SOUTHERN GERONTOLOGICAL SOCIETY

Journal of Applied Gerontology
2021, Vol. 40(12) 1768–1777

DOI: 10.1177/0733464821999223
journals.sagepub.com/home/jag
SAGE

# The Influence of Hearing Impairment on Driving Avoidance Among a Large Cohort of Older Drivers

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**Abstract**

As people age, some of the commonly experienced psychomotor, visual, and cognitive declines can interfere with the ability to safely drive, often leading to situational avoidance of challenging driving situations. The effect of hearing impairment on these avoidance behaviors has not been comprehensively studied. Data from the American Automobile Association (AAA) Longitudinal Research on Aging Drivers (LongROAD) study were used to assess the effect of hearing impairment on driving avoidance, using three measures of hearing. Results indicated that hearing loss plays a complex role in driving avoidance, and that an objective hearing measure was a stronger predictor than hearing aid use and self-rated hearing. Greater hearing impairment was related to less nighttime and freeway driving, more trips farther than 15 mi from home, and lower odds of avoiding peak driving times. The moderating influence of hearing on both vision and cognition is also discussed, along with study implications and future research.

**Keywords**

driving, hearing, vision, perceptual decline, sensory problems, driving exposure

## Introduction

Prior to driving cessation, most older adults engage in driving reduction behaviors, including less driving overall and avoiding challenging situations such as driving at night, on freeways, during peak traffic times, in poor weather, in unfamiliar areas, and long distances (Braitman & Williams, 2011; Dickerson et al., 2019; McGuckin & Fucci, 2018; Ryvicker et al., 2020). Such behaviors may allow older adults to continue providing for their own mobility for a longer time.

Factors associated with driving reduction and avoidance include the presence of health conditions, increased frailty, cognitive impairment, concern about crashing, lack of driving comfort, lifestyle changes, and perceptual (especially visual) declines (Crowe et al., 2020; Devlin & McGillivray, 2014; Dickerson et al., 2007; Kandasamy et al., 2018; Molnar et al., 2013; Ragland et al., 2004). The influence of vision problems on driving reduction/avoidance has been studied extensively. For example, better self-rated vision is significantly associated with distinguishing drivers from nondrivers (Anstey et al., 2017) and less situational driving avoidance (e.g., intersections and nighttime driving; Charlton et al., 2006). In a U.S.-based

**Manuscript received:** January 31, 2021; **final revision received:** January 31, 2021; **accepted:** February 5, 2021.

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longitudinal study, objectively measured visual acuity was related to driving cessation, whereas glaucoma and macular degeneration were not significant (Edwards et al., 2008). In that same study, however, visual acuity became nonsignificant after controlling for health and physical/cognitive performance. Another longitudinal study assessed the relationship between driving cessation and several different vision problems. Worse visual acuity, contrast sensitivity, and losses in the lower peripheral visual field were significantly related to driving cessation (Freeman et al., 2005). In other work, near visual acuity, contrast sensitivity, and useful field of view were all predictive of driving cessation, but not moving violations or crashes (Emerson et al., 2012). Although some of these findings are mixed, vision has been widely studied and findings generally suggest that it plays a role in driving outcomes. However, the type of visual problem (e.g., loss of acuity, contrast sensitivity, and visual field) seems to matter.

The evidence related to hearing impairment and driving outcomes is less clear, but critical to understand. Almost 25% of Americans aged 65 to 74 years have disabling hearing loss, as do 50% of those aged 75 years or older (National Institutes of Health, 2016). The potential effect of hearing loss on various driving outcomes have been assessed, using a variety of study designs and hearing measures. The findings are quite mixed and differences in how hearing has been measured may be a potential reason. For example, few studies have used objective measures of hearing to assess its relationship to driving outcomes, some studies have asked respondents about hearing aid use, and others have used self-reported (S-R) hearing. Among those using an objective assessment of hearing, two used an audioscope, but found no significant relationship with crash risk (Sims et al., 1998, 2000). Another study used a variety of hearing measures and found a significant interaction between hearing impairment (using audiometry) and distractors on driving performance (Hickson et al., 2010). Specifically, older adults with moderate or severe hearing impairment performed significantly worse in the presence of a distractor (a moderating effect). This suggests that hearing loss may increase demand on attentional capacity, thus increasing the negative effects of distraction while driving.

Results related to hearing aid use are also mixed. Use of a hearing aid was not significantly related to crash risk in some studies (McGwin et al., 2005; Sims et al., 2000), whereas at least one study found that it may increase risk for crash-related injuries (McCloskey et al., 1994). In a study where at-fault crashes were compared with controls, hearing aid use was nonsignificant (McGwin et al., 2005). Use of a hearing device was also found to be unrelated to driving status in a different study (MacLeod et al., 2014).

