Journal of Aging and Health
2020, Vol. 32(7–8) 724–734

DOI: 10.1177/0898264319848866
journals.sagepub.com/home/jah

Characteristics and Health Outcomes Associated With Hearing Loss and Hearing Aid Use Among Older Adults

Timothy S. Wells, PhD[1], Lorraine D. Nickels, BSN, MS[2], Steven R. Rush, MA, LP[2], Shirley A. Musich, PhD[1], Lizi Wu, PhD[1], Gandhi R. Bhattarai, PhD[1], and Charlotte S. Yeh, MD[3]

Abstract

Background: This study recruited older adults to explore physical and psychosocial conditions and other health outcomes associated with hearing loss (HL) and hearing aid use. **Method:** Survey data were used to categorize 20,244 participants into five groups: no HL, unaided mild HL, aided mild HL, unaided severe HL, and aided severe HL. **Results:** Individuals with unaided severe HL were more likely to report poor-fair self-rated health and were less likely to leave the home, or exercise 4 to 7 days per week, while there were no such associations for those with aided mild or severe HL. In addition, those with aided hearing were less likely to report depression, low social support, or mobility limitations. **Discussion:** In several instances, hearing aid use reduced associations between HL and negative psychosocial and physical characteristics, and health outcomes. More research using longitudinal study designs is needed to better understand the true implications of these findings.

Keywords

hearing loss, hearing aids, Medicare, psychosocial factors, older adults

Introduction

Hearing loss (HL) is a significant public health problem (The National Academies of Sciences, Engineering, and Medicine, 2016), and will likely gain importance as the proportion of individuals aged 65 years and older in the U.S. population continues to grow (Institute of Medicine, 2008). In the United States, HL affects about 27% of adults aged between 60 and 69 years, about 55% of adults aged between 70 and 79 years, and about 79% of adults aged between 80 years and older (Lin, Niparko, & Ferrucci, 2011). About 19% of individuals aged 70 years and older with HL use hearing aids, including 3% of those with mild HL, while 40% and 77% of those with moderate and severe HL, respectively, use hearing aids (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011).

An extensive body of literature exists regarding the association between HL and poorer physical as well as psychosocial and cognitive health. Among the more recent publications related to physical health, HL has been associated with poor physical health (Choi, Betz, Deal, et al., 2016; Mikkola et al., 2015), an increased risk of falls (Gopinath, McMahon, Burlutsky, & Mitchell, 2016; Kamil et al., 2016), and frailty (Liljas et al., 2017). Among the more recent publications related to psychosocial and cognitive health, HL has been associated with depression (Gopinath, Hickson, et al., 2012), poor self-rated health (McKee, Winters, Sen, Zazove, & Fiscella, 2015), as well as loneliness (Mick, Parfyonov, Wittich, Phillips, & Kathleen Pichora-Fuller, 2018; Pronk, Deeg, & Kramer, 2013; Sung, Li, Blake, Betz, & Lin, 2016) and lower social support (Mick et al., 2018).

With three exceptions (Gopinath et al., 2016; Gopinath, Schneider, et al., 2012; Liljas et al., 2017), these studies were cross-sectional in nature making it difficult to further explore the true relationship between HL and measures of poorer health. However, a past summary of the literature describing a positive association between HL and cognitive impairment discussed existing theories regarding this relationship (Pichora-Fuller, Mick, & Reed, 2015). In this article, the authors describe possible biological and cognitive mechanisms. For example, one biological mechanism described indicates that a process such as neurodegeneration may

[1]Optum, Ann Arbor, MI, USA
[2]UnitedHealth Group, Minnetonka, MN, USA
[3]AARP Services, Inc., Washington, DC, USA

Corresponding Author:
Timothy S. Wells, Associate Director, Research for Aging Populations, Optum, 315 E. Eisenhower Parkway, Suite 305, Ann Arbor, MI 48108, USA.
Email: Tim.Wells@optum.com

simultaneously lead to both HL and dementia. Meanwhile, one cognitive mechanism described related to the suggestion that HL may lead to fewer signals being transmitted to the brain, resulting in changes in brain structure, functional brain networks, and behavioral performance. Thus current evidence suggests that either a causal relationship between HL and cognition exits, or that both are adversely affected by the same pathological processes (Logroscino & Panza, 2016). It is likely that these complex relationships impact many of the associations described here.

These relationships may become even more complicated when trying to be understood in the context of those who do and do not use hearing aids. To date, evidence regarding how these associations are influenced by the use of hearing devices, such as hearing aids or cochlear implants (i.e., aided hearing), has been somewhat inconsistent. The strongest evidence for a benefit associated with hearing aid use may be for depression, where three recent observational studies (Boorsma et al., 2012; Gopinath et al., 2009; Mener, Betz, Genther, Chen, & Lin, 2013) and two small prospective studies that used hearing aids as an intervention (Acar, Yurekli, Babademez, Karabulut, & Karasen, 2011; Boi et al., 2012) reported a decreased risk for depression among individuals who wore hearing aids. Otherwise, most studies suggest that aided hearing is associated with little to no improvement in physical functioning (Chen et al., 2015; Chen, Genther, Betz, & Lin, 2014; Gispen, Chen, Genther, & Lin, 2014; Gopinath, Schneider, et al., 2012), while one recent study found a benefit (Dawes, Cruickshanks, et al., 2015). Similarly, two recent studies suggest aided hearing can reduce the risk of falling (Rumalla, Karim, & Hullar, 2015; Stevens, Barbour, Gronski, & Hullar, 2016), while two other recent studies found no benefit (Gopinath et al., 2016; Weaver, Shayman, & Hullar, 2017). Among the recent studies on HL and cognitive impairment, at least three found that aided hearing attenuated the association (Amieva et al., 2015; Castiglione et al., 2016; Dawes, Emsley, et al., 2015), while at least one found no difference (Dawes, Cruickshanks, et al., 2015). Finally, three studies found reduced loneliness among those with HL and wore hearing devices (Contrera, Sung, Betz, Li, & Lin, 2017; Pronk et al., 2013; Weinstein, Sirow, & Moser, 2016). However, in one of these studies, the benefit was only observed for social loneliness, not emotional loneliness (Pronk et al., 2013), whereas in another, the association was reduced only among those who had cochlear implants, but not for those who wore hearing aids (Contrera et al., 2017).

Statement of Purpose

Although much is known regarding HL and its associations with poorer health, there is less evidence regarding how the use of hearing aids impacts these associations. This study was designed to help fill this knowledge gap. Therefore, our purpose was to further explore physical and psychosocial conditions and other health outcomes associated with HL but more importantly, the benefits associated with hearing aid use among older adults.

