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Research Article

Hearing Loss and Physical Activity Among Older Adults in the United States

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Abstract

Background: Hearing loss is associated with adverse health outcomes among older adults. Lower physical activity levels may partly explain these observations, yet the association between hearing loss, hearing aid use, and physical activity among older adults is understudied.

Methods: Cross-sectional analysis of National Health and Aging Trends Study (2021) participants. The better-hearing ear pure-tone average (BPTA) at speech frequencies (0.5–4 kHz) was modeled continuously (10-dB increments) and categorically (no: ≤25 dB, mild: 26–40 dB, moderate or greater: >40 dB hearing loss). Activity measures were wrist accelerometry-derived (Actigraph) total activity counts, daily active minutes, activity fragmentation (using active-to-sedentary transition probability), and self-reported participation in vigorous activities and walking for exercise in the last month. We used multivariable regression adjusted for sociodemographic and health covariates.

Results: Among 504 participants excluding hearing aid users (mean age = 79 years, 57% female, 9% Black), 338 (67%) had hearing loss. Worse hearing (continuously and categorically) was associated with fewer counts and active minutes, more fragmented activity, and greater odds of not reporting recent vigorous activities. Among 472 participants with hearing loss including hearing aid users, nonusers (n = 338) had more fragmented activity and greater odds of not reporting walking for exercise compared to users.

Conclusions: Older adults with hearing loss are less physically active. This may mediate the association between hearing loss and other adverse outcomes. Recognition of this potential association is essential for providers to better support older adults in maintaining an active lifestyle. Future research is warranted to understand the impact of hearing interventions.

Keywords: Accelerometry, Audiology, Exercise, Hearing impairment

Physical activity is an essential component of healthy aging. Older adults who are physically active are more likely to maintain independence, have fewer chronic diseases, and live longer (1–4). Despite the widespread benefits, physical activity levels decline with age (5) and around 80% of adults in the United States do not meet national recommendations (6,7). Identifying risk factors for lower physical activity levels among older adults is important for clinical and public health preventative measures.

Hearing loss is highly prevalent among older adults, and the prevalence is projected to increase as the population ages (8). Age-related hearing loss is associated with frailty, poorer physical function, and falls (9–11); it is possible that low physical activity levels partially explain these associations (12). There are several potential mechanisms through which hearing loss may contribute to physical inactivity, including a decline in the perception of environmental auditory cues while moving (13), social isolation (14), and increased allocation of cognitive resources for listening, leaving limited attention for simultaneous tasks (15,16). Importantly, hearing aid use may address these issues via easier cognitive processing and improved communication.

Findings from previous studies suggest that older adults with hearing loss are less physically active using self-report (17) and accelerometry (18,19) measures. However, some studies categorized physical activity levels based on moderate-to-vigorous intensity activity, which may be a less sensitive measure for older adults who tend to engage in primarily light-intensity activity. The National Health and Aging Trends Study (NHATS), a nationally representative sample of older adults in the United States, introduced clinical-standard audiometric hearing testing and an accelerometry module in their 2021 round, in addition to existing self-reported activity measures. Using this data, we studied the association of hearing loss with accelerometry-measured and self-reported physical activity and investigated

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differences in physical activity levels by hearing aid use. Additionally, we explored whether the associations vary by sex. We hypothesized that older adults with hearing loss are more physically active than those without, and that, among those with hearing loss, nonusers are less physically active than hearing aid users.

Method

Study Population

NHATS is an ongoing cohort study of a nationally representative sample of Medicare beneficiaries ages 65 years and older in the United States. The study design includes oversampling of the oldest old (80+) and Black adults, as well as in-home interviews, providing a rich data source to study populations that are commonly underrepresented or missed due to travel or mobility restrictions. In Round 11 (2021), 644 participants had physical activity and audiometric hearing assessments. We excluded participants with missing covariates (hypertension = 1, education = 1), and restricted our primary analysis to participants who reported no hearing aid use (excluded 138 aid users); thus, our primary analytic sample was 504. In secondary analyses, we restricted our sample to participants with hearing loss, allowing aid users in the sample, and investigated differences in physical activity by hearing aid use; we excluded those with missing data on covariates (hypertension = 1, education = 1); thus, had a secondary analytic sample of 472 participants. The NHATS was approved by the Institutional Review Board at the Johns Hopkins Bloomberg School of Public Health. All study participants or proxy respondents signed informed consent at the time of enrollment. All data used for this study are deidentified and publicly available.

Assessment of Physical Activity

Accelerometry-derived measures

Data on physical activity were collected through wrist accelerometry using the triaxial and water-resistant Actigraph CentrePoint Insight Watch ("Activity Watch"). During the in-home study visit, the watch was fitted, and participants were asked to wear the device continuously on their nondominant wrist for the following 7 days, only removing it for water exposure >30 minutes (eg, bathing, swimming). After 7 days, the participants returned the device via U.S. mail. Data were processed to derive physical activity measures. We included participants with ≥3 valid days of data collection (nonwear time <144 minutes [10% of a 24-hour cycle] (20)) in our analysis (n = 9 excluded). Activity counts for nonwear minutes were imputed using the average across all available days for each participant (21). We used 3 accelerometry-derived measures to examine daily physical activity: (1) daily total activity counts (TAC); the vector magnitude of TAC across the 3 axes; (2) daily active minutes, calculated as the sum of minutes per day spent above a threshold of 1 853 counts per minute (22); and (3) activity fragmentation, defined as the probability of transitioning from an active-to-sedentary state (ASTP) and calculated as the reciprocal of the mean active-bout duration. Higher ASTP values represent a more fragmented activity pattern, an indicator of high fatigability and poorer functional performance (23). For ease of interpretation, we expressed the values of ASTP as percentages.

