Hearing Loss, Hearing Aid Use, and Neuropsychiatric Symptoms among Persons Living with Dementia: Findings from NACC

Ahjeetha Shankar BS , Emmanuel E. Garcia Morales PhD , Jeannie-Marie Leoutsakos PhD, MHS , Valerie T. Cotter DrNP, CRNP , Milap A. Nowrangi MD , Sevil Yasar MD, PhD , Constantine G. Lyketsos MD, MHS , Esther S. Oh MD, PhD , Carrie L. Nieman MD, MPH

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Highlights:

- What is the primary question addressed by this study?
    - Is there an association between self-reported functional hearing loss, hearing aid use, and the number or severity of neuropsychiatric symptoms?
- What is the main finding of this study?
    - NPS are highly prevalent among individuals with self-reported functional hearing loss.
    - Among participants with self-reported hearing loss, hearing aid use was associated with fewer and less severe neuropsychiatric symptoms.
- What is the meaning of the finding?
    - Hearing aid use among persons living with dementia and concurrent functional hearing loss may have a role in the management of NPS, representing an underutilized, non-pharmacological intervention to aid in addressing neuropsychiatric symptoms.

Hearing Loss, Hearing Aid Use, and Neuropsychiatric Symptoms among Persons Living with Dementia: Findings from NACC

Ahjeetha Shankar, BS[1]; Emmanuel E. Garcia Morales PhD[2,3]; Jeannie-Marie Leoutsakos PhD, MHS[4,5]; Valerie T. Cotter DrNP, CRNP[6]; Milap A. Nowrangi MD[4,5]; Sevil Yasar MD, PhD,[5,7]; Constantine G. Lyketsos MD, MHS[4,5]; Esther S. Oh MD, PhD[4,5,6,7,8]; Carrie L. Nieman MD, MPH[6,8,10]

1. Johns Hopkins University School of Medicine, Baltimore, MD, USA
2. Department of Population Health, New York University Grossman School of Medicine, New York, NY, USA
3. Department of Otolaryngology-Head and Neck Surgery, New York University Grossman School of Medicine, New York, NY, USA
4. Department of Psychiatry and Behavioral Sciences, Johns Hopkins University School of Medicine, Baltimore, MD, USA
5. Richman Family Precision Medicine Center of Excellence in Alzheimer's disease, Johns Hopkins University School of Medicine, Baltimore, MD, USA
6. Johns Hopkins University School of Nursing, Baltimore, MD, USA
7. Division of Geriatric Medicine and Gerontology, Department of Medicine, Johns Hopkins University School of Medicine, Baltimore, MD, USA
8. Cochlear Center for Hearing & Public Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
9. Division of Neuropathology, Department of Pathology, Johns Hopkins University School of Medicine, Baltimore, MD, USA

10. Department of Otolaryngology–Head and Neck Surgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA

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Corresponding Author:

Carrie L. Nieman MD, MPH

Johns Hopkins Cochlear Center for Hearing & Public Health

2024 E. Monument St. Suite 2-700

Baltimore, MD 21205

410-502-6965

cnieman1@jhmi.edu

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2. Alzheimer's and related dementias
3. Age-related hearing loss
4. Nonpharmacological Interventions

Abstract:

Background: Hearing loss is a common comorbidity among persons living with dementia (PLWD), affecting >90% of individuals. Sensory impairments have been associated with an increased risk of neuropsychiatric symptoms (NPS), while hearing aid use may be protective.

Method: We analyzed cross sectional data from the National Alzheimer's Coordinating Center's Uniform Data Set. We estimated the association between functional hearing loss and number or severity of NPS in a negative binomial regression with robust variance adjusting for demographic and clinical characteristics. In the subsample with hearing loss, we estimated the association between hearing aid use and number or severity of NPS. Selection bias for hearing aid use was addressed using nearest neighbor matching (NNM) based on respondent demographic characteristics.

Result: 10,054 participants were included with a mean age of 75 (SD 8) years. 2,416 (24%) self-reported functional hearing loss with 3.4 (standard deviation [SD] 2.5) mean total number of NPS and mean NPS severity of 5.1 (SD 4.9). In fully adjusted models, hearing loss was not associated with more NPS (predicted prevalence difference (PPD):0.09; 95% confidence interval (CI):-0.06,0.25) or more severe (PPD=0.25; 95%CI:-0.06,0.56) NPS. In PLWD reporting hearing loss, 1,325 (54.8%) reported hearing aid use. After well-balanced matching, in adjusted models, hearing aid use was associated with fewer (PPD:-0.71; 95% CI:-0.93,-0.50) and less severe NPS (PPD:-1.79; 95% CI:-2.23,-1.34).

