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Research Article

Demographic and Socioeconomic Disparities in Life Expectancy With Hearing Impairment in the United States

Jessica S. West, MPH[1,*,†] and Scott M. Lynch, PhD[1,2,3]

[1]Department of Sociology, Duke University, Durham, North Carolina. [2]Duke University Population Research Institute, Duke University, Durham, North Carolina. [3]Center for the Study of Aging and Human Development, Duke University, Durham, North Carolina.

[†]These authors contributed equally to this manuscript.

*Address correspondence to: Jessica S. West, MPH, Department of Sociology, Duke University, 276 Sociology/Psychology Building, 417 Chapel Drive, Durham, NC 27708. E-mail: jessie.west@duke.edu

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Abstract

Objectives: Hearing impairment is one of the most common disabilities among older people, and its prevalence will increase as the U.S. population ages. However, little is known about social disparities in onset or transitions into and out of hearing impairment, nor how these transitions impact years of life to be spent impaired.

Method: We investigate the number of years an "average" person can expect to live with and without hearing impairment after age 50; sex, race, educational, and regional differences in these expectancies; and the implication of hearing impairment for remaining life expectancy. Bayesian multistate life table methods are applied to 9 waves of data from the Health and Retirement Study (1998–2014) to investigate social disparities in life expectancy with hearing impairment (n = 20,200) for the general population, people hearing impaired at age 50, and people hearing unimpaired at age 50.

Results: Men, Hispanics, persons with less educational attainment, and those born in the south can expect to live a larger proportion of their remaining lives hearing impaired. Although transitions from hearing impaired to unimpaired occur, those with some hearing impairment at age 50 can expect to live more years with hearing impairment, and hearing impairment does not shorten remaining life expectancy.

Discussion: Significant sociodemographic disparities in hearing impaired life expectancy exist. In contrast to past research, we find that hearing impairment does not affect total life expectancy. Future research should consider the consequences of hearing impairment for years to be lived with other age-related and potentially downstream health outcomes.

Keywords: Aging, Bayesian multistate life table methods, Hearing impairment, Life expectancy

An extensive literature documents trends and disparities in disability prevalence in adulthood. In recent decades, particular interest has emerged in identifying disparities in years to be lived with difficulty or inability to perform "activities of daily living" (ADLs)—tasks that are essential for independent living—and "instrumental activities of daily living" (IADLs)—tasks that facilitate independent living but are not crucial for such (Katz et al., 1963; Nagi, 1991). Recent trends indicate that years of life to be spent free from ADL and IADL disability (i.e., "active life expectancy" [ALE]) may be increasing (Beltran-Sanchez et al., 2015). However, the literature has largely ignored a highly and increasingly prevalent functional limitation that has significant implications for quality of life among older per-

sons: hearing impairment (see Author Note for discussion of terminology). Hearing impairment is very common at older ages (reported by 27.3% of those aged 65–74 and 45.1% of those aged 75 and older), tends to be progressive in later life, and impacts the quality of life of individuals *and* those close to them (CDC, 2017a; Ciorba et al., 2012; West, 2020). Further, hearing impairment may have implications for "downstream" health outcomes, including depression, dementia, ADLs, IADLs, and even mortality (Armstrong et al., 2018; Contrera et al., 2015; Genther et al., 2014; Loughrey et al., 2018; Strawbridge et al., 2000; West, 2017), by reducing physical activity levels, reducing social participation, increasing risk of falls, and more (Chen et al., 2015; Kamil et al., 2016; Mick et al., 2018).

Despite the ubiquity of hearing impairment and its potential implications for ALE, few studies have investigated hearing impaired life expectancy (HILE). Most research (Jagger et al., 2007; Kiely et al., 2016; Tareque et al., 2019) has used prevalence data on international samples and has ignored transitions into and out of hearing impairment, yet such transitions are possible. Hearing impairment in older adults is primarily progressive in nature, but it can temporarily result from ear infections, strokes, noise exposure, etc. (Fishman & Cullen, 2018; Kujawa & Liberman, 2009; Lechner et al., 2019). Importantly, individuals' *perceptions* of their hearing impairment may change over time and impact their perceived quality of life (Kamil et al., 2015). Further, even if the risk of hearing impairment for an individual monotonically increases across age, regression coefficients, odds ratios, and other metrics do not provide for an understanding of the lived experience of hearing impairment in terms of the number of years an individual will be affected by hearing impairment prior to death and how disparate such experience is across social groupings. The current study aims to fill this gap in the literature, using multistate life table methods applied to longitudinal and nationally representative U.S. data.

Background

The study of health among older persons has a long history in social science. Early and continuing epidemiologic research has involved prevalence samples and estimation of predictors of poor health using methods that identify static disparities in health across social groupings, such as linear and logistic regression modeling. In recent decades, the life course perspective has motivated researchers to use panel data sets and/or cross-sectional data sets linked to mortality data or life tables so that the implications of static disparities in health can be understood in terms of how social factors affect health over the life course (Elder et al., 2003). Thus, much recent research on (especially) disability in later life has used demographic methods that estimate years of life to be lived with/out various impairments. Most of this research (e.g., Crimmins et al., 2009; Jagger et al., 2007) has focused on ADL and IADL disability in order to estimate years of life older people can expect to live independently and with a high quality of life. However, ADL and IADL limitations are relatively late in the "disablement process," reflecting a culmination (or accumulation) of the effects of upstream insults such as pathologies and chronic conditions (see Nagi, 1991; Verbrugge & Jette, 1994), which themselves are unequally distributed in the population.

