RESEARCH BRIEF

Effects of Hearing Impairment on Driving Exposure and Patterns Among a Large Cohort of Older Drivers: AAA LongROAD Study

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Older drivers are at an elevated risk for crashes per mile driven (Insurance Institute for Highway Safety, 2017) due in part to declining sensory, cognitive, and psychomotor abilities. Such declining abilities result from age-related medical conditions and/or the medications used to treat them. To improve the safe mobility of older adults, better information is needed about their driving exposure and patterns (i.e., when, where, and under what conditions they drive; Marshall et al. 2007), and how these driving behaviors are affected by declines in abilities. Hearing is one area of functional decline receiving increased research attention. There is growing interest in not only how hearing impairment alone affects driving behavior but also how hearing impairment interacts with other forms of impairment, especially cognitive and visual impairment, to affect driving. For example, Green, McGwin and Owsley (2013) examined the association between visual and hearing impairment and crash involvement of older drivers. They found that older drivers with both hearing and visual impairment (either in visual acuity or contrast sensitivity) had higher crash rates than drivers with neither visual nor hearing impairment, or with visual acuity loss alone or hearing loss alone. This research brief used data from the AAA Longitudinal Research on Aging Drivers (AAA LongROAD) study to examine the effects of hearing impairment, alone and in combination with cognitive and visual impairment, on the driving exposure and patterns of study participants, as measured by GPS datalogger data.

METHODS

Data came from 2,046 participants in the AAA LongROAD study (Li et al., 2017). The AAA LongROAD study is a multisite prospective cohort study of drivers enrolled in five sites in the U.S. (Ann Arbor, MI; Baltimore, MD; Cooperstown, NY; Denver, CO; and San Diego, CA). Participants from the New York site were not included in the analysis because of differences in how this site administered the visual acuity test. Study participants were between 65 and 79 years of age at enrollment. Data for this study were collected from questionnaires assessing various aspects of driving and functioning, in-person clinical assessments conducted by research staff, and objective driving measures derived from GPS/datalogger data following procedures described in previous research (Molnar et al., 2013). Questionnaire and in-person assessment data for the current analysis came from a single point in time at baseline, but the driving data were collected continuously throughout the study.

To account for differences in exposure and seasonality, the analysis only included participants' first 12 months of driving, with the GPS variables averaged across the 12-month period.

Three measures of hearing impairment were examined as independent variables for the study. The first was a subjective measure from the questionnaire asking participants if they used a hearing aid. The second also came from the questionnaire and asked participants to rate their hearing as excellent, very good, good, fair, or poor (using a hearing aid as usual if appropriate). The third was the Whisper Voice Test (Whisper Test), an objective measure administered during the in-person assessment, which results in a pass/fail score for each ear. Other covariates used in this study included age, gender, race, relationship status, household income, education, visual acuity as measured by the Tumbling E chart, cognitive function as measured by the Trail Making Test Part B, and physical function as measured by the PROMIS Physical Function test. The dependent variables examined in the analysis included objective measures of four driving situations: driving at night, in rush-hour traffic, on high-speed roads, and greater than 15 miles from home (see Table 1 for descriptions of outcome and predictor variables).

The Tumbling E chart score for both eyes was converted into the Logarithm of the Minimum Angle of Resolution (LogMAR) score. In the LogMAR scale, a higher value is equivalent to worse vision. The potential interaction between vision and hearing impairment as well as cognition and hearing impairment was also explored using each of the hearing impairment variables.

Rush-hour traffic was explored as a combined outcome that included both morning and afternoon peak traffic periods. Several variables were reverse coded (to change the direction of their meaning) to better match others or for ease of interpretation:

- Percent of trips less than or equal to 15 miles was reversed to represent percent of trips greater than 15 miles.
- Trail Making Test Part B was reversed so that a higher number meant better cognition.
- Self-rated hearing was reversed so that a higher value meant better hearing.
- Whisper Test was reversed such that 0=failing both ears, 1=failing one ear, 2=passing both ears.

RESULTS

The mean age of participants was 70.9 years (ranging from 65.0 to 79.0 years), and women accounted for 51.9% of the participants. In terms of race, 83.5% were White, 8.4% were Black and 8.1% identified as another race. Participants were well educated, with 45.2% reporting a graduate degree, 24.2% a bachelor's degree, 22.4% more

Table 1. List of Objective Driving Outcome Measures and Key Predictors

	Description
Outcome Variables	
Average monthly % of trips at night	Percent of all trips during which at least 80% of trip was during nighttime (civil twilight or solar angle greater than 96 degrees)
Average monthly % trips in rush-hour periods	Percent of trips during 7–9 AM and 4–6 PM on weekdays (rush-hour periods)
Average monthly % trips on high-speed roads (proxy for driving on freeway)	Percent of trips where 20% of distance traveled was at a speed of 60 mph or greater
Average monthly % trips > 15 miles from home (proxy for driving in unfamiliar areas)	Percent of trips traveled 15 miles or further from home
Predictor Variables	
Vision (LogMAR)	Tumbling E scores converted to LogMAR; higher values represent worse vision
Cognition (Trail Making Test Part B)	Time to complete the test; reverse coded such that higher values represent better cognition
Hearing	
Use of hearing aid	Yes/no
Self-rated hearing	Scale from 1 to 5, reverse coded such that a higher score represents better hearing
Whisper Test	Performed in both ears with three possible outcomes: fail in both ears, pass in one ear/fail in one ear, pass in both ears