Using S-R measures to assess the effect of hearing on driving outcomes is most common in the literature. In terms of crash risk, a significant relationship was observed with S-R hearing loss in the right ear in an Australian study (where drivers sit on the right side of the vehicle and drive on the left side of the road; Ivers et al., 1999). In a French cohort study, no difference in S-R hearing difficulty was observed between crash-involved and non-crash-involved older adults (Lafont et al., 2008). Gallo and colleagues (1999) found a significant relationship between adverse driving events and S-R hearing impairment. The moderating effect of S-R hearing on the relationship between poor vision and crash rates has also been assessed. Findings suggested that hearing loss exacerbates the negative effect of vision problems (acuity and contrast sensitivity) on crashes (Green et al., 2013).

The relationship between S-R hearing impairment and driving reduction/cessation has also been assessed. Several studies compared hearing ability between older drivers and nondrivers. S-R hearing was worse among nondrivers than drivers (Kostyniuk et al., 2000) and among former drivers compared with current drivers (Forrest et al., 1997). Others have found no difference in S-R hearing between drivers and nondrivers (Anstey et al., 2017) or when comparing drivers with former drivers (Lafont et al., 2008). Gilhotra et al. (2001) reported that S-R severe hearing difficulty was significantly associated with driving cessation. S-R hearing impairment may also be related to driving fewer miles within the preceding 5 years (Forrest et al., 1997).

Collectively, these findings suggest that the relationship between hearing impairment and driving outcomes among older drivers is not well understood. It may also be a complex relationship, given that several studies identified hearing impairment as a potential moderator, amplifying the relationship between distractors on driving performance (Hickson et al., 2010) and poor vision on crashes (Green et al., 2013). Research that specifically focused on how hearing impairment may affect driving reduction/avoidance is particularly scarce. The goal of the current study was to clarify the role of hearing impairment on driving reduction/avoidance, using a large cohort of older drivers and several different measures of hearing (which could explain some mixed results in previous research). Specific hypotheses follow:

> **Hypothesis 1 (H1)**: Greater hearing impairment will be associated with more driving reduction and avoidance.
> **Hypothesis 2 (H2)**: The objective measure of hearing (Whisper Test [WT]) will have a stronger association with driving reduction/avoidance than other hearing measures.
> **Hypothesis 3 (H3)**: Greater hearing impairment will moderate the relationships between visual acuity and cognition with driving reduction/avoidance, resulting in an increase in those behaviors.

## Method

### *Data Source*

This study used data from the American Automobile Association (AAA) Longitudinal Research on Aging Drivers

(LongROAD) study, a large multisite prospective cohort study with five locations in the United States (Ann Arbor, MI; Baltimore, MD; Cooperstown, NY; Denver, CO; and San Diego, CA). LongROAD includes respondents from a variety of geographic locations and backgrounds, and includes a wealth of driving and sociodemographic information (see Li et al., 2017 for full detail). Data were collected using questionnaires, in person clinical assessments, and GPS/dataloggers installed in participants' vehicles. Data from 2,030 individuals were analyzed in this study. Participants from the New York site were not included because of differences in their administration of the visual acuity test. Baseline questionnaires/assessments were used for each participant (enrollment occurred between July, 2015 and March, 2017). Objective driving data were collected continuously, and the first 12 months of driving data were used to eliminate any seasonal differences. Study protocols were reviewed and approved by the University of Michigan institutional review board (HUM00094031).

## Measures

*Dependent variables.* Objectively measured dependent variables were derived from the dataloggers installed in participants' vehicles. The dataloggers automatically recorded location, time of day, vehicle speed, heading, and whether or not the actual participant was driving the vehicle. Percent of trips at night represented the percentage of all trips where at least 80% of a trip occurred during nighttime (defined as civil twilight or a solar angle greater than 96°). Percent of trips during peak times was the percentage of trips that occurred between 7:00 a.m. and 9:00 a.m. and between 4:00 p.m. and 6:00 p.m. on weekdays. Percent of trips on freeways was operationalized as the percentage of trips where at least 20% of the distance traveled was at a speed of at least 60 mph. Percent of trips in unfamiliar areas represented the percentage of trips at least 15 mi from home. Each of these was reverse-coded, such that a higher value represented more avoidance of these situations. These same behaviors were measured subjectively, using the question stem, "Do you try to avoid driving . . ." followed by the specific behavior, ". . . at night?" ". . . in rush hour traffic?" ". . . on the freeway?" and ". . . in unfamiliar areas?" Response choices included *yes* and *no* for each item.