Self-reported measures

Participants were asked if they performed vigorous activities and walked for exercise the month before the interview. Specifically, they were asked, "In the last month, did you ever spend time on vigorous activities that increased your heart rate and made you breathe harder" (eg, working out, swimming, running)? (yes/no), and "In the last month, did you ever go walking for exercise? (yes/no)." These measures were analyzed as binary outcomes, and we reversed them (outcome = no participation in such activities in the last month) for ease of interpretation of our estimates.

Assessment of Hearing

Pure-tone audiometry

Hearing was assessed through pure-tone audiometry using iPad-based portable audiometers (SHOEBOX Ltd, Ontario, Canada). The air conduction hearing thresholds, in decibels hearing level (dB HL), at which participants responded to sound at different frequencies in each ear were measured without hearing devices, if applicable. We calculated the 4-frequency (0.5, 1.0, 2.0, and 4.0 kHz) pure-tone average for each ear and used the better-hearing ear's PTA (BPTA) for our analyses. We used the BPTA as a continuous measure (scaled by 10 dB HL) and categorized into no hearing loss (BPTA ≤25 dB hearing level [dB HL]), mild hearing loss (BPTA >25–40 dB HL), and moderate or greater hearing loss (BPTA ≥40 dB HL). Hearing aid use was self-reported. Participants were asked: "In the last month, have you used a hearing aid or a hearing device? [yes/no]."

Covariates

Sociodemographic variables were self-reported and included age (continuous), sex (male, female), race/ethnicity (White, Black, and Other including Hispanic and non-Hispanic American Indian, Asian, Native Hawaiian, and Pacific Islander), education level (less than high school, high school, some college, and college or more), and household income (considering all sources of income).

Health conditions included self-reported physician diagnoses of hypertension and diabetes. Participants were asked: "Since the last interview, has a doctor told you that you had high blood pressure or hypertension/diabetes? [yes/no]. We combined those with previously reported and new diagnoses of having the condition. We also included body mass index (BMI, kg/m^2), calculated using self-reported height and weight.

In sensitivity analyses, we defined lower extremity physical function using the Short Physical Performance Battery (SPPB), a summary score ranging from 0 to 12 representing participants' performance on a 3-m walking test, balance activities (side-by-side, semi-tandem, full tandem, one leg eyes open, one leg eyes closed), and chair stands (24). We considered participants with a score of 8 or more as having adequate physical function (25).

Statistical Analysis

We compared participants' characteristics across hearing loss categories for descriptive analysis using analysis of variance for continuous variables and chi-squared tests for categorical ones. We plotted the median activity counts for each minute across hearing categories for crude comparisons of daily activity patterns (Figure 1).

Table 1. Sample Characteristics by Hearing Status from the National Health and Aging Trends Study, 2021 (*N* = 504)

	Total (*N* = 504)	No Hearing Loss (*n* = 166)	Mild Hearing Loss (*n* = 243)	Moderate or Greater Hearing Loss (*n* = 95)	*p* Value
Age, mean (*SD*)	78.49 (5.39)	76.00 (3.69)	78.97 (4.92)	81.62 (6.91)	<.001
Sex, % (*n*)					.15
Male	43.25% (218)	43.37% (72)	39.92% (97)	51.58% (49)	
Female	56.75% (286)	56.63% (94)	60.08% (146)	48.42% (46)	
Race, % (*n*)					.66
White	80.95% (408)	83.13% (138)	81.48% (198)	75.79% (72)	
Black	8.93% (45)	7.83% (13)	9.05% (22)	10.53% (10)	
Other[*]	10.12% (51)	9.04% (15)	9.47% (23)	13.68% (13)	
Education, % (*n*)					<.001
Less than high school	12.50% (63)	7.83% (13)	11.52% (28)	23.16% (22)	
High school diploma	24.80% (125)	12.65% (21)	30.04% (73)	32.63% (31)	
Some college	27.58% (139)	28.31% (47)	29.63% (72)	21.05% (20)	
College or more	35.12% (177)	51.20% (85)	28.81% (70)	23.16% (22)	
Household income, mean (*SD*)	62572.29 (56976.21)	80013.70 (63313.87)	57210.52 (55545.81)	45810.55 (38679.05)	<.001
BMI, mean (*SD*)	28.45 (7.58)	28.12 (6.40)	28.25 (6 × 07)	29.53 (11.79)	.30
Diabetes, % (*n*)	30.36% (153)	24.70% (41)	32.10% (78)	35.79% (34)	.12
Hypertension, % (*n*)	74.40% (375)	64.46% (107)	76.95% (187)	85.26% (81)	<.001
TAC in 1000's, mean (*SD*)	1684.63 (629.96)	1861.30 (644.68)	1664.59 (595.15)	1427.21 (599.19)	<.001
Daily active minutes, mean (*SD*)	340.59 (128.24)	373.40 (125.08)	338.83 (122.67)	287.73 (130.63)	<.001
ASTP, mean (*SD*)	29.20 (10.01)	26.95 (8.60)	29.06 (9.37)	33.50 (12.36)	<.001
Did not perform vigorous activities in last month, % (*n*)	59.92% (302)	51.81% (86)	59.26% (144)	75.79% (72)	<.001
Did not walk for exercise in last month, % (*n*)	37.10% (187)	28.92% (48)	36.63% (89)	52.63% (50)	<.001