Hearing impairment, among all disabilities, is perhaps the least studied upstream health outcome, especially from a life course perspective, and yet it (1) is ubiquitous among older adults (CDC, 2017a); (2) is unequally distributed and contributes to differentials in quality of life (Ciorba et al., 2012); and (3) has implications for subsequent disabilities and perhaps even mortality (Armstrong et al., 2018; Contrera et al., 2015; Genther et al., 2014; Strawbridge et al., 2000). Thus, hearing impairment plays an important role, from a life course perspective, in shaping later life. In recent years, cumulative inequality theory has emerged as a framework in which to consider life course health processes (DiPrete & Eirich, 2006; Ferraro et al., 2009; Willson et al., 2007). Two of the key contributions of the framework include (1) that health disparities exist across social groupings defined by differentials in access to resources and exposure to negative conditions earlier in life and (2) that health disparities tend to increase over the life course as a result of the accumulation of negative exposures and differential access to resources (Ferraro et al., 2009; O'Rand & Hamil-Luker, 2005; Shuey & Willson, 2008).

Hearing impairment, as an upstream health condition, surely plays a role in the process of accumulating inequality. Hearing impairment differentials exist by sex, race, education, and region. For example, hearing impairment prevalence is greater among men than women (Agrawal et al., 2008; Hoffman et al., 2017), perhaps because men experience more noise exposure occupationally (e.g., construction, manufacturing) and recreationally (e.g., shooting firearms, riding motorcycles) (Lie et al., 2016). It is also possible that estrogen and its signaling pathways play a role in sex differences (Shuster et al., 2019).

Epidemiologic studies consistently report that whites experience a disproportionate burden of hearing impairment compared to blacks (Agrawal et al., 2008; Helzner et al., 2005; Lin et al., 2011), despite the observation that blacks have greater exposure to factors harmful to hearing. Blacks are more likely to work in jobs that place them at increased risk for noise-induced hearing impairment (Seabury et al., 2017) or live in areas exposed to environmental noise pollution (Casey et al., 2017). A possible explanation is that melanocytes are present in the cochlea, suggesting that melanin in the inner ear may protect against age-related cellular declines (Lin et al., 2012, 2017). However, further research is needed, as skin pigmentation is associated with hearing impairment among Hispanics but *not* among whites or blacks (Lin et al., 2012, 2017).

Research linking socioeconomic status (specifically education) and hearing impairment generally finds that the

two are linked. Cross-sectionally, less education is associated with a higher prevalence of hearing impairment (Agrawal et al., 2008; Lin et al., 2011) and U.S.-based prospective studies have found that less education is associated with a greater risk for developing hearing impairment (Cruickshanks et al., 2015). In contrast, Australian research has found no association with incident hearing impairment (Mitchell et al., 2011) but a positive association with the prevalence of hearing impairment (Kiely, Gopinath, Mitchell, Luszcz, et al., 2012). In the Netherlands, educational level is not associated with baseline hearing or faster deterioration in hearing (Linssen et al., 2013).

Finally, little is known about how hearing impairment varies by location of birth or current residence, but there are several reasons to expect geographic disparities. First, there is regional variation in infections associated with hearing impairment. Poor living conditions are associated with the development of otitis media (ear infections), which, if not treated, can cause hearing impairment (Acuin, 2004). These factors vary by region, with those living in the south being less likely to access medical care (Lanska & Kryscio, 1994) or have health insurance (Barnett & Vornovitsky, 2016). Indeed, the incidence of acute otitis media is most common among southerners (Ren et al., 2018). Even within larger geographical areas, hearing impairment is clustered: infant hearing impairment in Durham County, NC is more prevalent in urban low-income neighborhoods (particularly among racial/ethnic minorities), which is attributed to the spatial distribution of cytomegalovirus (CMV), a cause of hearing impairment (Lantos et al., 2018). Second, environmental noise is geographically disparate. Noise from road and aircraft traffic is spatially distributed with regions predominantly occupied by minorities and low-income individuals experiencing the most noise (Casey et al., 2017). Third, there is evidence of regional variation in access to and utilization of hearing-related diagnostic care. A higher percentage of southerners do not use hearing aids compared to the other regions (Mahmoudi et al., 2018) and about 56.6% of U.S. counties (particularly those in southern and western states) lack audiologists (Planey, 2019).

Despite these known sociodemographic disparities in the prevalence of hearing impairment, we do not know how these disparities translate into years of life to be spent hearing impaired. Yet this is a natural metric for understanding the implications of hearing impairment differentials for disparities in quality of remaining life for older adults. To date, few studies, have calculated HILE. Research in the United Kingdom calculated that LE at age 65 was 15.3 years for men without hearing impairment and 15.0 for men with hearing impairment. LE at 65 was 19.3 and 19.2 years for women without and with hearing impairment, respectively (Jagger et al., 2007). A study in Singapore estimated that people with self-reported hearing impairment at age 60 had a LE of 23.6 years, those at age 70 had a LE of 16.3 years, and those at age 80 had a LE of 10.4 years (Tareque et al., 2019). Finally, using multistate methods applied to an Australian sample, Kiely et al. (2016) estimated that men and women aged 65 will live 10.4 and 12.9 years, respectively, with hearing impairment. Despite evidence of, and reasoning for, the existence of sociodemographic disparities in hearing impairment, the extent to which sex, racial, educational, and regional differences produce disparities in HILE is unclear, especially given known sociodemographic differences in LE (Crimmins & Saito, 2001; Farina et al., 2020; Olshansky et al., 2012; Vierboom et al., 2019).