Method

Study Population

This study included individuals with an AARP® Medicare Supplement plan insured by UnitedHealthcare Insurance Company (for New York residents, UnitedHealthcare Insurance Company of New York). These plans are offered in all 50 states, Washington, D.C., and various U.S. territories. Medicare is the U.S. federal health insurance program for people aged 65 years and older. Although fee-for-service Medicare covers most expenses, it features cost-sharing that can create a financial burden for individuals with high health care needs. Therefore, about 21% of fee-for-service Medicare beneficiaries purchase a Medicare Supplement (Medigap) plan to help defray the out-of-pocket expenses that fee-for-service Medicare does not cover (America's Health Insurance Plans, Center for Policy and Research, 2015). Study participants had to have completed a telephone survey in 2015, or later, and had at least 12 months continuous plan coverage between January 1, 2014, and March 30, 2017.

Telephone Survey

This study used self-reported HL and hearing aid use data from a survey administered using telephone interactive voice response (IVR). Surveys conducted using IVR combine automated telephone survey research and computer technology that asks individuals prerecorded questions and records their responses, usually using the telephone's keypad (Mundt, Searles, Perrine, & Walter, 1997). The survey was conducted in the latter part of 2015 and the first part of 2016 among a random sample of 150,000 residents of New Jersey, Missouri, Texas, and Washington.

The questionnaire included questions about perceived extent of HL and hearing aid use. The HL question is a modified version of one from the National Health and Nutrition Examination Survey (NHANES) (Centers for Disease Control and Prevention, National Center for Health Statistics, 2018). The HL question asked "Which statement best describes your hearing without a hearing aid? Would you say your hearing is excellent, good, that you have a little trouble, moderate trouble or a lot of trouble?" This question differs from that in NHANES by omitting "or are you/is s/he deaf?" as a possible response. Compared to using audiometric data, research suggests that older adults tend to underreport HL when asked this question, and that the underestimation increases with increasing age (Kamil, Genther, & Lin, 2015). The hearing aid use question was identical to the one in NHANES, which asks "In the past 12 months, have

you worn a hearing aid at least 5 hours a week?" with possible responses of "Yes" or "No."

Several other outcome variables were also derived from the survey and used to measure health outcomes, including self-rated health, loneliness, depression, lack of social support, need to stay at home, physical exercise, mobility limitations, and memory loss. Self-rated health was measured by asking "Would you say your health in general is . . . ?" with possible answers of poor, fair, good, very good, and excellent. Loneliness and depression were measured using the Three-Item Revised University of California, Los Angeles (UCLA-3) Loneliness Scale (Hughes, Waite, Hawkley, & Cacioppo, 2004) and Patient Health Questionnaire (PHQ-2) (Kroenke, Spitzer, & Williams, 2003). Lack of social support was ascertained by asking "How often can you count on members of your family or your friends for support?" and was internally developed based upon the Lubben Social Network Scale (Lubben, 1988; Lubben et al., 2006). Need to stay at home was asked using the question "Do you need to stay in the house most or all of the time?" Meanwhile physical exercise, mobility limitations, and memory loss were determined by asking "How many days per week do you get 30 minutes or more of light to moderate physical activity?" "In the past 12 months, have you had a problem with balance or walking?" and "Are you being treated for serious memory loss or have you been told you have serious memory loss?" Finally, the number of prescription drugs taken per day was determined by asking "How many different prescription drugs do you take each day?"

Characteristics Ascertained From Claims Data

Demographic variables included age and gender. Although the data lacked individual information on race/ethnicity and income, zip code–level correlates were assigned based on the zip code of residence. Using data from the 2010 U.S. Census, we coded for the percentage of minority individuals living in each zip code (U.S. Census Bureau, 2015). Binary indicators were created based on this ratio to account for the impact of living in low (below 15%) or medium-high (>15%) minority areas. Similarly, a binary income variable was created to denote low versus higher income level based on whether the median household income in the individual's zip code was among the bottom 30% of all U.S. zip code ranks.

Health status was additionally characterized using several variables from administrative databases, including the Hierarchical Condition Category (HCC) score, which is obtained from a standard risk adjustment tool that includes age, gender, and number of medical conditions (Centers for Medicare & Medicaid Services, 2014). The average Medicare insured has an HCC score of 1.0. Meanwhile, scores less than 1.0 predict future health care costs to be lower than average, suggesting better health, while scores greater than 1.0 predict future health care costs to be higher than average, suggesting poorer health. Next, variables were created for several disease conditions in the medical claims database that have been associated with HL (McKee, Stransky, & Reichard, 2018). To do so, the Optum™ Symmetry® EBM Connect® grouper software (Optum, 2016), which incorporates the principles of evidence-based medicine (EBM) (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996), was used to identify individuals with respiratory disease (i.e., asthma or chronic obstructive pulmonary disease), depression, diabetes, stroke, and cardiovascular disease (i.e., congestive heart failure, coronary artery disease, or atrial fibrillation).

Statistical Analyses

To provide the granularity desired for this study, five combinations of HL and hearing aid use were created. "Excellent" or "Good" self-reported hearing and no-reported hearing aid use were combined into the no HL group and used as the reference category when performing multivariate logistic regression modeling. Those who answered that they had "A Little Trouble" hearing were considered to have mild HL; this category was divided into those with (i.e., aided) and without (i.e., unaided) hearing aid use. Finally, those who answered that they had "Moderate" or "A Lot of Trouble" hearing were considered to have severe HL and were also divided into those with (i.e., aided) and without (i.e., unaided) hearing aid use.

A number of descriptive statistics were calculated testing for the significant differences between the five HL/hearing aid use categories. Chi-square tests were used to illustrate statistically significant differences in categorical variables. Several variables had a small amount (<5%) of missing data, and when they were included in subsequent multivariate modeling, those with the missing data were excluded from the model.

Many health outcomes used in this study came from the survey, and those who responded may have differed in important ways compared with those selected to participate but who chose not to do so. As a result, respondents may not be representative of the study population. To help minimize the effect of nonresponse on study findings, propensity weighted adjustment techniques (Little, 1986) were applied in the logistic regression analyses. Briefly, the propensity weighting utilized available demographic, socioeconomic, and health status variables as described, which could potentially influence survey response. These data were used to estimate the underlying probability of survey response for each individual. Next, the estimated probabilities were used to create and apply a weighting variable to the data, to make those who did respond better resemble all eligible insureds who received the survey. The utility of such propensity weighting models to adjust for external validity threats is described elsewhere (Faries, Leon, Haro, & Obenchain, 2010; Seeger, Williams, & Walker, 2005).

