Hearing Impairment and Physical Activity and Physical Functioning in Older Adults: Baseline Results from the ACHIEVE Trial

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Abstract

Background: Hearing loss is associated with restricted physical activity (PA) and impaired physical functioning, yet the relationship between severity of hearing impairment (HI) and novel PA measures in older adults with untreated HI is not well understood.

Methods: Analyses included 845 participants aged ≥70 years (mean=76.6y) with a better-hearing ear pure-tone average (PTA) ≥30 and <70 dB in the Aging and Cognitive Health Evaluation in Elders (ACHIEVE) study who wore an ActiGraph accelerometer for 7 days. Physical functioning measures included grip strength and the Short Physical Performance Battery (SPPB). Linear regression models estimated the association by HI level (moderate or greater [PTA≥40 dB] vs. mild [PTA<40 dB]) and continuous hearing with total daily activity counts, active minutes/day, activity fragmentation, grip strength, and gait speed. Logistic regression models estimated odds ratios (ORs) and 95% confidence intervals (CIs) of poor performance on the SPPB (≤6) and its subtests (≤2). Mixed-effects models estimated differences by HI level in activity by time of day.

Results: Participants with moderate or greater HI had poorer physical functioning, particularly balance (OR=2.17, 95% CI=1.29-3.67), vs. those with mild impairment. There was no association of HI level with activity quantities or fragmentation. For diurnal patterns of activity, participants with moderate or greater HI had fewer activity counts in the afternoon (12:00pm-05:59pm).

Conclusions: Older adults with worse hearing had shifted diurnal patterns and poorer balance performance. Exercise programs should be tailored to older adults with different levels of HI to maintain PA and physical functioning, particularly balance control.

Keywords: hearing loss, activity fragmentation, diurnal patterns, accelerometry, balance performance

Introduction

The prevalence of hearing loss increases with every decade after age 50 years.[1] According to statistics from 1999-2010 National Health and Nutrition Examination Survey (NHANES), one in three adults aged 65 to 74 had hearing loss, and almost half of the adults aged 75 and older reported difficulty hearing.[2] Previous studies have reported that older adults with hearing impairment experience social isolation, impaired physical functioning, and mobility limitations.[3–7] Specifically, older adults with hearing impairment tend to have poorer balance, slower gait speed, and reduced walking endurance,[4,5,8] as well as greater odds of difficulties with activities of daily living (ADL) or instrumental activities of daily living (IADL).[3]

Although these studies highlight the detrimental effects of impaired hearing on physical functioning, it is unknown whether physical performance differs by severity of hearing loss. Further, very few studies have examined whether hearing impairment may contribute to constrained participation in physical activity, which may further contribute to adverse health outcomes in older adults.[3,9] Previous studies investigating the association between hearing loss and physical activity have used mainly self-reported measures of activity, which may not adequately capture time spent in light activities and may be biased by problems with recall, particularly in older adults.[10] Accelerometers provide the opportunity to capture physical activity quantities and patterns in greater detail than questionnaires, but their use in research related to older adults with hearing impairment has been limited. Gipsen and colleagues examined the relationship between hearing impairment and accelerometer-measured physical activity in adults aged 70 and older but focused solely on time spent in moderate and vigorous activities per week which may be prone to misclassification or measurement error.[9] Moreover, novel metrics of daily activity quantity and patterns, such as activity fragmentation and diurnal patterns of activity, have been linked with measures of functional status and mortality over and above traditional measures of activity intensity in older adults.[11–13] Unraveling accelerometer-measured physical activity using these novel metrics in older adults with hearing impairment may shed light on the impacts of hearing impairment on daily activity.

We used baseline data from the Aging and Cognitive Health Evaluation in Elders (ACHIEVE) study to: (1) characterize physical activity quantities, activity fragmentation, diurnal patterns of activity, and physical functioning in this cohort of community-dwelling older adults with untreated hearing impairment and (2) investigate the cross-sectional associations between severity of hearing impairment and physical activity as well as physical functioning. Characterizing physical functioning among older adults with hearing impairment, and the potential modifying role of physical activity, may provide evidence for strategies to alleviate the effects of hearing impairment on daily activity and functioning.

