Fall-related Injuries Mediate the Relationship between Self-Reported Hearing Loss and Mortality in Middle-Aged and Older Adults

Dongjuan Xu, PhD[a,c] Melissa D. Newell, Au. D.[b] Alexander L. Francis, PhD[b,c]

[a]School of Nursing

[b]Department of Speech, Language and Hearing Sciences

[c]Center on Aging and the Life Course

Purdue University

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Address correspondence to Alexander L. Francis, Speech, Language & Hearing Sciences, Lyles-Porter Hall, 715 Clinic Dr., West Lafayette, IN 47907-2122, USA. Phone number: 765-494-3815; Email: francisa@purdue.edu. @PurdueSPACELab

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Abstract

Background: Hearing loss is associated with a greater risk of death in older adults. This relationship has been attributed to an increased risk of injury, particularly due to falling, in individuals with hearing loss. However, the link between hearing loss and mortality across the lifespan is less clear.

Methods: We used structural equation modeling and mediation analysis to investigate the relationship between hearing loss, falling, injury, and mortality across the adult lifespan in public-use data from the National Health Interview Survey and the National Death Index. We examined 1) the association between self-reported hearing problems and later mortality, 2) the associations between self-reported hearing problems and the risk of injury and degree and type of injury, 3) the mediating role of falling and injury in the association between self-reported hearing problems and mortality, and 4) whether these relationships differ in young (18-39), middle-aged (40-59) and older (60+) age groups.

Results: In all three age ranges, those reporting hearing problems were more likely to fall, were more likely to sustain an injury, and were more likely to sustain a *serious* injury, than those not reporting hearing problems. While there was no significant association between hearing loss and mortality in the youngest category, there was for middle-aged and older participants and for both fall-related injury was a significant mediator in this relationship.

Conclusions: Fall-related injury mediates the relationship between hearing loss and mortality for middle-aged as well as older adults, suggesting a need for further research into mechanisms and remediation.

Keywords: Hearing loss, falling, injury, mortality, SEM, mediation analysis

Introduction

Hearing loss has a significant effect on health and quality of life (Bainbridge & Wallhagen, 2014), and is associated with a roughly 20% greater risk of death in older adults (age 70-79) even when adjusted for cardiovascular and other risk factors (Genther et al., 2015a). However, the link between hearing loss and mortality in the broader population is less clear. Some population-based cohort studies that included younger adults have found a significant association between hearing impairment (objectively or subjectively measured) and mortality even after adjusting for demographic and various health factors while others have not. For example, a study by H.W. Lin and colleagues (2019) using the 2005-2009 National Health Interview Survey (NHIS) included adults ≥18 years of age. They examined three levels of self-reported hearing loss and found that reporting having "a lot of trouble hearing/deaf" was significantly associated with increased mortality compared to reporting having "excellent/good hearing" even after adjusting for demographics and comorbidities. However, there was no significant difference in mortality between those reporting "a little/moderate hearing loss" and those reporting "excellent/good hearing". On the other hand, a study using data from the population-based 2003-2004 National Health and Nutrition Examination Survey (NHANES) with follow-up through 2011 among adults aged 40-85 years old (Loprinzi & Crush, 2016) found that self-reported hearing impairment was *not* significantly associated with mortality after adjusting for demographics and health-related risk factors. To our knowledge, no existing cohort studies have examined the relationship between hearing loss and mortality in an age-stratified manner.

One possible explanation of the link between hearing loss and mortality is through an increased risk of injury, particularly due to falling. Hearing loss has been linked to an overall higher incidence of hospitalization, accidental injury, and falling (Genther et al., 2015b; Heitz,

Gianattasio, Prather, Talegawkar, & Power, 2019; Jiam, Li, & Agrawal, 2016; F. R. Lin & Ferrucci, 2012; H. W. Lin, Mahboubi, & Bhattacharyya, 2018; Mick, Foley, Lin., & Pichora-Fuller, 2018). Falls are the leading cause of fatal and non-fatal injury among older (65+) adults (Bergen, et al. 2016; Drew & Xu, 2020; Xu & Drew, 2016), and fall-related mortality is increasing, especially among those aged 75 years and older (Hartholt, Lee, Burns, & Van Beeck, 2019) for whom hearing loss is extremely prevalent (Goman & Lin, 2016). However, while it is well-established that problems with hearing often begin in middle age (e.g. early 40s) (Helfer & Jesse, 2020), it is not clear whether the relationships between hearing problems and falling, injury, or mortality also appear this early.

Finally, while there is ample evidence that hearing loss is related to increased risk of falling (F. R. Lin & Ferrucci, 2012), it is not clear whether the link between hearing loss and increased mortality risk can necessarily be attributed directly to increased risk of falling or fall-related injury. For example, in a study of older adults aged 76-81 years from the Health in Men Study and the Australian Longitudinal Study on Women's Health, Lopez and colleagues (2011) found that self-reported hearing impairment was significantly associated with increased risks of having a fall, but not with being injured from a fall. Thus, there is a question whether falling and/or injury serve to mediate the relationship between hearing loss and mortality.