Notes: ASTP, active-to-sedentary transition probability (ie, activity fragmentation); *SD* = standard deviation; TAC, total activity counts.
[*]Other including Hispanic and non-Hispanic American Indian, Asian, Native Hawaiian, and Pacific Islander.

For multivariable regression models, we built two sets of covariates for adjustment. In Model 1, we adjusted for sociodemographic variables (age, sex, race, and education level). In Model 2, we additionally adjusted for diabetes, hypertension, and BMI. We accounted for sampling weights specifically calculated for participants with accelerometry data in NHATS using Stata's *svy* suite for survey data analysis.

Using linear regression models, we evaluated the association between hearing and accelerometry-derived activity measures. We calculated the differences in TAC, daily active minutes, and ASTP per each 10 dB HL difference in BPTA and across hearing loss categories.

Using logistic regression models, we calculated odds ratios (ORs) of not participating in vigorous activities and walking for exercise (i.e., self-reported physical activity) in the last month across hearing measures.

Among participants with hearing loss (mild or greater), we investigated differences in physical activity measures between hearing aid users and nonusers. We used the models described above and additionally adjusted for BPTA and the log 10 transformation of total household income (a proxy for socioeconomic status) since differences in socioeconomic status may confound the association between hearing aid use and physical activity levels.

To explore sex differences in the association of hearing loss and physical activity, we introduced an interaction term between the hearing loss variables and sex. We ran sex-stratified analyses adjusted for covariates in Model 2.

We conducted sensitivity analyses where we (1) included hearing aid users in the analytic sample, (2) included depressive symptoms (binary variable, self-reported feeling "down, depressed, or hopeless" several days/week or more often) in Model 2, (3) compared hearing aid users and nonusers among participants with moderate or greater hearing loss only, because they are more likely to use and benefit from hearing aids, and (4) explored how physical function relates to the studied associations by first running our models only among participants with adequate physical function (SBBP ≥8) and second by including an interaction term between hearing and physical function (binary variable of poor vs adequate). Analyses for this study were conducted using Stata version 17 × 0 (StataCorp LLC, College Station, TX).

Results

Of 504 participants (Table 1), 166 (33%) had no hearing loss, 243 (48%) had mild hearing loss, and 95 (19%) had moderate or greater hearing loss. Participants without hearing loss were younger on average and more likely to be White and have higher educational attainment. Those with hearing loss were more likely to have hypertension and diabetes. In unadjusted comparisons, participants with hearing loss had lower activity counts throughout the day compared to those with no hearing loss (Figure 1).

Accelerometry-Derived Physical Activity Measures by Hearing Status

We found that worse hearing was associated with fewer activity counts and daily active minutes, and greater activity fragmentation (Table 2). Specifically, in Model 2, each 10 dB HL increase in BPTA was associated with −69.58 K fewer TAC per day (95% confidence interval [CI] −127.36 K, −11.81 K), 16.01 fewer active minutes per day (95% CI −28.08, −3.95), and 1.25% greater activity fragmentation (95% CI 0.22, 2.28). Across categories of hearing loss, participants with moderate or greater hearing loss had fewer TAC (β = −198.00 K; 95% CI −390.66, −5.35) and daily active minutes (β = −45.73; 95% CI −86.46, −5.01), and greater activity fragmentation (β = 3.54; 95% CI 0.35, 6.74) compared to participants with no hearing loss in Model 2.

Self-Reported Physical Activity Measures by Hearing Status

In model 1, moderate or greater hearing loss was associated with greater odds of not engaging in vigorous activities (OR = 2.16; 95% CI 1.25, 3.71) or going walking for exercise (OR = 1.96; 95% CI 1.11, 3.46) in the last month compared to those with no hearing loss (Table 3). In Model 2, after adjusting for health covariates, only the association with greater odds of not engaging in vigorous activities over the last month was statistically supported (OR = 1.92; 95% CI 1.11, 3.32).

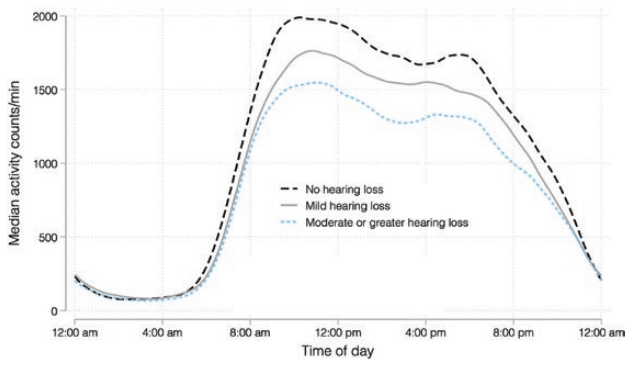

Figure 1. Differences in minute-level activity patterns across hearing loss groups among participants from the National Health and Aging Trends Study, 2021 (*N* = 504).**Unadjusted median activity counts per minute over 24 hours across hearing loss groups.

