., 2009). However, we highlight that previous research found that a history of any falls does increase future falls risk (Deandrea et al., 2010) and that our faller group scored significantly higher on the falls risk questionnaire (FROP-Com) compared to the non-faller group, thus providing support to our classification of participants. It is important to note that both groups did not score above 20 on the FROP-Com which indicates that both the non-faller and faller groups are categorized as mild-moderate falls risk, which may not be clinically significant. Future research should examine older adults at more extreme ends of the falls-risk spectrum.

Second, while we expected novel sounds to capture attention in our cross-modal task (Escera et al., 2001), we found that as a group, greater attention was dedicated to standard sounds compared to novel sounds in our study (indicated by larger N100 amplitude for standard sounds). One potential explanation for this unexpected finding is that the standard sound may have selectively been attended to by our participants and therefore used as a cue to prepare for the upcoming visual target. Specifically, Andrés et al. (2006) examined the effects of aging on the use of sound as a warning cue by comparing performance on an auditory-visual distraction task. Their results indicated that young and older adults were able to use sound to indicate that the visual target will be appearing next (Andrés et al., 2006). Sensory inputs can be processed separately or they can be combined to form a unified response. For example, in the environment, we are faced with multiple different sensory inputs and these inputs form how we perceive our surroundings (Hugenschmidt et al., 2009). The ability to use multisensory interactions is important and can be governed by higher order cognitive functions such as attention (Talsma & Woldorff, 2005). Therefore, in our study, participants may have dedicated more attention to standard sounds compared to novel sounds to selectively process the standard sound as a warning cue and form a unified response towards the visual target stimuli.

Third, our finding that the P3b component was larger for visual targets preceded by standard sounds compared to novel sounds suggests that overall, participants were dedicating greater cognitive resources to visual targets after hearing a standard sound.

What might explain this result? One potential explanation is the psychological refractory period (PRP), a term referring to the period of time during which the response to a second stimulus is significantly reduced because the first stimulus is still being processed (Pashler, 1994). Parmentier et al. (2011) found that the rarity of a novel sound is not what captures attention, but rather, the novel sound is violating an individual's expectation, resulting in a conflict with the perceptual trace of the previous sound. We suggest that compared to the standard sound, the novel sound may capture the participant's attention, thus reducing the amount of cognitive processing allocated towards the visual target stimuli. Notably, this appears to contradict our finding that the initial response to the standard sound received more attention compared to the novel sound. To reconcile this potential discrepancy, we highlight the importance of the P3a component, which is used for measuring distraction triggered by unexpected stimuli and orientation of attention towards that stimulus (Correa-Jaraba et al., 2016). As a group, the P3a component is visible, suggesting that participants allocated attention towards the novel sounds due its unforeseen probability of appearing. Previous research has shown that larger P3a associated with attended deviant tones is accompanied by smaller P3b associated with target stimuli. (Nash & Fernandez, 1996). Taking this into consideration, our data suggests that following a novel sound, participants dedicated a reduced amount of cognitive processing towards visual target stimuli (smaller P3b), due to novel sounds capturing attention and causing participants to process its novelty (P3a).

Fourth, while the cognitive processing and evaluation of visual stimuli are typically measured at midline *parietal* electrode sites, we found as a group an anterior shift in distribution of the P3b. Notably, the faller group exhibited greater P3b amplitudes at midline *frontal* electrode sites, compared the non-faller group. Previous research has shown that with age, P3b shifts from posterior to more anterior activity (Vesco et al., 1993). Younger participants are able to rapidly create a strong mental representation of task stimuli and assign stimulus processing to posterior attention regions (O'Connell et al., 2012), whereas older participants need to rely on the anterior networks of the brain to maintain similar task performance (O'Connell et al., 2012). Therefore, this posterior to anterior shift (PASA; Davis et al., 2007) suggests that our participants experienced diminished functions within posterior perceptual processing regions during an attention-