Conclusion: Hearing aid use may represent an underutilized, non-pharmacological intervention to address NPS. These findings suggest that hearing care may represent a promising non-pharmacological strategy to explore in managing NPS.

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OBJECTIVE

Neuropsychiatric symptoms (NPS), such as depression, apathy, agitation, and anxiety, are highly prevalent among persons living with dementia (PLWD). The prevalence of NPS ranges from 61% to 97%, and is associated with dementia severity.[1–3] NPS can have significant repercussions for PLWD as they are associated with poor health outcomes, institutionalization, prolonged hospitalization, higher care partner burden, and higher mortality.[4,5] Individuals with mild cognitive impairment (MCI) also commonly experience NPS, with a prevalence ranging from 35% to 85%. In people with MCI, which is a syndrome defined as cognitive decline greater than expected for an individual's age and education level but that does not interfere notably with activities of daily life,[6] NPS have been associated with declining cognitive performance and functional disability.[7] In addition to the physical and psychological toll of NPS on individuals and care partners, NPS are associated with increased financial burden, with a lifetime cost of care estimated at over $350,000 in 2020.[8] As NPS are highly prevalent and detrimental to PLWD, non-pharmacologic interventions are recommended as first-line treatments.[9] However, these interventions are often difficult to administer.[9] On the other hand, while pharmacologic interventions for NPS can be effective in some cases, these treatments are not universally helpful and can carry associated risk.[10] Management of NPS varies by severity, where risk and benefit of potential interventions must be weighed, particularly for milder NPS and considering non-pharmacologic versus pharmacologic interventions.

In considering NPS from the multi-factorial etiologic model proposed by Kales, Gitlin and Lyketsos, factors pertaining to the patient, care partner, and overall environment may result in NPS.[11,12] PLWD can face increased difficulty in conveying their needs to others and interacting with the environment, manifesting in disruptive behaviors. Changes in sensory

function, such as age-related hearing loss, which can influence individuals' ability to communicate and interact with care partners and their environment, may influence NPS. In a single-institution study based out of a subspecialty clinic, worse hearing loss has been independently associated with more NPS and more severe NPS severity.[13] After controlling for demographic and clinical factors, every 10 decibel increase in hearing loss severity was associated with one additional NPS.[13] Yet, among older adults, hearing loss is both underreported and undertreated, particularly among PLWD. Nationally representative estimates demonstrate 79.4% of PLWD have a clinically significant hearing loss, increasing to 94.2% in individuals ≥85 years.[14] As a result, hearing loss is one of the most common comorbidities among PLWD. However, only 21.7% of PLWD and hearing loss use hearing aids[14].

Although sensory impairments, such as hearing loss, have been associated with an increased risk of NPS, there is limited to mixed evidence that hearing aid use may act as a protective intervention against NPS. In one retrospective study, hearing aid use was associated with fewer NPS, lower severity, and less severe depressive symptoms.[13] The only relevant randomized placebo-controlled trial of hearing aids for PLWD and hearing loss did not demonstrate improvements in NPS. Yet, notable study limitations in the hearing aid fitting protocol employed may have affected the outome.[15,16]

To explore the potential relationship between age-related hearing loss and NPS in a larger, cross-institution national cohort, we analyze data from the National Alzheimer's Coordinating Center's (NACC) uniform data set, which is the largest study on the topic to date. We examined the following questions: (1) Is there an association between hearing loss and both number or severity of NPS? (2) Is hearing aid use associated with fewer or less severe NPS? We hypothesized that hearing loss is associated with more and more severe NPS and that use of

hearing aids would be associated with fewer and less severe NPS among PLWD. By gaining a better understanding of the interplay between hearing loss, NPS, and hearing aids, additional, complementary, non-pharmacological approaches may be developed for PLWD with NPS, targeting sensory impairment to optimize their health and well-being.