Hearing Aid Use and Physical Activity Measures Among Individuals With Hearing Loss

Among participants with hearing loss (Table 4, *n* = 472), nonusers had more fragmented activity compared to hearing aid users (Model 2, β = 2.49; 95% CI 0.42, 4.56). In addition, although not statistically supported, estimates from Model 2 were in the direction of lower TAC (β = −86.20; 95% CI −196.10, 23.76) and daily active minutes (β = −18.06; 95% CI −42.88, 6.75) among nonusers. Additionally, nonusers had greater odds of not reporting walking for exercise in the last month compared to hearing aid users (Model 2, OR = 1.85; 95% CI 1.08, 3.16), whereas findings for greater odds of not reporting vigorous activities were not statistically supported (Model 2, OR = 1.64; 95% CI 0.93, 2.89).

In sex-stratified analyses (Supplementary Table 1 and Supplementary Figure 1), findings for accelerometry measures were in the direction of fewer activity counts and active minutes, and more activity fragmentation with worse hearing among men and women. The associations between hearing loss and measured lower physical activity levels seemed stronger for men than women, but the interaction terms between the hearing measure and sex were not significant (Supplementary Table 1, *p* values for the interaction between sex and BPTA >0.05 for all). In terms of self-reported measures (Supplementary Table 2), we found that among men, moderate or greater hearing loss was associated with greater odds of not reporting engaging in vigorous activities over the last month compared to men without hearing loss (OR = 3.12; 95% CI 1.22, 8.00, Model 2, for moderate or greater hearing loss), whereas for women, the differences between those with and without hearing loss were smaller and not statistically significant. However, similarly, the interaction terms between hearing and sex were not significant (Supplementary Table 2, *p* values for the interaction between sex and BPTA >0.05).

Sensitivity Analyses

First, we included hearing aid users in our primary analytic sample, resulting in 640 participants. Their characteristics are shown in (Supplementary Table 3). In this sample, 43%

Table 2. Association of Hearing Loss With Accelerometry-Derived Activity Measures Among Participants From the National Health and Aging Trends Study, 2021 (*N* = 504).

	TAC (per 1 000 counts)		Daily Active Minutes		ASTP (in %)	
	β Coefficients (95% confidence intervals)					
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
BPTA, per 10 dB HL	**−97.14 (−155.23, −39.05)**	**−69.58 (−127.36, −11.81)**	**−21.24 (−33.34, −9.14)**	**−16.01 (−28.08, −3.95)**	**1.55 (0.48, 2.61)**	**1.25 (0.22, 2.28)**
No hearing loss (BPTA <25 dB HL), *n* = 166	Reference	Reference	Reference	Reference	Reference	Reference
Mild hearing loss (BPTA ≥25–<40 dB HL), *n* = 243	−132.81 (−280.46, 14.84)	−94.71 (−236.48, 47.05)	−24.98 (−55.50, 5.54)	−17.99 (−47.56, 11.57)	1.19 (−1.00, 3.38)	0.84 (−1.34, 3.03)
Moderate or greater hearing loss (BPTA ≥40 dB HL), *n* = 95	**−278.69 (−475.02, −82.36)**	**−198.00 (−390.66, −5.35)**	**−61.00 (−101.99, −20.01)**	**−45.73 (−86.46, −5.01)**	**4.39 (1.13, 7.65)**	**3.54 (0.35, 6.74)**

Notes: ASTP = active-to-sedentary transition probability (ie, activity fragmentation); BPTA = better-hearing ear's pure-tone average; dB HL = decibels hearing level; TAC = total activity counts. Bold represents statistically significant findings.
Model 1: adjusted for age, sex, race/ethnicity, and education.
Model 2: adjusted for covariates in model 1 and BMI, diabetes, and hypertension.

Table 3. Association of Hearing Loss With Self-Reported Physical Activity Measures Among Participants From the National Health and Aging Trends Study, 2021 (*N* = 504)

	Did Not Engage in Vigorous Activities in the Last Month		Did Not Walk for Exercise in the Last Month	
	Odds Ratios (95% Confidence Intervals)			
	Model 1	Model 2	Model 1	Model 2
BPTA, per 10 DB HL	1.17 (0.98, 1.39)	1.12 (0.93, 1.33)	**1.22 (1.03, 1.44)**	1.13 (0.94, 1.35)
No hearing loss (BPTA <25 dB HL), *n* = 166	Reference	Reference	Reference	Reference
Mild hearing loss (BPTA ≥25 to <40 dB HL), *n* =243	1.07 (0.73, 1.56)	1.01 (0.68, 1.50)	1.11 (0.72, 1.70)	1.00 (0.62, 1.61)
Moderate or greater hearing loss (BPTA ≥40 dB HL), *n* = 95	**2.16 (1.25, 3.71)**	**1.92 (1.11, 3.32)**	**1.96 (1.11, 3.46)**	1.60 (0.89, 2.89)

Notes: BPTA = Better-Hearing Ear's Pure-Tone Average; dB HL = decibels hearing level. Bold represents statistically significant findings.
Model 1: adjusted for age, sex, race/ethnicity, and education.
Model 2: adjusted for covariates in model 1 and bmi, diabetes, and hypertension.

