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Original Research Report

The Effects of Age and Hearing Loss on Dual-Task Balance and Listening

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Abstract

Objectives: Among older adults (OA), hearing loss is associated with an increased risk for falls. The aim of the present study was to experimentally investigate the cognitive compensation hypothesis, wherein decreased auditory and motor functioning are compensated by the recruitment of cognitive resources.

Method: Twenty-nine younger adults (YA), 26 OA, and 32 OA with age-related hearing loss (ARHL) completed a dual-task paradigm consisting of cognitive and balance recovery tasks performed singly and concurrently. The auditory stimuli were presented with or without background noise.

Results: Both older adult groups performed significantly worse than YA on the cognitive task in noisy conditions and ARHL also demonstrated disproportionate negative effects of dual-tasking and noise. The kinematic data indicated that OA and ARHL demonstrated greater plantarflexion when compared with YA. Conversely, YA showed greater hip extension in response to dual-tasking.

Discussion: The cognitive and balance results suggest that YA were able to flexibly allocate their attention between tasks, whereas ARHL exhibited prioritization of posture over cognitive performance.

Keywords: Auditory aging—Cognitive compensation—Motor aging—Postural recovery

With age, older adults (OA) experience increasing difficulty with cognitive, physical and sensory functioning, which in turn affects social functioning and impacts independent living. Epidemiological work demonstrates that poorer hearing acuity is associated with an increased risk of falling (Lin & Ferrucci, 2012; Viljanen et al., 2009). With age, both auditory functioning and balance increasingly rely on cognitive resources to compensate for peripheral changes (Li & Lindenberger, 2002), suggesting that both domains compete for common cognitive resources. However, despite the accumulating correlational evidence, little experimental research exists investigating this association. The present study was designed to test this hypothesis using an auditory-motor dual-task paradigm with young, older, and older adults with age-related hearing loss (ARHL).

Auditory Aging

With age, hearing is impacted by both peripheral and cognitive changes (Schneider, Pichora-Fuller, & Daneman, 2010), such as elevated thresholds for tone detection in the high frequency range (i.e., 4,000 Hz, 8,000 Hz) and

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suprathreshold difficulties when auditory stimuli are presented in multispeaker contexts and in environments with background noise (Schneider et al., 2010). Declines in cognitive and attentional processes such as inhibition, working memory, and processing speed also contribute to age-related difficulties in speech comprehension and auditory memory (Schneider et al., 2010).

Support for the association between cognitive and auditory aging can be found in experimental studies of speech perception wherein sensory load is manipulated. One common approach is to overlay target speech with background noise such as multispeaker babble, which is more detrimental to older listeners' performance than to young, and might prompt a greater reliance on top-down processes (Pichora-Fuller et al., 2016). Importantly, this utilization of top-down resources in speech perception may come at a cost to other cognitive processes such as those needed for memory encoding (e.g., Murphy, Craik, Li, & Schneider, 2000).

Another experimental strategy used to examine the cognitive contribution to hearing in old age is to add a concurrent task to the listening task (i.e., dual-tasking). For example, dual-task costs are exacerbated by aging and hearing loss during performance of an auditory recognition memory task (Gosselin & Gagné, 2011; Tun, McCoy, & Wingfield, 2009). Importantly, these patterns of age-differential cognitive costs persist even when the presentation level (in dB-A) is adjusted individually to control for hearing loss (e.g., Heinrich, Schneider, & Craik, 2008). Together, the available evidence indicates an increasing interaction between auditory and cognitive processing with age and a greater reliance on cognitive capacity for those with hearing loss (Heyl & Wahl, 2012).