In addition to descriptive analyses, a number of logistic regression models were performed. First, a multinomial

model was performed using the five HL/hearing aid use groups as the dependent variable to estimate characteristics associated with the HL/hearing aid use groups. Next, a series of binomial models were performed using poor-fair self-rated health, PHQ-2 depression, memory loss, social support, loneliness, staying at home, mobility limitations, and exercising 4 to 7 days per week as the outcome variables. In these models, the HL/hearing aid use groups were the main explanatory variables, while controlling for case mix differences. Separate models were performed for lonely women and lonely men, as model diagnostics confirmed effect modification between these two characteristics.

Finally, a sensitivity analysis was performed using a logistic regression model with the EBM depression variable as the outcome, and HL/hearing aid use groups as the primary explanatory variable, while controlling for case mix differences. This was done to assess to what extent the concept of health pessimism, as it relates to self-reported HL (Choi, Betz, Deal, et al., 2016), may have biased study findings, since HL, hearing aid use, and the majority of the outcomes were based upon self-report. If any bias was present among those with HL in our study, the likely result would be to overestimate positive associations between HL and self-reported outcomes.

Results

Among those contacted, 24,893 individuals (18%) returned the survey (Table 1). Nonrespondents were more likely to live in Texas, or in a zip code characterized as being high income or with a moderate percentage of minority residents. After cleaning the data and removing exclusions, 20,244 survey participants were included in this study, of which 41% (8,313) had self-reported HL, and 15% of all participants used hearing aids. When looking at the categories of HL from the survey, 77% of those with "A Lot of Trouble" hearing used hearing aids, followed by 50% of those with "Moderate Trouble" and 16% of those with "A Little Trouble" (data not shown). Finally, when combined into the possible combinations of HL and hearing aid use, 18% (3,574) had unaided mild HL, 3% (699) had aided mild HL, 9% (1,759) had unaided severe HL, and 11% (2,281) had aided severe HL.

In unweighted descriptive analyses using a difference of five percentage points as likely to be meaningful, those with HL were more likely to be of age 85 and older, men, have an HCC score of 0.8 to 2.0, or cardiovascular disease as well as self-reported loneliness or mobility limitations (Table 2).

Multivariate Logistic Regression Modeling

To explore characteristics associated with HL and hearing aid use, a multinomial logistic regression was performed using the five HL categories as the dependent variable (Table 3). In this model, generally speaking, those aged 75 years or older and men, those living in medium to low income zip codes, using five or more prescription drugs per day, and who had

Table 1. Sample Size, Attrition, and Distribution for Hearing Loss and Hearing Aid Use.

	N = 150,000	
Initial sample	Responders	Nonresponders
Initial responders and nonresponders (18% response rate)	27,116	122,884
Initial cleaning to be able to perform analysis for survey nonresponse bias included		
• Dropping duplicates	162	11
• Dropping those no longer eligible or had less than 12 months continuous claims coverage	2,061	5,893
Cleaned respondents and nonrespondents (18% response rate and used for analysis of nonresponse bias)	24,893	116,980
Additional cleaning for		
• Negative medical costs	532	
• Did not provide response to hearing loss question	972	
• Did not provide response to hearing aid use question	100	
• Reported no hearing loss, but wore hearing aids	162	
• Incomplete data in other variables of interest	2,883	
Sample available for study after all cleaning	20,244	
Distribution of hearing loss and hearing aid use		
Hearing loss category	Did not use hearing aids	Used hearing aids
No hearing loss	11,931	0
Mild hearing loss	3,574	699
Severe hearing loss	1,759	2,281

Table 2. Unweighted Descriptive Comparisons by Hearing Loss and Hearing Aid Use.

Characteristic	No hearing loss *n* = 11,931 (%)	Unaided mild hearing loss *n* = 3,574 (%)	Aided mild hearing loss *n* = 699 (%)	Unaided severe hearing loss *n* = 1,759 (%)	Aided severe hearing loss *n* = 2,281 (%)	*p*
Claims-based variables						
Age, years						<.001
65-74	41	35	18	29	20	
75-84	44	45	49	46	44	
≥85	15	20	33	25	35	
Female	72	59	48	55	49	<.001
HCC score						<.001
<0.8	62	54	53	45	47	
0.8-2.0	30	36	38	41	41	
>2.0	8	10	9	14	12	
Diabetes	18	23	19	28	23	<.001
Depression	8	10	7	11	10	<.001
Respiratory disease[a]	13	16	11	19	17	<.001
Stroke	5	6	7	7	7	<.001
Cardiovascular disease[b]	23	28	32	33	32	<.001
Income[c]						<.001
Low	13	14	13	16	12	
Medium	37	39	35	39	39	
High	50	47	52	45	48	
Low minority[c]	59	57	61	61	58	.037
Survey-based variables						
Poor-fair self-rated health	8	11	6	19	11	<.001
PHQ-2 depression	5	8	5	14	9	<.001
Memory loss	1	2	2	4	4	<.001
≥5 prescription drugs per day	30	39	34	47	41	<.001
Medium/high loneliness	26	36	34	40	39	<.001
Lack social support	6	8	9	10	10	<.001
Stays at home	8	11	8	20	13	<.001
Mobility limitations	22	32	27	44	38	<.001
Exercises ≥4 days/week	56	50	58	42	50	<.001

Note. HCC = Hierarchical Condition Category; PHQ = Patient Health Questionnaire.
[a]Includes asthma and chronic obstructive pulmonary disease.
[b]Includes congestive heart failure, coronary artery disease, and atrial fibrillation.
[c]Based upon U.S. Census data for zip code of residence.

respiratory disease were at increased risk for HL. Meanwhile, those most likely to report hearing aid use were older men.

We were also interested in exploring the association between combinations of HL and hearing aid use as independent variables with a number of self-reported health outcomes available from the survey as the dependent variable (Table 4). In some models, the use of hearing aids changed the interpretation of the findings. For example, only those with unaided severe HL were more likely to report poor-fair self-rated health (adjusted odds ratio [OR] = 1.63, 95% confidence interval [CI] = [1.39, 1.90]), or that they were more likely to stay at home (OR = 1.48, 95% CI = [1.26, 1.75]). Similarly, while those with unaided mild or severe HL were less likely to exercise 4 to 7 days per week (OR = 0.91, 95% CI = [0.84, 0.98] and OR = 0.78, 95% CI = [0.70, 0.87], respectively), there were no such associations for those with aided mild or severe HL. In other instances, the use of hearing aids appeared to attenuate the association. This included PHQ-2 depression, low social support, and mobility limitations, where in each instance those who used hearing aids were less likely to report these conditions than those who did not use hearing aids. Next, there were three instances in which hearing aid use did not appear to have a benefit. This was observed in the models for lonely women, lonely men, and memory loss. Finally, the sensitivity model that utilized depression measured from diagnosis codes as the dependent

Table 3. Adjusted Characteristics Associated With Hearing Loss and Hearing Aid Use.