Note: A trip is defined as a non-zero distance between vehicle engine on and engine-off time.
Linear regression techniques were used, with separate models for each driving outcome using SAS version 9.4.

than a high school education but less than a bachelor's degree and 8.2% a high school degree or less education. Most participants were married or partnered (66.1%), followed by 17.6% who were separated or divorced, 11.4% who were widowed and 4.9% who were never married. Only 3.3% of participants reported an income less than $20,000, with 19.5% reporting between $20,000 and $49,999 per year. About a quarter of participants (24.4%) reported a household income between $50,000 and $79,999 and an additional 15.4% made between $80,000 and $99,999. The largest group (37.4%) reported household incomes of $100,000 or higher.

Vision was assessed on the LogMAR scale, where a value of 0 represents normal vision, and ascending scores are progressively worse. Participants had a mean value of 0.093, which is slightly worse than normal. The Trail Making Test Part B had an average time to completion of about 91 seconds (within age-based population norms and below the time of 273 seconds, which is generally considered deficient). The PROMIS Physical Function test had an average score of 50.99 among participants (considered to be in the average range).

In terms of the hearing variables, 16.8% reported ever wearing a hearing aid, 78.1% passed the Whisper Test in both ears, 10.5% failed in one ear and 11.4% failed in both ears. Self-rated hearing had a mean value of 3.68 (between good and very good hearing). The objective driving measures included percent of trips at night (mean 7.4%), percent on high-speed roads (14.1%), percent of trips more than 15 miles from home (32.3%) and percent during rush hour (16.8%).

Results of regression models for the associations of hearing impairment and other covariates with objectively measured driving exposure and patterns

Tables 2–5 present regression models for each of the specific driving exposure outcomes. For each table, associations between the driving outcome and the hearing impairment variables and other covariates are shown. Model parameter estimates, standard errors, t-values and statistical significance are included.

Participants who passed the Whisper Test in either one or both ears drove a higher percentage of their trips at night than those failing the test in both ears (Table 2). Similarly, scores on the Trail Making Test Part B were significantly associated with percentage of trips driven at night, with higher scores (or better cognition) predicting a greater percentage of trips at night. Participants with better cognition and those who passed the hearing test in both ears (compared with those who failed in both ears) drove a higher percentage of their trips on high-speed roads (Table 3). Participants with better visual acuity drove a higher percentage of their trips more than 15 miles from home than their counterparts; however, participants who passed the hearing test in both ears drove a lower percentage of their trips more than 15 miles from home (Table 4). Cognition and the objective hearing

Table 2. Percent of Trips at Night

	ß	SE	*t*-value
Vision (LogMAR; higher=worse vision)	−0.034	1.062	−0.03
Trail Making Test Part B (higher=better cognition)	0.008	0.003	2.35*
Use of hearing aid (ref=no)	−0.042	0.339	−0.12
Self-rated hearing (higher=better hearing)	−0.208	0.132	−1.57
Whisper Test (ref=fail in both ears)			
Fail/pass in one ear	1.025	0.513	2.00*
Pass in both ears	0.975	0.410	2.38*

Notes: ß = parameter estimate; SE = standard error; LogMAR = logarithm of the minimum angle of resolution; ref = reference category. Age, gender, race, relationship status, income, education and physical function were also controlled for in the model. Asterisks denote statistical significance at the *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ level.

Table 3. Percent of Trips on High-Speed Roads

	ß	SE	*t*-value
Vision (LogMAR; higher=worse vision)	−2.906	2.163	−1.34
Trail Making Test Part B (higher=better cognition)	0.034	0.007	5.24***
Use of hearing aid (ref=no)	−0.366	0.690	0.53
Self-rated hearing (higher=better hearing)	−0.075	0.270	−0.28
Whisper Test (ref=fail in both ears)			
Fail/pass in one ear	−0.246	1.046	−0.24
Pass in both ears	1.675	0.835	2.01*

Notes: ß = parameter estimate; SE = standard error; LogMAR = logarithm of the minimum angle of resolution; ref = reference category. Age, gender, race, relationship status, income, education and physical function were also controlled for in the model. Asterisks denote statistical significance at the *p < 0.05, **p < 0.01 and ***p < 0.001 level.

Table 4. Percent of Trips Greater than 15 Miles from Home

	ß	SE	*t*-value
Vision (LogMAR; higher=worse vision)	−19.525	4.031	−4.84***
Trail Making Test Part B (higher=better cognition)	0.014	0.012	1.15
Use of hearing aid (ref=no)	−1.388	1.285	−1.08
Self-rated hearing (higher=better hearing)	−0.371	0.503	−0.74
Whisper Test (ref=fail in both ears)			
Fail/pass in one ear	−1.894	1.949	−0.97
Pass in both ears	−4.618	1.556	−2.97**

Notes: ß = parameter estimate; SE = standard error; LogMAR = logarithm of the minimum angle of resolution; ref = reference category. Age, gender, race, relationship status, income, education and physical function were also controlled for in the model. Asterisks denote statistical significance at the *p < 0.05, **p < 0.01 and ***p < 0.001 level.