The current study provides one of the first investigations of disparities in LE with hearing impairment. Using multistate life table methods, we estimate years of life to be spent with and without hearing impairment, a more meaningful metric than regression coefficients or odds ratios for understanding the population health consequences of hearing disparities (Saito et al., 2014). In particular, years of life to be spent in different states is directly interpretable at the individual level, whereas regression coefficients, odds ratios, and prevalence measures are only meaningful at the aggregate level. Moreover, the use of a large, nationally representative, longitudinal dataset allows us to produce generalizable results with sufficient power to precisely estimate hearing-impaired LE among sociodemographic subpopulations. Specifically, we investigate: (1) the number of years the average person can expect to live with and without hearing impairment after age 50; (2) sex, race, educational, and regional differences in these expectancies; and (3) the implication of hearing impairment for remaining LE for each sociodemographic group.

Method

Study Population

The Health and Retirement Study (HRS) is a longitudinal, nationally representative survey of U.S. adults over age 50 that has been conducted biennially since 1992 using a multi-stage probability sample of households (RAND Center for the Study of Aging, 2019). The sample (1992–2014) is comprised of 37,495 individuals. Given measurement inconsistencies prior to 1998, we restrict the sample to respondents interviewed in 1998 or after. After reducing the sample to one person per household and eliminating those who lived out of the country for at least one wave of the study ($n = 44$) or were not a member of an HRS cohort, our initial sample consisted of 20,651 respondents.

Of these respondents, few were missing on time-invariant covariates: 39 (0.2%) were missing on race, 21 (0.1%) on Hispanic ethnicity, 72 (0.4%) on educational attainment, and 388 (1.9%) on birth region. We imputed missing education with the modal category (12), missing race as "other race" and missing Hispanic ethnicity as non-Hispanic. We deleted individuals who reported no birth region, leaving us 20,219 respondents (98%).

The data structure used for our analyses consists of 2-year intervals spanning survey waves. For example, the first possible interval spans the 1998–2000 survey waves

and the last spans 2012–2014. Our 20,219 respondents were eligible to contribute 103,204 possible intervals, based on their year of entry into the HRS and their year of death (or censoring at 2014). After deleting intervals in which respondents were missing either at the beginning or end of an interval, we were left with 94,138 observed intervals (91.2%). Of these, we delete an additional 102 records in which marital status, current region of residence, or the outcome variable were unknown or unable to be reasonably imputed (n = 71, n = 35, and n = 1, respectively). Thus, our analytic sample consisted of 94,036 interval records, contributed by 20,200 persons.

Measures

The primary outcome variables are mortality and a measure of hearing impairment obtained from two self-report questions. First, participants reported whether they use a hearing aid. Second, they rated their hearing (while wearing a hearing aid as usual, if applicable) on a 5-point scale (excellent, very good, good, fair, poor). We dichotomized our hearing measure, with those responding "fair" or "poor" or reporting hearing aid use coded as "hearing impaired" (McKee et al., 2019). Pure-tone audiometry (PTA) is the gold standard for assessing hearing function, and some research suggests that subjective hearing reports may vary by age, sex, race/ethnicity, and education over and above observable hearing loss as measured by PTA (Kamil et al., 2015). However, some research indicates that self-report measures are reliable indicators of hearing impairment (Chou et al., 2011; Clark et al., 1991). Moreover, PTA has a limited relationship with the lived experience of disability (Demeester et al., 2012), especially self-reported comprehension in noisy environments (Kramer et al., 1996) or group conversations (Gatehouse & Noble, 2004). Thus, PTA fails to capture "hidden hearing loss": individuals with normal hearing thresholds who have deficits in speech discrimination and intelligibility (Chen et al., 2019).

Just under 5% of our intervals (4,541/94,036) had missing data on hearing status at either the beginning or the end of the interval. We imputed these missing data using the last-observation-carried-forward (LOCF) method. As stated above, we were able to impute all missing hearing measures in this way except for one record, which we deleted. A logistic regression model predicting missingness on this item indicated that older persons and those born in the Midwest were less likely to be missing, while those from younger birth cohorts, males, persons of other race, the foreign born, and those currently residing in the northeast were more likely to be missing. However, the pseudo R-square for this model was 0.012, suggesting few meaningful differences in missingness by the covariates.

Our model (below) used data on transitions between hearing impaired and unimpaired states. Our imputations yielded 3,564 intervals in which respondents remained hearing unimpaired and 974 intervals in which respondents remained hearing impaired. Results using listwise deletion did not differ substantially from those we report here, which is not surprising given the relatively low percentage of missingness.

Sociodemographic characteristics include sex, race/ethnicity, education, and region. Sex is measured with a dummy variable (male = 1). Race/ethnicity is measured with two sets of indicators: an indicator for Hispanic ethnicity and a pair of indicators for black and other races (reference = white). Education is measured as years of schooling. The relative contributions of birth versus current region to HILE is entirely unknown, so we include both birth region, measured with indicators for northeastern, Midwestern, or western birth (reference = southern), and current region, measured similarly but using residence at time of interview. Hearing impairment partially depends on exposure to deleterious conditions, and birth region provides a proxy for early and possibly long-term exposure to such conditions. We also include marital status (married = 1), birth cohort (birth year minus 1900), and respondent's age (continuous) based on the age of the respondent at the start of each interval.

