Research Article

Association of Hearing Impairment and Subsequent Driving Mobility in Older Adults

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Abstract

Purpose of the Study: Hearing impairment (HI) is associated with driving safety (e.g., increased crashes and poor on-road driving performance). However, little is known about HI and driving mobility. This study examined the longitudinal association of audiometric hearing with older adults’ driving mobility over 3 years.

Design and Methods: Secondary data analyses were conducted of 500 individuals (63–90 years of age) from the Staying Keen in Later Life (SKILL) study. Hearing (pure tone average of 0.5, 1, and 2 kHz) was assessed in the better hearing ear and categorized into normal hearing ≤25 dB hearing level (HL); mild HI 26–40 dB HL; or moderate and greater HI ≥41 dB HL. The Useful Field of View Test (UFOV) was used to estimate the risk for adverse driving events. Multivariate analysis of covariance compared driving mobility between HI levels across time, adjusting for age, sex, race, hypertension, and stroke. Adjusting for these same covariates, Cox regression analyses examined incidence of driving cessation by HI across 3 years.

Results: Individuals with moderate or greater HI performed poorly on the UFOV, indicating increased risk for adverse driving events (p < .001). No significant differences were found among older adults with varying levels of HI for driving mobility (p values > .05), including driving cessation rates (p = .38), across time.

Implications: Although prior research indicates older adults with HI may be at higher risk for crashes, they may not modify driving over time. Further exploration of this issue is required to optimize efforts to improve driving safety and mobility among older adults.

Key Words: Older drivers, Driving mobility, Driving cessation, Hearing loss, Hearing impairment

Although vision is considered to be the main sensory input for driving, hearing is also likely to be important, particularly with regard to providing information about approaching vehicles, hazards, or potential vehicle problems. However, a limited amount of research has explored the relationship between hearing and driving. This is problematic given that the prevalence of hearing impairment (HI) increases substantially in older age, affecting up to 30 million older adults in the United States (Chien & Lin, 2012; Cruickshanks et al., 1998). Understanding the relationship between hearing and driving is important in that maintaining safe driving mobility is vital for the health and well-being of older adults (Edwards, Lunsman, Perkins, Rebok, & Roth, 2009; Freeman, Gange, Munoz, & West, 2006; Marottoli et al.,
of challenging situations, or driving cessation. Maintaining exposure to challenging situations, difficulty with or avoidance of challenging situations, and driving cessation. Older adults’ needs for maintaining both driving safety and mobility must be balanced (Oxley & Whelan, 2008). Although older drivers are more likely to incur higher rates of at-fault crashes than are younger drivers, ceasing driving has numerous negative health ramifications (e.g., Freeman et al., 2006; Marottoli et al., 2000; Papa et al., 2014).

**Hearing and Driving Safety**

Prior research has established a link between HI and driving safety. A limitation of the existing literature linking hearing and driving safety is that most studies have explored this relationship using self-reported hearing measures. Self-reports of hearing loss underestimate actual HI (Chang, Ho, & Chou, 2009; Nondahl et al., 1998; Sindhusake et al., 2001) and thus confound our ability to determine the relationships between hearing and driving. One study found that after adjusting for covariates (i.e., age, sex, medications, and chronic health conditions), self-reported hearing loss among older adults was associated with higher crash involvement (Ivers, Mitchell, & Cumming, 1999). Hearing aid use was not related to crashes (Ivers et al., 1999). In another study hearing aid use, but not HI, was associated with higher injurious crash rates after adjusting for race, education, and miles driven (McCloskey, Koepsell, Wolf, & Buchner, 1994). Conversely, other studies have failed to find any associations between self-reported hearing and driving safety after adjusting for covariates such as age, race, sex, miles driven at baseline, and/or cognitive status (Gallo, Rebok, & Lesikar, 1999; Green, McGwin, & Owsley, 2013; Sims, McGwin, Allman, Ball, & Owsley, 2000). To our knowledge, only two studies have examined objectively measured hearing and driving safety. Among a sample of Canadian young and older adults (16–65 years of age), Picard and colleagues (2008) showed a significant relationship between objectively measured hearing and both crashes and citations other than speeding. In the only study examining objective hearing assessments and on-road driving performance, Hickson, Wood, Chaparro, Lacherzew, and Marszalek (2010) found that older Australian adults with moderate-to-severe HI demonstrated worse driving performance in the presence of distractors than those with good hearing.