*Independent variables of interest.* Hearing was operationalized using three methods. Hearing aid use was assessed by asking, "Do you ever wear a hearing aid?" with *yes* and *no* response options. Self-rated hearing was assessed with the question, "Is your hearing excellent, very good, good, fair, or poor?" coded such that a higher score represented worse hearing. For those who used hearing aids, this item did not specify whether they should assess their corrected or uncorrected hearing, so that was open to interpretation for those respondents. The WT (Pirozzo et al., 2003) was performed in both ears (with hearing aids in place for those who used them) and participants could pass or fail in each ear. This test has been compared with audiometric assessment, with results suggesting that it has strong performance indicators (sensitivity: 79%, specificity: 91%; Strawbridge & Wallhagen, 2017).

Visual acuity was measured using the Tumbling E chart and then converted to Logarithm of the Minimum Angle of Resolution (LogMAR) scores. In the LogMAR scale, zero is average (equivalent to 20/20) and higher values represent greater impaired acuity. The total range of this variable in our sample was approximately 0.8, so it was standardized when included in the regressions to allow for a meaningful interpretation of a 1-unit increase (representing a standard deviation increase). Cognition was operationalized using the Trail Making Test Part B. Higher values indicate longer time to complete the test, representing poorer cognitive function (see Tombaugh, 2004, for norms based on age and education).

*Control variables.* Control variables included age, gender, race, relationship status, household income, education, health, and depressive symptoms. Age was measured as a continuous variable. Gender was recorded as *male* or *female* by the interviewer. S-R race and ethnicity were collapsed to *White*, *Non-Hispanic; Black*, *Non-Hispanic*; and *Other* due to low numbers of people in some groups. Relationship status categories were collapsed to *married/partnered*, *separated/divorced*, *widowed*, and *never married* due to low cell counts and for ease of interpretation. Household income was measured in five groups, including less than US$20,000; US$20,000 to US$49,999; US$50,000 to US$79,999; US$80,000 to US$99,999; and US$100,000 or more. Education included high school or less, some college, bachelor's degree, and graduate degree. Health was measured by asking, "How satisfied are you with your health?" Responses ranged from 1 (*not at all satisfied*) to 5 (*completely satisfied*) on a 5-point scale. Depressive symptoms were represented by the summed responses to four items, which all began with the stem, "In the past 7 days, I felt . . ." followed by *worthless*, *helpless*, *depressed*, and *hopeless*. Response choices ranged from *never* to *always*. More than 76% of the sample reported *never* for all four items, so this variable was dichotomized to represent the *never* group and those who reported anything else.

## Data Management and Analysis

SAS Version 9.4 (SAS Institute Inc., 2016) was used for all analyses. Descriptive statistics were generated to assess variables and check for errors. Bivariate statistical tests were performed to assess initial relationships and inform regression model building. Linear regression techniques were used for the objective outcomes and binary logistic regression was used for the subjective outcomes, with separate models for each. Self-rated hearing (measured using an ordinal-level scale) was assessed separately as a categorical versus a continuous variable (given its reasonably normal distribution).

That assessment suggested that the continuous treatment of this variable produced more statistically significant relationships, so it was included as a continuous predictor in all models. Variance inflation factors (VIFs) were calculated to evaluate multicollinearity for all predictors and no problems were identified. VIFs also determined whether the three hearing variables could be included in the same models. Models with only one hearing variable included were also compared with models with all three hearing variables to see the extent to which parameter estimates changed when controlling for other hearing measures. We noted very little difference between models and no multicollinearity issues, thus models included all hearing variables together. Finally, two-way statistical interactions were assessed between each hearing variable with visual acuity and cognition for each outcome. When statistically significant interactions were observed, they were retained in the final model; when the interactions were not significant, they were removed and only main effects were reported. Our model-building process included the fitment of eight separate models with the same predictors. We began with control variables only, and then added vision, followed by cognition. We next added the hearing variables and assessed potential interactions. This process allowed us to examine changes in parameters and model statistics at each stage.

## Results

### Descriptive Findings

Results of descriptive statistics for control variables are shown in Table 1. Participants ranged in age from 65 to 79 years, with mean of 70.9 years. Women comprised 51.9% of the sample. The majority identified their race as White (83.5%) and were married/partnered (66.0%). Respondents reported relatively high incomes and educational levels. The mean health score was 3.77, which was close to *very satisfied*, and about three quarters of the sample reported never experiencing any depressive symptoms during the past 7 days.

Descriptive findings for key predictors of interest and outcome variables are shown in Table 2. The mean for visual acuity was 0.093 on the LogMAR scale, indicating slightly worse than average acuity (~20/25). The average time to complete the Trail Making Test Part B test was 91 s (within age-based norms; Tombaugh, 2004). The mean for self-rated hearing was 2.32 (between *good* and *very good* hearing). Only 16.7% reported wearing a hearing aid; 11.3% failed the WT in both ears, 10.6% failed in only one ear, and 78.1% passed both ears.