Here, we employ structural equation modeling and mediation analysis to investigate the complex relationship between hearing problems, falling, injury, and mortality across the adult lifespan. Using a recent and nationally representative sample of U.S. adults aged 18 years and older, this study examines 1) the association between self-reported hearing problems and later mortality, 2) the associations between self-reported hearing problems and the risk of injury, and whether the associations differ by characteristics of injury (i.e. due to a fall or another cause, and whether the

injury was minor or serious), 3) the mediating role of injury in the association between self-reported hearing problems and mortality, and 4) whether the above relationships vary by young, middle and old age groups.

Methods

Data and samples

This study uses public-use data files from the National Health Interview Survey (NHIS) and the National Death Index (NDI). The NHIS is an annual survey, collecting health and health care utilization information from a nationally representative sample of the U.S. non-institutionalized civilian population. The NDI contains information on death certificate records including calendar quarter and year of death. The sample for this study was limited to adults aged 18 years and older at the time of the NHIS survey who provided full information on all analysis variables. The percentages of missing data were less than 7% (mortality: 6.3%, injury: 1.2%, education: 0.1%, and marital status: 0.1%). List-wise deletion was used for handling missing data.

To estimate the association between self-reported hearing problems and later mortality, we used the linked 1997–2014 NHIS-NDI data files (N= 521,146). To estimate associations between self-reported hearing problems and injury incidence, we used data from 2004 to 2017 NHIS surveys (N= 412,661). To investigate the role of injury in the associations between self-reported hearing problems and mortality, we used the linked 2004–2014 NHIS-NDI data files (N= 310,787).

Measures

Based on their responses to trouble hearing without hearing aids or other listening devices, participants were categorized into three groups: (a) excellent/good, (b) a little /moderate trouble, and (c) a lot of trouble/deaf. Injury refers to a traumatic event in which a person was harmed

seriously enough by an external cause (e.g., fall, motor vehicle accident, poisoning, cut/pierce, or struck by object/person) to seek medical advice or treatment in the past three months. We used the type of care sought after injury to construct a three-category variable: serious injury (injury treated in an ER or hospital), minor injury (injury treated in a doctor's office, or in a consultation over the telephone), and no injury. We used the cause of injury to distinguish falls from other types of injuries (hereafter: non-fall injuries). Regarding mortality, the outcome of interest is the quarter of death; the NHIS-NDI file only provides the quarter and year of death for decedents. Control variables included sociodemographic characteristics (age, sex, race/ethnicity, education, and marital status), and health conditions (vision problem, diabetes, cancer, stroke, angina pectoris, hypertension, coronary heart disease, heart attack, and other heart condition/disease). Because the NHIS dataset does not include yearly assessments of balance-related measures, we were unable to include this as control variable, though these are obviously relevant (see Discussion, below). We also constructed three age groups: 18-39, 40-59, and 60+ years old.

Statistical analysis

All statistical analyses were first conducted for all 18+ adults and then stratified by three age groups (18-39, 40-59, and 60+ years old). Kaplan–Meier methods were conducted to estimate survival rates. We used a Cox proportional hazards model to assess the associations between self-reported hearing problems and later mortality. A test of the proportional hazards assumption was performed and the assumption was held for the three-category hearing problems variable. A binary logistic regression model was used to assess the associations between self-reported hearing problems and injury incidence. An ordered logistic regression model was used to assess the associations between self-reported hearing problems and severity of injury (serious, minor, and no injury). A test of the proportional odds assumption was performed and the assumption

was held except for adults aged 18-39 years old. Sensitivity analysis using a generalized ordered logistic model yielded identical results, indicating that the estimated associations between hearing problems and severity of injury were not influenced by violations of the proportional odds assumption in this young age group. A multinomial logistic regression model was used to assess the associations between self-reported hearing problems and cause of injury (fall, non-fall, and no injury).

A generalized structural equation model was used to assess the mediating effect of injury including injury incidence (yes or no), severity of injury (serious or minor) and cause of injury (fall and non-fall), on the relationship between self-reported hearing problems and mortality. In order to estimate the magnitude of any mediating effect, we calculated the indirect effect of self-reported hearing problems on mortality (i.e., the effect mediated through injury) by multiplying the effects of injury on mortality and the effects of hearing problems on injury where the latter effects were first converted to the probability scale (see Figure 2). The total effect was then computed as the sum of the direct effect and the indirect effect of hearing problems on mortality. All estimates were population weighted and standard errors were adjusted for complex survey design using the Stata *svy* commands; the mortality models used the person mortality weight. These adjustments follow the recommendations of the user guide for the NHIS dataset (IPUMS Health Surveys, 2021; National Center for Health Statistics, 2013). All statistical analyses were performed using Stata 16.1 (StataCorp). Statistical significance was accepted at the $p < 0.05$ (two-sided) level.

