The Impact of Multisensory and Cognitive Load on Older Adults' Complex Balance Performance *

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With age, older adults are increasingly subject to sensory, cognitive, and motor declines, placing them at a greater risk of falls. The impact of sensory impairment and increased cognitive load on older adults' complex balance performance has remained understudied. The purpose of the current study was to determine the impact that sensory loss and increased cognitive load have on older adults' single and dual-task balance performance. A total of 27 participants (11 healthy older adults (HOA), 16 age-related hearing loss (ARHL) between the ages of 56 to 90 were recruited. The participants underwent auditory, visual, and cognitive assessments, and their balance performance was tested under both single and dual-task conditions. A statistically significant main effect of balance task complexity was found, in which anterior-posterior sway increased with the addition of a sensory challenge and a cognitive load. There was no statistically significant interaction between hearing status and task complexity, thus indicating that individuals with ARHL performed similarly to HOA across balance conditions. Additionally, older adults with ARHL demonstrated a cognitive facilitation effect when considering cognitive dual-task costs. Those with ARHL had better cognitive performance in the dual-task in comparison to the single- task condition. An ineffective dual-task strategy of prioritizing cognition over balance may increase older adult's risk of falling.

Between 2015 and 2050, the world population aged 60 and over is expected to nearly double, reaching approximately 2 billion older adults [1]. With an increasingly older population, understanding the typical aging process is vital. As a function of age, older adults are subject to changes within their sensory [2, 3], cognitive [4, 5, 6], and balance [7] processes. Researchers have found that decreases in overall physical functioning are linked to an increased risk of falls, with approximately 46% of adults over the age of 85 having self-reported increases in instability [8]. Alarmingly, nearly 20 to 30% of older adults fall each year, and falls remain the leading cause of injury-related hospitalizations among Canadian seniors [9]. Understanding the functions that decline with increasing age and how they affect one another is essential to research regarding healthy aging. The current research was therefore designed to determine how older adults' balance and cognitive performance is impacted by hearing loss and the addition of a sensory challenge and cognitive load.

Sensory Loss and Aging

In Canada, an estimated 78% of older adults between the ages of 60 to 79 have at least slight hearing loss [9]. By age 80, nearly 90% of older adults have some form of hearing impairment [3]. Brennan et al. (2005) found that nearly one fifth of older adults reported hearing and vision loss and that both the number and the severity of dual-sensory impairment influenced participants'

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performance on a series of activities of daily living. Additionally, researchers have highlighted that an individual's risk of mortality increases as a result of dual-sensory loss [10]. Dual-sensory loss may therefore exacerbate the decline in functioning in older adults, as they can no longer compensate for the loss through greater recruitment of other senses [11]. In contrast, Alfaro and colleagues found that older adults with dual-sensory loss fared just as well on measures of cognition and activities of daily living, compared to individuals with sensory impairment in only one modality. These contradictory results highlight the importance of determining the impact of dual-sensory loss on cognitive performance [12].

Sensory Loss and Cognition

Hearing loss is negatively associated with cognition, since older adults with greater hearing loss have been found to perform more poorly on measures of cognitive functioning (i.e., working memory, inhibition, processing speed) [13, 14]. Hearing loss has been found to add a significant cognitive load and independently increase the rate of cognitive decline and cognitive impairment. More specifically, older adults presenting with greater hearing loss demonstrate greater annual decreases in cognitive performance [15, 16]. One interpretation of these associations between hearing and cognition is the Cognitive Load Hypothesis, which posits that older adults with hearing loss allocate greater cognitive resources to compensate for a degraded auditory signal, which diverts resources away from other cognitive tasks, potentially resulting in cognitive reserve depletion [17].

Dual-sensory loss is also seen to negatively impact cognitive functioning, in that with the additional sensory impairment, there is a notable decrease in measures of cognitive performance, such as short-term memory and decision making [18]. Cognitive impairment is therefore more prevalent in older adults with multiple sensory impairments [19]. For example, Davidson and Guthrie discovered that among their sample of older adults, the poorest cognitive performance was found in individuals with significant hearing and vision loss in comparison to those with either a single sensory impairment, or no sensory impairment [20]. Additionally, dual-sensory loss is found to increase an individual's risk of developing dementia [21].

Importantly, cognitive processes and frontal regions of the brain are more often utilized in older adults to compensate for sensory loss. For example, Du and colleagues' fMRI study highlighted that older adults show increased activation in frontal speech motor areas of the brain during a syllable identification task, to compensate for hearing loss [22]. Additionally, older adults with age-related vision or hearing loss demonstrate an increased reliance on cognitive resources for everyday functioning [23]. Thus, due to their increased utilization of cognitive processes and recruitment of frontal regions, older adults may have fewer cognitive resources to distribute efficiently to motor, or dual-task conditions.

Sensory Loss and Balance

In addition to the impact of sensory loss on cognition, hearing and vision loss are also positively associated with several measures of postural control. An individual's ability to balance efficiently is heavily influenced by the contribution of multiple sensory systems (i.e., proprioceptive, vestibular, auditory [24]. Among these sensory systems, which are subject to decline gradually with healthy aging, hearing loss has been shown to increase fall risk and instability [15]. Older adults with hearing loss are more likely to demonstrate poor postural performance, and this effect appears to be stronger for greater levels of hearing loss [25]. For example, Lin and Ferrucci found that with every 10-decibel (dB) increase in hearing loss, an individual was 1.4 times more likely to have reported a fall within the 12 preceding months [15]. Older adults with hearing loss will often struggle more in regaining their balance when performing a secondary task in comparison to their normal hearing counterparts [26].

Older adults with significant vision impairment also demonstrate increased postural instability and a greater risk of falling [27]. Hallot and colleagues found greater postural instability, specifically anterior-posterior changes (i.e., greater forward and backward sway) when using stimulated vision impairment goggles. Such changes are often determined using balance platforms that measure centre of pressure displacement [28]. Additionally, a more extreme eyes-closed visual manipulation has been found to increase centre of pressure displacements [29]. This signals greater postural sway and unsteadiness among the older adults. Thus, sensory loss as a result of typical aging, negatively impacts both cognition and balance performance and may influence the utilization of cognitive resources and recruitment of frontal brain regions.

Cognition and Aging

In addition to sensory and motoric changes, typical aging is accompanied by neurobiological changes which in turn affect cognitive processes [4]. Consequently, cognitive performance on tests of memory and attentional control decreases as a function of age [6]. Older adults also experience a decline in executive functioning with increasing age. Executive functions can be defined as a set of cognitive skills required for planning, monitoring, and executing a sequence of goal-directed complex actions [5]. These processes include inhibition, attentional switching or divided attention, and working memory capacity. In particular, older adults' decline in processing speed ability creates a greater difficulty in tasks requiring divided attention (e.g., having a conversation while walking) [30].