Characteristic[a]	Unaided mild hearing loss OR (95% CI)	Aided mild hearing loss OR (95% CI)	Unaided severe hearing loss OR (95% CI)	Aided severe hearing loss OR (95% CI)
Age, years				
65-74	1.00[a]	1.00[a]	1.00[a]	1.00[a]
75-84	1.21 [1.11, 1.32]	2.72 [2.22, 3.33]	1.37 [1.22, 1.55]	2.04 [1.81, 2.28]
≥85	1.56 [1.39, 1.75]	5.77 [4.59, 7.27]	2.15 [1.86, 2.49]	4.79 [4.20, 5.47]
Female	0.55 [0.51, 0.59]	0.33 [0.28, 0.39]	0.47 [0.42, 0.52]	0.34 [0.31, 0.37]
HCC score				
<0.8	1.00[a]	1.00[a]	1.00[a]	1.00[a]
0.8-2.0	1.10 [1.00, 1.21]	0.93 [0.77, 1.12]	1.28 [1.13, 1.45]	1.10 [0.99, 1.23]
>2.0	1.08 [0.93, 1.25]	0.78 [0.57, 1.07]	1.43 [1.19, 1.71]	1.06 [0.89, 1.27]
Income[b]				
High	1.00[a]	1.00[a]	1.00[a]	1.00[a]
Medium	1.15 [1.06, 1.25]	0.99 [0.83, 1.17]	1.19 [1.07, 1.33]	1.14 [1.03, 1.26]
Low	1.21 [1.08, 1.36]	1.08 [0.84, 1.37]	1.37 [1.18, 1.60]	1.07 [0.92, 1.24]
Low minority[b]	0.93 [0.87, 1.01]	1.13 [0.96, 1.31]	1.11 [1.00, 1.23]	1.01 [0.92, 1.11]
Prescription drugs				
0-4 per day	1.00[a]	1.00[a]	1.00[a]	1.00[a]
≥5 per day	1.35 [1.23, 1.47]	1.16 [0.97, 1.38]	1.68 [1.50, 1.88]	1.47 [1.32, 1.63]
Diabetes	1.08 [0.98, 1.19]	0.87 [0.70, 1.07]	1.24 [1.09, 1.40]	1.00 [0.89, 1.13]
Respiratory disease[c]	1.15 [1.02, 1.28]	0.81 [0.63, 1.05]	1.27 [1.10, 1.46]	1.26 [1.10, 1.44]
Cardiovascular disease[d]	0.97 [0.89, 1.07]	1.11 [0.92, 1.34]	0.95 [0.84, 1.07]	0.92 [0.83, 1.03]
Stroke	0.94 [0.80, 1.10]	1.09 [0.81, 1.47]	1.04 [0.85, 1.27]	1.07 [0.90, 1.28]

Note. OR = odds ratio; CI = confidence interval; HCC = Hierarchical Condition Category.
[a]Reference category.
[b]Based upon U.S. Census data for zip code of residence.
[c]Includes asthma and chronic obstructive pulmonary disease.
[d]Includes coronary artery disease, congestive heart failure, and atrial fibrillation.

Table 4. Adjusted ORs for Hearing Loss, Hearing Aid Use, and Health Outcomes.

Outcome[a]	Unaided mild hearing loss OR (95% CI)	Aided mild hearing loss OR (95% CI)	Unaided severe hearing loss OR (95% CI)	Aided severe hearing loss OR (95% CI)
Poor-fair self-rated health	1.14 [1.00, 1.31]	0.81 [0.58, 1.13]	1.63 [1.39, 1.90]	1.11 [0.94, 1.31]
PHQ-2 depression[b]	1.35 [1.15, 1.58]	0.89 [0.61, 1.30]	1.90 [1.59, 2.26]	1.39 [1.16, 1.67]
Depression[c]	1.19 [1.04, 1.35]	1.11 [0.83, 1.49]	1.26 [1.06, 1.49]	1.34 [1.14, 1.57]
Memory loss	1.04 [0.77, 1.39]	1.15 [0.66, 2.01]	1.80 [1.34, 2.41]	1.85 [1.40, 2.45]
Low social support	1.14 [0.99, 1.31]	1.23 [0.94, 1.61]	1.47 [1.24, 1.75]	1.29 [1.10, 1.52]
Lonely women	1.51 [1.35, 1.68]	1.49 [1.17, 1.91]	1.35 [1.16, 1.58]	1.57 [1.36, 1.81]
Lonely men	1.18 [1.03, 1.35]	1.28 [1.01, 1.62]	1.19 [1.01, 1.41]	1.19 [1.02, 1.38]
Stays at home	1.07 [0.93, 1.24]	0.82 [0.60, 1.12]	1.48 [1.26, 1.75]	0.97 [0.83, 1.15]
Mobility limitations	1.47 [1.34, 1.61]	1.23 [1.02, 1.48]	1.91 [1.69, 2.15]	1.71 [1.54, 1.91]
Exercises 4-7 days/week	0.91 [0.84, 0.98]	1.13 [0.96, 1.33]	0.78 [0.70, 0.87]	1.01 [0.92, 1.11]

Note. OR = odds ratio; CI = confidence interval; PHQ = Patient Health Questionnaire.
[a]Models adjusted for age, gender, number of prescription drugs taken, Hierarchical Condition Category score, diabetes, respiratory disease, stroke, living in a low minority, or low-income zip code.
[b]Self-reported depression using the PHQ-2.
[c]Depression ascertained from claims data using diagnostic codes.

variable resulted in ORs that provided the same interpretation as the PHQ-2 depression model, although the strengths of the associations were weaker.

Discussion

This study included 20,244 adults aged 65 years and older. This large sample allowed for creation of five HL and hearing aid combinations that integrated HL and hearing aid use into the same variable. This appears to be unique among the many recent HL studies, which allowed further exploration of the role that hearing aid use plays in these relationships. Consistent with previous publications, those with HL were more likely to be older men with lower incomes. Furthermore, study findings were generally consistent with previous publications for characteristics and health outcomes associated with HL.

Meanwhile, we observed that 50% of those with moderate HL and 77% of those with severe HL reported wearing hearing aids. These values compare favorably with another study that utilized NHANES data, including audiometric HL and the same hearing aid use question (Lin, Thorpe, et al., 2011). In this study, 40% with moderate HL and 77% with severe HL reported wearing hearing aids. Even though older individuals tend to underreport HL (Kamil et al., 2015), findings from this study, which used self-reported HL and hearing aid use, found hearing aid use prevalence similar to one that used audiometric HL data and self-reported hearing aid use. This suggests that our data on hearing aid use aligns well with nationally representative estimates. However, because only cross-sectional data were available for this study, the true nature of observed relationships (i.e., correlational or causal) cannot be explored, and must be considered correlational until further research is done.