Results

Population-weighted characteristics of community-dwelling adults from the 2004-2014 NHIS and NDI samples are presented in Table 1. Approximately 84% reported having excellent or

good hearing (18-39 years old: 94.17%, 40-59 years old: 84.77%, 60+ years old: 66.15%), 14% reported a little or moderate trouble hearing (18-39 years old: 5.35%, 40-59 years old: 13.61%, 60+ years old: 26.95%), and 2% reported having a lot of trouble hearing or being deaf (18-39 years old: 0.49%, 40-59 years old: 1.62%, 60+ years old: 6.90%). The mean age was 46 years (18-39: 40%; 40-59: 37%; and 60+: 24%), and those who reported hearing problems were older than those not reporting hearing problems. More than 48% of participants were male, and the male proportion increased with reported severity of hearing problems. The proportion of hypertension, stroke, angina pectoris, heart attack, coronary heart disease, other heart condition/disease, cancer, diabetes, or vision problems increased as the reported severity of hearing problems increased.

<Insert Table 1 about here>

Hearing problems and mortality

There was a clear difference in mortality risk by the severity of hearing problems. More than 27% who reported having a lot of trouble hearing or who were deaf died within the study period (Table 1), 12% who reported a little/moderate trouble hearing died, and 5% who reported having excellent/good hearing died. In Kaplan–Meier estimates of the unadjusted cumulative probability of survival (Figure 1, top left), we found that survival time for all 18+ participants who reported a lot of trouble hearing/deaf was significantly shorter when compared with survival times for those reporting a little/moderate trouble hearing or excellent/good hearing. The survival time for the little/moderate trouble hearing group was also significantly shorter than for the excellent/good hearing group. At 72 quarters, or 18 years, the probability of survival dropped to 43.7% for participants who reported having a lot of trouble hearing or were deaf, 63.2% for

participants who reported a little/moderate trouble hearing, and 83.6% for participants who reported having excellent/good hearing.

<Insert Figure 1 about here>

When further stratified by age group, the difference in mortality risk by the severity of hearing problems was significant among participants aged 40-59 and 60+ years old, respectively (Figure 1). In the fully adjusted model, participants who reported a lot of trouble hearing/deaf had a higher risk of death than those who reported excellent/good hearing (Table 2; hazard ratio of 1.17). This held for both the 40-59 age group (hazard ratio = 1.17) and 60+ age group (hazard ratio = 1.12). There was no significant difference in risks of death between a little/moderate trouble hearing and excellent/good hearing overall, nor for any age group. Among participants aged 18-39 years old, hearing problems were not significantly related to mortality.

Hearing problems and injury

For those who reported having a lot of trouble hearing or who were deaf, 4.3% were injured, 2.2% had a fall, 2.1% sustained a non-fall injury, 2.6% had a serious injury and 1.7% had a minor injury (Table 1). For all age groups, participants who reported having hearing problems (whether a little/moderate trouble or a lot of trouble/deaf) had significantly higher risks of injury compared with the excellent/good hearing group (Table 2). Moreover, participants who reported having hearing problems were more likely to have a serious injury than were those with excellent/good hearing, both overall and across all age groups (Table 2). Regarding cause of injury, participants with hearing problems (whether a little/moderate trouble or a lot of trouble/deaf) had significantly higher risks of fall-related injury overall, and across all age groups. Finally, participants with hearing problems were more likely to sustain a non-fall injury;

however, the relationships between a lot of trouble/deaf and non-fall injury were not statistically significant among 18-39 and 60+ age groups (Table 2).

<Insert Table 2 about here>

The mediating role of injury in the association between hearing problems and mortality

Overall, injury mediated the association between a lot of trouble hearing/deaf and mortality, but not between a little/moderate trouble hearing and mortality (Figure 2A). Approximately 43% of the total effect of a lot of trouble hearing/deaf on mortality was mediated by injury (Table 3). With respect to cause of injury (Figure 2B), fall-related injury mediated the relationship between serious hearing problems and mortality, accounting for 57% of the total effect, but non-fall injury did not mediate the association at all.With respect to severity of injury, both serious and minor injury mediated the relationship between serious hearing problems and mortality (Figure 2C), with about 49% of the total effect being mediated by serious injury, and 30% by minor injury (Table 3).

<Insert Figure 2 about here>

Examining effects by age group, for the 18-39 age group, there was no mediation effect of injury on the relationship between hearing problems and mortality. For the 40-59 age group, only fall-related injury and serious injury mediated the association between a lot of trouble hearing/deaf and mortality and the mediation effect was 62% and 39%, respectively (Table 3). For the 60+ age group, injury, minor injury, serious injury, and fall-related injury all mediated the association between a lot of trouble hearing/deaf and mortality (Table 3). About 51% of the total effect of a lot of trouble hearing/deaf on mortality was mediated by injury, and the largest mediation effect

was fall-related injury (59%), followed by serious injury (56%) and minor injury (38%) (Table 3).

<Insert Table 3 about here>

Discussion

Using the nationally representative NHIS linked to the longitudinal NDI, we examined the associations between self-reported hearing problems, injury, and mortality. The current study adds to the body of work that links hearing problems to mortality by distinguishing between minor and serious injury and between fall and non-fall injuries, and by examining effects within different age ranges. We also used a longer period of mortality follow-up than had previously been studied, investigating the risk of death up to 18.75 years after the initial interview.