Motor Aging

Similar to the auditory aging findings, patterns of cognitive compensation have been observed during balance and gait as expressed with behavioral and neural indices (Seidler et al., 2010; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008). Importantly, postural sway increases with age (Maylor & Wing, 1996) and is associated with subsequent falls (Maki, Holliday, & Fernie, 1990). When encountering dynamic postural challenges, such as an unpredictable platform movement (i.e., perturbation), typical postural recovery progresses from ankle, hip, to stepping strategies as perturbations become more challenging (Horak, Henry, & Shumway-Cook, 1997; Nashner & McCollum, 1985). Compared to younger adults, older adults generate a greater center of mass (i.e., COM) sway (Tsai, Hsieh, & Yang, 2014), which may be further exacerbated by postural threat or concurrent cognitive demands. In a study of postural recovery from a forward platform perturbation, older adults demonstrated a greater cognitive cost under dual-task conditions with a stepping strategy compared to an ankle strategy, whereas young adults did not show this pattern (Brown, Shumway-Cook, & Woollacott, 1999), suggesting that postural recovery strategies vary in their attentional demands.

Another notable age difference in motor strategy is that OA tend to prioritize physical safety over cognitive performance in the context of cognitive-motor dual-tasking (Li, Krampe, & Bondar, 2005). This pattern of prioritization has been termed the "posture first" response and is evident in cognitive-motor dual-task studies when OA show greater cognitive dual-task costs than young adults but comparable motor costs. Others have found that within dual-task conditions, OA exhibit less sensitivity to manipulations of cognitive task difficulty compared to younger adults, suggesting that they are less willing to relinquish resources to address increased cognitive demands (e.g., Lajoie, Teasdale, Bard, & Fleury, 1993).

In sum, the current research on mobility and aging strongly parallels the research on auditory aging, in showing an increasing role of cognitive resources to address sensory and motor declines. To merge these separate areas of research, our present thesis is that because both hearing and motor performance require greater cognitive capacity in aging, there is competition for compensatory cognitive resources, which may account for the extant correlations between hearing loss and mobility decline (Agmon, Lavie, & Doumas, 2016; Lin & Ferrucci, 2012).

Current Study

To experimentally integrate the domains of auditory and motor aging, a dual-task method was used to challenge YA, normal hearing OA, and OA with ARHL. In line with the cognitive compensation view, we paired a challenging auditory working memory task with a postural recovery task, expecting that ARHL would show disproportionately greater dual-task costs than normal hearing young and OA, due to greater reliance on cognitive resources with hearing loss. Listening difficulty was also manipulated by adding background noise to the auditory stimuli. Based on previous findings, we expected that under noisy listening conditions, both OA and ARHL would perform more poorly on the auditory cognitive task than YA. Finally, in line with the posture first principle, we anticipated that both older adult groups would prioritize balance performance over performance on the auditory cognitive task due to the ecological value of maintaining one's balance, whereas young adults would be able to more flexibly distribute their attentional resources between the auditory task and the balance task.

Method

Participants

The total sample consisted of 87 individuals: 29 healthy YA between the ages of 18 and 30 years old (M = 21.83, SD = 3.01, females = 25) recruited through the Concordia

University participant pool, 26 healthy OA between the ages of 65 and 85 years old (M = 65.19, SD = 3.26, females = 20), and 32 ARHL between the ages of 65 and 85 years old (M = 70.75, SD = 5.76, females = 15) recruited through an existing senior participant pool at Concordia and advertisements in a local senior paper. ARHL participants were defined as having an average pure-tone hearing threshold between 25 and 40 dB HL (i.e., decibel hearing level; re: American National Standards Institute, 2004), while normal hearing younger and OA were defined as having an average pure-tone hearing threshold below 25 dB HL. YA received course credits and older adults received an honorarium. Exclusion criteria included the existence of any progressive medical conditions and the use of any medication affecting cognitive or balance abilities. Further exclusion criteria included suspected presence of mild cognitive impairment as defined by the Montreal Cognitive Assessment (MoCA < 26/30; Nasreddine et al., 2005), hearing aid use and any self-reported difficulties in balance or mobility. Participants were also required to be fluent in English and have normal or corrected-to-normal visual acuity. Of the 141 participants screened, 54 were ineligible due to low MoCA scores, poor physical health, scheduling conflicts, or severity of hearing loss.

Materials

Session 1: Screening and Background

A health and demographics questionnaire was administered by telephone to evaluate eligibility. Eligible participants underwent in-person tests of sensory, motor, and cognitive functioning. Measures used for screening purposes are marked below with an asterisk.