For the objective measures of driving avoidance, most trips occurred during the day (92.6%), on non-freeways (85.9%), within 15 mi of home (67.6%), and during nonpeak time (83.2%). For the subjective measures, 34.2% reported that they avoid night driving, 10.5% avoid freeways, 16.1% avoid unfamiliar areas, and 61.0% avoid peak time driving. Three online supplemental tables (available in the online appendix) show descriptive statistics for each predictor and outcome as a function of each hearing variable. The Supplemental Table A1 shows results for hearing aid use, Supplemental Table A2 for self-rated hearing, and Supplemental Table A3 for the WT.

**Table 1.** Descriptive Statistics for Control Variables.

| Characteristic | *M* (*SD*) or *N* (%) |
|---|---|
| Age | 70.89 (4.08) |
| Gender | |
| Male | 978 (48.18%) |
| Female | 1,052 (51.82%) |
| Race | |
| White | 1,695 (83.50%) |
| Black | 170 (8.37%) |
| Other | 165 (8.13%) |
| Relationship status | |
| Married/partnered | 1,339 (65.96%) |
| Divorced/separated | 358 (17.64%) |
| Widowed | 233 (11.48%) |
| Never married | 100 (4.93%) |
| Income | |
| <US$20,000 | 66 (3.25%) |
| US$20,000–US$49,999 | 397 (19.56%) |
| US$50,000–US$79,999 | 496 (24.43%) |
| US$80,000–US$99,999 | 312 (15.37%) |
| >=US$100,000 | 759 (37.39%) |
| Education | |
| <High school | 166 (8.18%) |
| Some college | 458 (22.56%) |
| Bachelor's degree | 491 (24.19%) |
| Graduate degree | 915 (45.07%) |
| Health | 3.77 (0.82) |
| Depressive symptoms | |
| Never (all symptoms) | 1,547 (76.21%) |
| >Never | 483 (23.79%) |

### Multiple Regression Findings

Linear regression results from the objectively measured driving outcomes are shown in Table 3. Those outcomes represent the percentage of trips in less challenging situations (e.g., daytime), so a positive beta value can be interpreted as less travel in challenging situations, thus more driving avoidance. Note that some beta values are small because of the large range of the variable, and that a 1-unit increase represents only a modest change. These can be manually adjusted if assessing a larger change is desired. For example, to adjust age from a 1-year to a 5-year increase, the beta can simply be multiplied by 5.

As expected, many of the control variables were related to avoiding specific driving situations (see Table 3). Among variables of interest, worse visual acuity was only associated with more travel close to home. Worse cognition was

**Table 2.** Descriptive Statistics for Predictors of Interest and Outcomes.

| Characteristic | *M* (*SD*) or *N* (%) |
|---|---|
| Predictors of interest | |
| Visual acuity | 0.09 (0.12) |
| Cognition | 91.13 (40.57) |
| Hearing aid | |
| No | 1,690 (83.25%) |
| Yes | 340 (16.75%) |
| Self-rated hearing | 2.32 (0.95) |
| Whisper Test | |
| Pass both ears | 1,585 (78.08%) |
| Fail one ear | 215 (10.59%) |
| Fail both ears | 230 (11.33%) |
| Outcomes | |
| Objective | |
| % night | 7.38 (5.55) |
| % day | 92.62 (5.55) |
| % freeway | 14.09 (11.36) |
| % non-freeway | 85.91 (11.36) |
| % >15 mi | 32.35 (21.35) |
| % ≤ 15 mi | 67.65 (21.35) |
| % peak time | 16.76 (5.54) |
| % nonpeak | 83.24 (5.54) |
| Subjective | |
| Avoid night | 693 (34.14%) |
| No night avoid | 1,337 (65.86%) |
| Avoid freeway | 212 (10.44%) |
| No freeway avoid | 1,818 (89.56%) |
| Avoid unfamiliar | 327 (16.11%) |
| No unfamiliar avoid | 1,703 (83.89%) |
| Avoid peak time | 1,237 (60.94%) |
| No peak avoid | 793 (39.06%) |

significantly related to less nighttime and freeway travel. The three hearing variables differed in their relationships to objective driving behaviors (the assessment of H1 and H2). Neither hearing aid use nor S-R hearing was significantly related to any of the objective behaviors. However, failing the WT was related to all objective behaviors. Compared with passing the test in both ears, failing in both ears was related to less nighttime driving. Failing the test in one ear compared with passing in both was associated with less freeway driving ($p < .05$), and failing in both ears approached significance ($p = .06$). Counterintuitively, more trips over 15 mi were taken among those who failed the test in both ears ($p < .01$) and failing in one ear approached significance ($p = .09$). A significant interaction between cognition and the WT was observed for driving during peak times (an assessment of H3). Although the main effects were not significant, the significant interaction suggested that lower cognition increased avoidance of peak time driving only for those who failed the WT in both ears ($p < .05$). All other two-way interactions between each hearing variable and the visual acuity and cognition variables were separately assessed, but were not statistically significant.