Table 4. Association of Hearing Aid Use With Accelerometry-Derived and Self-Reported Physical Activity Measures Among Participants From the National Health and Aging Trends Study With Hearing Loss, 2021 (*N* = 472)

	Accelerometry-Derived Measures B-Coefficients (95% confidence intervals)		
	Hearing Aid Users (*n* = 134)	Nonusers (*n* = 338)	
		Model 1	Model 2
TAC, 1 000 counts	Reference	−105.60 (−225.20, 13.91)	−86.20 (−196.10, 23.76)
Daily active minutes	Reference	−22.30 (−49.01, 4.41)	−18.06 (−42.88, 6.75)
ASTP, %	Reference	**2.76 (0.51, 5.00)**	**2.49 (0.42, 4.56)**
	Self-reported measures Odds ratios (95% confidence intervals)		
Did not engage in vigorous activities in the last month	Reference	1.71 (0.97, 3.04)	1.64 (0.93, 2.89)
Did not walk for exercise in the last month	Reference	**1.99 (1.16, 3.41)**	**1.85 (1.08, 3.16)**

Notes: ASTP = active-to-sedentary transition probability (ie, activity fragmentation); BPTA = Better-Hearing Ear's Pure-Tone Average; TAC = total activity counts. Bold represents statistically significant findings.
Model 1: adjusted for age, sex, race/ethnicity, education, income, and BPTA.
Model 2: adjusted for covariates in Model 1 and BMI, diabetes, and hypertension.

had mild hearing loss (of those, 12% wore hearing aids), and 31% (of those, 51% wore hearing aids) had moderate or greater. The estimated associations of our primary analyses were attenuated after including hearing aid users in the exposed categories (Supplementary Tables 4 and 5). Second, further adjusting for depressive symptoms in Model 2 did not change our findings (Supplementary Tables 6–8). Third, among 195 participants with moderate or greater hearing loss (Supplementary Table 9), hearing aid nonusers had fewer activity counts (β = −190.24; 95% CI −352.40, −28.08), active minutes (β = −47.79; 95% CI −84.11, −11.47), and more fragmented activity (β = 4.97; 95% CI 1.80, 11.47) compared to users in Model 2. In addition, nonusers had greater odds of not walking for exercise in the last month than users (OR = 2.54; 95% CI 1.19, 5.43). Lastly, in analyses restricted to participants with adequate lower extremity function (*N* = 417 with data on SPPB and score ≥8), the magnitude of the associations between hearing loss and all physical activity measures was attenuated but in the direction of lower and more fragmented activity. When we included a hearing (categorical) and physical function (binary) interaction term in our models (*N* = 468 with data on SPPB), our only statistically significant finding was a stronger association between moderate or greater hearing loss and more fragmented activity (p = .025) among participants with lower physical function. Models in which we tested for interaction using physical function as a continuous variable were not statistically significant.

Discussion

We found that among adults aged 70 and older, worse hearing was associated with lower and more fragmented activity measured by wrist accelerometry, as well as greater odds of not engaging in vigorous activities in the last month. For example, those with moderate or greater HL had 3.5% higher activity fragmentation compared to participants without hearing loss, which is comparable to an age difference of roughly 9 years (based on the age coefficient from the same model for ASTP [β coefficient per 1 year difference in age = 0.4%]). Among older adults with hearing loss, nonusers had more fragmented activity and greater odds of not walking for exercise in the last month compared to hearing aid users, although this was not reflected in their accelerometry-derived measures of activity counts and minutes. These findings contribute to our understanding of how older adults with hearing loss engage in physical activity.

Our findings are consistent with the literature on the association of hearing loss and lower levels of physical activity and expand our understanding by including an older population than previous studies, and by examining differences in hearing aid use among older adults with hearing loss. Studies using different accelerometry-derived measures to quantify physical activity, such as weekly minutes of moderate-to-vigorous physical activity, log-transformed TAC, and Monitor-Independent Movement Summary units, reached similar conclusions (12,18,19). Furthermore, the differences in diurnal patterns of activity across hearing groups, whereby lower counts throughout the day were observed with worse hearing, were consistent with findings from the National Health and Nutrition Examination Survey (18). Additionally, we also found that worse hearing is associated with more fragmented physical activity, consistent with Kuo et al. (18). Specifically, they found the age equivalent of the association of hearing loss with ASTP to be 10.95 years (95% CI −1.24, 23.15), similar in magnitude to our estimate of 9 years. Higher activity fragmentation is a novel metric that represents decreased endurance and is associated with disability, frailty, and mortality (26).

In terms of self-reported measures of physical activity, Gispen et al. found that those with moderate or greater hearing loss reported less physical activity than participants with no hearing loss (17). In contrast, our results were only significant regarding the report of vigorous activities. These discrepancies may be due to differences in the instruments used to assess self-reported physical activity. Our assessment was limited to two questions about the last month's participation in vigorous activity and walking for exercise, whereas Gispen et al. used a more detailed questionnaire, including information about the frequency, intensity, and duration of activities, increasing their sensitivity to detect differences in self-reported physical activity.