Analytic Strategy

We examine sociodemographic differences in hearing/impairment for persons aged 50+ using multistate life tables (MSLTs). MSLT methods produce estimates of years to be spent in different states (here, hearing impaired vs not) prior to death based on transitions between states across age. Traditional multistate methods require population-level data on transition rates but such data are often unavailable or are produced at a coarse level, such as by age and sex only. Thus, we use a Bayesian method first developed by Lynch and Brown (2005), and recently extended by Zang and Lynch (2018), which allows for production of MLSTs for detailed subpopulations. The method involves (1) simulating parameters from a discrete time multinomial logit model with age and other covariates as predictors of transitions between states across intervals using Markov chain Monte Carlo (MCMC) methods; (2) applying the parameter samples to a specified covariate profile with a sequence of ages to estimate age-specific transition probabilities; (3) assembling these transition probabilities into a sequence of transition probability matrices for MSLT calculations; and (4) producing MSLTs using standard demographic calculations (Palloni, 2000).

In this study, states include hearing unimpaired (H), hearing impaired (I), and dead (D), so that our multinomial logit model is five dimensional, with transition HH as the reference against which probabilities of HI, HD, IH, II, and ID transitions are modeled. Figure 1 shows the study state space and transitions. Age, sex, race/ethnicity, education, birth region, current region, marital status, and birth cohort are covariates in the model predicting the transitions. The states a respondent occupies at the start and end of

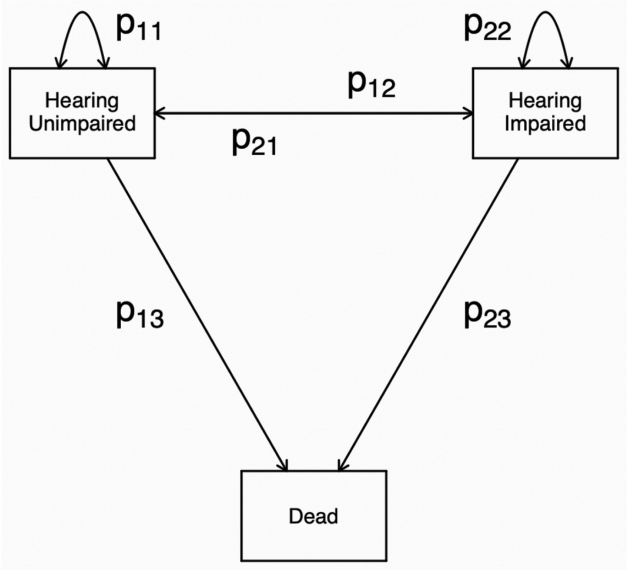

Figure 1. State space and transitions used in multistate life table modeling.

an interval define the transition, with the ending state of one interval being the starting state for the next interval. The dataset is in "long" format, with individuals contributing multiple intervals until death or the end of the survey period (Allison, 2014; Lynch & Brown, 2005). We assume that intervals are independent, conditional on the observed covariates.

MCMC sampling produces multiple samples from the posterior distribution for the model parameters, much like bootstrapping produces multiple samples from a sampling distribution. Each sample of parameters is combined with specific covariate values (a sociodemographic "profile"), with age incremented from 50 to 110+, to produce a collection of age-specific predicted values that are then converted into sets of age-specific transition probability matrices reflecting the state space of interest. These matrices are then used in standard multistate calculations to produce state expectancies for the profile. Following these steps for each MCMC sample produces a distribution of life tables, which allows for the construction of interval estimates and statistical comparisons of state expectancies across profiles. Our MCMC sampling method does not involve the use of sample weights for several reasons. First, the key covariates that comprise the weights are included in the model (Winship & Radbill, 1994). Second, appropriate incorporation of weights in longitudinal analyses is an unsettled issue. Third, in similar analyses, a weighted bootstrap resampling approach involving the sample weights yielded only very minor differences in widths of interval estimates (Lynch & Brown, 2010). Finally, as discussed below, our analyses produced LE estimates that are consistent with national estimates, suggesting that weighting is not necessary to produce estimates that are reflective of the general population.

We produce life tables by sex, race/ethnicity, education, and region. For each sociodemographic profile, we set values of all other covariates to their sample means thereby controlling on compositional differences in the other covariates. The choice of radix for our life tables (the proportion of the population in each state at the earliest age) determines whether the life table is "population-based" or "status-based." For population-based tables, the proportion of the population in each hearing state at age 50 is set to the proportion in each state in the population implied by the predicted scores. For status-based tables, the proportion of the population that begins in each hearing state is set to a meaningful individual-level value. Here, we generate three sets of tables: (1) population-based, (2) status-based for persons impaired at 50, and (3) status-based for persons unimpaired at 50. Comparing these results allows us to evaluate how hearing impairment influences subsequent years to be lived (un)impaired and in total.

Results

Table 1 presents descriptive statistics for the interval data: 55% of the intervals are contributed by females, 77.3% are contributed by whites, and average educational attainment across intervals is 12.2 years. Roughly 36% of intervals are contributed by southern-born persons while 41% are contributed by persons living in the south at the time of interview. Table 1 also shows the counts of observed transitions across all intervals. In 75.7% of the intervals, individuals began hearing unimpaired, and 83.6% of those remained unimpaired, 10.5% became impaired, and 5.8% died. Of the 24.3% of the intervals in which individuals began impaired, 25.3% recovered, 62.3% remained impaired, and 12.4% died. The transition data reveal, first, that those who began an interval impaired were more than twice as likely to die than those who began an interval unimpaired. This mortality difference partly reflects the fact that both hearing impairment and death are age-dependent, and the table contains data across the age range. Second, recovery from hearing impairment is more likely than death, suggesting that ignoring recovery propensities may lead to overestimation of the implications of hearing impairment for LE. Finally, the propensity to recover from impairment is more than twice as great as the propensity to become impaired. These transition patterns have implications for years lived in each state, as captured in the MSLTs.