METHODS

We analyzed data from the National Alzheimer's Coordinating Center's Uniform Data Set (NACC-UDS V3) which included data on 43,517 individuals as of the March 2021 dataset closing date. NACC-UDS collects standardized neuropsychological measures, demographic information, and medical history each year.[17,18] Parent study inclusion and exclusion criteria of participants vary according to each Alzheimer's Disease Research Center (ADRC).[17,18] Depending on a given ADRC's practice, an assigned UDS diagnosis is made by a consensus panel or by a single physician (typically the one who conducted the neurological examination).[17] We restricted the analysis to participants with a consensus diagnosis dementia (N=15,034). We then excluded individuals younger than 60 years of age (N=1,838) and those with missing data on hearing functionality (N=456) and Neuropsychiatric Inventory-Questionnaire (NPI-Q) (N=482). We further excluded individuals with missing covariates (N=2,111) consisting of the following non-mutually exclusive missing covariates: race/ethnicity (N=23), education (N=118), depression (N=1,486), diabetes (N=38), congestive heart failure (N=42), hypertension (N=37), MoCA/MMSE scores (N=769), use of antidepressants (N=26), antipsychotic medications (N=26), or anxiety medications (N=26), total number of medications (N=26), hearing aid use (N=59), or living arrangements (N=31) yielding a final analytic sample of N=10,054 individuals. ADRCs in the NACC-UDS obtained informed consent from all participants before each study

visit as well as approval from institutional regulatory boards.[17,18] All participants and care partners provided written informed consent to participate in the study via individual participating Alzheimer's Disease Research Centers (ADRCs), as approved by individual institutional review boards (IRBs). Use of deidentified data from the NACC-UDS database is provided by the University of Washington.

Neuropsychiatric Symptoms

The Neuropsychiatric Inventory Questionnaire (NPI-Q) was used to measure the presence and severity of 12 NPS: delusions, hallucinations, agitation/aggression, dysphoria/depression, anxiety, euphoria/elation, apathy/indifference, disinhibition, irritability/lability, aberrant motor behaviors, night-time behavioral disturbances and appetite/eating disturbances.[19] The questionnaire assesses the presence (yes v. no) and severity (mild, moderate, severe) of each symptom. The number of symptoms ranges from 0 to 12, while severity ranges from 0 to 36 with higher values representing worse outcomes.

Hearing Measures

As part of the questionnaire participants were asked "Without a hearing aid(s), is the subject's hearing functionally normal?" Participants who answered yes to this question were classified as having normal functionality, otherwise participants were classified as having functional hearing loss. In addition, hearing aid use was assessed using the question "Does the subject usually wear a hearing aid(s)?"

Other Covariates

Covariates were selected for their known relationship with either hearing loss or neuropsychiatric symptoms. In our analyses we included the following demographics: age in years, sex (male, and female), self-reported race and ethnicity (Asian, Black, Hispanic, White, and other), educational attainment (less than a high school education, high school diploma or equivalent, and some college or more), marital status (married vs. divorced, widowed, separated, never married), and living arrangements (alone or not).

Covariates included participant health characteristics such as depression status (based on the Geriatric Depression Scale (GDS) and classified as no (GDS score: 0-4), mild (5-8), moderate (9-11) and severe (12-15) depression), self-reported diagnosis of a chronic condition (diabetes, hypertension, and congestive heart failure). After 2015, most study participants had available scores for the Montreal Cognitive Assessment (MoCA), however, prior to that year majority of participants had data for the Mini-Mental State Examination (MMSE) assessment. In order to maximize data availability all MOCA scores were transformed to MMSE scores (range 0-30)[20]. Finally, the analyses included self-reported use of medications for depression and anxiety, use of antipsychotics, and total number of medications taken by the participant.

Statistical Analysis

In this cross-sectional study, we first compared baseline demographic and clinical characteristics by self-reported functional hearing loss using Pearson's chi-squared tests (for categorical variables) or Kruskal-Wallis ANOVA (for numerical variables). We then estimated predicted prevalence differences (PPD) and 95% confidence intervals (CI) for the association between functional hearing loss and number and severity of NPS using a multivariate negative binomial regression with robust variance. For the analyses we implemented a sequential model

building approach, the first model includes only the exposure variable. The second model adjusts for hearing aid use and demographic characteristics, while the third model additionally adjusted for health characteristics and medications.