Several mechanisms have been proposed to explain the relationship between hearing loss and physical activity. Persons with hearing loss may experience social isolation (14,27) and are at greater risk for depression (28), which may affect their activity levels. Hearing loss also increases cognitive load (29) and can make it more difficult for individuals to focus on other tasks simultaneously, such as being attentive while moving or being aware of their surroundings. Older adults with hearing loss are also at greater risk for falls (11), and avoiding physical activity may be a preventative coping mechanism. Although the conceptual framework behind our hypothesis is that hearing loss is associated with lower physical activity levels and downstream poorer physical function, we explored the role of physical function in sensitivity analyses. Although findings were not statistically significant, they remained in the direction of lower and more fragmented activity.

A novel finding in this study is that compared to hearing aid users, nonusers had more fragmented physical activity measured via wrist accelerometry. Furthermore, although effect estimates suggested lower counts and minutes of activity among nonusers compared to hearing aid users in the sample including all participants with hearing loss, findings were not statistically significant, consistent with the study by Gispen et al. (17). This may be partly due to a small sample size of hearing aid users and a lack of information on individual patterns of use. However, we did find significant associations when we restricted to those with moderate or greater hearing loss in sensitivity analyses. Older adults with moderate or greater hearing loss are more likely to use and benefit from hearing aids compared to those with milder hearing loss, and our findings suggest that it is possible that hearing aid use is beneficial in increasing physical activity. However, we remain cautious with our inferences given the small sample size in this analysis. Interestingly, a study from the Baltimore Longitudinal Study of Aging found that hearing aid users had better walking endurance on a 400-m walk test (30). We also found that participants who did not use hearing aids had greater odds of not walking for exercise in the last month compared to those who did. These findings may indicate that hearing aid users may be more likely to engage in deliberate activity, or are more conscious about their health and activity, but future research with randomized controlled trials is needed to understand how their overall physical activity changes.

Our findings do not support that there are sex differences in the association between hearing loss and physical activity. While findings were consistently stronger, and more often statistically supported in men than women, the interaction terms between hearing and sex were not significant. The sex differences we described may be explained by different statistical power rather than moderation by sex. Still, previous studies indicate that, in general, men are more physically active mainly through vigorous activities but spend more time sedentary than women who tend to engage in light-intensity activity more consistently throughout the day (31,32). In that context, it is possible that men with hearing loss may stop performing vigorous activities, and consequently, their overall physical activity levels are more affected than women. Although research on this association is sparse, Gispen et al. (17) found no significant sex differences in both accelerometer-measured and self-reported activities. Future studies with larger samples may be better suited to identify whether sex differences in the association between hearing and physical activity exist.

There are some limitations in our study. First, the cross-sectional nature of the analysis prevents us from establishing temporality in the associations we investigated. However, previous research on physical activity as a risk factor for hearing loss suggests that this relationship is modest, making it unlikely that our findings can be explained by reverse causation (ie, low physical activity leading to hearing loss) (33,34). Second, our binary hearing aid use measure misses patterns and time using aids, and unmeasured factors such as comprehensive socioeconomic status, health literacy, hearing care access, and acceptability prevent us from making inferences about the role of hearing aids in improving physical activity among older adults with hearing loss. Third, the relatively small sample size limits our statistical power to have more precise comparisons in subgroup analyses. Fourth, the accelerometry data from NHATS does not differentiate inactivity from sleep, limiting our ability to fully characterize the 24-hour physical behavior. Lastly, we did not categorize active minutes into different activity intensities (eg, light, moderate, and vigorous). Although this would improve the characterization of physical activity patterns, activity counts-per-minute thresholds to classify intensities using wrist-worn accelerometers have not been validated among older adults (23). Thus, we opted for only differentiating between inactive and active minutes.

One strength of this study is the reporting of population-level physical activity data among older adults, a group that often has been overlooked in physical activity research. Epidemiological data are vital for developing and advocating for resources to increase physical activity in populations with hearing loss (35). Another strength is the use of both accelerometry-derived and self-report measures to capture different aspects of physical activity (36–38). For instance, accelerometry provides data on activity counts and patterns over the day as a function of hearing loss. Specifically, wrist accelerometry has been widely used in epidemiological studies due to its low burden and better compliance among participants. Although there are some inherent limitations, such as detecting posture or type of physical activity, evidence shows that it is a valid and reliable tool to quantify activity (23). On the other hand, self-reported measures provide insight into the variations in types of physical activities related to hearing loss. Together, these data contribute to a better understanding of physical activity behavior in this population of older adults which can help guide the development of targeted physical activity behavior-change interventions (39).

Conclusion

In a representative sample of older adults in the United States, hearing loss was associated with lower activity counts, fewer active minutes, and more fragmented activity. Being active is fundamental for healthy aging, and providers should consider hearing loss as a potential barrier to physical activity when caring for older adults. Future research to better understand how hearing loss affects physical activity among older adults and whether hearing interventions play a protective role is warranted.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of Interest

N.S.R. is an advisor to Neosensory. J.A.S. is part of the editorial team of *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*. The other authors declare no conflict.