Cognitive measures

Global cognitive functioning was assessed using the Montreal Cognitive Assessment "MoCA"* (Nasreddine et al., 2005) with a score of 26/30 or greater indicating normal cognitive performance. Cognitive processing speed and working memory were assessed using the Coding (Digit Symbol) Task and Letter Number Sequencing subtests of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008) respectively. Executive functioning was measured using the Trail Making subtest of the Delis Kaplan Executive Functioning Scale "D-KEFS" (Delis, Kaplan, & Kramer, 2001), which assesses visuomotor processing speed (Conditions 2 and 3) and task switching (Condition 4). To isolate the executive component of the task, the average time to complete the visuomotor processing speed conditions was subtracted from the task switching condition.

Sensory measures

Air-conduction pure-tone audiometry* was administered using a Maico (MA 42) audiometer to assess hearing acuity for group classification, and to derive an average pure-tone threshold, which was then used to determine the appropriate intensity at which to present the auditory experimental stimuli. Participants were presented with pure tones at varying frequencies (250–8,000 Hz) following standard procedure. The mean detection threshold of hearing corresponded to the average of the tone detection thresholds assessed at 500, 1,000, 2,000, and 3,000 Hz, in both ears. Participants were also administered the Listening Self Efficacy Questionnaire (LSEQ: Smith, Pichora-Fuller, Watts, & La More, 2011), as a subjective index of hearing ability.

Physical measures

Global mobility was assessed using the Dynamic Gait Index (DGI: Shumway-Cook, Baldwin, Polissar, & Gruber et al., 1997), a multicomponent assessment (e.g., turning, stair ascent). The maximum possible score on the DGI is 24 and scores of 19 or less have been related to increased incidence of falls in the elderly (Shumway-Cook et al., 1997). Mobility was further assessed using the Sit-to-Stand task (Puthoff, 2008), which measures total time to stand up five times from a seated position with their arms crossed. The Activities-Specific Balance Confidence Scale "ABC Scale" (Powell & Myers, 1995) assessed self-reported balance confidence during different activities.

Session 2: Experimental Tasks

Balance task

The balance task involved a custom made perturbation platform (H2W, California) that delivered perturbations in the forward direction for a distance of 50 mm at a maximum velocity of 130–135 mm/s and an acceleration of 600–650 mm/s^2 (Quant, Adkin, Staines, Maki, & McIlroy, 2004). These parameters were designed to produce a mild perturbation that would not elicit a stepping response. A motion capture system made up of 8 MX-T20 cameras sampling at 100Hz (Vicon Motion Systems Ltd., Oxford, UK) was used to measure 3-dimensional positioning of major landmarks on the body (i.e., legs, chest, arms, head) using a standard whole-body 35 marker placement protocol (Plug-in Gait, 2010) and four markers on the moving platform.

Participants stood on the platform with their feet positioned shoulder width apart. They were instructed to remain as stable as possible with their hands on their hips and look forward at a stationary target (7.5 × 2 cm) located 4.4 m away. During each 30-s trial, participants experienced zero, one, or two perturbations, in random order. Perturbations occurred in one of two time windows (i.e., the first or second time window). For trials with two perturbations (one in each time window), the second perturbation occurred no less than 5 s after first to allow for adequate recovery time. Three short beeps signaled the beginning of each trial and a single beep signaled the end of the trial.

Cognitive task

The auditory working memory "n-back" task (Kirchner, 1958) served as the experimental cognitive task. In each

trial, participants were presented with fifteen pseudorandomly ordered (without consecutive repetition) single digit numbers between 1 and 10 excluding the two-syllable numeral seven at a fixed presentation rate of one digit per second. The stimuli were presented via insert headphones (E-A-RLINK 3A) at 50 dB greater than each participant's average pure-tone threshold, as determined in Session 1. Participants were asked to report the number presented one step prior to the currently presented number (1-back) while the tester recorded their verbal responses. Half the trials were presented in quiet and half were presented in background noise (i.e., multitalker babble consisting of six people speaking simultaneously) at a fixed signal-to-noise ratio (SNR) of –6 dB.