In separate analyses, we examined whether use of hearing aids was associated with lower number and severity of NPS among participants with functional hearing loss (N=2,416). However, we recognize that among those with functional hearing loss, hearing aid users are intrinsically different from non-users in that users tend to be wealthier and more educated among other socioeconomic differences.[21,22] To control for selection bias, we implemented a nearest neighbor matching (NNM) approach with replacement between hearing aid users and non-users based on participant socio-demographic characteristics including age, race and ethnicity, education, marital status, and living arrangements. The matching procedure yielded an analytic sample of N=2,650 participants (N=1,325 hearing aid users and N=1,325 non-users). We then estimated the association between hearing aid use and NPS using a fully adjusted multivariate negative binomial regression with robust variance within the matched samples. The threshold for statistical significance was $\alpha = 0.05$. All analyses were performed using Stata/SE 18.0.

RESULTS

In the analytic sample of 10,054 participants (mean age 75.2 years, standard deviation [SD]: 8.1, 51.1% female, 11.2% Black, and 78.1% White) a total of 2,416 (24.0%) reported functional hearing loss, while 7,638 (76.0%) were classified as having no functional hearing loss.

Compared to participants without functional hearing loss, those with hearing loss were older (78.2 years vs. 74.2 years), more likely to identify as White (82.6% vs. 76.7%), male (62.0% vs 44.7%), and more educated (65.9% vs. 63.5% more than a high school education)

(Table 1). Participants with hearing loss experienced slightly less severe (5.1 vs. 5.4), but a similar number of (3.3 vs.3.4), NPS than participants without hearing loss. The most common NPS reported were apathy (43.5% among those with hearing loss and 45.2% for those without hearing loss) and irritability (40.4% vs. 41.0%). The least common symptoms were hallucinations (9.6% vs 9.0%) and elation (5.8% vs. 5.5%). (Table 2).

In fully adjusted models, we estimated that when compared to normal hearing, self-reported hearing loss was not associated with more (predicted prevalence difference [PPD]: 0.09; 95% confidence interval [CI]: -0.06, 0.25) or more severe (PPD: 0.25; 95% CI: -0.06, 0.56) NPS. Further investigation showed that the inclusion of hearing aid use as a covariate changed the direction of this association, and that hearing aid use was in turn significantly associated with fewer (PPD: -0.23; 95% CI: -0.42, -0.05) and less severe (PPD: -0.52; 95% CI: -0.87, -0.17) NPS (Table 3).

Prompted by this finding, we investigated the association between hearing aid use and NPS in participants with hearing loss. However, as already mentioned, hearing aid users are different from non-users and those differences are also associated with fewer symptoms. To reduce this selection bias, in participants with hearing loss, we implemented an NNM approach among hearing aid users and non-users. Our matching procedure was successful at matching samples with similar socio-demographic characteristics between hearing aid users and non-users (Supplemental Table S1). In fully adjusted models, hearing aid use was significantly associated with fewer (PPD: -0.71; 95% CI: -0.93, -0.50) and less severe (PPD: -1.79; 95% CI: -2.23, -1.34) NPS when compared to non-users (Table 4).

DISCUSSION

In this study of 10,054 older adults with dementia from a national sample, self-reported functional hearing loss was not associated with either a larger number and greater severity of NPS. However, among individuals with self-reported hearing loss, hearing aid use was associated with fewer and less severe NPS. This is perhaps the largest study to report that hearing aid use was associated with fewer and less severe NPS among PLWD and concurrent hearing loss.

Our findings contribute to understanding the potential role of hearing loss in the development and management of NPS among PLWD. Our null finding related to the association between functional hearing loss and NPS contrasts existing literature. In one community-based study, among older adults who self-reported hearing loss, a higher prevalence of NPS was observed in those with major neurocognitive disorders (e.g., dementia).[23] Another study reported that nursing home residents, with *proxy-rated sensory loss*, had a higher incidence of new NPS at the 12-month follow-up.[24] In prior studies, as with this one, measures of hearing status often rely on self- and proxy-reports, which are known to be limited and underestimate the prevalence of clinically significant audiometric hearing loss by both self- and proxy-reports.[25] For example, in one study, sensitivity of self-reported hearing status was 61.1% among persons with mild cognitive impairment and 52.6% among PLWD and, similarly low for proxy-reported, 65.7% and 73.3% for individuals with mild cognitive impairment and PLWD, respectively[25]. Thus, our results might have been biased towards the null (i.e. the non-significant association found between hearing status and NPS in this dataset) potentially due to the misclassification of hearing loss due to chronic underreporting by both individuals and proxies. Our findings may have also been limited by confounding variables unaccounted for in the fully adjusted models, such as