Table 2 presents posterior means and 84% interval estimates for years of total (TLE), hearing impaired (HILE), and hearing unimpaired (HULE) life expectancy, and the proportion of remaining life to be spent impaired (%HILE), at age 50 obtained from population-based (P) and status-based life tables (U/I). The table is organized by demographic characteristic, with population- and status-based results presented within these groupings. Given the large number of regional subgroups, we show those results in Figure 2. Population-based results show the number of

Table 1. Descriptive Statistics for Covariates and Counts of Observed Transitions Between States Across All Intervals: HRS, 1998–2014 (n = 94,036 Intervals)

Covariates	Mean (*SD*) or %
Male	45.0
Race	
White (ref.)	77.3
Black	17.4
Other	5.3
Hispanic	9.7
Education (years)	12.2 (3.4)
Birth region	
South (ref.)	36.0
Northeast	18.6
Midwest	26.6
West	8.0
Foreign	10.8
Current region	
South (ref.)	41.0
Northeast	16.5
Midwest	24.1
West	18.4
Age (years)	69.1 (10.8)
Married	52.8
Cohort[a]	35.7 (11.9)

Transitions[b]

Time 1 (Interval Start) ↓	Time 2 (Interval End) H	I	Dead	Total
H	59,535 (83.6%)	7,500 (10.5%)	4,141 (5.8%)	71,176 (75.7%)
I	5,791 (25.3%)	14,242 (62.3%)	2,827 (12.4%)	22,860 (24.3%)
Dead	0	0	ALL	
Total	65,326 (69.5%)	21,742 (23.1%)	6,968 (7.4%)	94,036 (100%)

Notes: [a]Cohort is computed as birth year minus 1900.
[b]States include being hearing unimpaired (H), hearing impaired (I), or dead. Percentages add to 1 by row.

years, on average, a person with a given covariate profile will live in each state at age 50. Status-based results show the number of years to be lived in each state for persons who are hearing impaired or unimpaired at age 50.

Of note, there is no set standard in Bayesian statistics for a choice of interval width, in part because Bayesians do not test null hypotheses (Lynch, 2007). We use 84% intervals because it is common for individuals to visually compare interval estimates across groups to assess "significance" of differences between them. Ninety-five percent intervals overlap even when classical statistical tests of between-group differences reveal "significant" differences. Eighty-four percent intervals generally provide a more accurate approach for visual testing (Balbo & Arpino, 2016). However, our results in fact have a Bayesian interpretation: the true value of the state expectancies is expected to fall in the interval with probability 0.84.

The top three rows of the table show results for the overall population (all covariates set to means). TLE at age 50 is 30.8 years in the population-based table. This is consistent with U.S. (period) life tables from 1998 and 2014, which report that TLE at age 50 was 29.8 years and 31.7 years, respectively (CDC, 2017b). Of these years, the "average" person can expect to spend 23.9 years without hearing impairment and 6.9 years impaired (22% of remaining life). Status-based results show that TLE for a person unimpaired at age 50 is 30.8 years, and this person will live 6.6 years impaired (22% of remaining life). TLE for a person impaired at age 50 is also 30.8 years, with expectations for 9.9 years impaired (32% of remaining life).

There are substantial differences in expectancies across demographic groups. First, although women live longer than men in both population- and status-based results, men will spend more years and a larger proportion of their remaining lives with hearing impairment: 7.8 years (28% of remaining life) versus 6.3 years (19% of remaining life) for men and women, respectively (population-based). Status-based results are similar, but for both sexes, those who are impaired at age 50 will spend the greatest proportion of their remaining lives impaired: 10.7 years or 38% (men) and 9.2 or 28% (women). Altogether, hearing impairment at 50 does not shorten TLE but implies a greater proportion of remaining life with hearing impairment for both sexes.

Second, racial/ethnic disparities in HILE exist. In both population- and status-based results, Hispanics have a longer HILE than non-Hispanics. Blacks, regardless of ethnicity, will live the fewest years impaired: for non-Hispanics, 5.1 years impaired (17%) and for Hispanics, 6.9 years impaired (22%). The status-based results yield similar patterns, but all races/ethnicities that are hearing impaired at age 50 will live a greater proportion of their lives with hearing impairment: 33% for non-Hispanic whites, 25% for non-Hispanic blacks, and 37% for white Hispanics. Thus, being hearing impaired does not shorten TLE for any racial/ethnic group but implies a larger proportion of

Table 2. Posterior Means and 84% Credible Intervals for Hearing Unimpaired and Hearing-Impaired State Expectancies by Sociodemographic Characteristics: HRS, 1998–2014