Procedure

All participants were tested individually at the PERFORM Centre of Concordia University. In Session 1, participants completed the demographic questionnaire and background measures of cognition, mobility and audition. During Session 2, participants completed the experimental cognitive and balance tasks under single and dual-task conditions. Participants first practiced on each of the experimental tasks separately. Following practice, participants were administered blocks of five trials of the cognitive and balance tasks separately without feedback, followed by two dual-task blocks of five trials in which the 1-back and balance tasks were performed concurrently. Under the dual-task condition, participants were instructed to treat each task as equally important. Finally, single-task blocks of the balance and cognitive tasks were administered again. This entire sequence was performed twice—once under quiet conditions and once under noise conditions. Participants were given a seated break between any consecutive blocks involving the balance task. The order of task (balance or cognitive task) and auditory condition (quiet or noise) was counterbalanced between participants.

Data Analyses

Balance data

All motion capture data was imported into Matlab using the BiomechZoo system toolbox (Dixon, Loh, Michaud-Paquette, & Pearsall, 2017). Raw trajectory data collected via the motion capture system were filtered with a recursive low-pass Butterworth filter at 6 Hz. The filtered data were then used to compute ankle and hip angular displacements in the sagittal plane (see Supplementary Figure 1). The analysis window was 5 s long; 1 s before each perturbation onset and 4 s after. The ankle plantarflexion amplitude refers to the most plantarflexion (i.e., foot pointed down) compared to the participant's baseline standing position prior to the perturbation. The hip extension amplitude refers to the most hip extension (i.e., sway-back or leaning backwards) compared to the participant's baseline standing position prior to the perturbation.

Cognitive data

Cognitive performance was defined as the total number of correct responses identified in a given trial (maximum of 14 correct per trial). The number of correct responses was then summed across all 10 trials per condition and converted to a percentage. To further explore the degree of interference from the secondary motor task, dual-task costs were calculated for the cognitive data by subtracting dual-task scores from single-task scores in both noise and quiet conditions for each participant.

Results

Data Screening

All measures were checked for outliers (i.e., > 3.5 SD) both in terms of intraindividual and interindividual variability. One OA and one ARHL participant were each found to have one extreme score on a cognitive trial and therefore their scores were replaced with the next most extreme value on that trial type for that age group.

Background Measures

Descriptive statistics and between-groups analyses are shown for all background measures in Table 1. To examine group differences on the background measures, a series of one-way ANOVA with follow-up Bonferroni corrected contrasts were performed for measures administered to all three groups of participants. For measures only administered to the older adults (MoCA, DGI), independent samples *t* tests were conducted to compare the OA and ARHL groups. Notably, compared to the ARHL group, the OA group performed better on processing speed measures (i.e., Coding and DKEFS Trails Condition 3), task switching (DKEFS Trails Condition 4) and the MoCA. Furthermore, the OA group demonstrated higher confidence in both their balance (ABC) and listening (LSEQ) than the ARHL group, and performed better on the objective measure of global mobility (i.e., DGI). However, after controlling for age, OA and ARHL groups only differed significantly on the ABC scale.

Cognitive Accuracy

To assess cognitive performance on the 1-back working memory task, a Group (YA vs. OA vs. ARHL) × Attentional Load (single task vs. dual task) × Auditory Challenge (quiet vs. noise) mixed factorial ANOVA was performed using the accuracy scores (%; see Figure 1). The analysis revealed a significant main effect of auditory challenge, $F(1, 84) = 413.22$, $p < .001$, $\eta_p^2 = .84$, such that cognitive performance was higher in quiet ($M = 97.79$, $SE = 0.29$) than noise conditions ($M = 62.21$, $SE = 1.80$). A significant main effect of group was also observed, $F(2, 84) = 3.81$, $p = .026$, $\eta_p^2 = .08$. Pairwise comparisons with Bonferroni correction revealed that YA ($M = 83.61$, $SE = 1.63$) performed significantly better than