**Hearing and Driving Mobility**

Driving mobility can be quantified by miles driven, driving space, exposure to challenging situations, difficulty with or avoidance of challenging situations, or driving cessation. Maintaining driving mobility is an important issue for older adults in that driving cessation is associated with numerous negative outcomes such as decreased access to health care, declining health, increased depression, and greater risk of nursing home admissions (Edwards, Lunsman, et al., 2009; Freeman et al., 2006; Marottoli et al., 2000). Studies investigating the association of HI and driving mobility are few, primarily include subjective assessments of hearing, and are typically cross-sectional. Gallo and colleagues (1999) found in cross-sectional analyses that self-reported hearing was not associated with reduced driving mobility among older adults after adjusting for age, sex, and miles driven. Conversely, worse self-reported hearing was independently related to restricted driving mobility including higher rates of driving cessation in cross-sectional analyses (Forrest, Bunker, Songer, Coben, & Cauley, 1997; Gilhotra, Mitchell, Ivers, & Cumming, 2001). In an Australian study, poorer hearing thresholds were not longitudinally associated with subsequent driving cessation over 5 years after adjusting for age, sex, and education (Anstey, Windsor, Luszcz, & Andrews, 2006). To our knowledge, no previous studies have longitudinally examined objective assessments of hearing with subsequent aspects of driving mobility other than driving cessation (e.g., driving habits such as miles driven, driving space, exposure to challenging situations, or avoidance of challenging situations). No studies have examined the longitudinal associations of objectively assessed hearing and driving safety or mobility among older adults in the United States.

**Hypotheses**

Secondary data analyses were conducted with the Staying Keen in Later Life (SKILL) study, a prospective cohort study of sensory, cognitive, and everyday function (including driving) among older adults in the southeast region of the United States. The aim was to examine the longitudinal relationship of objective measures of hearing with subsequent self-report indices of driving mobility across a 3-year period. Driving mobility was quantified as driving space (i.e., the distance driven from one’s home); driving challenges (exposure to challenging driving situations such as driving at night); difficulty in such challenging situations (Edwards, Myers, et al., 2009; Owsley, Stalvey, Wells, & Sloane, 1999); and driving cessation. We hypothesized that, after controlling for appropriate risk factors, hearing loss would be associated with subsequent restrictions in driving mobility among older adults.

**Design and Methods**

**Participants**

Participants included 500 older adults who completed the baseline phase of the SKILL study, defined themselves as current drivers at baseline, and were successfully contacted for interviews 3 years later (Edwards, Myers, et al., 2009; Edwards, Wadley, et al., 2005). The original SKILL baseline study enrolled 895 community-dwelling adults aged 60 years and older, who were
recruited from mass-mailings to residents of Birmingham, Alabama, Bowling Green, Kentucky, and surrounding areas. The inclusion criteria for the SKILL baseline study required that participants have “adequate vision” to be able to visually resolve the study materials (distance visual acuity 20/80 or better measured binocularly, using standard procedures, with habitual correction).

Participants who were drivers at the baseline visit \((N = 640)\) were invited to complete a longitudinal follow-up interview. Five hundred of these potential participants (78%) were successfully contacted and agreed to participate. These participants included more women \((n = 275)\) and Caucasians \((n = 443)\), but also included African American individuals \((n = 53)\). Education levels ranged between 6th grade and PhD. These characteristics match those of the overall SKILL baseline sample (Edwards, Wadley, et al., 2005). Of the 140 baseline SKILL participants who were eligible but were not interviewed, 32 were unable to be reached, 30 were deceased, and 78 refused to participate (Edwards, Myers, et al., 2009).