Subgroup	Table	TLE	HULE	HILE	%HILE
Overall	(P)	30.8 [30.5, 31.1]	23.9 [23.7, 24.1]	6.9 [6.8, 7.1]	0.22 [0.22, 0.23]
	(U)	30.8 [30.5, 31.1]	24.2 [24.0, 24.4]	6.6 [6.5, 6.8]	0.22 [0.21, 0.22]
	(I)	30.8 [30.5, 31.1]	20.9 [20.7, 21.2]	9.9 [9.6, 10.1]	0.32 [0.31, 0.33]
Male	(P)	27.9 [27.5, 28.2]	20.1 [19.9, 20.4]	7.8 [7.5, 8.0]	0.28 [0.27, 0.28]
	(U)	27.8 [27.5, 28.2]	20.6 [20.3, 20.8]	7.3 [7.1, 7.5]	0.26 [0.26, 0.27]
	(I)	28.0 [27.7, 28.3]	17.3 [17.0, 17.6]	10.7 [10.4, 11.0]	0.38 [0.37, 0.39]
Female	(P)	33.3 [32.9, 33.7]	27.1 [26.8, 27.4]	6.3 [6.1, 6.5]	0.19 [0.18, 0.19]
	(U)	33.4 [32.9, 33.7]	27.3 [27.0, 27.6]	6.1 [5.9, 6.3]	0.18 [0.18, 0.19]
	(I)	33.3 [32.9, 33.6]	24.1 [23.7, 24.5]	9.2 [8.9, 9.5]	0.28 [0.27, 0.28]
NH white	(P)	30.7 [30.4, 31.0]	23.6 [23.4, 23.9]	7.1 [6.9, 7.3]	0.23 [0.23, 0.24]
	(U)	30.7 [30.4, 31.1]	23.9 [23.7, 24.2]	6.8 [6.6, 7.0]	0.22 [0.22, 0.23]
	(I)	30.7 [30.4, 31.0]	20.5 [20.2, 20.8]	10.2 [9.9, 10.5]	0.33 [0.32, 0.34]
NH black	(P)	30.1 [29.6, 30.7]	25.0 [24.5, 25.4]	5.1 [4.9, 5.4]	0.17 [0.16, 0.18]
	(U)	30.1 [29.6, 30.7]	25.2 [24.7, 25.6]	5.0 [4.7, 5.2]	0.16 [0.16, 0.17]
	(I)	30.2 [29.7, 30.7]	22.6 [22.1, 23.1]	7.6 [7.3, 8.0]	0.25 [0.24, 0.26]
NH other	(P)	30.4 [29.3, 31.5]	23.1 [22.2, 23.9]	7.3 [6.7, 8.0]	0.24 [0.23, 0.26]
	(U)	30.4 [29.3, 31.5]	23.4 [22.5, 24.2]	7.0 [6.4, 7.7]	0.23 [0.21, 0.25]
	(I)	30.5 [29.4, 31.6]	20.2 [19.3, 21.1]	10.3 [9.6, 11.1]	0.34 [0.32, 0.36]
White Hispanic	(P)	32.8 [31.8, 33.6]	23.5 [22.7, 24.1]	9.2 [8.7, 9.9]	0.28 [0.27, 0.30]
	(U)	32.7 [31.8, 33.6]	23.8 [23.1, 24.5]	8.9 [8.3, 9.5]	0.27 [0.26, 0.29]
	(I)	32.7 [31.8, 33.6]	20.7 [19.9, 21.5]	12.0 [11.3, 12.7]	0.37 [0.35, 0.38]
Black Hispanic	(P)	32.3 [31.1, 33.4]	25.3 [24.4, 26.2]	6.9 [6.3, 7.6]	0.22 [0.20, 0.23]
	(U)	32.3 [31.1, 33.4]	25.5 [24.6, 26.4]	6.7 [6.2, 7.4]	0.21 [0.19, 0.23]
	(I)	32.4 [31.2, 33.4]	23.2 [22.3, 24.1]	9.1 [8.5, 9.9]	0.28 [0.27, 0.30]
Other Hispanic	(P)	32.6 [31.3, 33.9]	23.0 [22.0, 24.0]	9.6 [8.8, 10.5]	0.29 [0.27, 0.32]
	(U)	32.6 [31.3, 33.9]	23.3 [22.3, 24.3]	9.2 [8.4, 10.2]	0.28 [0.26, 0.31]
	(I)	32.6 [31.4, 34.0]	20.5 [19.5, 21.6]	12.2 [11.2, 13.2]	0.37 [0.35, 0.40]
8 years education	(P)	28.3 [27.9, 28.7]	20.6 [20.3, 20.9]	7.7 [7.5, 8.0]	0.27 [0.27, 0.28]
	(U)	28.3 [27.9, 28.7]	21.0 [20.7, 21.3]	7.3 [7.1, 7.6]	0.26 [0.25, 0.27]
	(I)	28.5 [28.1, 28.8]	17.9 [17.6, 18.3]	10.5 [10.2, 10.8]	0.37 [0.36, 0.38]
12 years education	(P)	30.6 [30.4, 30.9]	23.7 [23.5, 23.9]	7.0 [6.8, 7.1]	0.23 [0.22, 0.23]
	(U)	30.6 [30.4, 30.9]	24.0 [23.8, 24.2]	6.7 [6.5, 6.8]	0.22 [0.21, 0.22]
	(I)	30.7 [30.4, 30.9]	20.8 [20.5, 21.0]	9.9 [9.7, 10.1]	0.32 [0.32, 0.33]
16 years education	(P)	33.2 [32.8, 33.6]	27.0 [26.7, 27.3]	6.2 [6.0, 6.4]	0.19 [0.18, 0.19]
	(U)	33.2 [32.8, 33.6]	27.2 [26.9, 27.5]	6.0 [5.8, 6.2]	0.18 [0.18, 0.19]
	(I)	33.1 [32.7, 33.5]	23.8 [23.4, 24.2]	9.3 [9.0, 9.5]	0.28 [0.27, 0.29]

Note: NH = non-Hispanic. State expectancies include total life expectancy (TLE), hearing unimpaired life expectancy (HULE), and hearing-impaired life expectancy (HILE). %HILE = proportion of remaining life expectancy to be spent hearing impaired.

remaining life (%HILE) with hearing impairment for each group, especially whites and other Hispanics.