We found that participants reporting any hearing problems were more likely to fall, were more likely to sustain an injury, and were more likely to sustain a *serious* injury, than were those not reporting any hearing problems. This pattern held both overall and for each of the three age groups. In contrast, there was no significant association between self-reported hearing problems and mortality in the 18-39 age group, and among adults aged 40+ increased mortality risk was associated only with reporting serious hearing problems. However, the significant association between serious hearing problems and mortality was greatly mediated by injury (about 43% of the total effect). In particular, the largest mediation effect was fall-related injury, followed by serious and minor injury. Our findings highlight the importance of addressing hearing problems in terms of injury, falling and mortality across the lifespan. An association between hearing loss, injury and falling holds for all age groups we examined, and thus addressing hearing problems may have the potential to reduce injury, falling, and severity of injury for all adults. However,

the observation of an association between severe hearing loss, fall-related injury, and mortality risk in the 40-59 and 60+ age groups, suggests that addressing hearing problems in middle aged and older adults may also have the potential to reduce mortality risk via reducing risk of falling and injury.

The finding that the link between hearing problems and mortality obtains only for the most severely impaired category of participants (a lot of trouble hearing/deaf) in the present sample is consistent with previous research that suggests that the relationship between hearing loss and mortality is generally stronger for those with a greater degree of loss (Genther, et al. 2015a; H. W. Lin et al. 2019; Lee, et al. 2020). However, the finding that this association is already present in the middle-aged group, but not in the younger group, suggests the need for further research into the interaction between age, hearing loss and mortality in middle-aged and older adults. While this finding suggests that the relationship between hearing problems and mortality strengthens with age, this may also reflect the dominance of different etiologies of hearing loss in the various cohorts. For example, in the present data set we cannot distinguish between individuals with hearing loss acquired in (middle to late) adulthood, perhaps as a result of exposure to noise or ototoxic drugs, and those with congenital or childhood onset hearing loss. It seems likely that the second type may be more prevalent in the younger group, while the first might dominate in the older two groups and are also closely associated with vestibular involvement (Campo, et al. 2013; Sedó-Cabezón et al. 2014; Yilmaz, et al. 2018). Ultimately, this uncertainty highlights the need for further research into the mechanisms that link hearing loss to mortality.

When considering only the significant relationship between the highest level of self-reported hearing problems and mortality, we found that injury, including both serious and minor,

mediated the relationship between hearing loss and mortality, as did fall-related but not non-fall related injury. When considering patterns for each age group, we found that age again played an important role in modifying the relationship between hearing problems and mortality. In particular, we found no mediation effects for the youngest group (18-39), and for the middle-aged group (40-59) we found only mediation effects of serious injury and fall-related injury. For the oldest age group (60+) both minor and serious injury and fall-related injury were all significant mediators of the relationship between hearing problems and mortality. This pattern suggests again that age affects the relationship between hearing problems, injury, and mortality, at least to the extent that older adults seem to be more susceptible to the consequences of injuries, possibly because of increased frailty in older age (Kamil, Betz., Powers, Pratt, Krichevsky, Ayonayon, et al. 2016). Moreover, the finding that fall-related injury but not non-fall related injury is a significant mediator between hearing problems and mortality even for middle-aged adults with serious hearing problems again highlights the need for further research into the mechanisms that link hearing impairment, fall-related injury and mortality across the adult age span.

Previous researchers have proposed that the relationship between hearing loss and increased risk of injury and fall may arise through three potentially overlapping mechanisms (Campos, Ramkhalawansingh, & Pichora-Fuller, 2018; Jiam et al., 2016; F. R. Lin & Ferrucci, 2012). First, hearing problems are often comorbid with vestibular dysfunction and balance difficulties in older adults (Da, Lee, & Lee, 2015; Viljanen, Kaprio, Pyykkö, Sorri, Pajala, et al., 2009) , likely due to developmental, anatomical, and physiological similarities between the vestibular and auditory organs as well as overlap between their associated neural pathways (Zuniga et al., 2012) , and their common susceptibility to environmental risk factors such as solvents and noise (Guest,

Boggess, D'Este, Attia, & Brown, 2011). Both systems are also susceptible to age-related changes in calcium metabolism that may also be related to increase frailty and susceptibility to injury in older age (Singh, Jha, Gargeshwari, & Kumar, 2018). Therefore, especially in cases such as the present study in which only hearing problems are reported, the factor of hearing loss may also represent vestibular and balance disorders that make falling more likely and more harmful. Further research in this field must explicitly assess vestibular function as well as hearing and balance.