Procedure
The SKILL study was conducted in several phases, including screening, baseline, cognitive training, and immediate post-training as well as a follow-up telephone interview 3 years later (Edwards, Myers, et al., 2009; Edwards, Wadley, et al., 2005; K. M. Wood et al., 2005). At the screening visit, vision and hearing were assessed, and the Mobility Questionnaire (MQ) was administered (Ball et al., 1998; Owlsley et al., 1999; Stalvey, Owlsley, Sloane, & Ball, 1999). The baseline visit included cognitive and physical performance assessments in addition to questions about health (Edwards, Wadley, et al., 2005; K. M. Wood et al., 2005). A subsample \((n = 134)\) of the participants who had baseline cognitive difficulties was invited to participate in the cognitive training phase of the study. As done in previous research, participation in training was controlled for as a covariate for the purpose of these analyses (Edwards, Perkins, Ross, & Reynolds, 2009). Further details about the SKILL study have been published elsewhere (Edwards, Myers, et al., 2009; Edwards, Reynolds, et al., 2009; Edwards, Wadley, et al., 2005).

Follow-up interviews occurred within 3 years ± 3 months of the participants’ last assessment. At the appropriate time, potential participants were contacted via information letters, which were followed by telephone calls. Participants were re-administered the mobility questionnaire and answered questions about their health via telephone.

Measures

Mobility Questionnaire
At screening and the 3-year follow-up interview, participants completed the Mobility Questionnaire (MQ) to assess driving mobility. This questionnaire has good test–retest reliability and construct validity (Owlsley et al., 1999). Only those who reported being drivers at baseline defined by the MQ as “someone who has driven a car within the last 12 months and someone who would drive a car today if they needed to” were included. The remaining MQ items measure driving space, driving exposure (i.e., challenging situations), and driving difficulty. As per previous research (Edwards, Myers, et al., 2009; O’Connor, Edwards, Small, & Andel, 2012), composites of driving mobility were formed based on confirmatory factor analyses and included driving space, driving in challenging situations (i.e., exposure), and two composites of driving difficulty in such challenging situations (3 items and 5 items). Prior research has indicated that the test–retest reliability is 0.86 for the driving space composite, 0.83 for the driving in challenging situations composite (i.e., exposure), and 0.60 for the driving difficulty in challenging situations composite (Owlsley et al., 1999). See Table 1 for details.

Driving Space
Participants were asked how far they had driven from their home in both the previous week and the prior 2 months to places ranging beyond their property to out of the region. The driving space composite score indicates the extent to which participants had driven beyond their home in the previous week (beyond their own property, neighborhood, or community) and beyond their city, state, or region in the previous 2 months. Items were summed so that larger numbers indicated a larger driving space with a range of 0–6.

Driving Challenges
The number of challenging driving situations encountered was summed and ranged between 0 and 8, with higher numbers reflecting better driving mobility. Participants were asked to indicate whether they had encountered any of eight challenging driving situations during the previous 2 months. These challenging situations included (i) making lane changes, (ii) making left-hand turns across oncoming traffic, (iii) driving alone, (iv) driving in high traffic, (v) driving at night, (vi) driving during rush hour, (vii) driving in the rain, or (viii) merging into traffic.

Driving Difficulty
For each of the eight challenging driving situations reported in the questionnaire, participants were asked to rate their level of difficulty \((1 = \text{no difficulty} \text{ to } 4 = \text{extreme difficulty})\). For example, participants were asked whether they had driven on interstates or expressways in the previous 2 months, and if so, how much difficulty they encountered in that situation. As in previous research, scores were coded as extreme difficulty if the participant had not encountered the situation because they avoided the situation (Edwards, Myers, et al., 2009; O’Connor et al., 2012). Based on factor analyses and prior research (Edwards, Myers, et al., 2009; O’Connor et al., 2012), two driving difficulty in challenging situations composites were derived. The 3-item difficulty
composite included making lane changes, making left-hand turns across oncoming traffic, and driving alone, with a range of 3 to 12 and represents everyday driving situations, which tend to be less challenging. The 5-item difficulty composite included driving in high traffic, at night, during rush hour, or in the rain, as well as merging, and ranged from 5 to 20, including situational driving conditions, which tend to be more challenging. For both of the difficulty composites, higher values indicate greater levels of difficulty.