Third, there are educational disparities in HILE. In the population-based results, more education is associated with longer TLE. People with less education will spend more years (and a larger proportion) of their lives with hearing impairment compared to those with more education (7.7 years or 27% vs 6.2 years or 19%, respectively). A similar pattern exists in the status-based results for people with hearing impairment at age 50: 10.5 years impaired (37%) for those with <8 years of education and 9.3 years impaired (28%) for those with 16+ years of education. Altogether, TLE by education is not impacted by hearing impairment, but less educated people will spend a greater proportion of their lives with hearing impairment compared to more educated people.

Finally, Figure 2 shows the proportion of remaining life to be spent hearing impaired (%HILE) for the population (solid line), persons unimpaired at 50 (dotted line), and persons impaired at 50 (dashed line). The population-based results reveal that the southern-born will spend the greatest percentage of life impaired, especially those currently living in the west (25% of remaining life) or Midwest (24%). Similarly, being born in the west but currently living in the Midwest (24%) is harmful. In contrast, people born abroad and currently living in the northeast will spend 19% of their remaining life with hearing impairment. Patterns for people who are hearing impaired at 50 suggest that

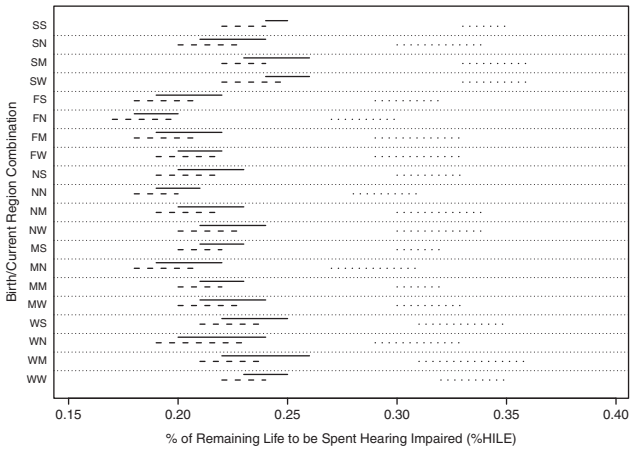

Figure 2. Interval estimates of proportion of remaining life to be lived with hearing impairments at age 50 by birth and current region and population vs status-based life tables 1998–2014. *Note*: First letter indicates birth region, and second letter indicates current region. S = south; N = northeast; M = Midwest; W = west; F = foreign born.

southern birth is harmful, as it is associated with spending 34% of remaining life with hearing impairment if one currently lives in the south, Midwest, or west. Being foreign-born is slightly protective, as it is associated with spending 28% (current northeast), 30% (current south), or 31% (Midwest and west) of remaining life with hearing impairment. Again, hearing impairment at age 50 does not appear to shorten TLE for any given birth/current region combination, but each hearing-impaired group will spend a larger proportion of their lives hearing-impaired rather than unimpaired, especially those born in the south.

Discussion

Despite much research documenting cumulative inequality in health and mortality, comparatively less has explored (1) the impact of poor hearing for LE and (2) how sociodemographic characteristics impact HILE. Our study examined how long people will live with and without hearing impairment, how this varies across sociodemographic groups, and how hearing impairment affects TLE. First, we find that, on average, individuals at age 50 can anticipate living almost 7 years with hearing impairment, indicating a significant proportion of remaining life to be lived with a potential reduction in quality of life. Moreover, 7 years may be economically costly, directly via hearing aid costs and indirectly via "downstream" consequences (e.g., cognitive and physical decline) that also have implications for healthcare spending (Wilson et al., 2017).

Second, hearing impairment is unequally distributed across demographic subpopulations. Consistent with previous research, we find that males and those with less education will spend a large proportion of their remaining lives with hearing impairment while non-Hispanic blacks will spend a small proportion of their remaining lives impaired. While these demographic *patterns* in hearing impairment prevalence are well-known, we provide the first estimates of the number of years these groups will be impaired. This metric, in contrast to odds ratios or regression coefficients, offers a more interpretable metric for understanding the life course implications of these differences in prevalence (Saito et al., 2014).

It is important to highlight the results by sex, as previous studies included sex in their analyses. In the current study, men at age 50 can expect to spend more years with hearing impairment than women (7.8 vs 6.3 years). The only other currently published study to estimate HILE estimated that at the age of 65, Australian men and women will live 10.4 and 12.9 years, respectively, with hearing impairment (Kiely et al., 2016). These differences may be due, in part, to methodological differences including the measure of hearing (PTA for Australian study, self-report for current study) or different age cut points.