Binary logistic regression results from the subjective outcomes are shown in Table 4. Note that odds ratios (ORs) are included for all variables, but should be interpreted with caution for those with a significant interaction, as that makes them conditional (conditional ORs are reported in text with an explanation). Some betas/ORs are small because they represent only a modest change in the predictor. These can be manually adjusted by multiplying the beta by the factor of interest (e.g., by 5 for a 5-year increase in age), and then exponentiating the resulting value to calculate the OR.

Many of the control variables were related to subjective driving avoidance (see Table 4). In terms of the variables of interest, worse visual acuity was significantly associated with higher odds of subjective nighttime driving avoidance and approached significance for freeways ($p = .08$ for the main effect). Lower cognition was related to increased odds of all avoidance behaviors except peak time. Hearing aid use was significantly related to lower odds of freeway avoidance but no other behaviors (H1 and H2). Worse S-R hearing approached significance for peak time avoidance ($p = .09$, H1 and H2). For freeway avoidance, the interaction between S-R hearing and visual acuity was significant (H3). Conditional ORs were calculated for hearing at various levels of vision. The relationship was only significant for those with low vision (at least 0.495 LogMAR [about 20/63 on the Snellen scale]). For those with the worst vision in the sample (LogMAR = .699), worse self-rated hearing was associated with *lower* odds of reporting freeway avoidance (OR = 0.428, $p < .05$).

The WT was not significantly related to nighttime driving avoidance, but was related to the other three behaviors (H2). Compared with passing in both ears, failing in both was related to 69% higher odds of reporting freeway avoidance. There was a statistically significant interaction between cognition and the WT for avoiding unfamiliar areas, and conditional ORs were calculated for cognition at each level of hearing (H3). For respondents who passed in both ears only, every 10-s increase in time to complete the Trail Making Test was related to 8.3% higher odds of reporting unfamiliar area avoidance (OR = 1.008, $p < .05$). No other interactions between any hearing variables and vision/cognition on any of the subjective behaviors were statistically significant.

The WT was also significantly related to subjective peak time avoidance, where those who failed in both ears had significantly *lower* odds (33.8%) of reporting avoidance (H1 and H2). Results for those who failed in one ear were similar (22.8% lower), but only approached significance ($p = .09$). To assess whether hearing loss in a specific ear mattered (as suggested by Ivers et al., 1999), models were also explored that used WT results from each individual ear, rather than the combined measure. Individual ear measures were only significant for two of the eight outcomes assessed, with a different ear for each outcome.