Hearing
At screening, pure-tone air conduction hearing thresholds were measured with a Grason-Stadler GSI-17 portable audiometer at 0.5, 1, and 2 kHz in each ear. Participants were tested in a quiet room, using supraural headphones, by a trained Research Assistant. Ambient noise levels were not recorded. The average of the three pure-tone thresholds in the better hearing ear (pure tone average [PTA]) was used in correlational analyses. We further categorized HI as normal hearing (PTA ≤ 25 dB; n = 313), mild HI (PTA 26–40 dB; n = 153), or moderate and greater HI (PTA 41–90 dB; n = 34) to examine the associations of HI with driving mobility and cessation (Martin & Clark, 2011). Hearing aid use was reported by 6% of participants. Among those with moderate-to-severe HI, 55% reported using aids.

Useful Field of View
The UFOV, a strong predictor of subsequent at-fault crash risk and on-road driving performance (Ball et al., 1998; Ball et al., 2006; J. M. Wood, Chaparro, Lacherez, & Hickson, 2012), was administered to assess baseline cognitive speed of processing for visual attention tasks. This well-studied, reliable, and validated test has been described in detail elsewhere (Edwards et al., 2006; Edwards, Vance, et al., 2005). The test includes three increasingly difficult subtests in which participants identify a central visual target (car or truck) either alone or while simultaneously localizing a peripheral target (car) both with and without distractors (triangles surrounding the peripheral target), which are measures of divided and selective attention. For each subtest, display speeds are varied between 16.67 and 500 ms, and the 75% correct threshold display speed is determined. Scores are combined into a composite. UFOV performance was compared across HI categories as an indicator of risk for adverse driving events.

Covariates
Common risk factors for both HI and driving safety include older age and health conditions such as cardiovascular disease, diabetes, and stroke (Forrest et al., 1997; Helzner, Cauley, & Pratt, 2005). Although male sex and

### Table 1. Demographics and Driving Mobility Across 3 Years by Hearing Impairment Category

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal hearing</th>
<th>Mild hearing impairment</th>
<th>Moderate and greater hearing impairment</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 313</td>
<td>n = 153</td>
<td>n = 34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M or (n) SD or (%)</td>
<td>M or (n) SD or (%)</td>
<td>M or (n) SD or (%)</td>
<td>F or (X²) Partial η²</td>
</tr>
<tr>
<td>Age** ***</td>
<td>71.47 4.63</td>
<td>73.98 5.27</td>
<td>77.82 4.91</td>
<td>34.13 .12</td>
</tr>
<tr>
<td>Sex (Female)</td>
<td>(176) (56%)</td>
<td>(84) (54%)</td>
<td>(15) (44%)</td>
<td>(1.82)</td>
</tr>
<tr>
<td>Race (Caucasian)</td>
<td>(270) (86%)</td>
<td>(141) (91%)</td>
<td>(32) (94%)</td>
<td>(4.29)</td>
</tr>
<tr>
<td>Hypertension (number reporting)</td>
<td>(153) (48%)</td>
<td>(80) (52%)</td>
<td>(19) (55%)</td>
<td>(0.85)</td>
</tr>
<tr>
<td>Stroke (number reporting)</td>
<td>(30) (9%)</td>
<td>(16) (10%)</td>
<td>(1) (3%)</td>
<td>(1.87)</td>
</tr>
<tr>
<td>Useful Field of View Test (ms)** ***</td>
<td>811.48 259.25</td>
<td>859.58 268.87</td>
<td>1,014.00 285.37</td>
<td>9.62 .04</td>
</tr>
<tr>
<td>Driving space</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>3.69 1.21</td>
<td>3.59 1.24</td>
<td>3.78 1.11</td>
<td>&lt;1 &lt;.01</td>
</tr>
<tr>
<td>3 Years</td>
<td>3.65 1.41</td>
<td>3.45 1.41</td>
<td>3.30 1.23</td>
<td></td>
</tr>
<tr>
<td>Driving challenges</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>7.66 0.76</td>
<td>7.59 0.88</td>
<td>7.48 0.75</td>
<td>1.65 &lt;.01</td>
</tr>
<tr>
<td>3 Years</td>
<td>7.49 1.16</td>
<td>7.25 1.61</td>
<td>7.00 1.75</td>
<td></td>
</tr>
<tr>
<td>Everyday driving difficulty**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>3.23 0.62</td>
<td>3.30 0.85</td>
<td>3.30 0.76</td>
<td>1.69 &lt;.01</td>
</tr>
<tr>
<td>3 Years</td>
<td>3.51 1.06</td>
<td>3.68 1.47</td>
<td>4.12 1.55</td>
<td></td>
</tr>
<tr>
<td>Situational driving difficulty**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>10.13 2.79</td>
<td>10.61 3.19</td>
<td>10.30 2.48</td>
<td>2.27 &lt;.01</td>
</tr>
<tr>
<td>3 Years</td>
<td>11.04 3.65</td>
<td>12.15 4.43</td>
<td>12.60 4.55</td>
<td></td>
</tr>
<tr>
<td>Driving cessation at 3 years (number ceased)</td>
<td>(28) (8%)</td>
<td>(18) (11%)</td>
<td>(4) (11%)</td>
<td></td>
</tr>
</tbody>
</table>