more robust measures of socioeconomic position, health literacy, access to specialized care such as dementia and/or hearing care. Furthermore, models were adjusted for global cognitive function as measured by the MoCA or the MMSE but were not adjusted for dementia stage or severity, such as the Clinical Dementia Rating (CDR) scale. While our findings related to functional hearing loss and the number and severity of NPS are null, the finding that hearing aid users, participants with presumed clinically significant audiometric hearing loss that has been addressed, have fewer and less severe NPS show the potential role of hearing aids as a modifier for the association between hearing loss and NPS. This finding highlights the potential role of optimizing sensory health in the management of NPS. Beyond a single institution, this study extends prior findings to a large, national sample, supporting the potential generalizability of the findings, while emphasizing the importance of obtaining objective audiometric measures of hearing among PLWD.

Our study adds to the growing literature of the potential value of hearing aid use among PLWD and the management of NPS through non-pharmacological interventions, such as ensuring access to effective communication. Although the data are limited, other studies have reported similar associations between hearing aid use and management of NPS. In one study, hearing aid use was associated with fewer NPS, lower severity, and less severe depressive symptoms.[13] Moreover, hearing aids are well-tolerated and reduce disability associated with hearing loss among PLWD.[26] Another study demonstrated that hearing aids have promising benefits for patients with depressive symptoms.[27] However, the findings on the potential benefit of hearing aids in the management of NPS contrasts those of Adrait et al., that reported no association between hearing aid use and NPS improvement with a hearing aid intervention,[15] although those findings were challenged by limitations in the hearing aid fitting protocol

employed.[16] Furthermore, as hearing, vision, and cognitive impairment commonly co-occur in older adults,[24,28,29] researchers in one home-based trial developed sensory interventions to support hearing and vision in PLWD, where participants with mild-to-moderate dementia and hearing and/or vision impairment were given a hearing and vision assessment and provided glasses and/or hearing aids.[30] The study found that participants who received these sensory interventions demonstrated clinically significant improvements in quality of life and sensory functional ability.[30] Participants were more socially engaged, experienced less isolation, were less dependent on care partners, and reported improved functional ability and communication.[30] Given the clear link between hearing loss and dementia that has been established in the literature, there is a growing body of research that suggests that those who wear hearing aids for age-related hearing problems maintain better cognitive function over time than those who do not.[31]

There are several limitations to our study. Of note, we relied on self-reported hearing status. Compared to audiometry, an objective form of hearing assessment, self- and proxy-rated hearing assessments have low sensitivity that is even lower with worse impairment and may contribute to hearing loss often being underreported and unaddressed among PLWD.[25] Moreover, in a cross-sectional analysis, as performed in our study, causal relationships cannot be assessed. While a relatively large sample size, findings from NACC are not nationally representative and may have limited generalizability. As of the most recent data freeze on December 1, 2024 and looking at all of the subjects with dementia (prior to any of the exclusions), the NACC-UDS subject demographic breakdown by race was 84% white, 9% Black or African American, <1% American Indian or Alaska Native, <1% Native Hawaiian or Pacific Islander, 2% Asian, 2% Multiracial, and 2% Unknown or ambiguous.[32] Similarly, looking at the same set of individuals, the NACC-UDS subject demographic breakdown by ethnicity was 92%

non-Hispanic, 8% Hispanic, and <1% Missing/Unknown.[32] Additionally, although we tried to address selection biased by implementing an NNM approach to match hearing aid users and non-users, our findings may be limited by unobserved bias. Furthermore, other socioeconomic variables were not available for adjustment such income and financial resources, nor were variables related to health literacy, ability to navigate and/or access specialized care, such as dementia and/or hearing care. Hearing aid use among older adults has been consistently associated with socioeconomic position, which were not robustly captured in this analysis, only relying upon educational level[33–35]. Furthermore, such variables may also influence the recognition and management of NPS and were unaccounted for this study[36–38].