demanding cognitive task and therefore are relying on frontal networks of the brain to support task performance. This is supported by the fact that non-fallers and fallers did not have differences in behavioural performance. Due to limitations of EEG spatial resolution, we cannot infer which underlying brain regions are implicated specifically in our study, but previous work can provide insight into the regions that may be involved. In a recent study by Halliday et al. (2017) looking at older adults with and without a history of falls, they found that fallers showed more oxygenated hemoglobin in the prefrontal cortex compared to non-fallers. The authors suggest that the cognitive task used in their study was more difficult for the older adults with a history of falls, which elicited greater cortical activation in prefrontal brain regions to be able to complete the task at a comparable level to non-fallers. Halliday et al. (2017) also suggest that in the absence of performance differences, greater activation of brain regions occurs due to compensation or by dedifferentiation, which refers to the recruitment of more general neural tissue area to perform a task. Taken together, our work therefore suggests that older adults with a history of falls may have to exert more effort in frontal brain regions to perform even basic cognitive tasks, and consequently potentially leaving less resources available for attention-demanding postural control and balance.

4.2 **Limitations**

Importantly, there are several key issues to consider regarding our findings. A primary limitation of our study is that non-faller and faller groups did not have an equal number of participants. To increase the homogeneity within groups and decrease the variance of results across participants, it is beneficial to have equal group numbers as this increases the likelihood of finding an effect and difference between groups. Furthermore, our sample size is relatively small, therefore, future work should focus on how the relationship between falls history and allocation of attention may differ in more equal and larger sample size, because by having a larger sample size, this decreases the likelihood of type 2 errors within the data set. However, it is important to note that we found low effect sizes and power for our between group results that were non-significant, indicating that our results were likely not due to having a small and unequal sample size.

Additionally, our sample consisted of very high functioning and highly educated

older adults, which may not be representative of the general older adult population. Future research should explore allocation of attention in lower functioning older adults with a history of falls. Alternatively, we suggest that a different task should be used that is targeted at higher functioning community dwelling older adults. For example, to identify balance impairments that are associated with risk of falling in higher functioning older adults, Boulgarides et al. (2003) suggest that more challenging tests are needed. Given the nature of our participants, this means that our results are likely conservative estimates of the effects of relationship between allocation of attention and falls, indicating that the posterior to anterior shift may be even more exaggerated in lower functioning and higher risk groups.

While participants were classified as either non-fallers or fallers based on self-reported falls history, there is the possibility that a fall occurred by chance or that participants did not properly recall if they fell or not. This would result in participants being misclassified into their respective groups, and as a consequence, groups would be more similar in their overall ability to complete the required measures and tasks in our study. Future research would possibly benefit by recruiting only recurrent fallers who have fallen two or more times in the previous 12 months or by using prospective measures of falls such as a fall calendar to classify participants as non-fallers versus fallers, thereby increasing our confidence in our classification. However, within our results this is not a concern as participants were all provided with a well-defined explanation of what a fall was, and were further asked specifics about the fall or falls experienced using the FROP-Com questionnaire. Upon completion, falls were matched with the provided definition of what a fall consisted of, to reduce the possibility of a fall occurring by chance. Further, this would also likely lead to a conservative estimate of our results, suggesting that the results we obtained may be larger in more divergent groups.

The majority of our data was analyzed using parametric tests such as ANOVAs. While the majority of our variables were normally distributed, we note that some were not. However, we used ANOVA's because: 1) we were interested in measuring the interactions between group and sound type, 2) results are generally robust under violations of normality, and 3) we were interested in making inferences about population

parameters. Future work may consider using non-parametric tests to examine whether the results concur statistically.

We acknowledge that our study used ERPs to measure scalp distribution, therefore we cannot infer which specific brain regions were involved in attentional and cognitive processing. However, our findings are suggesting a trend towards how older adults with and without a history of falls recruit neural resources while performing basic cognitive tasks. Therefore, we suggest that future research would benefit from further examining this frontal shift in activity by using neuroimaging techniques such as functional magnetic resonance imaging (fMRI) to better understand the underlying neural structures involved during cognitive processing.