Notes. **Higher scores reflect worse performance; Race and Useful Field of View n = 499. Driving space—the extent one drives beyond their home over prior 2 months; driving challenges—number of challenging driving situations encountered; everyday driving difficulty—difficulty making lane changes, left-hand turns, and driving alone; situational driving difficulty—difficulty driving in high traffic, at rush hour, during the rain, and merging.***Significant group differences at p < .001.
Caucasian race are risk factors for peripheral hearing loss (Cruickshanks et al., 1998; Helzner et al., 2005; Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011), women and racial minorities are more likely to cease driving (e.g., Choi, Mezuk, Lohman, Edwards, & Rebok, 2013). Thus, such variables available in the data were examined as covariates in analyses. A previously validated (Jobe et al., 2001) health questionnaire was administered and included self-report of whether a doctor or nurse had ever informed participants of having any of the following conditions, which are potential risk factors for HI or mobility declines: diabetes, heart disease, hypertension, Parkinson’s disease, or stroke. These self-reported health conditions were examined as potential covariates.

Analyses

Chi square analyses compared the three HI categories on demographics (sex and race) and incidence of relevant health conditions (diabetes, heart disease, hypertension, Parkinson’s disease, and stroke). The three HI categories were also compared across age, education, UFOV performance, and baseline driving mobility using multivariate analysis of variance (MANOVA).

To determine which covariates to include in subsequent analyses (in addition to training group), Spearman correlations were calculated between demographics (age, sex, and race), health conditions (diabetes, heart disease, hypertension, Parkinson’s disease, or stroke), baseline hearing (PTA in the better ear), and baseline driving mobility variables (driving space, driving challenges, and difficulty with driving challenges). Demographic and health indices that significantly correlated with baseline hearing or driving mobility were included as covariates.

To longitudinally examine the influence of HI on driving mobility, repeated measures MANOVA compared participants with normal hearing \((n = 313)\), mild HI \((n = 153)\), or moderate-to-severe HI \((n = 33)\) on the driving mobility composites across baseline to 3 years. A significant group by time interaction would indicate an effect of the level of HI on driving mobility across time. To further examine a significant overall group by time interaction, repeated measures analysis of variance (ANOVA) comparing the three groups across time on each of the four driving mobility composites were planned.

Finally, Cox hazard regression analysis was used to examine whether HI was predictive of driving cessation across the 3-year period after controlling for covariates.

Results

Five hundred of the 640 participants were successfully contacted for follow-up interviews. The attrition rate was 21.8%. Of those who completed the 3-year follow-up interview, one participant refused to report race, one participant did not report incidence of diabetes, Parkinson’s disease, or hypertension, and one participant refused to complete the UFOV.