Table 1. Means and Standard Deviations for all Baseline Measures

Source	YA	OA	ARHL	Differences
Age (years)	21.83 (3.01)	65.19 (3.26)	70.75 (5.76)	1, 2, 3
Education (years)	14.15 (1.10)	16.88 (1.66)	16.47 (3.32)	1, 2
Average hearing threshold (dB)	11.72 (3.81)	18.48 (3.14)	29.07 (3.78)	1, 2, 3
Letter–number sequencing (max 30)	19.66 (2.04)	19.04 (2.81)	18.78 (2.55)	—
Digit symbol (max 135)	81.54 (8.79)	72.81 (12.78)	61.88 (12.17)	1, 2, 3
DKEFS Trails Condition 2 (seconds)	24.14 (4.43)	32.82 (13.28)	37.37 (12.96)	1, 2
DKEFS Trails Condition 3 (seconds)	26.27 (6.05)	32.20 (10.47)	40.30 (15.49)	2, 3
DKEFS Trails Condition 4 (seconds)	63.24 (21.84)	73.37 (26.73)	102.36 (38.44)	2, 3
DKEFS Trails Difference (seconds)	38.04 (20.05)	42.03 (18.72)	63.53 (32.24)	2, 3
MoCA (max 30)	—	27.88 (1.77)	26.78 (1.93)	3
ABC (max 100)	95.33 (3.24)	96.78 (2.85)	90.68 (9.14)	2, 3
LSEQ (max 100)	89.82 (7.32)	84.42 (9.89)	75.36 (17.04)	2, 3
Sit to stand (seconds)	10.07 (1.59)	13.09 (3.10)	12.96 (3.57)	1, 2
DGI (max 24)	—	23.73 (0.53)	22.71 (1.74)	3

Note: 1 denotes a statistically significant group difference between YA and OA, 2 denotes a statistically significant group difference between YA and ARHL, and 3 denotes a statistically significant group difference between OA and ARHL at $p < .05$. ABC = Activities-Specific Balance Confidence Scale; ARHL = older adults with age-related hearing loss; DKEFS = Delis Kaplan Executive Function System; DGI = Dynamic Gait Index; LSEQ = Listening Self-Efficacy Questionnaire; MoCA = Montreal Cognitive Assessment; OA = older adults; YA = younger adults.

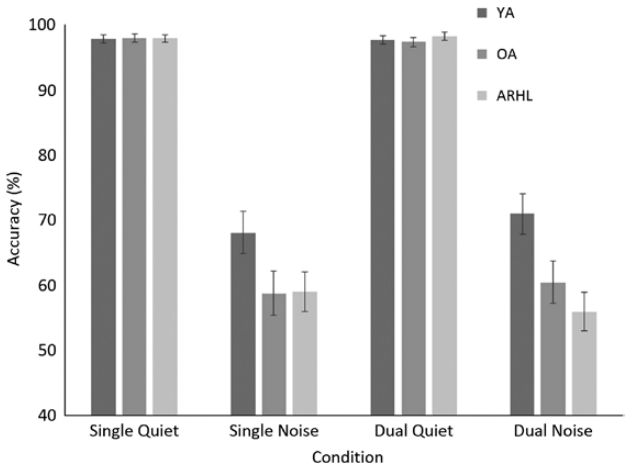


Figure 1. Cognitive 1-back task accuracy (%) as a function of age group, auditory challenge, and attentional load. Error bars represent 1 standard error of the mean. ARHL = older adults with age-related hearing loss; OA = older adults; YA = younger adults.

ARHL ($M = 77.77$, $SE = 1.55$) across all conditions ($p = .033$). All other pairwise comparisons between groups were not statistically significant ($ps \geq .114$). Statistically significant two-way interactions were observed for group and auditory challenge, $F(2, 84) = 4.82$, $p = .010$, $\eta_p^2 = .10$, and group and attentional load, $F(2, 84) = 5.26$, $p = .007$, $\eta_p^2 = .11$. These were qualified by a significant three-way interaction of group, auditory challenge, and attentional load, $F(2, 84) = 7.30$, $p = .001$, $\eta_p^2 = .15$. This significant three-way interaction was preserved even when controlling for age and sex, $F(2,81) = 3.21$, $p = .046$, $\eta_p^2 = .073$. All remaining main effects and interactions were not statistically significant ($ps \geq .448$).