Interesting however, is the idea that older adults may use compensatory mechanisms to reduce the age-related gap in cognitive performance. When comparing the performance of younger and older adults in a cognitive task where younger adults are seen to recruit regions of one hemisphere, older adults may utilize additional frontal brain regions and demonstrate bilateral activation [31]. Older adults who show bilateral activation may perform more similarly to their younger aged counterparts on cognitive tests.

Individuals with mild cognitive impairment may also demonstrate this pattern of activation [32] Approximately 19% of older adults over the age of 65 will be affected by Mild Cognitive Impairment (MCI), which is an intermediate state between normal aging and dementia [33]. Nearly 50% of adults with MCI will progress to dementia within five years of the initial MCI diagnosis [34]. Characterized by greater cognitive decline than would be typically expected for an individual's age and level of education, MCI does not appear to largely interfere with activities of everyday life in comparison to dementia, which affects daily functioning [34]. Importantly, greater decline in cognitive ability (i.e., dementia or severe cognitive impairment) can lead to increased difficulty in performing everyday activities, and an increased risk of falling, thus highlighting the importance of maintaining healthy cognitive and motor functioning [35].

Cognition and Balance

Additionally, there is a relationship between changes in older adults' cognitive functioning and subsequent balance performance [36]. Older adults demonstrate a reduced ability in allocating their limited cognitive resources among multiple tasks [37]. Impaired performance on tasks involving divided attention can be determined using a dual-task paradigm [38]. A dual-task paradigm is used to assess how attentional resources are allocated among particular tasks of interest [39].The paradigm allows for the comparison of the performance of two tasks completed individually with the performance of both tasks completed simultaneously. Dual-task performance can be estimated by considering dual-task costs, which are determined by subtracting the performance on the dual-task condition by performance on the single-task condition, and further dividing it by the single-task performance [38]A positive dual-task cost value indicates reduced dual-task ability or maladaptive performance when performing both tasks. A negative dual-task value would be indicative of an improvement in dual-task performance compared to single-task performance. Participants with a negative dual-task cost would therefore be demonstrating a facilitative performance [38]. Older adults are more likely to demonstrate greater dual-task costs (i.e., positive dual-task cost value) in comparison to their younger-aged counterparts. Brustio and colleagues highlighted a significant main effect of age, where older adults demonstrated greater dual-task costs in the cognitive domain, compared to younger adults, when undergoing both motor and cognitive tasks simultaneously [40]. Huxhold and colleagues found the greatest dual-task costs in the motor domain, in older adults undergoing a balance and working memory load paradigm [41].

While most research has highlighted the idea that postural stability is compromised by the addition of a cognitive load or cognitive impairment [41, 42], performance on a dual task may change as a result of postural prioritization. The posture-first principle states that when undergoing a cognitive-motor dual task, older adults will allocate more resources to the balance task to avoid falling, which as a result would impair their performance on the cognitive task [43]. Contradictory evidence where postural performance declines as function of a dual-task paradigm may be explained through alterations in the complexity of both the balance and cognitive tasks [29, 44].

Cognitive decline is negatively associated with complex balance performance, where older adults presenting with greater cognitive decline are more likely to demonstrate increased postural instability [36]. For example, Shin and colleagues found that older adults with MCI demonstrated greater mediolateral sway than their cognitively normal counterparts. Furthermore, increases in cognitive load also negatively impact older adults balance performance [45]. Older individuals will typically demonstrate greater postural instability with the addition of a cognitive load [41, 42]. For example, researchers using a Wii balance board to measure cognitive-motor dual-task performance found greater sway with increased cognitive load (i.e., serial subtraction task) compared to single-task balance conditions [46].

To summarize the relevant literature, there is abundance of evidence that sensory modalities (i.e., vision and hearing) [21], cognition, [4], and balance [7] decline as a function of increasing age. Additionally, these three functions appear to be highly interrelated. Sensory loss is negatively related to cognition, where increases in hearing loss or multiple sensory impairments are associated with worsened performance in multiple tests of cognitive functioning [16]. Further, sensory loss is positively related to balance performance where greater levels of hearing loss are associated with increases in postural instability [15]. Lastly, greater cognitive decline and added cognitive loads appear to negatively impact older adults' balance performance [36, 42]. However, less is known about the impact of multisensory impairments and cognitive load on older adults' complex balance performance.

Present Study

The purpose of the current study was to determine the impact that sensory losses and increased cognitive load have on older adults' single- and dual-task balance performance. More specifically, we were interested in the impact of hearing loss and simulated visual impairment on older adults' cognitive functioning and complex balance performance. We therefore hypothesized that with the addition of both a cognitive load and visual challenge, complex balance performance would decrease. Next, we hypothesized that individuals with age-related hearing loss ARHL would demonstrate worsened complex balance performance with increasing complexity relative to healthy older adults HOA. Regarding postural dual-task costs, we hypothesized that under dual-task conditions, all individuals would demonstrate decreased balance performance. Additionally, we expected that postural dual-task costs would be greater in the ARHL group than in the HOA group. Lastly, regarding cognitive dual-task costs, we hypothesized that the presence of hearing loss and increased cognitive load while balancing would result in reduced cognitive performance in the dual-task condition in comparison to the single-task condition. We therefore hypothesized that when undergoing dual-task conditions individuals would demonstrate both postural and dual-task costs, however likely not to the same degree.

Method

Participants

The present sample was drawn from an existing data set of 27 older adults between the ages of 56 and 90 (*M* = 74.74, *SD* = 9.51) Among the participants 16 were female and 11 were male. Within the sample, 11 participants were HOA and 16 had ARHL. Based on an a priori G*POWER [47] analysis, a minimum of 26 participants were needed to achieve a medium effect size of 0.5 with a power of 0.8, thus the present sample size was deemed adequate.

Older adults were recruited from the engAGE Living Lab, located in the Cote Saint-Luc Cavendish Mall. Data collection occurred during a 3.5-week residency, which was part of a larger funded project aiming to provide an interactive space to help older adults combat social isolation and participate in collaborative research. Older adults interested in the research would simply walk into the centre and sign up to be a part of the study. The residency allowed for data to be collected in a natural setting, allowing for a more diverse aging population to be recruited. Participants were included if they were 50 years or older and had normal or corrected-to-normal vision. The cut-off of 50 years was chosen as many individuals begin to undergo hearing loss screening as of that age [48]. Participants were excluded if they had any vestibular disorders, artificial limbs, or any neurodegenerative diseases. Such exclusions were determined through self-report measures.