4.3 **Conclusion**

To conclude, our study reveals an important link between aging, falls history, and electrical brain activity during an attention-demanding cognitive task. Our results concur with current findings that older adults exhibit an anterior shift in their electrical brain activity to maintain their cognitive performance (Davis et al., 2007). Such shifts in activity in fallers may indicate the increased need of higher level control regions, which may leave less available resources for other important tasks such as postural control and balance, thus increasing risk of falling. We highlight the importance of studying falls related changes in brain activity, cognition, and attention to better understand the neurological mechanisms associated with falls and risk of falling. Future research should consider the posterior to frontal shift in electrical brain activity and determine whether the results obtained in our study are upheld in additional studies examining fallers.

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Appendices

Appendix A: Letter of Information and Consent

Western

Letter of Information and Consent

Project Title: EEG and Mobility

Invitation to Participate: You are being invited to participate in this research study about the underlying brain mechanisms that are responsible for cognitive processing and mobility in older adults.

Introduction: With our aging society, there is an important need to understand the brain mechanisms that are responsible for healthy aging. Such research has the potential to inform future screening and intervention strategies to promote healthy aging and prevent cognitive and mobility decline in older adults.

The purpose of this study is to identify what brain processes are associated with various domains of cognitive functioning and mobility. Secondly, we are interested in examining the association between changes over the course of two years in brain mechanisms and cognitive- and mobility-related measures.

Study Length: It is expected that you will be in the study for two sessions over the course of two weeks and each visit will take approximately one to two hours. A subsample may be asked to come back to the lab after one year and two years for follow-up assessments. Further, you may be asked to complete questionnaires (by mail or phone) once per month for up to 24 months.

Procedure: If you agree to participate, you will be asked to complete two sessions in the lab.

Session 1: Consent and study information, screening, demographic questionnaires, cognitive tasks, falls risk questionnaire, and mobility tasks. The mobility tasks will require you to walk a distance of four metres at your usual pace, stand up from a seated position, and balance with both feet on the floor. None of these tasks will be more difficult than what you would experience in every day life. If you are not comfortable completing any of these measures, you can choose to not complete them.

Session 2: We will record electrical brain signals (electroencephalogram; EEG) while you are completing experimental tasks. This will involve the application of recording electrodes either individually with tape (eye position) or by a tight-fitting electrode cap. Application of the electrodes involves the use of electrode gel under each electrode.

Follow-Up Sessions: You are asked to complete monthly questionnaires (by mail or phone) once per month for up to 24 months. Furthermore, you **may** be asked to come in for follow-up sessions in one and/or two years. The follow-up sessions will be optional and you will still be eligible to participate in the first part of the study if you do not wish to complete the follow-up sessions.

Inclusion Criteria: 1) Living in your own home in London, Ontario; 2) Aged 60 to 80 years; 3) Completed high school education; 4) Read, write, and speak English fluently; 5) Able to walk independently; 6) Right Handed.

Exclusion Criteria: 1) Diagnosed with a neurodegenerative disease; 2) Diagnosed with a psychiatric condition (e.g., depression); 3) Diagnosed with dementia or cognitive impairment; 4) Sustained a concussion due to a fall in the last 12 months based on self report; 5) Experienced a stroke; 6) Have severe musculoskeletal or joint disease; 7) Taking psychotropic medication or cholinesterase inhibitors; 8) Have a history of dizziness or vertigo; 9) Women who have been on hormone replacement therapy in the last 24 months.

Risks and Benefits: There are no known or anticipated risks or discomforts associated with participating this study.

You may not directly benefit from participating in the study but information gathered may provide benefits to society as a whole, which include furthering our understanding the underlying neural mechanisms responsible for cognition and mobility.

Withdrawing: You have the right to withdraw from the study at any point without any consequences. If you decide to withdraw from the study, the information that was collected prior to you leaving the study will still be used to answer the research questions. You have the right to have all of your data removed/deleted from the study upon request. No new information will be collected without your permission.