The second hypothesis is that individuals with sensory dysfunction, including hearing loss, may experience reduced auditory and spatial awareness of their immediate surroundings, making them more likely to experience accidents and accidental injury (Campos et al., 2018). Finally, hearing loss may increase cognitive load (Pichora-Fuller et al., 2016), reducing the cognitive capacity remaining for balance, perhaps especially during walking (Viljanen, Kaprio, Pyykkö, Sorri, Koskenvuo, et al., 2009). In support of this proposed mechanism, previous research suggests that even young adults tend to fall most frequently while walking, especially while walking and talking simultaneously (Heijnen & Rietdyk, 2016), a highly cognitively demanding dual-task situation (Raffegeau, Haddad, Huber, & Rietdyk, 2018). Recent work by Li and colleagues (e.g. Bruce, et al. 2019; Carr, et al. 2020; Lau, et al. 2016) lends strong support to this hypothesis, showing that increased listening demands may impair balance (Carr, et al. 2020), and that listeners may prioritize safe walking over listening (Lau, et al. 2016), perhaps especially listeners with hearing loss (Bruce, et al. 2019).

The present results are not able to definitively distinguish between these three possibilities. In order to distinguish between the first (non-causal) hypothesis and the other two, it would be advisable to include measurements of vestibular function, vertigo, and/or balance in future

epidemiological datasets along with hearing-related measures (Heitz et al., 2019; Loprinzi & Crush, 2016) . Additional experimental research could also be conducted to address the second and third hypothesized mechanisms, for example to determine whether hearing loss imposes the kind and degree of limitations on spatial awareness or cognitive processing that would be required to increase fall and/or injury risk under specific circumstances (e.g. when walking while talking) (see Bruce, et al. 2019; Carr, et al. 2020; Lau, et al. 2016; Helfer, et al. 2020 for examples of work going in this direction).

Determining the role of different mechanisms by which hearing loss contributes to injury and fall risk is important for developing hearing-based interventions to reduce mortality due to falls and injury. For example, if it is shown that use of hearing aids by individuals with hearing loss reduces fall or injury risk by improving spatial awareness and/or reducing cognitive load, this information may be used to promote hearing aid adoption and retention among older adults concerned about falling and injury. Furthermore, better identification of the mechanisms by which hearing loss affects fall and injury risk may inform the adoption of specific remediation strategies, especially if fall risk is attributable to different mechanisms in different individuals or contexts. For example, use of binaural hearing aids and/or complex microphone arrays may improve spatial awareness (Lundbeck et al., 2018), while noise reduction algorithms may reduce cognitive load during communication (Sarampalis, Kalluri, Edwards, & Hafter, 2009). However, different noise reduction methods have differential effects on spatial localization (Van den Bogaert, Doclo, Wouters, & Moonen, 2008), meaning that cognitive load-related risks of falling and injury may be better mitigated by a different type of acoustic processing algorithm than would be optimal for reducing risks related to hearing-related loss of spatial awareness.

Limitations

This study has several limitations. First, we used self-reported degree of hearing problems, not objectively measured hearing impairment (i.e., via audiogram) and the relationship between these two measures may vary (Kamil, Genther, & Lin, 2015). Second, we were unable to include physiological or behavioral assessments of vestibular function or balance because vestibular measures were not collected in the NHIS dataset and balance measures were collected only in two years. Thus, unobserved characteristics, such as vestibular disorders, may bias our results by attributing the negative consequences of vestibular dysfunction to hearing problems. Third, less serious and fatal injuries were not included in this study, because the NHIS only collects information of participants who sustained an injury serious enough to seek medical treatment (i.e. hospitalization, ER, a doctor's office, or a call to a medical professional). Fourth, injury information was retrospective (injuries sustained in the past three months) and subject to recall bias. Also, injury was reported by a single respondent for each family who may be unaware of other family members' injuries. This may introduce the possibility of underreporting. Fifth, the NHIS sampling frame excludes institutionalized persons, however, persons institutionalized after the NHIS interview were included in the linked NHIS-NDI data. The causal associations between hearing problems, injury, and mortality should be interpreted with caution and more prospective cohort studies should be taken to explore the extent of concomitant cochlear and vestibular pathology.

Conclusions

In summary, participants who reported a lot of trouble hearing/deaf had a higher risk of death, and survival time was significantly shorter, and this relationship held true for both middle-aged and older adults. Both serious and minor injury mediated the relationship between the highest level of hearing problems and mortality, as did fall-related but not non-fall related injury.

However, looking across age groups, none of the mediating effects were significant for the younger group (18-39), and minor injury was only a significant mediating factor for the oldest participants (60+). Future research should be directed toward understanding the mechanisms by which hearing impairment increases the risk of fall-related injury in particular, and how these mechanisms are influenced by age and experience with hearing impairment.

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Table 1. Characteristic of the population of community-dwelling adults, 2004-2014.