Measures

Cognition

The Montreal Cognitive Assessment (MoCA) was used as a measure of global cognition [49]. The MoCA is comprised of eight sections, each assessing a different domain of cognitive functioning. More specifically the test includes the categories of visuospatial/executive naming, attention, language, abstraction, delayed recall, and orientation. A total of 30 points were available, and participants were given an extra point if they had less than 12 years of education. A lower score on the MoCA indicates poorer cognitive performance. More specifically, a score of less than 26 is suggestive of the presence of MCI. The MoCA has good internal consistency (Cronbach's α =

.83) [49]. The duration of the test was approximately 10 minutes. Participants with MoCA scores indicative of Mild Cognitive Impairment remained eligible.

The serial 7s subtraction task was used as a measure of working memory [50]. The same task was also given concurrently within the dual task balancing conditions. Participants completed this task in a seated position wearing control clear goggles, while fixating their view on a target icon on the wall in front of them (single-task cognition). Participants were required to count backwards by 7s from 175 for 30 seconds. Participants gave their answers verbally and the percentage of correct responses was recorded and used as an indicator of cognitive performance. In the case of a calculation error, participants were permitted to continue and the correct subtractions from that point onward were counted. The internal consistency of a sample of older adults was found to be a Cronbach's α of 0.764 [50].

Audition

ShoeBOX Audiometry (Clearwater Clinical Limited) was used to measure hearing acuity. ShoeBOX Audiometry is clinically validated for auditory assessment outside of a sound-attenuated booth [51]. Specially calibrated DD 450 Headphones were used to deliver pure tones, which ranged in frequency (e.g., 200, 500, 1000, 2000, 3000, 4000, and 8000 Hz) and were presented to the left followed by the right ear. Participants responded using a touch-sensitive tablet and were instructed to click on a blue disk to begin each trial. Depending on whether or not they heard a presented tone, they were told to drag the blue disk to the green (heard) speaker or the red (not heard) speaker. ShoeBOX Audiometry has been validated against standardized pure tone testing methods and was chosen to facilitate the unconventional setting of our testing locale.

Participants were classified according to grades of hearing acuity which were calculated using pure tone averages (PTA) for the better ear as an average of four frequencies (e.g., 500, 1000, 2000, 4000 hertz (Hz)). A higher PTA would indicate poorer hearing acuity; that is a greater sound intensity (dB HL) would be needed to detect that tone [52]. As recruitment for this project did not involve actively seeking out individuals with hearing loss, we created two broad categories of hearing status by pooling all individuals with PTAs above 25 dB hearing loss (HL) in the better ear (i.e., ARHL: > 25 dB HL, HOA: < 25 dB HL) in keeping with the World Health Organization classification scheme for hearing impairment [1].

Complex Balance Performance

To assess postural stability, a Nintendo Wii Balance Board (Nintendo, Kioto Japan) was paired with custom software (RombergLab) that recorded centre of pressure displacements [53]. The Wii Balance Board is similar to typical force plates as it contains four gauge-based load sensors. To measure postural instability, the following centre of pressure displacements were considered. Medial-lateral sway amplitude (mm), a distance between the farthest point leftward and rightward. Anterior-posterior sway amplitude (mm), the distance between the most forward and backward point. Lastly total path length was considered. Total path length included both medial-lateral and anterior-posterior amplitude sway measures and is the total distance travelled in millimetres. Data for center of pressure displacements are shown in Appendix A.

During the balance conditions involving the addition of a sensory challenge, 20/80 vision impairment goggles were used. The vision impairment goggles were designed to mimic the visual acuity of an individual with vision impairment and could be worn over glasses if relevant. A simulated visual acuity of 20/80 was chosen as it is the level of visual impairment needed to qualify for vision rehabilitation in Quebec. As a more extreme manipulation of visual impairment, an eyes-closed condition was included. For balance conditions not involving a visual manipulation, clear control goggles were used, which did not impair vision. All participants underwent five balance conditions: balance eyes closed, balance and control goggles, balance control goggles and serial 7s task, balance and 20/80 vision impairment goggles, balance 20/80 vision impairment goggles and serial 7s task. The five conditions were used to determine how both a sensory challenge and a cognitive load influence the centre of displacement measures (i.e., total path length, medial-lateral (ML) amplitude, anterior-posterior (AP) amplitude). To account for potential learning and fatigue effects, the order of the balance test conditions was counterbalanced.

General Procedure

Prior to participating, individuals were required to sign a consent form Once having completed the measures of global cognition (MoCA), single cognitive task (serial 7s subtraction), and hearing acuity (ShoeBOX), participants underwent each of the five balance conditions. Once all of the measures were completed, participants were debriefed, and contact information was provided in the case of follow up questions from the participants.

Results

Data Integrity

Prior to conducting the statistical analyses, the data were examined for normality, outliers, skewness, and kurtosis. Specifically, descriptive statistics were assessed (see Table 1). The scores from hearing, cognitive, and balance measures were converted to z-scores and inspected to ensure that they fell within 3 standard deviations of the mean. One participant's scores consistently did not meet this cut-off for balance and therefore their case was removed from the analyses. Additionally, there were no missing values within the dataset. The final sample size was 27.

Table 1

Means (SD) for Participant Characteristics

	Total Sample (N=27)	HOA (n=11)	ARHL (n=16)	*t*	*p*
Age (years)	74.74 (9.51)[a]	71.27 (11.30)[a]	77.13 (7.53)[a]	-1.62	.118
Gender (male, female)	11, 16	3, 8	8, 8		
MoCA (max. = 30)	22.96 (3.79)[a]	24.00 (3.29)[a]	22.25 (4.04)[a]	1.19	.246
Hearing Acuity (PTA)	30.46 (12.25)[a]	19.20 (5.82)[a]	38.20 (8.99)[a]	-6.16	.000**

Note. [a] Mean (standard deviation). MoCA= Montreal Cognitive Assessment. MoCA scores of < 26 are suggestive of MCI. PTA= pure tone average.
A higher pure tone average value indicates poorer hearing acuity. Independent samples *t*-tests were used to compare HOA and ARHL.
**p* < .05 ***p* < .001

The assumptions needing to be met to conduct a mixed analysis of variance (ANOVA) and independent sample t-tests were also considered. The assumption of independence was met, indicating that the sample was both randomly and independently sampled. Regarding the repeated measures ANOVA, Mauchly's test of sphericity was not significant, therefore we interpreted the results using a Greenhouse-Geisser correction. Regarding independent samples t-tests, Levene's test for equal variances was not significant, and we therefore interpreted the results using equal variances assumed.