In several instances, the use of hearing aids eliminated the association between HL and the outcome. This was observed between aided severe HL and poor-fair self-rated health, staying at home, and lack of exercise. We also observed that those with aided mild HL had no associations with either PHQ-2 or diagnosed depression or lack of exercise. In other models, the use of hearing aids reduced the magnitude of the association. This was observed among those with aided severe HL for associations with PHQ-2 depression, low social support, and mobility limitations, and also applied for the association between aided mild HL and mobility limitations.

The existing literature provides support for both correlational and causal relationships for several of our observations. As a possible correlational relationship, older individuals who play a more active role in managing their health are probably also less likely to stay at home, more likely to exercise, and to use hearing aids. Individuals who fit this scenario have been described as activated patients, defined as those with the knowledge, skills, and confidence to manage their health (Blakemore et al., 2016). Similarly, a correlational relationship may exist for individuals with high self-efficacy, defined as "how well one can execute courses of action required to deal with prospective situations" (Bandura, 1977). Also, individuals with higher incomes are more likely to use hearing aids (Bainbridge & Ramachandran, 2014; Barnett et al., 2017; Mamo, Nieman, & Lin, 2016), to be in better health, and to have more resources to manage their health as compared to those with lower socioeconomic status (Adler & Newman, 2002). A causal relationship may exist if hearing aid use directly helps to mitigate some of the harmful effects of HL, allowing individuals to maintain their health at a higher level than if they were not using hearing aids. This suggested relationship is supported in a review published by the American Academy of Audiology, which concluded that hearing aids improved adults' health-related quality of life (Chisolm et al., 2007). There is also recent evidence that hearing aids and cochlear implants may improve balance, which would support those who wished to remain mobile and exercise (Negahban, Bavarsad Cheshmeh Ali, & Nassadj, 2017; Rumalla et al., 2015; Vitkovic, Le, Lee, & Clark, 2016).

Some of our findings for aided hearing were supported by existing literature, while others were not. For instance, we observed fewer mobility limitations and more exercise associated with aided hearing. This finding was supported by one prospective study of individuals aged 48 years or older, which found significantly better physical health scores among hearing aid users (Dawes, Cruickshanks, et al., 2015). Conversely, other studies have determined no evidence for improvement in physical performance measures (Chen et al., 2015) or self-reported or accelerometer-measured physical activity (Gispen et al., 2014). It is unclear why these differences occurred, although the two studies did utilize different measures to identify HL.

Meanwhile, we found no marked improvement in memory loss associated with aided hearing, a finding supported by several prospective studies that reported no improvements in cognition associated with hearing aid use (Dawes, Cruickshanks, et al., 2015; van Hooren et al., 2005). Conversely, a 25-year prospective study among individuals aged 65 years and older found that those with unaided self-reported HL had significantly greater declines in cognition compared with controls or those with aided HL (Amieva et al., 2015). In another prospective study of 125 individuals aged 65 years and older, individuals with hearing aids had significant improvements in short-term memory (Castiglione et al., 2016). More recently, a randomized study of 32 older adults with moderate to severe HL found that those randomized to hearing aid use demonstrated improved memory after 6 months of hearing aid use; the authors concluded that hearing aid use may improve cognition (Karawani, Jenkins, & Anderson, 2018). Thus, it appears that larger prospective controlled trials are needed to understand whether or not hearing aids improve cognition among those with HL.

In this study, aided hearing was associated with a decreased risk for PHQ-2 depression and improved social

support among those with severe HL, but no improvements in loneliness for either those with mild or severe HL. To date, the findings for the associations between hearing aid use, depression, loneliness, and social support have been mixed. Studies have found that loneliness improves with cochlear implants, but not with hearing aids (Contrera et al., 2017). Elsewhere, another study found improvements in loneliness with hearing aid use (Pronk et al., 2013), while a similar third study found higher loneliness scores among hearing aid users (Bosdriesz, Stam, Smits, & Kramer, 2018). Contrasting results have also been reported for depression, with at least two studies reporting improvements in depression with cochlear implants (Castiglione et al., 2016; Choi, Betz, Li, et al., 2016), while another reported no improvements in mental health outcomes associated with hearing aid use (Dawes, Cruickshanks, et al., 2015). While we found an improvement in social support among those with aided severe HL, at least two studies found no improvement (Dawes, Emsley, et al., 2015; Mick, Kawachi, & Lin, 2014). These inconsistent findings confirm that more research is needed in this area.

As discussed, evidence exists to suggest better health is associated with the use of hearing devices, although the majority of older individuals with HL do not use them (Bainbridge & Ramachandran, 2014; Chien & Lin, 2012). An in-depth discussion of the many reasons for this is beyond the scope of this article and has been covered in other publications (Barnett et al., 2017; Gopinath et al., 2011; Laplante-Levesque, Hickson, & Worrall, 2012; McCormack & Fortnum, 2013; Saunders, Frederick, Silverman, Nielsen, & Laplante-Levesque, 2016). Recently, the National Academies of Sciences, Engineering, and Medicine (2016) published a report that explored how to improve the access and affordability of hearing health care. Among their recommended actions included further research, making hearing diagnosis and treatment more accessible and affordable, improving the quality of hearing devices and other hearing technologies, and providing consumers with better education regarding the significance of HL and available treatment options.

Strengths and Limitations

The greatest strengths of this study include the large sample of adults aged 65 years and older and the inclusion of hearing aid use data. This allowed the creation and analysis of five HL/hearing aid use categories, which can be difficult to do with smaller samples. In addition, this study explored the association of HL and hearing aid use with characteristics and health outcomes derived from both claims and survey data. In addition, the use of survey data allowed the study of certain outcomes that are traditionally unavailable from claims data. This study's strengths were also related to some of its limitations. As previously described, the survey was conducted using IVR, an automated telephone technology that could possibly make hearing-impaired individuals less likely to participate. We did observe a lower prevalence of HL than reported in other studies (Lin, Niparko, & Ferrucci, 2011), but it is unclear if this was due to nonresponder bias associated with the survey design, the fact that older individuals are more likely to underreport HL (Kamil et al., 2015), a combination of both, or perhaps other factors. For example, this population was able to afford the monthly premiums of their Medicare Supplement plans, and are therefore higher income on average than the overall U.S. population; and those with lower incomes are more likely to have HL (Genther, Frick, Chen, Betz, & Lin, 2013). If the lower prevalence of HL in this study is due to underreporting, this most likely would tend to bias the magnitude of any positive or negative associations toward the null. In addition, the response to the survey was 18%, indicating that the study population may not be representative of all individuals with an AARP Medicare Supplement Plan. To make the results more representative, propensity score weighting was used to account for survey nonresponse. Finally, at least one study reported that older adults with HL and have a pessimistic attitude about their health are more likely to report having other health conditions, which increases the likelihood of finding false-positive associations (Choi, Betz, Deal, et al., 2016). In this study, we did observe a number of positive associations between HL and self-reported health outcomes. However, the results from the sensitivity analysis and the fact that results from this study align with findings from previous studies are somewhat reassuring that our study was not overly influenced by this bias.