To explore the three-way interaction of group, attentional load, and auditory challenge, a series of Attentional Load ANOVAs were performed for each group to investigate the impact of attentional load in noise conditions. Among YA, a main effect of attentional load was observed in noise conditions, $F(1, 28) = 8.77$, $p = .006$, $\eta_p^2 = .24$ such that cognitive accuracy was higher in dual-task noise ($M = 70.96$, $SD = 13.29$) conditions compared with single-task noise conditions ($M = 68.10$, $SD = 14.83$). Among the ARHL group, a main effect of attentional load was also observed in noise conditions, $F(1, 31) = 5.50$, $p = .026$ $\eta_p^2 = .15$ with significantly worse performance in dual-task noise conditions ($M = 55.93$, $SD = 18.99$) compared with single-task noise conditions ($M = 59.00$, $SD = 19.47$). All other main effects were nonsignificant ($ps \geq 0.239$).

To further explore dual-tasks costs, a Group × Auditory Challenge ANOVA was performed using 1-back dual-task costs. Analyses revealed a significant main effect of group, which was qualified by a statistically significant two-way interaction of group and auditory challenge, $F(2, 84) = 7.30$, $p = .001$, $\eta_p^2 = .15$. To explore this interaction, a series of one-way ANOVA were performed to compare groups on dual-task costs in noise and quiet conditions separately. In noise conditions, there was a statistically significant effect of group on dual-task cost $F(2, 84) = 6.81$, $p = .002$, with Bonferroni corrected pairwise comparisons revealing that ARHL ($M = 3.07$, $SE = 1.31$) demonstrated greater dual-task costs than both YA ($M = -2.86$, $SE = 0.96$) and OA ($M = -1.67$, $SE = 1.39$).

Balance Analysis

Ankle plantarflexion amplitude (degrees)

A Group × Attentional Load × Auditory Challenge mixed factorial ANOVA was performed using the amplitude of plantarflexion (i.e., foot pointed down) exhibited by the

ankles (see Figure 2). Results revealed a main effect of group, $F(2, 81) = 6.60$, $p = .002$, $\eta_p^2 = .140$, with follow-up Bonferroni contrasts indicating that both OA ($M = -0.90$, $SE = 0.14$) and ARHL ($M = -0.93$, $SE = 0.12$) demonstrated greater plantarflexion across all conditions when compared with YA ($M = -0.35$, $SE = 0.13$). The same ANOVA analysis performed using only the two older adult groups and covarying out age and sex revealed nonsignificant findings ($p_s \geq .151$).

Additionally, there was a main effect of attentional load, $F(1, 81) = 11.36$, $p = .001$, $\eta_p^2 = .123$, such that all participants demonstrated greater plantarflexion in single-task ($M = -0.80$, $SE = 0.08$) compared with dual-task ($M = -0.65$, $SE = 0.07$) conditions. To further explore the interference from a secondary cognitive task, dual-task costs (DTC) were calculated by subtracting single-task performance from dual-task performance for both quiet and noisy listening conditions. A Group × Listening Condition ANOVA using DTC as the dependent variable revealed nonsignificant findings ($p_s \geq 0.196$).

Hip extension amplitude (degrees)

A Group × Attentional Load × Auditory Challenge mixed factorial ANOVA was performed using amplitude of hip extension (see Figure 2). Analyses revealed an interaction of group and attentional load, $F(2, 81) = 4.38$, $p = .016$, $\eta_p^2 = .098$. Simple main effects analyses were carried out to explore this interaction. Analyses revealed a main effect of attentional load among YA, $F(1, 28) = 5.62$, $p = .025$, $\eta_p^2 = .167$, such that they exhibited more hip extension in dual-task ($M = -0.85$, $SE = 0.16$) compared with single-task ($M = -0.66$, $SE = 0.16$) conditions. All other main effects across age groups were not statistically significant ($p_s \geq .062$). The same ANOVA analysis performed using only the two older adult groups and covarying out age and sex revealed nonsignificant findings ($p_s \geq .054$).