Main Results

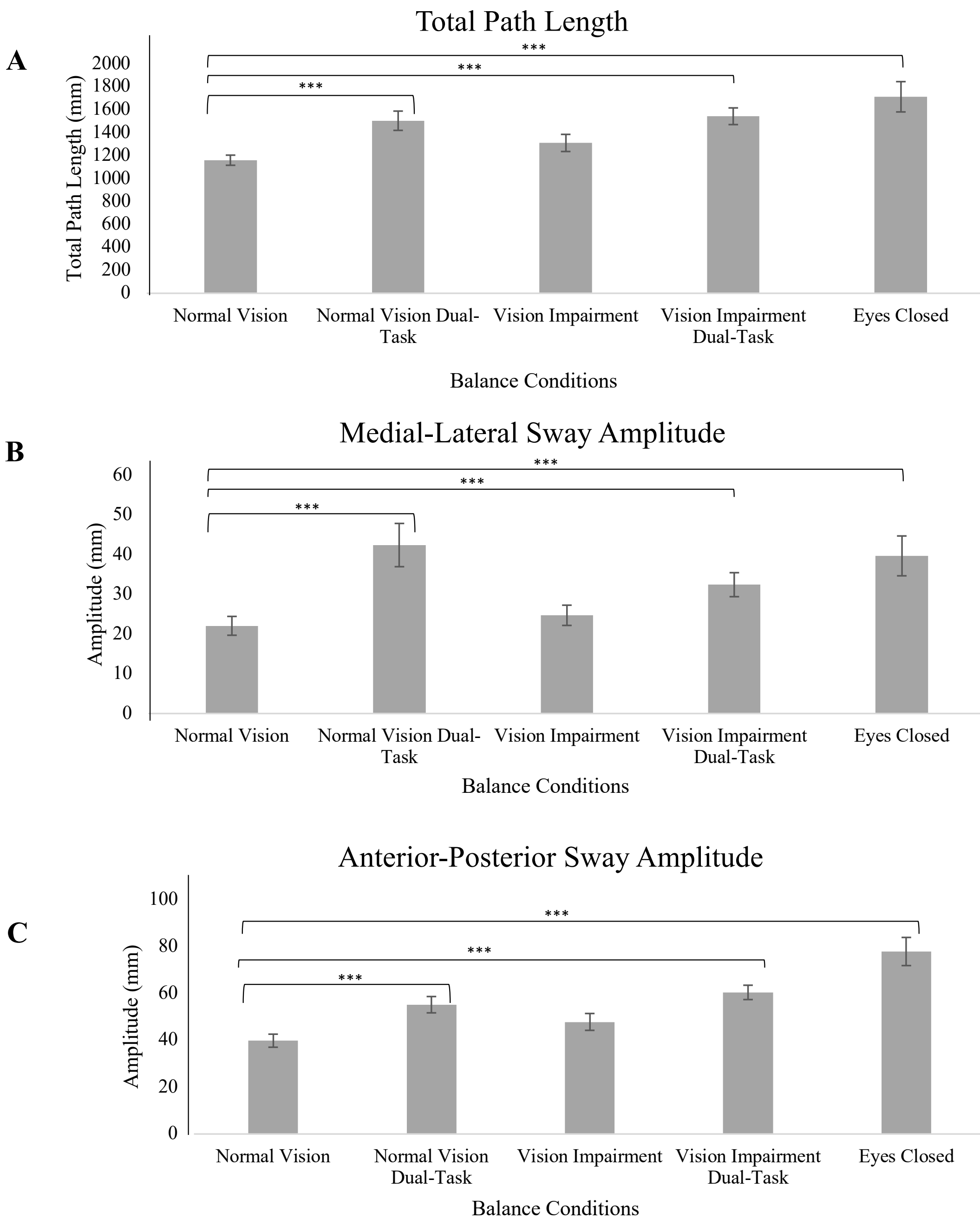
Prior to conducting hypotheses driven analyses, independent samples t-tests were used to assess group differences in cognitive performance. Regarding MoCA scores, 9 participants had scores of less than 26 (M = 20.94, SD = 2.92) and 18 participants had scores greater than 26 (M = 27.00, SD = 1.00). MoCA Scores were lower in the ARHL group (M = 22.25, SD = 4.04) in comparison to the HOA group (M = 24.00, SD = 3.29). The difference in MoCA scores between groups was not found to be statistically significant ($t(25) = 1.19$, p = .246). Participant characteristics are shown in Table 1.

Hypothesis 1

First, we hypothesized that with the addition of both a sensory challenge and cognitive load, complex balance performance would decrease. To evaluate the effect of increasing task complexity on balance performance, we conducted a 2 x 5 mixed analysis of variance ANOVA. Specifically, the within-subjects factor was Task Complexity with 5 levels: normal vision, normal vision & serial 7s, vision impairment, vision impairment & serial 7s, eyes closed. Additionally, Hearing Status was used as a between-subjects factor. A statistically significant main effect of task complexity was observed in anterior-posterior sway amplitude, $F(2.23, 55.82) = 6.396$, p =.002, $\eta^2 = .204$. Total path length did not show a significant complexity effect, $F(1.80, 44.89) = 1.96$, p =.157, $\eta^2 = .073$, but the same task complexity factor approached significance for medial-lateral amplitude, $F(2.07, 51.84) = 2.626$, p =.080, $\eta^2 = .095$. Data for all complexity conditions are shown per balance parameter in Figure 1. Post-hoc pairwise comparisons using Bonferroni corrections were used to identify which balance conditions differed specifically from one another. We found that when using the normal vision single-task balance condition as a reference point, total path length increased with the addition of a cognitive load (i.e., normal vision dual-task; MD = -344.05, SE = 60.86, 95% CI [-531.38,-156.72], $p < .001$), with a cognitive and sensory challenge (i.e., vision impairment + serial 7s: MD = -383.126, SE = 53.75, 95% CI [-548.57, -217.68], $p < .001$), and with the complete removal of a visual input (i.e., eyes closed; MD = -552.83, SE = 113.91, 95% CI [-903.46, -202.20], p = .001). No statistically significant difference was observed when comparing the normal vision condition to the vision impairment condition (MD = - 150.50, SE = 54.40, 95% CI [-317.94, 16.95], p = .105). We concluded the addition of a visual challenge alone did not impair balance performance in comparison to the normal vision baseline condition, possibly because there were adequate cognitive resources to compensate for the visual challenge.