Chi Square analyses indicated no significant differences between the HI categories in sex, race, or self-reported incidence of diabetes, heart disease, or Parkinson’s disease \(p \text{ values} > .05\). See Table 1 for details.

MANOVA compared baseline age, education, UFOV performance, and driving mobility among the three HI groups. Results indicated overall group differences, Wilks’ \(\Lambda = .855\), \(F(14, 982) = 5.58, p < .001\), partial \(\eta^2 = .99\). Univariate ANOVAs (reported in Table 1) showed significant group differences in age and UFOV performance. See Table 1 for descriptive data. Fisher’s least significant difference (LSD) test indicated that those with mild HI were significantly older than those with normal hearing, whereas those with moderate-to-severe HI were significantly older than either those with normal hearing or mild HI \((p \text{ values} < .001)\). Fisher’s LSD test also revealed that those with moderate-to-severe HI performed significantly worse on the UFOV as compared with either those with normal hearing \((p < .001)\) or those with mild HI \((p = .002)\).

There were no significant differences between HI categories in years of education or baseline driving mobility as indicated by driving space, driving in challenging situations, everyday driving difficulty, or situational driving difficulty. See Table 1 for statistics.

Spearman correlations revealed significant associations of baseline hearing with age \((r = .35, p < .001)\) and race \((r = .12, p = .004)\), but no significant associations were found with health conditions \((p \text{ values} > .05)\). Individuals of older age and minorities tended to have worse hearing. With regard to driving mobility, older age \((r = -.12)\), minority race \((r = -.15)\), female sex \((r = .24–.36)\) as well as self-reported hypertension \((r = -.09)\) and stroke \((r = -.09)\) were associated with restricted baseline driving mobility. Thus, age, sex, race, hypertension, and stroke were included as covariates in subsequent analyses. See Table 2 for correlations.

Repeated measures multivariate analysis of covariance compared the three groups of participants with normal hearing, mild HI, and moderate-to-severe HI on driving mobility across baseline to 3 years. Covariates were training condition, age, sex, race, hypertension, and stroke. Results are detailed in Table 3 and indicated no significant main effect of hearing loss on subsequent driving mobility, no significant effect of time, and no significant Group × Time interaction. Patterns of driving mobility did not vary by levels of HI across 3 years.

Cox regression analyses examining driving cessation across 3 years (including age, sex, race hypertension, and stroke as covariates) indicated that HI was not significantly associated with rates of driving cessation over time, hazard ratio = 1.01, 95% confidence interval 0.99–1.04, \(p = .38\).

The above analyses were repeated among the 640 participants invited to participate in the study substituting for missing data. SPSS was used to perform multiple imputation, which applies a fully conditional specification.
Table 2. Correlations Among Baseline Hearing and Driving Mobility at Baseline and 3 Years

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hearing pure-tone average in better ear across 0.5, 1, 2 kHz</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Driving Space Baseline</td>
<td>−.032</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Driving Space Three Years</td>
<td>−.109*</td>
<td>.445*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Driving Challenges Baseline</td>
<td>−.071</td>
<td>.413</td>
<td>.367</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Driving Challenges Three Years</td>
<td>−.113*</td>
<td>.336**</td>
<td>.580**</td>
<td>.566**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Everyday Driving Difficulty at Baseline</td>
<td>.071</td>
<td>−.125**</td>
<td>−.141**</td>
<td>−.303**</td>
<td>−.167**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Everyday Driving Difficulty at Three Years</td>
<td>.118**</td>
<td>−.147**</td>
<td>−.344**</td>
<td>−.341**</td>
<td>−.614**</td>
<td>.319**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Situational Driving Difficulty at Baseline</td>
<td>.061</td>
<td>−.246**</td>
<td>−.293**</td>
<td>−.541**</td>
<td>−.401**</td>
<td>.499**</td>
<td>.385**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9 Situational Driving Difficulty at Three Years</td>
<td>.153**</td>
<td>−.255**</td>
<td>−.379**</td>
<td>−.424**</td>
<td>−.609**</td>
<td>.287**</td>
<td>.710**</td>
<td>.603**</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes. Higher scores reflect worse performance. Driving space—the extent one drives beyond their home over prior 2 months; driving exposure—number of challenging driving situations encountered; everyday driving difficulty—difficulty making lane changes, making left-hand turns across oncoming traffic and driving alone; situational driving difficulty—difficulty driving in high traffic, at night, during rush hour, or in the rain, as well as merging. *p < .05. **p < .01.