A novel contribution of our study is that we investigate regional differences in HILE. Early exposure to the south appears harmful regardless of where people later move, as southern birth is associated with the greatest proportion of remaining life to be lived with hearing impairment. The patterns in these results may be partially driven by the higher incidence of otitis media in the south (Ren et al., 2018), although this study was mostly comprised of individuals under the age of 18 (79.9%). Occupational variation may contribute to the difference. For example, military service is linked to hearing impairment (Helfer et al., 2011) and varies by region, with southerners comprising 36.9% of enlistees in 2015 (Quester & Shuford, 2017). The patterns may also reflect availability of hearing healthcare services, as counties in southern and western states disproportionately lack audiologists (Planey, 2019). Without access to audiological services, individuals with hearing problems may not be screened and referred to physicians who could treat the onset of correctable hearing impairments. Such regional variation can have health implications for areas that are high in need but low in services.

Finally, our results reveal that hearing impairment does not impact TLE. While this finding seemingly contradicts prior research linking hearing impairment with mortality (Genther et al., 2014), no real contradiction exists. Our multistate method allows for reverse transitions from the impaired state. Although the risk of death is twice as great from the hearing-impaired state as from the unimpaired state, the "risk" of recovery from the hearing-impaired state is twice as great as the risk of death at any age. Individuals are more likely to return to the unimpaired state, with its lower risk of death, than they are to die while impaired. Thus, the consequence of hearing impairment for TLE is null, even though hearing impairment affects the instantaneous risk of death (simulation results available on request). Moreover, recent research using MSLTs also reported that TLE estimates were similar for people with and without hearing impairment in Singapore (Tareque et al.,

2019). Our results therefore urge caution when drawing life course implications from hazard models that do not explicitly model the competing risk of recovery.

It is important to note that, in contrast to other status characteristics, disability is not always an ascribed or achieved status—people may transition into and out of disability at different times over the life course (Barnartt, 2010). Our measure of hearing allows individuals to transition between hearing and hearing-impaired states. Many factors may contribute to recovery from hearing impairment. First, hearing impairment may result from transient physical exposures, such as noise exposure causing "temporary" threshold shifts in hearing (Kujawa & Liberman, 2009). Removing wax buildup can improve hearing (Fishman & Cullen, 2018) and intratympanic steroid injections can treat sudden sensorineural hearing loss (Lechner et al., 2019). Second, hearing impairment may have social explanations. Younger individuals tend to overestimate their hearing impairment while older individuals tend to underestimate their hearing impairment (Kamil et al., 2015; Kiely, Gopinath, Mitchell, Browning, et al., 2012). This age variation may occur because hearing impairment is more common at older ages, making it appear more "normal" and thus not necessary to report. In contrast, since it is less common at younger ages and perhaps more critical to work and social engagement, younger individuals may be more likely to perceive and/or report hearing difficulties. In sum, both physical and social factors may play a role in transitions between hearing and hearing-impaired states.

Limitations

The current study is not without limitations. First, as discussed previously, the hearing measure we use is a limitation as subjective hearing reports may vary by demographic characteristics (Kamil et al., 2015). However, PTA is also subject to limitations especially when it comes to capturing the difficulties that individuals experience in their everyday lives (Chen et al., 2019; Demeester et al., 2012; Gatehouse & Noble, 2004; Kramer et al., 1996). Self-rated hearing is the only measure available in the HRS. While other datasets collect audiometric hearing measurements, the HRS is an advantageous dataset to use for this research question given its large sample size, rich demographic characteristics, and ability to examine data longitudinally.

Second, measures of age of onset or duration of hearing impairment prior to observation were not collected by the HRS. Although timing and duration of events on various outcomes is important, we are unable to distinguish age-related versus congenital hearing impairment. However, our data captures a synthetic cohort of individuals beginning at age 50 (not the entire lifetime), a time when hearing impairment is mostly age-related (NIDCD, 2016).

Third, HRS data collection occasions are two years apart, so we cannot capture all potential transitions between hearing states between measurement occasions. The data that is available allows us to capture some transitions, but we probably miss others. We can only assume what happens to respondents when they are not being measured; there is no assumption-free approach nor any way to definitively validate such assumptions.

Conclusion

Hearing impairment is a major public health and social concern (Wilson et al., 2017) because it affects a large proportion of the aging population and affects quality of life for those with impairment and their partners. To our knowledge, our study is the first to examine HILE by subpopulation in the United States. Using a representative, longitudinal dataset, we found that males, Hispanics, persons born in the south, and persons with less education will spend a larger proportion of their lives with hearing impairment. Our estimates provide new evidence on hearing-related disparities in the United States and can be used to inform public health initiatives or policy recommendations about hearing impairment and devices.

Author Note

Disability studies scholars have long stressed the impact that language can have on how people with disabilities are viewed (e.g., Linton, 1998). Many terms have been used to refer to people with hearing impairments, including (but not limited to) Deaf, deaf, hard of hearing, hearing impaired, and having hearing loss (Brueggemann, 2009). Given the weighted nature of language around disability, we drew on the disablement process (Nagi, 1965, 1979, 1991; Verbrugge & Jette, 1994), which describes the pathway linking pathology, impairment, functional limitations, and disability. Verbrugge and Jette (1994) considered hearing to be among the fundamental physical actions that are required to connect an individual to the social and physical environment, and therefore classified difficulty hearing as a functional limitation. Accordingly, we should probably use the terms "people with hearing limitations" and "hearing limited"; however, these terms are not commonly used. Moreover, hearing "loss" assumes that all individuals can "lose" their hearing, which does not include those who are d/Deaf from birth and therefore never had any audiometric hearing to "lose." Thus, we use the term "hearing impairment.".

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Conflict of Interest

None declared.

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