Figure 1

Centre of Pressure Displacements for the Total Sample



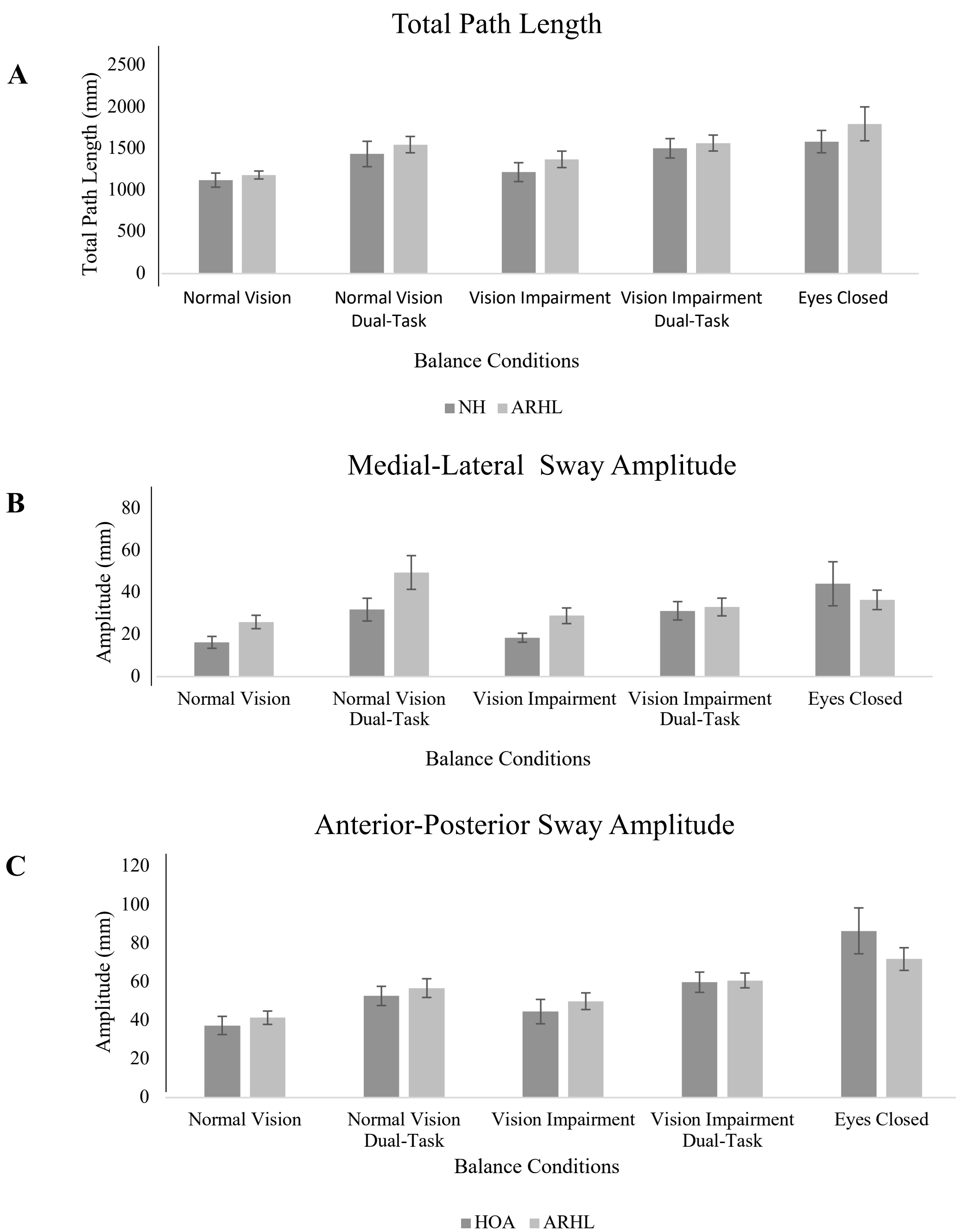
Hypothesis 2

Second, we hypothesized individuals with ARHL would demonstrate worsened complex balance performance with increasing task complexity. No statistically significant main effect of hearing status group was observed for total path length ($F(1, 25) = .43$, $p = .518$, $\eta^2 = .017$), medial-lateral amplitude ($F(1, 25) = 2.24$, $p = .147$, $\eta^2 = .082$), and anterior-posterior amplitude ($F(1, 25) = .03$, $p =$

.876, $\eta^2 = .01$). No statistically significant interaction between task complexity and hearing status was observed for total path length ($F(1.80,44.89) = .32$, $p = .706$, $\eta^2 = .024$), medial-lateral amplitude ($F(2.07, 51.84) = .70$, $p = .506$, $\eta^2 = .027$), and anterior-posterior amplitude ($F(2.23, 55.82) = 1.24$, $p = .299$, $\eta^2 = .047$). Balance performance data separated by hearing status group are shown in Figure 2. We therefore concluded that individuals with hearing impairment did not have poorer balance performance with increased task complexity, as we had originally hypothesized.

Figure 2

Centre of Pressure Displacements by Hearing Status

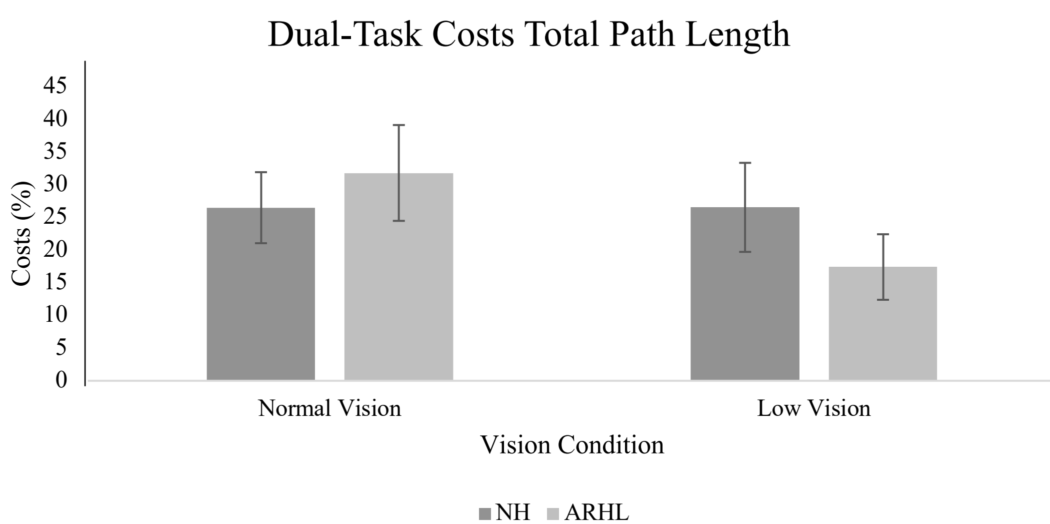


Hypothesis 3

Third, regarding postural dual-task costs, we hypothesized that under dual-task conditions, individuals would demonstrate decreased balance performance. Additionally, we expected that postural dual-task costs would be greater in the ARHL group in comparison to the HOA group. In partial support of our hypothesis, participants did demonstrate postural dual-task costs. Older adults with ARHL presented with 31.84% dual-task costs in the normal vision condition and 17.42% dual-task costs within the low vision condition. For HOA, dual-task costs were 26.52% and 26.56% for normal and low vision conditions respectively. Additionally, upon visual inspection, in the normal vision condition, the postural dual-task costs appear greater in the ARHL group in comparison to the HOA group (see Figure 3). However, results from an independent t-test revealed that the difference in dual-task costs within the normal vision condition when comparing the between the ARHL group and HOA groups was not statistically significant ($t(25) = -.52$, $p = .611$). The dual-task costs within the low vision condition did not support our hypothesis. With inspection alone, individuals in the ARHL group appeared to demonstrate fewer postural dual-task costs in comparison to the HOA group. This result however was not found to be statistically significant ($t(25) = 1.06$, $p = .299$). Within dual-task conditions, those with ARHL appear to allocate more attention to their balance in the low vision condition in comparison to the normal vision condition. A paired sample t-test revealed this result to approach significance ($t(15) = 2.03$, $p = .06$).