Conclusion

This study and others suggest, HL appears to be positively associated with a number of negative physical and psychosocial conditions and other poor health outcomes. However, further research is needed to better understand whether these observations are correlational or causal, and if causal, the underlying means by which HL causes these outcomes and by which hearing aid use in certain circumstances mitigates the relationship. Because evidence also suggests that the use of hearing devices may mitigate some of the adverse consequences of HL, we support the continued use of prospective studies to further explore HL as recommended by the National Academies of Sciences report. In addition, further studies surrounding the relationship between HL and hearing aid use with psychosocial outcomes may help to further define the role of HL and hearing aid use in healthy aging.

Acknowledgments

The authors thank Stephanie J. MacLeod, MS, for her editorial assistance and critical review of this manuscript. She is also employed by UnitedHealth Group.

Ethical Approval

The conduct of this study has been approved by the New England Independent Review Board (NEIRB 16-093).

Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: T.S.W., L.D.N., S.R.R., S.A.M., L.W., and G.B. are all employed by UnitedHealth Group and have stock with UnitedHealth Group. C.S.Y. is employed by AARP Services, Inc. However, their compensation was not dependent upon the results obtained in this research, and the investigators retained full independence in the conduct of this research.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was funded by the Medicare Supplement Health Insurance Program.

ORCID iD

Timothy S. Wells https://orcid.org/0000-0002-5824-0870

References

Acar, B., Yurekli, M. F., Babademez, M. A., Karabulut, H., & Karasen, R. M. (2011). Effects of hearing aids on cognitive functions and depressive signs in elderly people. *Archives of Gerontology and Geriatrics*, *52*, 250-252. doi:10.1016/j.archger.2010.04.013

Adler, N. E., & Newman, K. (2002). Socioeconomic disparities in health: Pathways and policies. *Health Affairs*, *21*, 60-76. doi:10.1377/hlthaff.21.2.60

America's Health Insurance Plans, Center for Policy and Research. (2015). *Beneficiaries with Medigap coverage*. Retrieved from https://www.ahip.org/beneficiaries-with-medigap-coverage/

Amieva, H., Ouvrard, C., Giulioli, C., Meillon, C., Rullier, L., & Dartigues, J. F. (2015). Self-reported hearing loss, hearing aids, and cognitive decline in elderly adults: A 25-year study. *Journal of the American Geriatrics Society*, *63*, 2099-2104. doi:10.1111/jgs.13649

Bainbridge, K. E., & Ramachandran, V. (2014). Hearing aid use among older U.S. adults: The National Health and Nutrition Examination Survey, 2005-2006 and 2009-2010. *Ear and Hearing*, *35*, 289-294. doi:10.1097/01.aud.0000441036.40169.29

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*, 191-215.

Barnett, M., Hixon, B., Okwiri, N., Irungu, C., Ayugi, J., Thompson, R., . . . Bush, M. L. (2017). Factors involved in access and utilization of adult hearing healthcare: A systematic review. *Laryngoscope*, *127*, 1187-1194. doi:10.1002/lary.26234

Blakemore, A., Hann, M., Howells, K., Panagioti, M., Sidaway, M., Reeves, D., & Bower, P. (2016). Patient activation in older people with long-term conditions and multimorbidity: Correlates and change in a cohort study in the United Kingdom. *BMC Health Services Research*, *16*(1), Article 582. doi:10.1186/s12913-016-1843-2

Boi, R., Racca, L., Cavallero, A., Carpaneto, V., Racca, M., Dall' Acqua, F., . . . Odetti, P. (2012). Hearing loss and depressive symptoms in elderly patients. *Geriatrics & Gerontology International*, *12*, 440-445. doi:10.1111/j.1447-0594.2011.00789.x

Boorsma, M., Joling, K., Dussel, M., Ribbe, M., Frijters, D., van Marwijk, H. W., . . . van Hout, H. (2012). The incidence of depression and its risk factors in Dutch nursing homes and residential care homes. *American Journal of Geriatric Psychiatry*, *20*, 932-942. doi:10.1097/JGP.0b013e31825d08ac

Bosdriesz, J. R., Stam, M., Smits, C., & Kramer, S. E. (2018). Psychosocial health of cochlear implant users compared to that of adults with and without hearing aids: Results of a nationwide cohort study. *Clinical Otolaryngology*, *43*, 828-834. doi:10.1111/coa.13055

Castiglione, A., Benatti, A., Velardita, C., Favaro, D., Padoan, E., Severi, D., . . . Martini, A. (2016). Aging, cognitive decline and hearing loss: Effects of auditory rehabilitation and training with hearing aids and cochlear implants on cognitive function and depression among older adults. *Audiology and Neuro-Otology*, *21*(Suppl. 1), 21-28. doi:10.1159/000448350

Centers for Disease Control and Prevention, National Center for Health Statistics. (2018). *National Health and Nutrition Examination Survey*. Retrieved from https://www.cdc.gov/nchs/nhanes/index.htm

Centers for Medicare and Medicaid Services. (2014). *Medicare Managed Care Manual Chapter 7 – Risk Adjustment*. Retrieved from https://www.cms.gov/Regulations-and-Guidance/Guidance/Manuls/downloads/mc86c07.pdf

Chen, D. S., Betz, J., Yaffe, K., Ayonayon, H. N., Kritchevsky, S., Martin, K. R., . . . Health ABC Study. (2015). Association of hearing impairment with declines in physical functioning and the risk of disability in older adults. *Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *70*, 654-661. doi:10.1093/gerona/glu207

Chen, D. S., Genther, D. J., Betz, J., & Lin, F. R. (2014). Association between hearing impairment and self-reported difficulty in physical functioning. *Journal of the American Geriatrics Society*, *62*, 850-856. doi:10.1111/jgs.12800

Chien, W., & Lin, F. R. (2012). Prevalence of hearing aid use among older adults in the United States. *Archives of Internal Medicine*, *172*, 292-293. doi:10.1001/archinternmed.2011.1408

Chisolm, T. H., Johnson, C. E., Danhauer, J. L., Portz, L. J., Abrams, H. B., Lesner, S., . . . Newman, C. W. (2007). A systematic review of health-related quality of life and hearing aids: Final report of the American Academy of Audiology Task Force On the Health-Related Quality of Life Benefits of Amplification in Adults. *Journal of the American Academy of Audiology*, *18*, 151-183.