CONCLUSION

We report that hearing aid use among PLWD and concurrent functional hearing loss may have a role in reducing the risk of NPS. Hearing care may represent an underutilized, non-pharmacological intervention to address NPS. This study emphasizes the importance of continuing to explore the importance of identifying and addressing hearing loss in a rigorous fashion among PLWD who are aging with hearing loss.

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Data Sharing Statement: This study analyzed data from the National Alzheimer's Coordinating Center's (NACC) uniform data set, which can be found on The NIA Alzheimer's Disease Research Centers Program: National Alzheimer's Coordinating Center website, under the "Data collection" tab, and then navigating to "Forms & documentation."

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Table 1. Participants Characteristics by Self-Reported Hearing Function

	Total	**Hearing Loss**	**No Hearing Loss**	**p-value**
	N=10,054	N=2,416	N=7,638	
Age, mean (SD)	75.2 (8.1)	78.2 (8.1)	74.2 (7.9)	<0.001
Race\Ethnicity, N (%)				<0.001
White not Hispanic	7,856 (78.1)	1,996 (82.6)	5,860 (76.7)	
Black not Hispanic	1,130 (11.2)	181 (7.5)	949 (12.4)	
Hispanic	798 (7.9)	168 (7.0)	630 (8.2)	
Asian	159 (1.6)	37 (1.5)	122 (1.6)	
Other	111 (1.1)	34 (1.4)	77 (1.0)	
Education Level, N (%)				0.045
Less than HS	1,169 (11.6)	281 (11.6)	888 (11.6)	
HS Diploma or Equiv.	2,446 (24.3)	543 (22.5)	1,903 (24.9)	
Some College or more	6,439 (64.0)	1,592 (65.9)	4,847 (63.5)	
Sex, N (%)				<0.001
Male	4,915 (48.9)	1,499 (62.0)	3,416 (44.7)	
Female	5,139 (51.1)	917 (38.0)	4,222 (55.3)	
Married, N (%)	6,997 (69.6)	1,733 (71.7)	5,264 (68.9)	0.009
Living Alone, N (%)	1,494 (14.9)	325 (13.5)	1,169 (15.3)	0.026
GDS Categories, N (%)				0.740
No Depression	7,956 (79.1)	1,914 (79.2)	6,042 (79.1)	
Mild Depression	1,526 (15.2)	371 (15.4)	1,155 (15.1)	

Moderate Depression	411 (4.1)	90 (3.7)	321 (4.2)	
Severe Depression	161 (1.6)	41 (1.7)	120 (1.6)	
MMSE Score, mean (SD)	21.1 (5.6)	21.6 (5.2)	21.0 (5.7)	<0.001
CHF, N (%)	293 (2.9)	96 (4.0)	197 (2.6)	<0.001
Hypertension, N (%)	5,452 (54.2)	1,322 (54.7)	4,130 (54.1)	0.580
Diabetes, N (%)	1,363 (13.6)	322 (13.3)	1,041 (13.6)	0.710
Number of Medications, mean (SD)	6.2 (3.8)	6.4 (3.9)	6.2 (3.8)	0.001
Medications for…, N (%)				
Depression	3,879 (38.6)	909 (37.6)	2,970 (38.9)	0.270
Psychosis	689 (6.9)	149 (6.2)	540 (7.1)	0.130
Anxiety	1,103 (11.0)	268 (11.1)	835 (10.9)	0.830
Hearing Aid Use, N (%)	1,409 (14.0)	1,325 (54.8)	84 (1.1)	<0.001

Abbreviations: SD: standard deviation; HS: high school; GDS: geriatric depression score; MMSE: mini mental score examination; CHF: congestive heart failure.
Notes: P-value corresponding to Pearson's chi-squared tests, for categorical variables, and Kruskal-Wallis ANOVA for numerical variables.