Figure 3

Postural Dual-task Costs by Vision Condition and Hearing Status



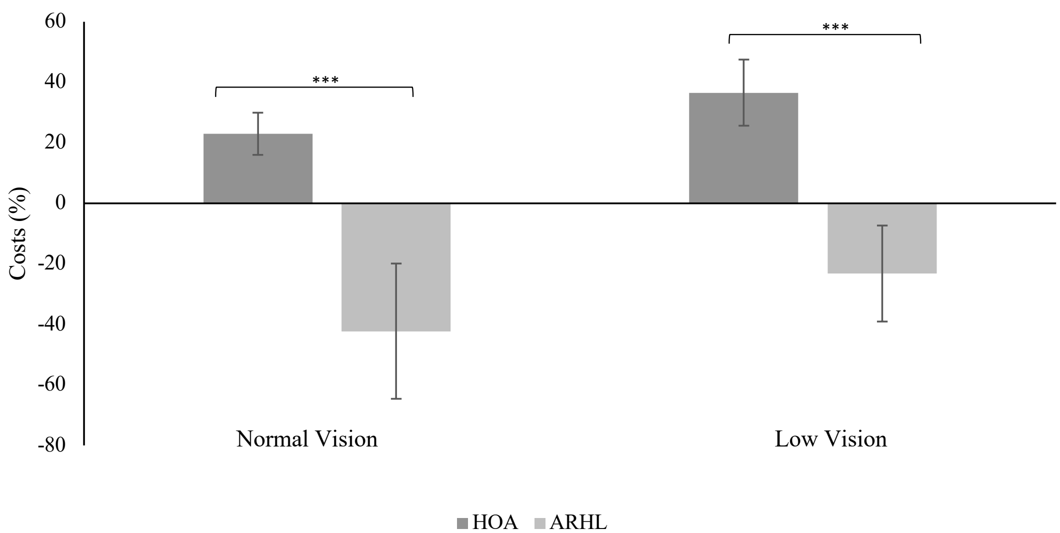
Hypothesis 4

Finally, regarding cognitive dual-task costs, we hypothesized that the presence of hearing loss and a cognitive load while balancing would result in significant cognitive dual-task costs. Contrary to what was hypothesized, not only did those with ARHL not demonstrate greater cognitive dual-task costs in comparison to HOA, but they appeared to demonstrate dual-task facilitation.

That is, ARHL participants showed superior cognitive performance (i.e., serial 7s subtraction) in the dual-task, compared to the single-task condition. This facilitation effect was also observed, however to a lesser degree in the low vision condition. Our hypothesis was therefore not supported. An independent samples t-test was conducted to compare the cognitive dual-task costs of participants with ARHL and HOA. Within the normal vision condition, we observed a statistically significant difference between the two groups in the magnitude of their cognitive dual-task facilitation ($t(25) = 2.23$, $p = .032$, $d = 0.68$) such that the ARHL group exhibited facilitation whereas the HOA group exhibited dual-task costs. Additionally, a statistically significant difference between ARHL and HOA groupings was observed in the low vision condition ($t(25) = 2.72$, $p = .012$, $d = 0.86$) again with the HOA group exhibiting costs and the ARHL group exhibiting facilitation (see Figure 4).

Figure 4

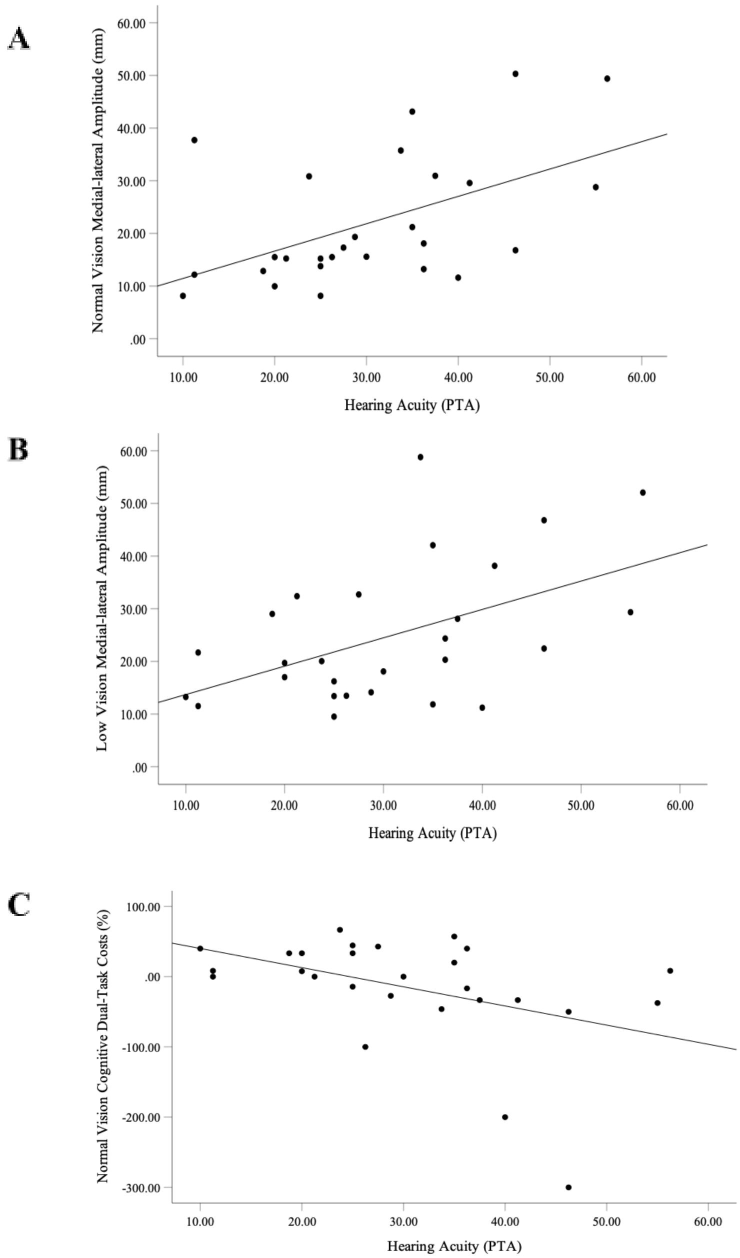
Cognitive Dual-task Costs by Vision Condition and Hearing Status