Choi, J. S., Betz, J., Deal, J., Contrera, K. J., Genther, D. J., Chen, D. S., . . . Lin, F. R. (2016). A comparison of self-report and audiometric measures of hearing and their associations with functional outcomes in older adults. *Journal of Aging and Health*, *28*, 890-910. doi:10.1177/0898264315614006

Choi, J. S., Betz, J., Li, L., Blake, C. R., Sung, Y. K., Contrera, K. J., & Lin, F. R. (2016). Association of using hearing aids or cochlear implants with changes in depressive symptoms in older adults. *JAMA Otolaryngology–Head & Neck Surgery*, *142*, 652-657. doi:10.1001/jamaoto.2016.0700

Contrera, K. J., Sung, Y. K., Betz, J., Li, L., & Lin, F. R. (2017). Change in loneliness after intervention with cochlear implants or hearing aids. *Laryngoscope*, *127*, 1885-1889. doi:10.1002/lary.26424

Dawes, P., Cruickshanks, K. J., Fischer, M. E., Klein, B. E., Klein, R., . . . Nondahl, D. M. (2015). Hearing-aid use and long-term health outcomes: Hearing handicap, mental health, social engagement, cognitive function, physical health, and mortality. *International Journal of Audiology*, *54*, 838-844. doi:10.3109/14992027.2015.1059503

Dawes, P., Emsley, R., Cruickshanks, K. J., Moore, D. R., Fortnum, H., Edmondson-Jones, M., & Munro, K. J. (2015). Hearing loss and cognition: The role of hearing AIDS, social isolation and depression. *PLoS ONE*, *10*(3), e0119616. doi:10.1371/journal.pone.0119616

Faries, D. E., Leon, A. C., Haro, J. M. & Obenchain, R. L. (Eds.). (2010). *Analysis of observational health care data using SAS*. Cary, NC: SAS Institute Inc.

Genther, D. J., Frick, K. D., Chen, D., Betz, J., & Lin, F. R. (2013). Association of hearing loss with hospitalization and burden of disease in older adults. *Journal of the American Medical Association*, *309*, 2322-2324. doi:10.1001/jama.2013.5912

Gispen, F. E., Chen, D. S., Genther, D. J., & Lin, F. R. (2014). Association between hearing impairment and lower levels of physical activity in older adults. *Journal of the American Geriatrics Society*, *62*, 1427-1433. doi:10.1111/jgs.12938

Gopinath, B., Hickson, L., Schneider, J., McMahon, C. M., Burlutsky, G., Leeder, S. R., & Mitchell, P. (2012). Hearing-impaired adults are at increased risk of experiencing emotional distress and social engagement restrictions five years later. *Age and Ageing*, *41*, 618-623. doi:10.1093/ageing/afs058

Gopinath, B., McMahon, C. M., Burlutsky, G., & Mitchell, P. (2016). Hearing and vision impairment and the 5-year incidence of falls in older adults. *Age and Ageing*, *45*, 409-414. doi:10.1093/ageing/afw022

Gopinath, B., Schneider, J., Hartley, D., Teber, E., McMahon, C. M., Leeder, S. R., & Mitchell, P. (2011). Incidence and predictors of hearing aid use and ownership among older adults with hearing loss. *Annals of Epidemiology*, *21*, 497-506. doi:10.1016/j.annepidem.2011.03.005

Gopinath, B., Schneider, J., McMahon, C. M., Teber, E., Leeder, S. R., & Mitchell, P. (2012). Severity of age-related hearing loss is associated with impaired activities of daily living. *Age and Ageing*, *41*, 195-200. doi:10.1093/ageing/afr155

Gopinath, B., Wang, J. J., Schneider, J., Burlutsky, G., Snowdon, J., McMahon, C. M., . . . Mitchell, P. (2009). Depressive symptoms in older adults with hearing impairments: The Blue Mountains Study. *Journal of the American Geriatrics Society*, *57*, 1306-1308. doi:10.1111/j.1532-5415.2009.02317.x

Hughes, M. E., Waite, L. J., Hawkley, L. C., & Cacioppo, J. T. (2004). A short scale for measuring loneliness in large surveys: Results from two population-based studies. *Research on Aging*, *26*, 655-672. doi:10.1177/0164027504268574

Institute of Medicine. (2008). *Retooling for an aging America: Building the health care workforce*. Washington, DC: The National Academies Press.

Kamil, R. J., Betz, J., Powers, B. B., Pratt, S., Kritchevsky, S., Ayonayon, H. N., . . . Health ABC Study. (2016). Association of hearing impairment with incident frailty and falls in older adults. *Journal of Aging and Health*, *28*, 644-660. doi:10.1177/0898264315608730

Kamil, R. J., Genther, D. J., & Lin, F. R. (2015). Factors associated with the accuracy of subjective assessments of hearing impairment. *Ear and Hearing*, *36*, 164-167. doi:10.1097/AUD.0000000000000075

Karawani, H., Jenkins, K., & Anderson, S. (2018). Restoration of sensory input may improve cognitive and neural function. *Neuropsychologia*, *114*, 203-213. doi:10.1016/j.neuropsychologia.2018.04.041

Kroenke, K., Spitzer, R. L., & Williams, J. B. (2003). The Patient Health Questionnaire-2: Validity of a two-item depression screener. *Medical Care*, *41*, 1284-1292. doi:10.1097/01.MLR.0000093487.78664.3C

Laplante-Levesque, A., Hickson, L., & Worrall, L. (2012). What makes adults with hearing impairment take up hearing AIDS or communication programs and achieve successful outcomes? *Ear and Hearing*, *33*, 79-93. doi:10.1097/AUD.0b013e31822c26dc

Liljas, A. E. M., Carvalho, L. A., Papachristou, E., Oliveira, C., Wannamethee, S. G., Ramsay, S. E., & Walters, K. (2017). Self-reported hearing impairment and incident frailty in English community-dwelling older adults: A 4-year follow-up study. *Journal of the American Geriatrics Society*, *65*, 958-965. doi:10.1111/jgs.14687

Lin, F. R., Niparko, J. K., & Ferrucci, L. (2011). Hearing loss prevalence in the United States. *Archives of Internal Medicine*, *171*, 1851-1852. doi:10.1001/archinternmed.2011.506

Lin, F. R., Thorpe, R., Gordon-Salant, S., & Ferrucci, L. (2011). Hearing loss prevalence and risk factors among older adults in the United States. *Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *66*, 582-590. doi:10.1093/gerona/glr002

Little, R. J. A. (1986). Survey nonresponse adjustments for estimates of means. *International Statistical Review*, *54*, 139-157.