Table 3. Results of Repeated Measures Multivariate Analysis of Variance Examining Driving Mobility Across 3 Years by Levels of Hearing Impairment

<table>
<thead>
<tr>
<th></th>
<th>Wilks’ Λ</th>
<th>Df</th>
<th>F</th>
<th>p Value</th>
<th>Partial η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing impairment</td>
<td>0.98</td>
<td>8,948</td>
<td>1.22</td>
<td>.28</td>
<td>.01</td>
</tr>
<tr>
<td>Time</td>
<td>0.96</td>
<td>4,474</td>
<td>1.84</td>
<td>.12</td>
<td>.02</td>
</tr>
<tr>
<td>Hearing impairment × Time</td>
<td>0.99</td>
<td>8,948</td>
<td>&lt;1</td>
<td>.51</td>
<td>.01</td>
</tr>
</tbody>
</table>

Note. Adjusted for training condition, age, sex, race, hypertension, and stroke. With multiple imputation for missing data, there was a significant effect of time indicating a trend for reduced driving mobility across 3 years.

Discussion

The present study examined the longitudinal relationship of HI with driving mobility among older adults over a 3-year period. Contrary to our hypothesis, there were no significant differences in patterns of driving mobility over time between older adults with varying levels of HI. Furthermore, HI was not significantly associated with rates of driving cessation among older drivers across 3 years. This finding is particularly relevant and potentially concerning given that we also present novel evidence that older adults with moderate-to-severe HI perform significantly worse on the UFOV, indicating higher risk for unsafe driving performance. Sensitivity analyses were conducted by repeating all statistical analyses excluding older adults randomized to cognitive training (instead of adjusting for training condition as a covariate), and the results were replicated. Neither were effects different when stratified by sex.

This research makes several unique contributions to the existing literature. Prior examinations of the association between hearing and driving safety primarily used self-reported hearing ability and included only cross-sectional analyses. No previous research has examined the longitudinal association of objectively assessed hearing with driving safety or mobility among older drivers in the United States. This study is the first to demonstrate that objectively assessed HI is not longitudinally associated with older drivers’ driving mobility. We report novel evidence that objectively measured hearing loss is not associated with longitudinal patterns of driving mobility as indicated by driving space, driving in challenging situations, and difficulty in challenging situations. These results extend previous findings among Australian older drivers (Anstey et al., 2006), similarly indicating that hearing loss is not longitudinally associated with driving cessation over a 3-year period.

Our finding that drivers with HI do not restrict their driving mobility is of potential concern given prior research showing a significant relationship between objectively measured hearing to crashes, citations other than speeding, and worse on-road driving performance in the presence of distractors (Hickson et al., 2010; Picard et al., 2008). A key finding of our study is that older adults with HI perform worse on the UFOV. Performance on this test is a strong indicator of subsequent at-fault crash risk and on-road driving performance (Ball et al., 1998; Ball et al., 2006; J. M. Wood et al., 2012), suggesting that participants in our study with moderate-to-severe HI may be at higher risk for crash involvement (Ball et al., 1998; Ball et al., 2006; J. M. Wood et al., 2012). Older drivers with poor UFOV are 2–3 times more likely to have an at-fault crash, and are 4–17 times more likely to incur a crash with injuries (Owsley, Ball et al., 1998; Owsley, McGwin, & Ball, 1998). UFOV performance has 93% specificity in predicting on-road performance (Classen, Wang, Crizzle, Winter, & Lanford, 2013).
However, it should be noted that our data are correlational and the relationship of hearing and UFOV performance is confounded by age. In addition, in this study we did not have access to crash data. Further investigation of the longitudinal association of objectively measured hearing loss with UFOV performance and driving safety is needed.