An additional series of correlations were conducted to examine the relationship between hearing loss and balance task complexity, and hearing loss and cognitive dual-task costs. Specifically, we aimed to determine the direction of the relationships. Regarding hearing status and task complexity, we found a statistically significant positive correlation between hearing acuity (PTA) and single-task low vision ($r(26) = .498$, $p = .008$) and single-task normal vision in the medial-lateral amplitude parameter ($r(26) = .517$, $p = .006$). A negative correlation was observed between hearing acuity (PTA) and cognitive dual-task costs in the normal vision condition ($r(26) = -.424$, $p = .027$; see Figure 5). Thus, indicating that participants with greater hearing loss demonstrated more greater facilitation in their cognitive performance when comparing normal vision single-task to dual-task. Additionally, we aimed to determine if MoCA scores influenced either hearing status or cognitive performance. MoCA scores were negatively correlated with age ($r(26) = -.428$, $p = .026$), indicating poorer cognitive functioning with increasing age. However, no statistically significant correlations were found between MoCA scores and hearing acuity (PTA), or with cognitive performance. Therefore, the participants degree of cognitive functioning did not appear to influence their auditory performance, nor their performance on the serial 7s task.

Figure 5

Associations Between Hearing Acuity and Medial-lateral Amplitude for Normal and Low Vision Conditions and Hearing Acuity and Normal Vision Dual-task Costs



Note. PTA = pure tone average.Positive dual-task costs indicate a maladaptive performance. Negative dual-task costs indicate a facilitative performance

Discussion

The aim of the current research was to determine the impact that sensory loss and cognitive load have on older adults' balance performance. Given that many of our analyses either did not reach or only approached significance, we must be careful when interpreting the results.

First, to determine whether there was an effect of task complexity on balance performance, we considered centre of pressure displacements for the entire sample. Overall, the whole sample appeared to demonstrate worsened postural performance with increased complexity of the balance conditions. Interestingly, adding a visual challenge alone did not appear to impact balance performance in comparison to the normal vision baseline condition. Performance instead was relatively similar among the two conditions. This may be due to the amount of time spent wearing the vision impairment goggles. The vision impairment goggles were only worn for 30 seconds at a time, which may not have been long enough to see an effect of sensory load alone. Additionally, the vision goggles only partially obscured vision, thus older adults may still have the cognitive capacity to compensate for the impairment. By contrast, with the addition of a cognitive or both a sensory challenge and a cognitive load, the participants centre of pressure displacements (i.e., total path length, AP amplitude, ML amplitude) increased. In support of our findings, researchers have highlighted that with increasing balance task complexity, or the addition of cognitive and sensory loads, individuals demonstrate poorer balance performance [46]. In contrast, Deviterne and colleagues found that with the addition of a cognitive load, participants demonstrated improved postural performance, highlighting how they may allocate more resources toward the postural task rather than the cognitive task [54]. Contradictory evidence to what we had found in our study further highlights the need for future replication by other researchers.

To address Hypothesis 2, the main effect of hearing status and the interaction of hearing status and task complexity was considered. We compared centre of pressure displacements among HOA individuals and those with ARHL. There was no statistically significant main effect of hearing status on task complexity. Thereby, the increase in task complexity did not appear to be impacted by hearing loss. Additionally, a statistically significant interaction was not observed, in that both normal hearing older adults and those with age-related hearing loss were similarly affected by the complexity manipulation. This finding was not in support of the second hypothesis, which predicted that those with ARHL would be more negatively affected by increased balance task complexity. This may be due to the distribution of hearing loss severity in the current ARHL sample, which was largely in the mild range. More specifically, only a few individuals had moderate hearing loss and no individuals had severe hearing loss. Perhaps having more individuals with a greater degree of hearing loss, as well as a more even distribution among hearing loss categories would have allowed for the discovery of an effect of hearing status on balance performance.

To address postural dual-task costs, Hypothesis 3 predicted that under dual-task conditions, participants would demonstrate significant dual-task costs in their balance performance. Additionally, we expected that these costs would be greater among those with ARHL. Within the normal vision condition, we observed postural dual-task costs in both groups, however the magnitude of these costs did not differ between HOA and ARHL groups. In the low vision condition, we found that those with age-related hearing loss demonstrated numerically fewer postural dual-task costs than those without hearing loss, however this result did not reach significance. When considering the normal and low vision conditions among ARHL individuals, postural dual-task costs decreased with the addition of the visual challenge. This finding suggests that there was something about the addition of the vision impairment goggles among those with ARHL that caused these individuals to allocate more attention towards the preservation of their balance. Similarly, Bruce and colleagues found that older adults with ARHL demonstrated postural prioritization (i.e., preserved balance performance) when undergoing dual-task conditions [55]. In contrast, other researchers found that with the addition of a cognitive load, balance performance was impaired in comparison to the single-task balance condition [46]. Essentially, within the low vision condition, those with ARHL are comparable to individuals with dual-sensory loss. Dual-sensory impairment has been linked to poorer balance performance and an increased risk of falls [56].

Lastly, to address cognitive dual-task costs, Hypothesis 4 predicted that individuals with age-related hearing loss would demonstrate greater cognitive dual-task costs in comparison to HOA. Greater cognitive dual-task costs have been found in studies demonstrating preserved postural performance at the expense of the cognitive task [42].Contrary to expectation, we found a facilitation effect among those with ARHL, meaning that the participants improved in performance on the serial 7s subtraction task from single- to dual-task conditions. Interestingly, a study conducted by Hazamy and colleagues found that with a concurrent motor task, participants prioritized their cognitive performance, thus demonstrating improved N-back performance in the dual-task condition in comparison to the single-task condition. N-back tests are used as a way to measure working memory capacity [57]. While not as strong as in the normal vision condition, this facilitation effect was also observed in the low vision condition. This may have been due to a potential cohort effect. The mean age of the ARHL group was 5.86 years older than in the HOA group. Therefore, we believe that individuals with ARHL may feel as if they had more to prove cognitively, due to their increasing age. In the future, it would be beneficial to add a self-report questionnaire to evaluate whether or not they fear conforming to age stereotypes and how they believe their cognitive performance varies among multiple tasks. This would help to address whether age-related stereotypes of cognitive decline influence participants degree of dedication toward the cognitive task. The cognitive facilitation effect however is an ineffective dual-task strategy because older adults were allocating more of their attentional resources toward cognition and as a result less toward their balance performance. Sometimes termed the posture-second strategy this pattern is considered maladaptive and may lead to an increased risk of falling [58].