Confidentiality: Your personal information will remain private and confidential. Only the Principal Investigator and research personnel will have access to the data. We will not share your data with anyone outside the study unless required by law. Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to your study-related records to monitor the conduct of the research.

While we do our best to protect your information, there is no guarantee that we will be able to do so. We will keep any personal information about you in a secure and confidential location for a minimum of 7 years. A list linking your study number with your name will be kept by the researcher in a secure place, separate from your study file. If the results of the study are published, your name will not be used.

Compensation: You will be compensated $10/hour for your participation in this study (including the potential follow-up sessions). If you do not complete the entire study, you will still be compensated for the time you have completed. In addition, you will be reimbursed for parking at a rate of $6/hour, if applicable. For completion of the monthly follow-up questionnaires, you will be entered into a draw for each month that you complete the questionnaire to win a $10 gift card.

Rights of Participants: Your participation in this study is voluntary. You may decide not to be in this study. Even if you consent to participate you have the right to not answer individual questions or to withdraw from the study at any time. If you choose not to participate or to leave the study at any time it will have no consequences for you.

We will give you new information that is learned during the study that might affect your decision to stay in the study.

You do not waive any legal right by signing this consent form.

You will be given a copy of this Letter of Information once it has been signed.

Consent:

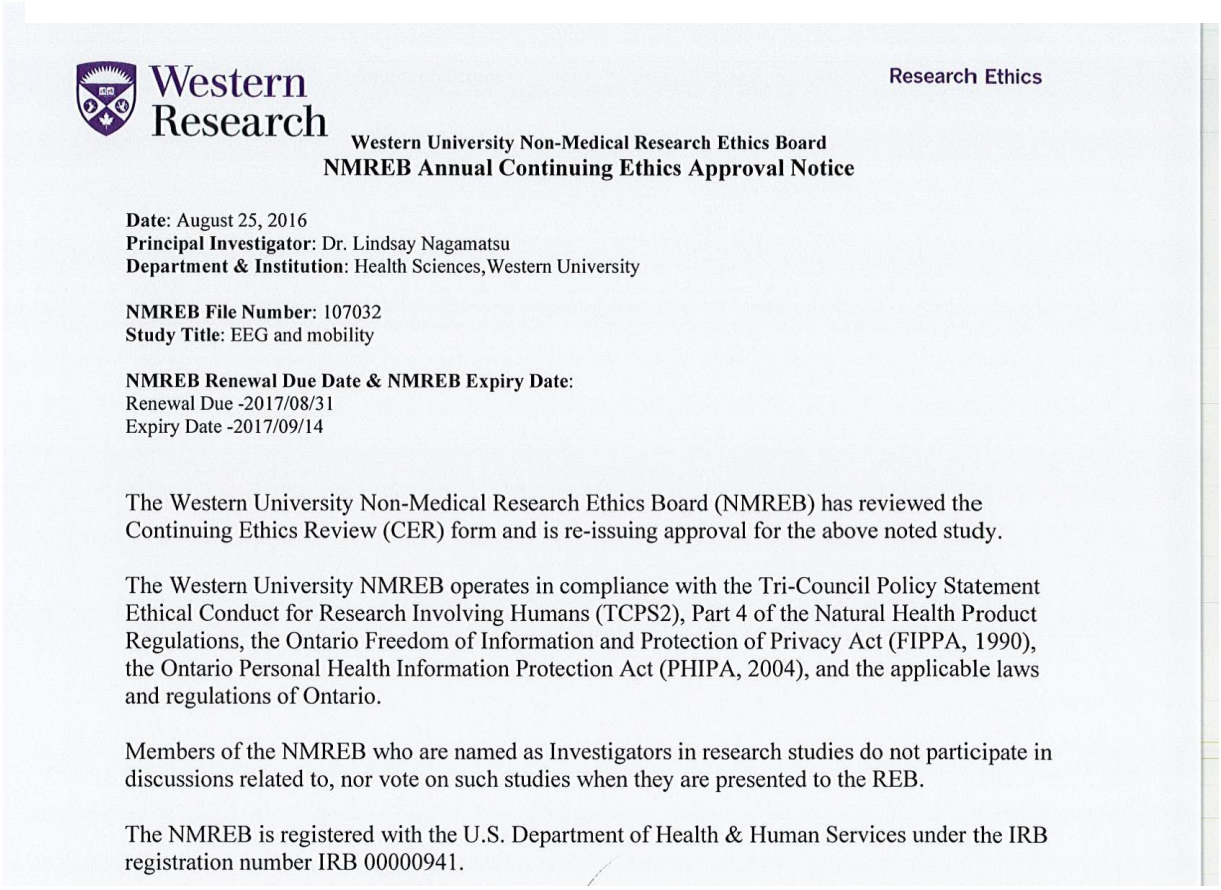
Project Title: EEG and Mobility

Document Title: Letter of Information and Consent

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Print Name of Participant	Signature	Date *(DD-MMM-YYYY)*
Print Name of Researcher	Signature	Date *(DD-MMM-YYYY)*

Appendix B: Ethics Approval Forms



Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Annual Continuing Ethics Approval Notice

Date: August 25, 2016
Principal Investigator: Dr. Lindsay Nagamatsu
Department & Institution: Health Sciences,Western University

NMREB File Number: 107032
Study Title: EEG and mobility

NMREB Renewal Due Date & NMREB Expiry Date:
Renewal Due -2017/08/31
Expiry Date -2017/09/14