**Table 3.** Regression Results for Objective Driving Avoidance Variables.

| Variable | Daytime driving (avoiding night) β | SE | Lower speed (avoiding freeway) β | SE | Near home (avoiding far trips) β | SE | Nonpeak (avoiding peak) β | SE |
|---|---|---|---|---|---|---|---|---|
| Age | 0.160*** | 0.032 | 0.138* | 0.065 | 0.519*** | 0.121 | 0.096** | 0.033 |
| Gender (ref = male) | | | | | | | | |
| Female | 1.803*** | 0.259 | 2.337*** | 0.527 | 5.381*** | 0.982 | 0.229 | 0.264 |
| Race (ref = White) | | | | | | | | |
| Black | −2.544*** | 0.464 | 2.550** | 0.945 | 9.049*** | 1.762 | 0.360 | 0.476 |
| Other | −0.732† | 0.444 | −1.991* | 0.903 | 3.334* | 1.684 | −0.646 | 0.453 |
| Relationship status (ref = married/partnered) | | | | | | | | |
| Divorced/separated | −1.663*** | 0.362 | −0.272 | 0.737 | −1.095 | 1.375 | −0.362 | 0.370 |
| Widowed | −1.372*** | 0.413 | 0.328 | 0.840 | −1.843 | 1.566 | 0.138 | 0.421 |
| Never married | −2.085*** | 0.582 | −0.300 | 1.183 | 4.129† | 2.207 | 0.640 | 0.594 |
| Income (ref >= US$100,000) | | | | | | | | |
| <US$20,000 | −0.058 | 0.752 | 4.373** | 1.530 | 9.070** | 2.853 | 1.053 | 0.768 |
| US$20,000–US$49,999 | 0.113 | 0.393 | 3.959*** | 0.800 | 4.294** | 1.492 | 1.463*** | 0.402 |
| US$50,000–US$79,999 | 0.212 | 0.329 | 3.155*** | 0.700 | −0.265 | 1.249 | 0.728* | 0.336 |
| US$80,000–US$99,999 | 0.242 | 0.364 | 0.884 | 0.740 | −2.043 | 1.381 | 0.552 | 0.371 |
| Education (ref ≤ HS) | | | | | | | | |
| Some college | −0.480 | 0.494 | −1.772† | 1.005 | −2.409 | 1.874 | −0.530 | 0.504 |
| Bachelor's degree | −0.179 | 0.503 | −0.352 | 1.024 | −1.617 | 1.909 | −0.531 | 0.514 |
| Graduate degree | −0.751 | 0.488 | −0.859 | 0.994 | −2.237 | 1.853 | −0.834† | 0.498 |
| Health | −0.071 | 0.154 | −0.099 | 0.314 | −0.907 | 0.585 | −0.236 | 0.157 |
| Depressive symptoms (ref = never) | | | | | | | | |
| >Never | −0.257 | 0.293 | 0.325 | 0.595 | 2.672* | 1.110 | 0.051 | 0.299 |
| Visual acuity (z) | −0.002 | 0.124 | 0.300 | 0.253 | 2.219*** | 0.471 | 0.138 | 0.127 |
| Cognition | 0.008* | 0.003 | 0.034*** | 0.007 | 0.013 | 0.012 | 0.003 | 0.004 |
| Hearing aid (ref = no) | 0.066 | 0.341 | −0.256 | 0.693 | 1.574 | 1.293 | 0.086 | 0.348 |
| Self-rated hearing | −0.222† | 0.135 | −0.125 | 0.274 | −0.513 | 0.511 | −0.241† | 0.138 |
| Whisper Test (ref = pass both) | | | | | | | | |
| Fail one ear | −0.065 | 0.403 | 1.939* | 0.820 | −2.577† | 1.529 | 0.901 | 0.944 |
| Fail both ears | 0.930* | 0.414 | 1.575† | 0.842 | −4.782** | 1.570 | −1.887† | 1.019 |
| Cognition*WT1 | *ns* | — | *ns* | — | *ns* | — | −0.005 | 0.009 |
| Cognition*WT2 | *ns* | — | *ns* | — | *ns* | — | 0.020* | 0.009 |

*Note.* ref = reference category; z = standardized; WT1, WT2 = Whisper Test fail in one ear, two ears; *ns* = not significant.
†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

## Discussion

Three hypotheses were assessed in this study: H1—worse hearing would be associated with more driving reduction/avoidance, H2—the objective measure of hearing would have a stronger association with driving avoidance than subjective measures, and H3—hearing would moderate the relationships between visual acuity and cognition with driving avoidance, leading to greater avoidance. The second hypothesis was supported, whereas the other two were partially supported.

Regarding H1, worse hearing was related to a higher level of some aspects of driving reduction/avoidance, but there was no effect or the opposite effect in others. Worse hearing (assessed by the WT) was significantly related to less objectively measured nighttime and freeway driving, but more trips 15 mi or farther away from home. Worse hearing (WT) was also significantly related to higher odds of reporting freeway and unfamiliar area avoidance. However, this test was counterintuitively related to decreased odds of peak time avoidance. These mixed results suggest that the effect of hearing on driving avoidance is complex and differs depending upon the measurement approach to hearing and driving avoidance. Differences between objective and subjective driving may be due to S-R measures being assessed at baseline, while driving was measured continuously during participants' first study year. Early modeling also addressed H1, using objective driving *exposure* outcomes (e.g., number of days driven). None of the hearing variables were associated with those outcomes, so results are not reported here, given the focus on hearing impairment.

H2 was supported in that the WT (the objective hearing measure) was statistically related to more factors than the other hearing measures. Results of the multicollinearity