Table 2. Presence and Severity of Neuropsychiatric Symptoms by Self-Reported Hearing Function (N=10,054)

	Total	**Hearing Loss**	**No Hearing Loss**	**p-value**
	N=10,054	N=2,416	N=7,638	
Number of Symptoms, mean (SD)	3.4 (2.5)	3.3 (2.5)	3.4 (2.5)	0.007
Severity of Symptoms, mean (SD)	5.3 (4.9)	5.1 (4.9)	5.4 (4.9)	0.035
Presence of Neuropsychiatric Symptoms, N (%)				
Delirium	1,673 (16.6)	382 (15.8)	1,291 (16.9)	0.210
Hallucinations	920 (9.2)	231 (9.6)	689 (9.0)	0.420
Agitation	3,507 (34.9)	806 (33.4)	2,701 (35.4)	0.072
Depression	4,104 (40.8)	930 (38.5)	3,174 (41.6)	0.008
Anxiety	4,073 (40.5)	912 (37.7)	3,161 (41.4)	0.002
Elation	558 (5.6)	139 (5.8)	419 (5.5)	0.620
Apathy	4,503 (44.8)	1,052 (43.5)	3,451 (45.2)	0.160
Disinhibition	2,348 (23.4)	545 (22.6)	1,803 (23.6)	0.290
Irritability	4,104 (40.8)	976 (40.4)	3,128 (41.0)	0.630
Motor Disturbance	2,240 (22.3)	508 (21.0)	1,732 (22.7)	0.089
Nighttime Behavior	3,169 (31.5)	780 (32.3)	2,389 (31.3)	0.350

Appetite	2,995 (29.8)	666 (27.6)	2,329 (30.5)	0.006

Abbreviations: SD: standard deviation.
Notes: P-value corresponding to Pearson's chi-squared tests, for categorical variables, and Kruskal-Wallis ANOVA for numerical variables.

Table 3. Negative binomial regressions model for the association between by self-reported hearing function and number and severity of Neuropsychiatric Symptoms (N=10,054)

	Model 1 PPD (95% CI)	P-val	Model 2 PPD (95% CI)	P-val	Model 3 PPD (95% CI)	P-val
			Number of Neuropsychiatric Symptoms			
Functional Hearing						
No Hearing Loss	REF		REF		REF	
Hearing Loss	-0.16 (-0.28, -0.04)	0.011	0.12 (-0.05, 0.28)	0.160	0.09 (-0.06, 0.25)	0.243
Hearing Aid Use						
Non-Users			REF		REF	
Users			-0.28 (-0.47, -0.09)	0.006	-0.23 (-0.42, -0.05)	0.015
			Severity of Neuropsychiatric Symptoms			
Functional Hearing						
No Hearing Loss	REF		REF		REF	
Hearing Loss	-0.24 (-0.47, -0.01)	0.043	0.32 (-0.00, 0.64)	0.049	0.25 (-0.06, 0.56)	0.110
Hearing Aid Use						
Non-Users			REF		REF	
Users			-0.59 (-0.95, -0.24)	0.002	-0.52 (-0.87, -0.17)	0.005

Abbreviations: PPD: predicted prevalence differences; CI: confidence intervals.
Note: For these analyses we followed a model building approach. Model 1 includes only the exposure variable (functional hearing). Model 2 adjusts for participant's hearing aid use, age (years), race/ethnicity (White, Black, Hispanic, Asian, other), education level (less than high school, high school, some college or more), marital status (married, divorced/widowed/separated), living alone. Model 3 additionally adjusts for depression (mild, moderate, severe depression, and no depression), congestive heart failure, diabetes, and hypertension status, MMSE score (continuous), number of medications taken, and whether or not participants take medication for psychosis, anxiety, and depression.

Table 4. Negative binomial regression model for the association between hearing aid use and number and severity of Neuropsychiatric Symptoms among participants with self-reported hearing loss. Nearest Neighbor Matching for hearing aid users. (N=2,650).

	Number of NPS		Severity of NPS	
	PPD (95% CI)	**P-val**	**PPD (95% CI)**	**P-val**
Hearing Aid Use				
Non-Users	REF		REF	
Users	-0.71 (-0.93, -0.50)	<0.001	-1.79 (-2.23, -1.34)	<0.001

Abbreviations: NPS: neuropsychiatric symptoms; PPD: predicted prevalence differences; CI: confidence intervals.
Note: Models adjusted for participant's hearing aid use, age (years), race/ethnicity (White, Black, Hispanic, Asian, other), education level (less than high school, high school, some college or more), marital status (married, divorced/widowed/separated), living alone, depression (mild, moderate, severe depression, and no depression), congestive heart failure, diabetes, and hypertension status, MMSE score (continuous), number of medications taken, and whether or not participants take medication for psychosis, anxiety, and depression.