		Self-Reported Hearing Problems		
	All	**Excellent/good**	**A little /moderate trouble**	**A lot of trouble/deaf**
	Percent (95% CI) (sample N=310,787) (population N= 224,166,351)	Percent (95% CI) (sample N= 259,139) (population N=188,387,977)	Percent (95% CI) (sample N= 43,534) (population N= 30,320,407)	Percent (95% CI) (sample N= 8,114) (population N= 5,457,967)
Self-reported hearing problems				
excellent/good	84.0 (83.8−84.3)			
a little /moderate trouble	13.5 (13.3 −13.7)			
a lot of trouble/deaf	2.4 (2.4−2.5)			
Death	6.3 (6.2−6.5)	4.8 (4.6−4.9)	12.4 (12.0−12.8)	27.2 (25.9−28.4)
Injury	2.8 (2.7−2.9)	2.6 (2.5−2.6)	3.9 (3.6−4.1)	4.3 (3.8−4.9)

fall	1.0 (0.9−1.0)	0.8 (0.8−0.9)	1.6 (1.5−1.8)	2.2 (1.9−2.7)
non-fall injury	1.8 (1.8−1.9)	1.7 (1.7−1.8)	2.3 (2.1−2.5)	2.1 (1.7−2.5)
Severity of injury				
minor injury	1.3 (1.2−1.3)	1.2 (1.1−1.2)	1.7 (1.6−1.9)	1.7 (1.4−2.1)
serious injury	1.5 (1.5−1.6)	1.4 (1.4−1.5)	2.1 (2.0−2.3)	2.6 (2.2−3.1)
Age (mean, year)	46.0 (45.9−46.2)	43.6 (43.5−43.8)	57.5 (57.3−57.8)	66.0 (65.5−66.5)
18-39	39.6 (39.1−40.0)	44.3 (43.9−44.8)	15.6 (15.1−16.2)	8.0 (7.2−8.8)
40-59	36.6 (36.3−36.9)	36.9 (36.5−37.2)	36.8 (36.1−37.4)	24.4 (23.1−25.7)
60+	23.9 (23.5−24.2)	18.8 (18.5−19.1)	47.6 (46.8−48.4)	67.7 (66.3−69.1)
Sex				
male	48.2 (48.0−48.5)	46.6 (46.3−46.8)	56.6 (56.0−57.2)	58.8 (57.4−60.1)
female	51.8 (51.5−52.0)	53.4 (53.2−53.7)	43.4 (42.8−44.0)	41.2 (39.9−42.6)
Race/ethnicity				
non-Hispanic white	69.0 (68.4−69.5)	66.3 (65.8−66.9)	82.4 (81.8−82.9)	85.9 (84.9−86.8)
non-Hispanic black	11.7 (11.3−12.0)	12.6 (12.2−13.0)	6.9 (6.5−7.3)	4.8 (4.2−5.3)
other	19.4 (19.0−19.8)	21.1 (20.6−21.5)	10.8 (10.3−11.2)	9.4 (8.6−10.2)

Marital status				
separated/divorced/windowed/never married	38.3 (37.9−38.7)	38.7 (38.3−39.2)	35.6 (35.0−36.3)	38.6 (37.3−40.0)
married/partnered	61.7 (61.3−62.1)	61.3 (60.8−61.7)	64.4 (63.8−65.0)	61.4 (60.0−62.7)
Education				
less than high school	12.8 (12.5−13.1)	12.2 (11.9−12.5)	14.7 (14.2−15.1)	23.3 (22.2−24.5)
high school graduate	29.9 (29.6−30.2)	29.3 (28.9−29.6)	32.9 (32.3−33.6)	35.1 (33.8−36.5)
some college	30.1 (29.8−30.4)	30.3 (29.9−30.6)	29.9 (29.3−30.5)	25.7 (24.4−27.0)
college graduate	27.2 (26.8−27.7)	28.3 (27.8−28.8)	22.5 (21.9−23.2)	15.9 (14.9−16.9)
Health conditions				
hypertension	28.6 (28.3−28.9)	24.9 (24.6−25.2)	46.7 (46.1−47.3)	55.1 (53.7−56.5)
stroke	2.6 (2.5−2.7)	1.8 (1.8−1.9)	5.8 (5.5−6.0)	11.2 (10.4−12.1)
angina pectoris	2.2 (2.1−2.2)	1.4 (1.4 − 1.5)	5.4 (5.2−5.7)	9.6 (8.8−10.5)
heart attack	3.3 (3.2−3.3)	2.2 (2.2−2.3)	7.7 (7.4−7.9)	13.7 (12.8−14.6)
coronary heart disease	4.4 (4.3−4.5)	3.1 (3.0−3.2)	10.4 (10.1−10.8)	18.2 (17.2−19.3)
heart condition/disease	7.4 (7.2−7.5)	5.9 (5.8−6.1)	14.1 (13.7−14.5)	20.6 (19.5−21.7)

cancer	7.9 (7.8−8.1)	6.3 (6.2−6.4)	15.5 (15.0−16.0)	21.8 (20.7−22.8)
diabetes	8.5 (8.3−8.6)	7.0 (6.9−7.2)	15.2 (14.8−15.6)	20.3 (19.2−21.5)
vision problems	9.4 (9.2−9.6)	7.5 (7.3−7.6)	18.6 (18.1−19.2)	24.1 (22.9−25.4)

Note: Statistics are population weighted. CI: confidence interval.