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References

1. Cunningham C, O' Sullivan R, Caserotti P, Tully MA. Consequences of physical inactivity in older adults: a systematic review of reviews and meta-analyses. *Scand J Med Sci Sports*. 2020;30(5):816–827. https://doi.org/10.1111/sms.13616
2. Leveille SG, Guralnik JM, Ferrucci L, Langlois JA. Aging successfully until death in old age: opportunities for increasing active life expectancy. *Am J Epidemiol*. 1999;149(7):654–664. https://doi.org/10.1093/oxfordjournals.aje.a009866
3. Hardy SE, Kang Y, Studenski SA, Degenholtz HB. Ability to walk 1/4 mile predicts subsequent disability, mortality, and health care costs. *J Gen Intern Med*. 2011;26(2):130–135. https://doi.org/10.1007/s11606-010-1543-2
4. Sun F, Norman IJ, While AE. Physical activity in older people: a systematic review. *BMC Public Health*. 2013;13:449. https://doi.org/10.1186/1471-2458-13-449
5. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181–188. https://doi.org/10.1249/mss.0b013e31815a51b3
6. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. 2020;54(24):1451–1462. https://doi.org/10.1136/bjsports-2020-102955
7. Piercy KL, Troiano RP, Ballard RM, et al. The Physical Activity Guidelines for Americans. *JAMA*. 2018;320(19):2020–2028. https://doi.org/10.1001/jama.2018.14854
8. Goman AM, Reed NS, Lin FR. Addressing estimated hearing loss in adults in 2060. *JAMA Otolaryngol Head Neck Surg*. 2017;143(7):733–734. https://doi.org/10.1001/jamaoto.2016.4642
9. Tian R, Almeida OP, Jayakody DMP, Ford AH. Association between hearing loss and frailty: a systematic review and meta-analysis. *BMC Geriatr*. 2021;21(1):333. https://doi.org/10.1186/s12877-021-02274-y
10. Chen DS, Betz J, Yaffe K, et al.; Health ABC study. Association of hearing impairment with declines in physical functioning and the risk of disability in older adults. *J Gerontol A Biol Sci Med Sci*. 2015;70(5):654–661. https://doi.org/10.1093/gerona/glu207
11. Jiam NT, Li C, Agrawal Y. Hearing loss and falls: a systematic review and meta-analysis. *Laryngoscope*. 2016;126(11):2587–2596. https://doi.org/10.1002/lary.25927
12. Martinez-Amezcua P, Suen JJ, Lin F, Schrack JA, Deal JA. Hearing impairment and objectively measured physical activity: a systematic review. *J Am Geriatr Soc*. 2022;70(1):301–304. https://doi.org/10.1111/jgs.17529
13. Campos J, Ramkhalawansingh R, Pichora-Fuller MK. Hearing, self-motion perception, mobility, and aging. *Hear Res*. 2018;369:42–55. https://doi.org/10.1016/j.heares.2018.03.025
14. Shukla A, Harper M, Pedersen E, et al. Hearing loss, loneliness, and social isolation: a systematic review. *Otolaryngol Head Neck Surg*. 2020;162(5):622–633. https://doi.org/10.1177/0194599820910377
15. Wunderlich A, Vogel O, Šömen MM, et al. Dual-task performance in hearing-impaired older adults—study protocol for a cross-sectional mobile brain/body imaging study. *Front Aging Neurosci*. 2021;13:773287. https://doi.org/10.3389/fnagi.2021.773287
16. Sharma RK, Chern A, Golub JS. Age-related hearing loss and the development of cognitive impairment and late-life depression: a scoping overview. *Semin Hear*. 2021;42(1):10–25. https://doi.org/10.1055/s-0041-1725997
17. Gispen FE, Chen DS, Genther DJ, Lin FR. Association between hearing impairment and lower levels of physical activity in older adults. *J Am Geriatr Soc*. 2014;62(8):1427–1433. https://doi.org/10.1111/jgs.12938
18. Kuo P, Di J, Ferrucci L, Lin FR. Analysis of hearing loss and physical activity among US adults aged 60-69 years. *JAMA Netw Open*. 2021;4(4):e215484. https://doi.org/10.1001/jamanetworkopen.2021.5484
19. Martinez-Amezcua P, Dooley EE, Reed NS, et al. Association of hearing impairment and 24-hour total movement activity in a representative sample of US adults. *JAMA Netw Open*. 2022;5(3):e222983. https://doi.org/10.1001/jamanetworkopen.2022.2983
20. Schrack JA, Skehan ME, Zipunnikov V, Freedman VA. 2022. *National Health and Aging Trends Study Accelerometry User*

Guide: Beta Release. Baltimore, MD: Johns Hopkins University Bloomberg School of Public Health. https://www.nhats.org/sites/default/files/2022-07/NHATS%20Accelerometry%20Beta%20User%20Guide.pdf