Logroscino, G., & Panza, F. (2016). The role of hearing impairment in cognitive decline: Need for the special sense assessment in evaluating cognition in older age. *Neuroepidemiology*, *46*, 290-291. doi:10.1159/000445988

Lubben, J. (1988). Assessing social networks among elderly populations. *Family and Community Health: The Journal of Health Promotion & Maintenance*, *11*, 42-52.

Lubben, J., Blozik, E., Gillmann, G., Iliffe, S., von Renteln Kruse, W., Beck, J. C., & Stuck, A. E. (2006). Performance of an abbreviated version of the Lubben Social Network Scale among three European community-dwelling older adult populations. *Gerontologist*, *46*, 503-513.

Mamo, S. K., Nieman, C. L., & Lin, F. R. (2016). Prevalence of untreated hearing loss by income among older adults in the United States. *Journal of Health Care for the Poor and Underserved*, *27*, 1812-1818. doi:10.1353/hpu.2016.0164

McCormack, A., & Fortnum, H. (2013). Why do people fitted with hearing aids not wear them? *International Journal of Audiology*, *52*, 360-368. doi:10.3109/14992027.2013.769066

McKee, M. M., Stransky, M. L., & Reichard, A. (2018). Hearing loss and associated medical conditions among individuals 65 years and older. *Disability and Health Journal*, *11*, 122-125. doi:10.1016/j.dhjo.2017.05.007

McKee, M. M., Winters, P. C., Sen, A., Zazove, P., & Fiscella, K. (2015). Emergency department utilization among deaf American sign language users. *Disability and Health Journal*, *8*, 573-578. doi:10.1016/j.dhjo.2015.05.004

Mener, D. J., Betz, J., Genther, D. J., Chen, D., & Lin, F. R. (2013). Hearing loss and depression in older adults. *Journal of the*

American Geriatrics Society, *61*, 1627-1629. doi:10.1111/jgs.12429

Mick, P., Kawachi, I., & Lin, F. R. (2014). The association between hearing loss and social isolation in older adults. *Otolaryngology–Head and Neck Surgery*, *150*, 378-384. doi:10.1177/0194599813518021

Mick, P., Parfyonov, M., Wittich, W., Phillips, N., & Kathleen Pichora-Fuller, M. (2018). Associations between sensory loss and social networks, participation, support, and loneliness: Analysis of the Canadian Longitudinal Study on Aging. *Canadian Family Physician*, *64*(1), e33-e41.

Mikkola, T. M., Polku, H., Portegijs, E., Rantakokko, M., Rantanen, T., & Viljanen, A. (2015). Self-reported hearing status is associated with lower limb physical performance, perceived mobility, and activities of daily living in older community-dwelling men and women. *Journal of the American Geriatrics Society*, *63*, 1164-1169. doi:10.1111/jgs.13381

Mundt, J. C., Searles, J. S., Perrine, M. W., & Walter, D. (1997). Conducting longitudinal studies of behavior using interactive voice response technology. *International Journal of Speech Technology*, *2*, 21-31.

The National Academies of Sciences, Engineering, and Medicine. (2016). *Hearing health care for adults: Priorities for improving access and affordability.* Washington, DC: Author.

Negahban, H., Bavarsad Cheshmeh Ali, M., & Nassadj, G. (2017). Effect of hearing aids on static balance function in elderly with hearing loss. *Gait & Posture*, *58*, 126-129. doi:10.1016/j.gaitpost.2017.07.112

Optum. (2016). *Symmetry EBM connect*. Retrieved from https://www.optum.com/resources/library/symmetry-ebm-connect.html

Pichora-Fuller, M. K., Mick, P., & Reed, M. (2015). Hearing, cognition, and healthy aging: Social and public health implications of the links between age-related declines in hearing and cognition. *Seminars in Hearing*, *36*, 122-139. doi:10.1055/s-0035-1555116

Pronk, M., Deeg, D. J., & Kramer, S. E. (2013). Hearing status in older persons: A significant determinant of depression and loneliness? Results from the longitudinal aging study Amsterdam. *American Journal of Audiology*, *22*, 316-320. doi:10.1044/1059-0889(2013/12-0069)

Rumalla, K., Karim, A. M., & Hullar, T. E. (2015). The effect of hearing aids on postural stability. *Laryngoscope*, *125*, 720-723. doi:10.1002/lary.24974

Sackett, D. L., Rosenberg, W. M., Gray, J. A., Haynes, R. B., & Richardson, W. S. (1996). Evidence based medicine: What it is and what it isn't. *British Medical Journal*, *312*, 71-72.

Saunders, G. H., Frederick, M. T., Silverman, S. C., Nielsen, C., & Laplante-Levesque, A. (2016). Health behavior theories as predictors of hearing-aid uptake and outcomes. *International Journal of Audiology*, *55*(Suppl. 3), S59-S68. doi:10.3109/14992027.2016.1144240

Seeger, J. D., Williams, P. L., & Walker, A. M. (2005). An application of propensity score matching using claims data. *Pharmacoepidemiology & Drug Safety*, *14*, 465-476. doi:10.1002/pds.1062

Stevens, M. N., Barbour, D. L., Gronski, M. P., & Hullar, T. E. (2016). Auditory contributions to maintaining balance. *Journal of Vestibular Research*, *26*, 433-438. doi:10.3233/VES-160599

Sung, Y. K., Li, L., Blake, C., Betz, J., & Lin, F. R. (2016). Association of hearing loss and loneliness in older adults. *Journal of Aging and Health*, *28*, 979-994. doi:10.1177/0898264315614570

U.S. Census Bureau. (2015). *2010 census urban and rural classification and urban area criteria*. Retrieved from https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2010-urban-rural.html

van Hooren, S. A., Anteunis, L. J., Valentijn, S. A., Bosma, H., Ponds, R. W., Jolles, J., & van Boxtel, M. P. (2005). Does cognitive function in older adults with hearing impairment improve by hearing aid use? *International Journal of Audiology*, *44*, 265-271.

Vitkovic, J., Le, C., Lee, S. L., & Clark, R. A. (2016). The contribution of hearing and hearing loss to balance control. *Audiology and Neuro-Otology*, *21*, 195-202. doi:10.1159/000445100

Weaver, T. S., Shayman, C. S., & Hullar, T. E. (2017). The effect of hearing aids and cochlear implants on balance during gait. *Otology & Neurotology*, *38*, 1327-1332. doi:10.1097/MAO.0000000000001551

Weinstein, B. E., Sirow, L. W., & Moser, S. (2016). Relating hearing aid use to social and emotional loneliness in older adults. *American Journal of Audiology*, *25*, 54-61. doi:10.1044/2015_AJA-15-0055