**Table 4.** Regression Results for Subjective Driving Avoidance Variables.

| | Nighttime avoidance | | | Freeway avoidance | | | Unfamiliar avoidance | | | Peak avoidance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | β | OR | *SE* | β | OR | *SE* | β | OR | *SE* | β | OR | *SE* |
| Age | −0.003 | 1.003 | 0.013 | −0.036† | 0.964 | 0.020 | 0.003 | 1.003 | 0.017 | 0.011 | 1.011 | 0.012 |
| Gender (ref = male) | | | | | | | | | | | | |
| Female | 0.867*** | 2.380 | 0.109 | 0.894*** | 2.444 | 0.177 | 0.654*** | 1.924 | 0.141 | −0.165† | 0.848 | 0.100 |
| Race (ref = White) | | | | | | | | | | | | |
| Black | 0.404* | 1.498 | 0.185 | 0.433† | 1.542 | 0.239 | 0.419* | 1.521 | 0.212 | −0.207 | 0.813 | 0.178 |
| Other | 0.382* | 1.480 | 0.179 | −0.013 | 0.987 | 0.279 | 0.512* | 1.669 | 0.208 | −0.169 | 0.844 | 0.171 |
| Relationship status (ref = married/partnered) | | | | | | | | | | | | |
| Divorced/separated | −0.068 | 0.934 | 0.147 | −0.495* | 0.610 | 0.221 | −0.400* | 0.671 | 0.190 | −0.012 | 0.988 | 0.140 |
| Widowed | 0.114 | 1.120 | 0.164 | 0.043 | 1.044 | 0.225 | −0.068 | 0.934 | 0.200 | 0.113 | 1.119 | 0.160 |
| Never married | −0.172 | 0.842 | 0.234 | −1.359** | 0.257 | 0.485 | −0.025 | 0.976 | 0.279 | 0.576* | 1.778 | 0.244 |
| Income (ref >= US$100,000) | | | | | | | | | | | | |
| <US$20,000 | 0.786** | 2.194 | 0.302 | 1.155** | 3.174 | 0.403 | 0.712* | 2.038 | 0.347 | 0.448 | 1.565 | 0.302 |
| US$20,000–US$49,999 | 0.510** | 1.665 | 0.162 | 1.041*** | 2.832 | 0.250 | 0.529** | 1.698 | 0.204 | 0.283† | 1.327 | 0.154 |
| US$50,000–US$79,999 | 0.328* | 1.388 | 0.138 | 0.755*** | 2.127 | 0.224 | 0.314† | 1.369 | 0.180 | 0.026 | 1.027 | 0.127 |
| US$80,000–US$99,999 | 0.502*** | 1.652 | 0.152 | 0.497† | 1.643 | 0.260 | 0.281 | 1.325 | 0.203 | 0.119 | 1.126 | 0.141 |
| Education (ref =< high school) | | | | | | | | | | | | |
| Some college | −0.145 | 0.865 | 0.199 | −0.475† | 0.622 | 0.257 | −0.257 | 0.774 | 0.227 | 0.076 | 1.079 | 0.190 |
| Bachelor's degree | −0.042 | 0.959 | 0.203 | −0.220 | 0.803 | 0.266 | −0.360 | 0.698 | 0.239 | 0.253 | 1.288 | 0.194 |
| Graduate degree | −0.093 | 0.911 | 0.198 | −0.309 | 0.734 | 0.262 | −0.294 | 0.745 | 0.230 | 0.187 | 1.206 | 0.187 |
| Health | −0.370*** | 0.691 | 0.065 | −0.097 | 0.908 | 0.094 | −0.219** | 0.803 | 0.079 | −0.196** | 0.822 | 0.061 |
| Depressive symptoms (ref = never) | | | | | | | | | | | | |
| >Never | 0.181 | 1.199 | 0.118 | 0.315 | 1.371 | 0.171 | 0.274† | 1.315 | 0.145 | 0.374** | 1.454 | 0.117 |
| Visual acuity (z) | 0.190*** | 1.209 | 0.051 | 0.359† | 1.432 | 0.203 | 0.098 | 1.103 | 0.064 | −0.057 | 0.945 | 0.048 |
| Cognition | 0.003* | 1.003 | 0.001 | 0.006** | 1.006 | 0.002 | 0.008*** | 1.008 | 0.002 | −0.000 | 1.000 | 0.001 |
| Hearing aid (ref = no) | −0.192 | 0.825 | 0.147 | −0.542* | 0.581 | 0.260 | −0.268 | 0.765 | 0.197 | −0.064 | 0.938 | 0.131 |
| Self-rated hearing | 0.078 | 1.081 | 0.056 | −0.001 | 0.999 | 0.087 | 0.031 | 1.031 | 0.071 | 0.088† | 1.091 | 0.053 |
| Whisper Test (ref = pass both) | | | | | | | | | | | | |
| Fail one ear | 0.045 | 1.045 | 0.167 | 0.010 | 1.010 | 0.269 | 1.108* | 3.029 | 0.496 | −0.259† | 0.772 | 0.155 |
| Fail both ears | 0.000 | 1.000 | 0.175 | 0.523* | 1.688 | 0.257 | 0.461 | 1.585 | 0.546 | −0.413** | 0.662 | 0.159 |
| Visual acuity (z)*SR hearing | *ns* | — | — | −0.163* | 0.850 | 0.081 | *ns* | — | — | *ns* | — | — |
| Cognition*WT1 | *ns* | — | — | *ns* | — | — | −0.011* | 0.989 | 0.005 | *ns* | — | — |
| Cognition*WT2 | *ns* | — | — | *ns* | — | — | −0.005 | 0.995 | 0.005 | *ns* | — | — |

*Note.* OR = odds ratio; ref = reference category; z = standardized; SR = self-rated; WT1, WT2 = Whisper Test fail in one ear, two ears; *ns* = not significant.
†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

assessment also showed that the three hearing measures accounted for different aspects of driving avoidance. Although use of a hearing aid indicates declining auditory ability, it improves hearing and can compensate for declining ability. That may explain why hearing aid use was only related to one outcome and it suggested *lower* odds of freeway avoidance. The main effect of S-R hearing was unrelated to all outcomes (the significant interaction is discussed later). Overall, the measurement of hearing is important, which is consistent with previous research comparing how different hearing measures are related to a variety of functional outcomes (Choi et al., 2016). Future researchers should consider that there may be a stronger association between objective (compared with perceived) hearing measures and driving avoidance.