The present study had several limitations, which should be considered when interpreting the findings and proposing future directions. First, the participants' years or level of education was not recorded. This information may have helped explain the cognitive facilitation effect among the participants with ARHL. Perhaps these individuals were performing well cognitively because of a greater level of education in comparison to those without hearing loss. There may also be greater expertise with mental arithmetic in older generations [59]. Thus, future studies may benefit from matching by chronological age across groups, to consider whether those in older generations are more likely to perform better on arithmetic tasks. Additionally, the balance task itself (i.e., standing on the Wii Balance Board) may not have been challenging enough to see the dual-task costs we had originally anticipated. More specifically, the balance task required participants to stand similarly to how they would on a bathroom scale. To address the difficulty of the balance task itself, in the future it would be interesting to see how the participants balance performance may differ with the addition of a more threatening balance task, and whether we would observe worsened dual-task costs among ARHL individuals. For example, many studies have used a moving platform to evaluate balance performance [60].

Furthermore, the sample size was relatively small with an uneven distribution of individuals with either mild or moderate hearing impairment, and no individuals with severe hearing impairment. This may explain why we were unable to find an effect of hearing status on balance performance. Finally, we only considered individuals with hearing loss and added the sensory challenge (i.e., vision impairment goggles). We did not consider individuals with actual vision loss or with dual-sensory loss and how their impact on balance performance may differ. In the future, it would be beneficial to consider individuals with vision loss while adding a hearing impairment, as well as individuals with dual-sensory loss to see how the different impairments affect balance performance independently and in conjunction.

There were also several strengths to this research project. Having the study conducted in a mall setting allowed for an inclusive representation of a general population. Additionally, the environment allowed for a relatively stress-free experiment experience.

In conclusion, this study aimed to determine the impact that sensory losses and increased cognitive load had on older adults' single-and-dual task balance performance. We discovered that with increased balance task complexity, participants demonstrated poorer balance performance. In addition, under dual-task conditions, individuals demonstrated increased postural dual-task costs and cognitive facilitation.

As previously mentioned, approximately 78% of Canadians between the ages of 60 to 79 have some form of hearing loss [9]. Within the 60 to 69 age group, only 9% of those with hearing loss were hearing aid users. Among the 70 to 79 age group, only 24% of individuals with hearing loss were hearing aid users. Thus, among a population greatly affected by hearing loss, very few individuals choose to correct their hearing. Interestingly, within our sample only one participant wore a hearing aid. Despite unexpectedly finding decreased postural and cognitive dual-task costs among our ARHL group, our results highlight how untreated hearing impairment may impact both cognitive and motor abilities.

In the low vision condition, the normal hearing individuals demonstrated dual-task costs in both postural and cognitive domains. It is reported than among individuals 80 and over, approximately 8% have uncorrected vision [9]. This finding further highlights the importance of correcting vision impairment when it occurs, as it can affect both older adult's balance as well as cognitive performance.

Ultimately, it is important to consider how both uncorrected hearing, vision, or both may impact older adults balance, cognitive functioning, and dual-task ability. Furthering the understanding the influence of visual and hearing aids can be pivotal in decreasing life-threatening injuries and falls among older adults

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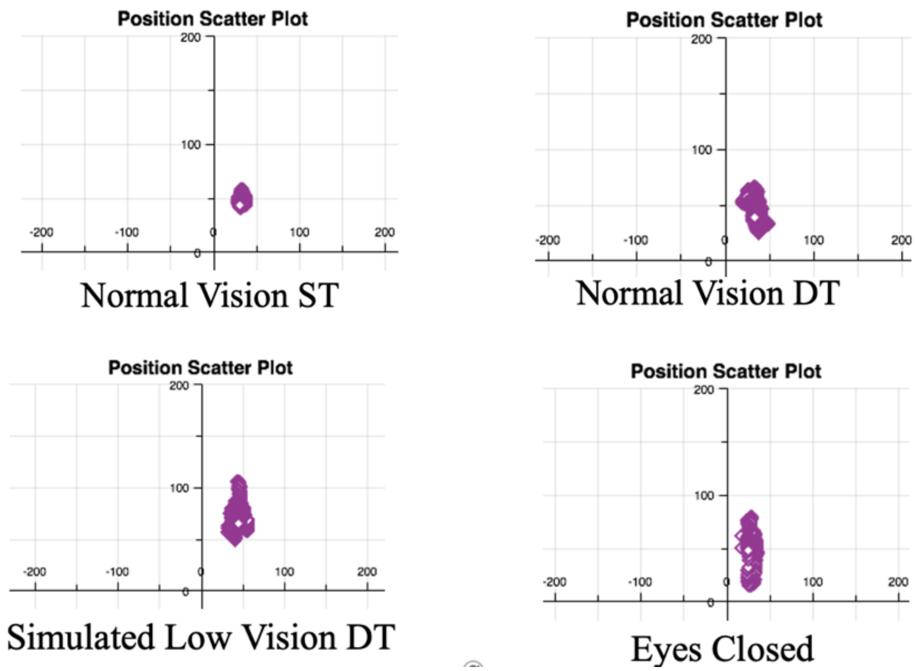
Appendix A

Centre of Pressure Displacements Scatter Plots



Note. Normal Vision ST= normal vision single task. Normal Vision DT= normal vision dual task. Simulated Low Vision DT= simulated low vision dual task.

Appendix B

Source Tables for Repeated Measures Analysis of Variance

Table B1

Analysis of Variance for Total Path Length Across Task Complexity

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Task Complexity	8313.43.65	1.80	462967.795	1.96	.157	.073
Task Complexity * Hearing Status	134960.53	1.80	75157.303	.32	.706	.013
Error	10607402.80	44.89	236286.688	Error		

Table B2

Analysis of Variance for Medial-lateral Sway Amplitude Across Task Complexity

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Task Complexity	3826.82	2.07	1845.462	2.63	.08	.095
Task Complexity * Hearing Status	1020.70	2.07	492.23	.70	.506	.027
Error	36435.40	51.84	702.83			

Table B3

Analysis of Variance for Anterior-posterior Sway Amplitude Across Task Complexity

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Task Complexity	7830.64	2.23	3507.23	6.40	.002	.204
Task Complexity * Hearing Status	1521.65	2.23	681.53	1.24	.299	.047
Error	30605.94	55.82	548.32			

Appendix C

Correlations between Hearing Acuity and Medial-Lateral Amplitude Across Task Complexity

Variables	1	2	3	4	5	6
1.Hearing Acuity (PTA)	-					
2. Normal Vision	.517**	-				
3.Normal Vision & serial 7s	.065	-.024	-			
4. Vision Impairment	.498**	.764**	-.137	-		
5.Vision Impairment & Serial 7s	.093	.242	.462*	-.007	-	
6. Eyes Closed	-.014	.489**	-.144	.242	.146	-

N*ote.* Hearing Acuity was determined using pure tone averages (PTA). A higher value of pure tone average indicates poorer hearing acuity.

*p<.05, **p<.01