Table 5. Percent of Trips during Rush Hour (total of AM and PM)

	ß	SE	*t*-value
Vision (LogMAR; higher=worse vision)	−19.525	4.031	−4.84***
Trail Making Test Part B (higher=better cognition)	0.014	0.012	1.15
Use of hearing aid (ref=no)	−1.388	1.285	−1.08
Self-rated hearing (higher=better hearing)	−0.371	0.503	−0.74
Whisper Test (ref=fail in both ears)			
Fail/pass in one ear	−1.894	1.949	−0.97
Pass in both ears	−4.618	1.556	−2.97**
Trail Making Test Part B*Whisper Test (one ear)	−0.024	0.012	−2.01*
Trail Making Test Part B*Whisper Test (both ears)	−0.018	0.009	−1.96*

Notes: ß = parameter estimate; SE = standard error; LogMAR = logarithm of the minimum angle of resolution; ref = reference category. Age, gender, race, relationship status, income, education and physical function were also controlled for in the model. Asterisks denote statistical significance at the *p < 0.05, **p < 0.01 and ***p < 0.001 level.

test (Whisper Test) were both significantly related to rush-hour trips. The significant interaction observed in these analyses suggests that the effect of cognition on rush-hour trips depends on one's hearing (and vice versa). For someone who passed the Whisper Test in both ears, every one-second increase in speed of completing the Trail Making Test Part B (better cognition) was related to a small but statistically significant increase (ß=0.004) in rush-hour trips, compared with people who failed the Whisper Test in both ears. The effect of cognition on rush-hour trips differed for those who failed the Whisper Test in one ear. For those individuals, every one-second faster time in the Trail Making Test Part B was related to a small but significant decrease (ß=0.002) in rush-hour trips, compared with those who failed in both ears (Table 5).

DISCUSSION

A major strength of this study was that it examined driving exposure and patterns among a large cohort of older drivers using objectively measured real-world driving, as well as a combination of self-reported and objective measures of hearing impairment and objective measures of vision and cognition. Collectively, results showed that passing an objective hearing test in both ears (therefore, not having a hearing impairment) was significantly associated with driving a higher percentage of trips at night, on high-speed roads, and in rush-hour traffic. However, the pattern was reversed for driving more than 15 miles from home, with passing the hearing test in both ears being significantly associated with driving a lower percentage of trips further from home. It is unclear why this was the case. It could be that the association between hearing and driving more than 15 miles from home is mediated by other driver characteristics (e.g., employment status). There is clearly an opportunity for further research in this area to take into account potential mediating factors.

Better vision was significantly associated with driving more than 15 miles from home. Better cognition was significantly associated with the other three scenarios – driving at night, on high-speed roads, and during rush hour. The only significant interaction was between the objective hearing test and the Trail Making Test Part B. Interestingly, the effect of cognition on percentage of rush-hour trips depended on one's level of hearing. As expected, those with good hearing in both ears (compared with those with poor hearing in both ears) drove more trips during rush hour as cognition increased. In contrast, those with good hearing in only one ear drove fewer rush-hour trips as cognition increased, compared with those who had bad hearing in both ears. The reason for this result is unclear, but it may be that hearing loss in only one ear could increase awareness of the deficit for those with better cognition, thus resulting in fewer rush-hour trips.

The finding that participants without a hearing impairment drove a higher percentage of their trips in three of the four driving scenarios is consistent with previous literature that suggests a link between impairment and difficulties with driving including driving reduction and cessation (Hickson, Wood, Chaparro, Lacherez, & Marsalek, 2010). The negative interaction between hearing and cognition for driving in rush-hour traffic is counterintuitive given previous research highlighting the link between cognitive workload and hearing loss. For example, results from Thorslund, Peters, Lidestam, and Lyxell (2013) suggest that the effect of increasing complexity in the driving situation is larger among drivers with hearing loss than among their counterparts. Thus, one would expect that impaired cognition could increase cognitive workload, thereby amplifying the burden imposed by hearing impairment. Further research in this area is warranted.

Results presented in this research brief provide practical insights on the role of hearing impairment in driving exposure and patterns. Findings suggest that hearing should be taken into account in assessing the driving of older adults and developing strategies to keep them safe. Specifically, testing for hearing impairment should be a standard part of driver assessment. In addition, educating older adults about the potential effects of hearing impairment, both alone and in combination with visional and/or cognitive impairment, should be part of education and training programs to help them maintain safe driving and mobility.

A limitation of the study is that the sample may not be representative of all older drivers across the United States.

However, the study sites do represent a wide range of communities with diverse geography, population density, and racial, ethnic and socioeconomic distribution (Li et al., 2017). The longitudinal cohort design will allow us to follow these participants over time to assess changes in driving as their visual, cognitive, and hearing abilities change with age.

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