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed the Continuing Ethics Review (CER) form and is re-issuing approval for the above noted study.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), Part 4 of the Natural Health Product Regulations, the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Amendment Approval Notice

Principal Investigator: Dr. Lindsay Nagamatsu
Department & Institution: Health Sciences,Western University

NMREB File Number: 107032
Study Title: EEG and mobility

NMREB Revision Approval Date: September 07, 2016
NMREB Expiry Date: September 14, 2017

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Other	FROP-COM.	2016/08/11
Revised Letter of Information & Consent		2016/08/11
Revised Western University Protocol	Received August 30, 2016	

The Western University Non-Medical Science Research Ethics Board (NMREB) has reviewed and approved the amendment to the above named study, as of the NMREB Amendment Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

Curriculum Vitae

Name:	Phil Parrot-Migas
Post-secondary Education and Degrees:	University of Western Ontario London, Ontario, Canada 2015-2017 Master of Science in Kinesiology The University of Western Ontario London, Ontario, Canada 2011-2015 B.A. Honors Specializing in Kinesiology
Honours and Awards:	Travel Award - Institute Community Support CIHR Summer Aging Program 2017 Academic All Canadian 2015-2017
Related Work Experience:	Teaching Assistant The University of Western Ontario 2015-2017

Posters and Talks Presented at:

Parrot-Migas, P., Fuhr, S., Ghahari, D., Nagamatsu, L. S., (2016). *Uncovering neural signatures of falls risk in older adults*. Poster presented at the Kinesiology Graduate Students Association (KGSA) Symposium, Western University, London, Ontario, Canada.

Parrot-Migas, P., Fuhr, S., Ghahari, D., Nagamatsu, L. S., (2016). *Uncovering neural signatures of falls risk in older adults*. Poster presented at the Faculty of Health Science (FHS) Research Day, Western University, London, Ontario, Canada.

Parrot-Migas, P., Fuhr, S., Ghahari, D., Nagamatsu, L. S., (2016). *Uncovering neural signatures of falls risk in older adults*. Poster presented at the Neuroscience Research Day, Western University, London, Ontario, Canada.

Parrot-Migas, P., Fuhr, S., Ghahari, D., Nagamatsu, L. S., (2016). *Uncovering neural signatures of falls risk in older adults*. Poster presented at the Exercise is medicine on campus (EIMC), Western University, London, Ontario, Canada.

Parrot-Migas, P., Fuhr, Furlano, J., Wong, M., Nagamatsu, L. S., (2017). *Is allocation of attention impaired in older adults who are at risk of falls? An event-related potential study*. Presented at the Exercise is medicine on campus (EIMC), Western University, London, Ontario, Canada.