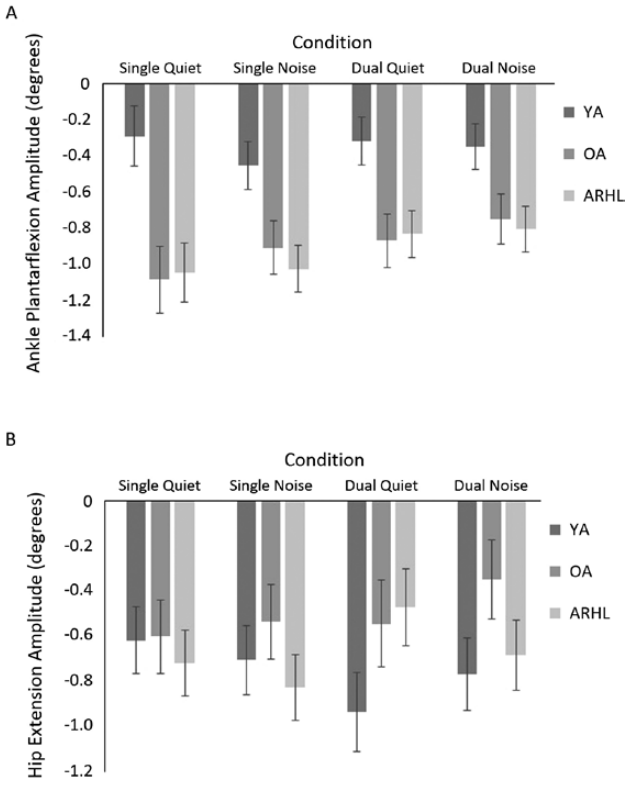


Figure 2. Ankle Plantarflexion Amplitude in degrees (A) and hip extension amplitude in degrees (B) as a function of age group, auditory challenge, and attentional load. Error bars represent 1 standard error of the mean. ARHL = older adults with age-related hearing loss; OA = older adults; YA = younger adults.

Discussion

The purpose of the current study was to experimentally integrate the two domains of auditory and motor functioning to better understand their correlation, as shown in epidemiological studies (Viljanen et al., 2009). We used a dual-task design to challenge YA, OA, and ARHL and evaluated the impact of auditory challenge and cognitive load on dual-task balance performance. As hypothesized, both older adults exhibited disproportionate negative effects with increases in auditory challenge (i.e., noise) and the ARHL group demonstrated greater dual-task costs in noise when compared with OA and YA. Furthermore, in line with the posture first principle, the ARHL group prioritized balance performance over cognitive performance likely due to the ecological value of balancing, whereas YA were able to more flexibly distribute their attentional resources between the auditory task and the balance task.

Auditory Working Memory Performance

The present study was based on the assumption that with age, cognitive resources become more limited and therefore performance might be more negatively impacted by an increased attentional load or when information was presented in a noisy environment. As predicted, the ARHL group demonstrated lower cognitive performance on the 1-back task when compared with YA. Furthermore, all participants were negatively impacted by the addition of noise. Most importantly, for our hypothesis and congruent with prior research on the negative impact of babble on word identification and memory encoding (Murphy, Daneman, & Schneider, 2006), this noise effect was magnified among the ARHL group. This finding is notable given that the presentation level of the auditory stimuli was adjusted to correct for individual differences in hearing acuity. In addition, the ARHL group demonstrated a drop in cognitive performance when moving from single- to dual-task conditions in the presence of noise, demonstrating a dual-task cost not present in the other two groups. In contrast, we observed an increase in cognitive performance among YA when moving from single- to dual-task conditions in noise, suggesting an ability to modulate task emphasis as conditions change.

The correlational results further support the cognitive compensation viewpoint (Li & Lindenberger, 2002). Among the ARHL group, 1-back accuracy in the most challenging dual-task noise condition correlated significantly with a measure of working memory (r = .38, p = .031) but not with average hearing thresholds (r = −.08, p = .519), suggesting that peripheral hearing loss is not enough to account for group differences. Additionally, although the ARHL group demonstrated decreased cognitive abilities on numerous background measures consistent with previous work (e.g., Lin, 2011), controlling for individual differences on background cognitive measures generated the same pattern of findings.