21. Schrack JA, Zipunnikov V, Goldsmith J, et al. Assessing the "physical cliff": detailed quantification of age-related differences in daily patterns of physical activity. *J Gerontol A Biol Sci Med Sci.* 2014;69(8):973–979. https://doi.org/10.1093/gerona/glt199
22. Koster A, Shiroma EJ, Caserotti P, et al. Comparison of sedentary estimates between activPAL and hip- and wrist-worn ActiGraph. *Med Sci Sports Exerc*. 2016;48(8):1514–1522. https://doi.org/10.1249/MSS.0000000000000924
23. Liu F, Wanigatunga AA, Schrack JA. Assessment of physical activity in adults using wrist accelerometers. *Epidemiol Rev.* 2022;43(1):65–93. https://doi.org/10.1093/epirev/mxab004
24. Freedman VA, Schrack JA, Skehan ME, Kasper JD. 2022. *National Health and Aging Trends Study User Guide: Rounds 1-11 Final Release*. Baltimore. MD: Johns Hopkins University School of Public Health. https://www.nhats.org/sites/default/files/2022-11/NHATS_User_Guide_R11_Final_Release.pdf. Accessed Feb 3, 2023
25. Phu S, Kirk B, Bani Hassan E, et al. The diagnostic value of the Short Physical Performance Battery for sarcopenia. *BMC Geriatr.* 2020;20(1):242. https://doi.org/10.1186/s12877-020-01642-4
26. Wanigatunga AA, Di J, Zipunnikov V, et al. Association of total daily physical activity and fragmented physical activity with mortality in older adults. *JAMA Netw Open*. 2019;2(10):e1912352. https://doi.org/10.1001/jamanetworkopen.2019.12352
27. Mick P, Kawachi I, Lin FR. The association between hearing loss and social isolation in older adults. *Otolaryngol Head Neck Surg.* 2014;150(3):378–384. https://doi.org/10.1177/0194599813518021
28. Shukla A, Reed NS, Armstrong NM, Lin FR, Deal JA, Goman AM. Hearing loss, hearing aid use, and depressive symptoms in older adults—findings from the Atherosclerosis Risk in Communities Neurocognitive Study (ARIC-NCS). *J Gerontol B Psychol Sci Soc Sci*. 2021;76(3):518–523. https://doi.org/10.1093/geronb/gbz128
29. Lin FR, Ferrucci L, Metter EJ, An Y, Zonderman AB, Resnick SM. Hearing loss and cognition in the Baltimore Longitudinal Study of Aging. *Neuropsychology.* 2011;25(6):763–770. https://doi.org/10.1037/a0024238
30. Martinez-Amezcua P, Kuo P, Reed NS, et al. Association of hearing impairment with higher-level physical functioning and walking endurance: results from the Baltimore Longitudinal Study of Aging. *J Gerontol A Biol Sci Med Sci.* 2021;76(10):e290–e298. https://doi.org/10.1093/gerona/glab144
31. Schrack JA, Cooper R, Koster A, et al. Assessing daily physical activity in older adults: unraveling the complexity of monitors, measures, and methods. *J Gerontol A Biol Sci Med Sci.* 2016;71(8):1039–1048. https://doi.org/10.1093/gerona/glw026
32. Martin KR, Koster A, Murphy RA, et al. Changes in daily activity patterns with age among US men and women: NHANES 2003–2004 and 2005–2006. *J Am Geriatr Soc.* 2014;62(7):1263–1271. https://doi.org/10.1111/jgs.12893
33. Martinez-Amezcua P, Garcia Morales E, Gabriel KP, et al. The association between midlife leisure-time physical activity and hearing loss in late-life in the Atherosclerosis Risk in Communities (ARIC) Study. *J Gerontol A Biol Sci Med Sci.* 2023;78(7):1292–1299. https://doi.org/10.1093/gerona/glac194
34. Haas PJ, Bishop CE, Gao Y, Griswold ME, Schweinfurth JM. Relationships among measures of physical activity and hearing in African Americans: the Jackson Heart Study. *Laryngoscope.* 2016;126(10):2376–2381. https://doi.org/10.1002/lary.25924
35. Martin Ginis KA, van der Ploeg HP, Foster C, et al. Participation of people living with disabilities in physical activity: a global perspective. *Lancet.* 2021;398(10298):443–455. https://doi.org/10.1016/S0140-6736(21)01164-8
36. Ma JK, McCracken LA, Voss C, Chan FHN, West CR, Martin Ginis KA. Physical activity measurement in people with spinal cord injury: comparison of accelerometry and self-report (the Physical Activity Recall Assessment for People with Spinal Cord Injury). *Disabil Rehabil.* 2020;42(2):240–246. https://doi.org/10.1080/09638288.2018.1494213
37. Nigg CR, Fuchs R, Gerber M, et al. Assessing physical activity through questionnaires—a consensus of best practices and future directions. *Psychol Sport Exerc*. 2020;50:101715. https://doi.org/10.1016/j.psychsport.2020.101715
38. Ramsey KA, Meskers CGM, Maier AB. Every step counts: synthesising reviews associating objectively measured physical activity and sedentary behaviour with clinical outcomes in community-dwelling older adults. *Lancet Healthy Longev*. 2021;2(11):e764–e772. https://doi.org/10.1016/S2666-7568(21)00203-8
39. Michie S, Atkins L, West R. 2014. *The Behaviour Change Wheel: A Guide to Designing Interventions*. London: Silverback Publishing. http://www.behaviourchangewheel.com