In terms of H3, hearing was extensively explored as a moderator in the current study and three significant interactions were observed. Lower cognition increased objective peak time avoidance for those who failed the WT in both ears, the predicted direction of influence. This is consistent with previous research where the effect of a cognitive distractor on driving ability was exacerbated for those with severe hearing loss (Hickson et al., 2010).

The interactions for subjective outcomes were unexpected. Worse cognition increased the odds of reporting unfamiliar area avoidance, but only for those with good hearing. An explanation for this inconsistency is unclear and attempts at replication with different samples should be assessed in future research. For participants with poor vision, worse S-R hearing was related to *lower* odds of reporting freeway avoidance. This is contrary to findings by Green and colleagues (2013), where hearing loss worsened the effect of poor vision on crash risk. Variable differences could explain this inconsistency: an objective measure of crash involvement over 5 years versus reported avoidance of freeways. Those with both poor vision and hearing may find freeway driving easier than the negotiation of intersections and traffic more common on surface streets. Different measures of vision (e.g., contrast sensitivity) could also produce different results. Although the current study assessed driving avoidance, and most previous research assessed different driving outcomes, the mixed hearing-related findings in the current study are consistent with previous mixed results (see Anstey et al., 2005; MacLeod et al., 2014 for reviews).

Results related to control variables are similar to previous research (see Dickerson et al., 2019, 2007; Eby et al., 2019, for reviews). Age, gender, race, relationship status, socioeconomic status, health, and depressive symptoms were all related to at least some outcomes. Future research might further explore whether such factors (e.g., gender) modify the relationship between hearing loss and driving avoidance, given known demographic differences in these outcomes. There was also general consistency in which control variables were related to objective versus subjective measures, but some factors were more strongly associated with one measure than another (e.g., age with objective measures; income with subjective, not objective nighttime avoidance). This suggests that driving avoidance behaviors are not all the same. These behaviors are predicted by somewhat different factors and are engaged in at different rates. The overall similar but slightly different findings between objective versus subjective outcomes is consistent with previous research (Molnar et al., 2018).

### *Limitations and Strengths*

This study has some limitations. The sample has higher educated and higher earning participants than the general population, but study sites represent people from diverse socioeconomic backgrounds (Li et al., 2017). The study did not allow for causal assessment, only associations. To address our hypotheses, we conducted eight different regressions and assessed several interactions per model; that number of tests may have resulted in some statistically significant findings due only to chance. The underlying reasons for differences observed in the study remain unclear; some people avoid driving situations as a response to declining abilities, whereas others may have always avoided them, or experienced a lifestyle change (Molnar et al., 2013). Finally, different measures of cognition, vision, or hearing could yield different results. For example, the S-R hearing item did not specify whether respondents should consider their hearing with or without correction, which may have introduced unwanted variance. Likewise, the WT was administered by trained researchers, not clinicians.

The strengths of this study include the large cohort of older drivers and the inclusion of both objective and subjective measures of a variety of avoidance behaviors. Three hearing measures were also included. The moderating effect of hearing on visual acuity and cognition was also comprehensively examined.

## Conclusion

Hearing impairment affects driving avoidance among older adults in a complex way. Worse hearing was related to less actual nighttime driving; less actual freeway driving, but more trips farther than 15 mi from home; and lower odds of reporting peak time avoidance. Hearing significantly interacted with visual acuity and cognition. Lower cognition was related to less peak time driving, but only for those with poor hearing. Worse S-R hearing was related to lower odds of freeway avoidance for those with poor visual acuity. Worse cognition was associated with higher odds of avoiding unfamiliar areas, but only for those with good hearing. Finally, the objective hearing measure was a better predictor of driving avoidance than hearing aid use or S-R hearing. These findings are important because hearing loss can sometimes be mitigated. As such, public health interventions designed to initiate hearing assessment and/or hearing aid use could point toward the possibility of continued driving as another potential benefit, particularly given other consequences (e.g., loneliness, social disengagement, and memory declines) of hearing loss (Huang et al., 2020; Moorman et al., 2020).

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This article was funded by the AAA Foundation for Traffic Safety.

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## Supplemental Material

Supplemental material for this article is available online.

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