Table 2. Associations between hearing problems and risk of mortality, injury, fall, non-fall injury, and severity of injury, respectively.

	All (18+ years old)	18-39 years old	40-59 years old	60+ years old
Mortality				
a little/moderate trouble	1.00 (0.98-1.03)	0.98 (0.85-1.13)	0.98 (0.93-1.04)	0.98 (0.96-1.01)
a lot of trouble/deaf	**1.17***** (1.13-1.21)	1.17 (0.86-1.58)	**1.17**** (1.05-1.31)	**1.12***** (1.08-1.17)
Injury				
a little/moderate trouble	**1.32***** (1.25-1.39)	**1.58***** (1.39-1.80)	**1.42***** (1.30-1.56)	**1.16***** (1.07-1.27)
a lot of trouble/deaf	**1.38***** (1.24-1.53)	**1.63**** (1.14-2.34)	**1.72***** (1.39-2.12)	**1.23**** (1.08-1.41)
Severity of Injury				
a little/moderate trouble	**1.32***** (1.25-1.40)	**1.59***** (1.40-1.81)	**1.42***** (1.30-1.56)	**1.16***** (1.07-1.27)
a lot of trouble/deaf	**1.38***** (1.24-1.54)	**1.64**** (1.15-2.35)	**1.71***** (1.39-2.11)	**1.23**** (1.08-1.41)
Fall				
a little/moderate trouble	**1.31***** (1.21-1.43)	**1.71***** (1.36-2.16)	**1.51***** (1.29-1.76)	**1.21**** (1.07-1.37)
a lot of trouble/deaf	**1.38***** (1.19-1.60)	**2.22*** (1.21-4.07)	**1.94***** (1.41-2.66)	**1.33*** (1.07-1.65)
Non-Fall Injury				

a little/moderate trouble	**1.33***** (1.23-1.43)	**1.54***** (1.33-1.79)	**1.38***** (1.23-1.55)	**1.13*** (1.01-1.27)
a lot of trouble/deaf	**1.32***** (1.13-1.55)	1.44 (0.93-2.22)	**1.60***** (1.23-2.08)	1.16 (0.97-1.37)

Notes: *p<0.05 **p<0.01 ***p<0.001. Bold values indicate statistical significance. The numbers in brackets are 95% confidence interval. All models control for sociodemographic characteristics (age, sex, race/ethnicity, education, and marital status), and health conditions (vision problem, diabetes, cancer, stroke, angina pectoris, hypertension, coronary heart disease, heart attack, and other heart condition/disease). When the outcome was mortality, we used the linked 1997-2014 NHIS-NDI data files; when the outcomes were injury-related variables, we used 2004-2017 pooled NHIS data files.

Table 3. Direct effects and indirect effects of self-reported hearing problems (a lot of trouble/deaf) on mortality mediated by injury, fall, minor, or serious injury.

Mediator	All (18+ years old)			40-59 years old			60+ years old		
	Indirect Effect	Total Effect	Indirect Effect/ Total Effect	Indirect Effect	Total Effect	Indirect Effect/ Total Effect	Indirect Effect	Total Effect	Indirect Effect/ Total Effect
Injury	0.15	0.35	43% (32%-55%)	0.13	0.33	38% (4%-71%)	0.14	0.28	51% (35%-66%)
Minor injury	0.09	0.29	30% (9%-51%)	-	-	-	0.08	0.22	38% (11%-64%)
Serious injury	0.19	0.39	49% (38%-61%)	0.13	0.34	39% (2%-76%)	0.17	0.31	56% (41%-72%)
Fall-related injury	0.27	0.47	57% (47%-68%)	0.34	0.55	62% (36%-88%)	0.19	0.33	59% (44%-73%)

Note: The numbers in brackets are 95% confidence interval. No mediation effects among adults aged 18-39 years old. Minor injury did not mediate the association between a lot of trouble hearing/deaf and mortality among adults aged 40-59 years old.

Figure Captions

Figure 1. Comparative Kaplan–Meier survival curves for participants aged 18 and older, and stratified by age groups, 1997-2014.

Figure 2. Structural equation and mediation models using data from all participants, (18+ years old) for (A) The mediating role of injury in the association between hearing problems and mortality; (B) The mediating role of fall and non-fall injury in the association between hearing problems and mortality; and (C) The mediating role of minor and serious injury in the association between hearing problems and mortality. Numbers are coefficients. * $p < 0.05$ *** $p < 0.001$.