Postural Recovery Strategies

Turning to the parameters reflecting postural recovery, as expected based on previous work (Horak et al., 1997; Nashner & McCollum, 1985), participants implemented more of an ankle strategy in response to less challenging perturbations (i.e., single-task) as compared with more difficult task conditions (i.e., dual-task). Furthermore, congruent with previous research (Brown et al., 1999; Quant et al., 2004), age differences in postural recovery strategy were found. YA exhibited a hip strategy in response to challenging task conditions whereas older adult groups exhibited greater use of an ankle strategy across all conditions, irrespective of hearing status. This finding is further evidence that older adults maintain an attentionally economical strategy to conserve cognitive resources, while YA adapt their strategy to increasing task challenge (Brown et al., 1999).

Task Prioritization

Considering the cognitive and balance results together, the current findings also converge with other research (Lajoie et al., 1993) in that YA were able to respond to task manipulations (i.e., addition of noise or concurrent task) and flexibly split attention between the two tasks, whereas older adults maintained a posture first response as a means of protecting balance. Postural prioritization among the ARHL group was further supported through cognitive dual-task costs in noisy conditions, suggesting that they reallocated their cognitive resources to maintaining their postural strategy in the most challenging condition (e.g., Doumas, Smolders, & Krampe, 2008).

These results are in line with the cognitive compensation view (Li & Lindenberger, 2002) in that the ARHL group demonstrated a drop in cognitive performance in the most challenging dual-task noise condition. Importantly, the postural strategy of both older adult groups was invariant in response to the noise manipulation suggesting that the ARHL group reallocated cognitive resources from the working memory to the motor task in order to maintain their posture. Interestingly, the ARHL group also demonstrated a lower score on a self-report measure of balance confidence even after controlling for age, suggesting that their pattern of prioritization may be influenced by a fear of falling. Similar cognitive dual-task costs were not observed for the OA group suggesting they had sufficient cognitive resources to maintain task performance in the most challenging condition. If the level of challenge was increased (e.g., faster perturbation), it is likely that the OA group would also demonstrate a trade-off in performance in favor of maintaining postural stability.

Limitations and Future Directions

One possible limitation to the interpretation of our findings is that we did not control for vestibular dysfunction despite using self-report measures of fall history and vertigo and an objective measure of mobility. However, controlling for vestibular function did not change the magnitude of the association between hearing loss and falls in a study of young adults and older adults (Lin & Ferrucci, 2012). Nevertheless, future studies would benefit from including objective assessment of vestibular impairment (Jacobson & Shepard, 2008). A further limitation is that the sample consisted of older adults with only mild hearing loss (i.e., average pure-tone thresholds of 25–40 dB-A). If OA with more severe hearing loss were tested in future, we expect that the effect of dual-tasking and noise would be exacerbated among individuals with moderate to severe hearing loss. Lastly, our older adult groups were not balanced for age and sex. However, these demographic variables are strongly correlated with hearing loss (Stenklev & Laukli, 2004) and therefore the current sample of older adult men is representative of the ARHL population. Moreover, group differences on the experimental working memory task were preserved even when controlling for these demographic variables.

Conclusions

The current work complements the epidemiological evidence linking hearing loss and reduced mobility (Viljanen et al., 2009) and provides new experimental evidence showing competition for common cognitive resources in the context of simultaneous auditory and motor demands even after correcting for individual differences in hearing acuity. For older adults with mild hearing loss, this competition for cognitive resources was even more apparent, suggesting that falls risk or reduced working memory efficiency could be exacerbated during everyday activities. Evidence of the interdependence of sensory, motor, and cognitive factors in old age could be used to inform rehabilitation programs in the fields of physical therapy and audiology by incorporating cognitive training (Li et al., 2010). Future research is needed to determine whether cognitive training might therefore reduce the risk of falling particularly in older adults with hearing loss.

Supplementary Material

Supplementary data is available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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Conflict of Interest

The authors declare no conflict of interest.

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