The underlying mechanisms of the association between hearing and driving safety are unknown. We speculate that HI may negatively affect divided attention, as measured by the UFOV, thereby potentially impairing driving safety. Driving requires dividing attention between both visual and auditory stimuli. Impairments in hearing are likely to make processing of auditory stimuli more effortful, leaving less resources available to perform visually related driving tasks, and hence impairing driving performance. This hypothesis is supported to some extent by the fact that the divided attention subtest of the UFOV has the strongest relationship to driving safety (Ball et al., 2006). In addition, HI may impair driving by negatively affecting selective attention. To this end, the presence of different levels of auditory distractors significantly impairs UFOV performance (J. M. Wood et al., 2006). Future research should examine these hypotheses.

In light of our findings, the relationship of measures of central auditory processing (i.e., the intermediate neural transmission of auditory information from the ear to the brain that occurs after lower-level sensory processing and prior to higher-level cognitive processing) with driving outcomes is of interest and should be explored in future research. Measures of central auditory processing often assess abilities under conditions of divided attention (i.e., dichotic), and performance may be more sensitive to age-related cognitive decline than measures of peripheral hearing (Gates, Beiser, Rees, D’Agostino, & Wolf, 2002; Gates et al., 2010).

A limitation of this research is that the SKILL data do not include objective measures of driving performance and hearing thresholds were only measured at baseline. In addition, these secondary data analyses are limited to some extent because the hearing thresholds were restricted to three frequencies and did not include high frequencies, which are typically most affected by aging. However, hearing loss in the mid frequencies would likely have a greater impact on day-to-day function. There are other known risk factors for hearing loss not available in the SKILL data such as smoking and noise exposure (Helzner et al., 2005; Kiely, Gopinath, Mitchell, Luszcz, & Anstey, 2012). We also do not have any data on the various actions that drivers may take which affect their hearing while driving (such as the use of entertainment systems, conversations by telephone, or with other passengers) or their attentiveness to auditory cues of driving hazards; these issues would be useful to explore in future studies. Finally, although our hearing indices were objective measures, the driving mobility variables and health covariates were derived by self-report. It may also be useful for future studies to determine whether hearing is related to objectively assessed, naturalistic driving mobility.

The present study indicates that hearing loss is not related to older adults’ driving mobility. Given prior research that hearing loss is associated with increased crash rates and citations, as well as worse on-road driving performance in challenging situations, this finding is noteworthy (Hickson et al., 2010; Picard et al., 2008). Potentially as a result of the scant attention on the relationship of hearing and driving in the literature and wider community, it could be that older adults are unaware of the possible negative effects of hearing on driving and do not adjust their driving mobility accordingly. Considered in context with the high prevalence of untreated hearing loss in the United States, this is particularly concerning. Only 16%–30% of adult hearing aid candidates actually use hearing aids (National Institute on Deafness and Other Communication Disorders, 2015). Even among those who do use hearing aids to treat hearing loss, there appears to be a disregard among older drivers for wearing their hearing aids while driving. For example, one study documented that although 45% of older drivers had hearing loss, only 15% wore hearing aids while driving (Hickson et al., 2010). However, it is not clear whether or not hearing aid use affects driving safety.

The effects of hearing loss on subsequent driving safety and mobility deserve further investigation. Further research should explore the underlying mechanisms of these relationships and determine whether correcting hearing can positively affect older adults’ UFOV performance, and ultimately, driving safety. Taken together with previous research, our results suggest that, although older adults with hearing loss may be at increased risk for crashes and may be more likely to have difficulty in challenging situations while driving (J. M. Wood et al., 2012), they may not be more likely to significantly modify their driving habits over time. HI is independently associated with driving safety, but is not related to driving mobility.

Clinical implications include the need to educate older adults and health professionals about the potential impact of hearing loss on driving safety. Practical implications include engineering automobiles to minimize auditory distractions and amplify hazard warnings. If future research confirms the current findings, potential policy implications may include tailoring strategies to promote safe driving in older adults to take into account HI.

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