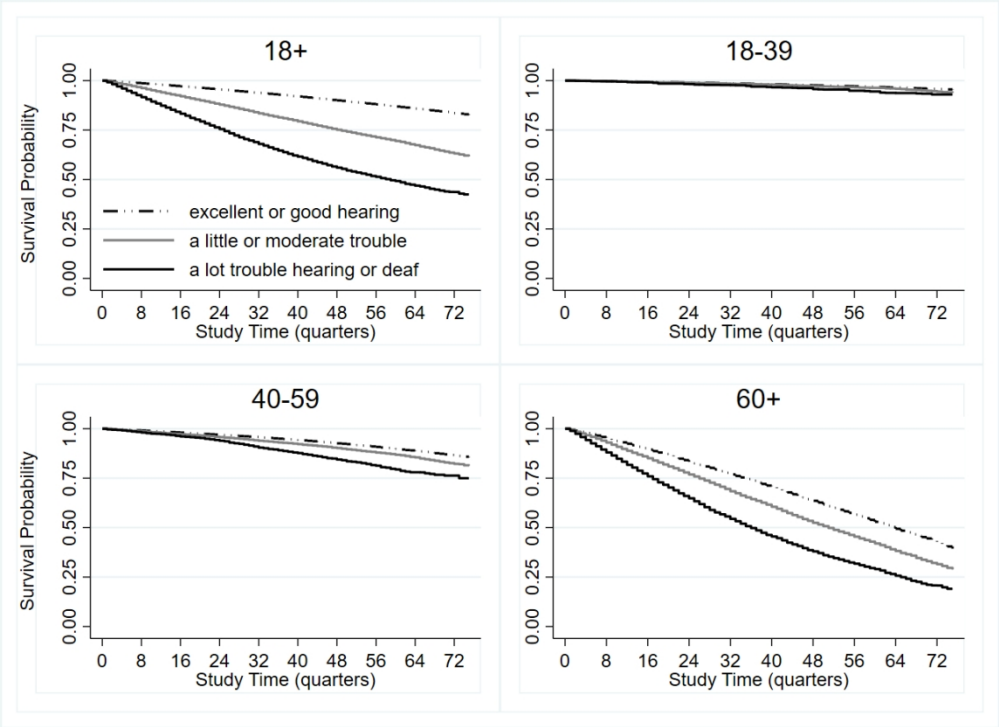

Figure 1. Comparative Kaplan–Meier survival curves for participants aged 18 and older, and stratified by age groups, 1997-2014.

108x78mm (300 x 300 DPI)

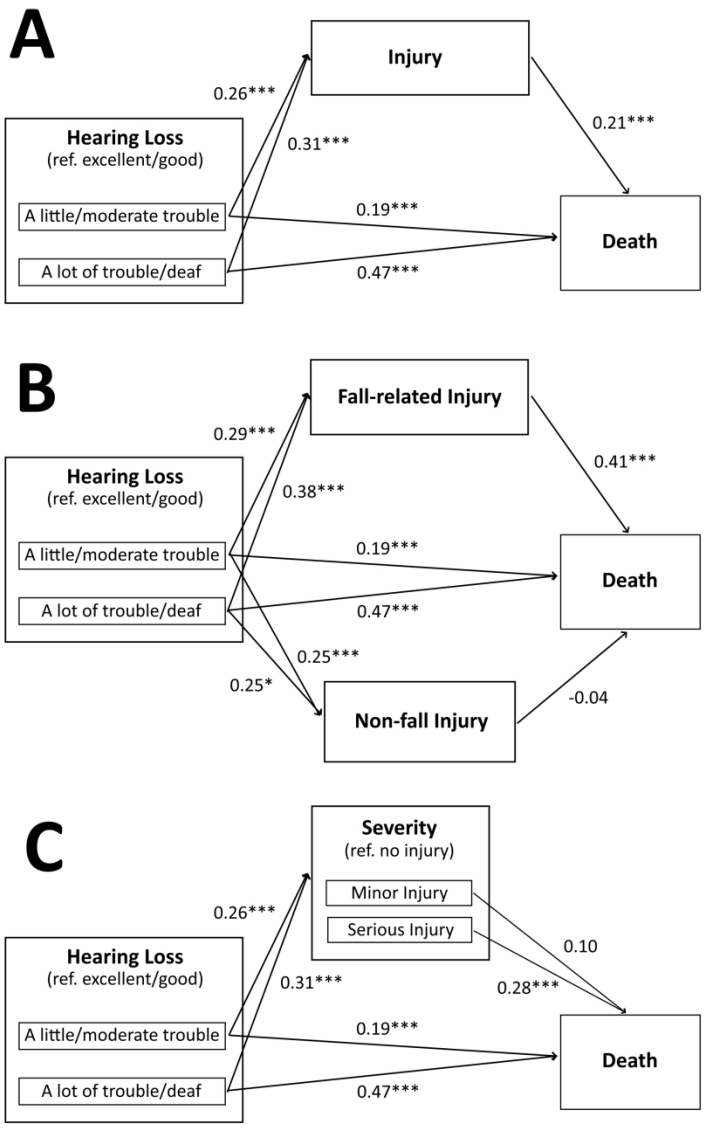

Figure 2. Structural equation and mediation models using data from all participants, (18+ years old) for (A) The mediating role of injury in the association between hearing problems and mortality; (B) The mediating role of fall and non-fall injury in the association between hearing problems and mortality; and (C) The mediating role of minor and serious injury in the association between hearing problems and mortality. Numbers are coefficients. * $p < 0.05$ *** $p < 0.001$.

165x264mm (300 x 300 DPI)