Methods

The ACHIEVE study is a randomized controlled trial that aimed to examine the efficacy of a best-practices hearing intervention compared to a successful aging health education control on rate of 3-year decline in global cognitive function. The detailed study methods were previously described.[14] Briefly, from 2018-2019, ACHIEVE recruited community-dwelling older adults aged 70 to 84 years with untreated hearing impairment (better-hearing ear pure-tone average (PTA) ≥30 and <70 decibels [dB] hearing level [HL]).[14] In addition, participants had a Word Recognition in Quiet score ≥60% in the better-hearing ear.

Approximately a quarter (n=238) of ACHIEVE participants were recruited from the ongoing Atherosclerosis Risk in Communities (ARIC) cohort study from four US communities: Forsyth County, NC; Jackson, MS; suburbs of Minneapolis, MN; and Washington County, MD, and the rest (n=739) were newly recruited ("de novo") from the surrounding communities. At the time of enrollment, participants had to be free of substantial cognitive impairment, determined by Mini-Mental State Exam (MMSE) score ≥23 for those with a high school degree or less and ≥25 for those with some college education or more.[15] Older adults were excluded if they had: 1) self-reported difficulty in two or more activities of daily living, 2) prior dementia diagnosis, 3) vision impairment, 4) medical contraindication to hearing treatment, 5) untreatable conductive hearing impairment, or 6) unwillingness to regularly wear hearing aids. The current study uses the baseline visit data collected between 2018 and 2019. Informed consent was obtained from all participants and the study protocol was approved by the Institutional Review Board governing each field center.

Audiometric Hearing Assessment

All participants in the ACHIEVE study had untreated adult-onset bilateral hearing impairment. Hearing was defined using the better-hearing ear PTA for four frequencies: 0.5, 1, 2, and 4 kHz. We used both continuous PTA level and a dichotomous measure of severity of hearing impairment (moderate or greater: PTA ≥40 dB vs. mild: PTA <40 dB) for the analyses.

Physical Activity

Physical activity was assessed using a triaxial wrist-worn ActiGraph GT9X accelerometer (ActiGraph Corp., Pensacola, FL) worn on the non-dominant wrist for 7 days, 24 hours per day in the free-living environment. Movement in units of gravity (g) was collected at a sampling rate of 80Hz per second. Participants returned the accelerometer to the clinical research center by mail after completing the 7-day data collection. Data were downloaded and preprocessed into 1-minute epoch level activity counts using ActiLife Software (version 6.13.4). For data analysis, a minimum of 3 valid days was required for inclusion; days with more than 10% of data missing were excluded. For valid days (≤10% of data missing), missing values were imputed as the average activity counts for the same minute over all other valid days for each participant.[11]

For each participant, we averaged the activity counts across valid days for each minute. Total daily physical activity counts (TAC) were derived by summing the activity counts for each minute of the day from 05:00 am to 10:59 pm. Because of potential non-normality of the distribution for TAC, we also log transformed total activity counts using the natural logarithm to derive logged total activity counts (LTAC). Diurnal patterns of activity counts were summarized into total activity counts for each of four 6-hour time intervals (12:00 am to 5:59 am, 6:00 am to 11:59 am, 12:00 pm to 5:59 pm, and 6:00 pm to 11:59 pm).[11,16]

To calculate daily active and sedentary time, each minute was labeled as an active state if the activity counts in that minute were ≥1,853 and as a sedentary if the activity counts were <1,853.[17] Active minutes and sedentary minutes were derived by summing up total time spent in active states and sedentary states over a day from 05:00 am to 10:59 pm, respectively. Consecutive active minutes were summed to derive active bouts. We then calculated an activity fragmentation index (defined as an active-to-sedentary transition probability [ASTP]) as the reciprocal of the mean activity bout length for the day from 05:00 am to 10:59 pm.[12] A higher activity fragmentation index indicates bouts of activity are more fragmented or "broken up" throughout the day, and that the participant is more likely to transition from an active state to a sedentary state.

Physical Functioning

Grip strength was measured using a Jamar Hydraulic Hand Dynamometer with two trials of the participant's preferred or best hand, with the maximum grip strength used for the analysis. The Short Physical Performance Battery (SPPB) was used to measure chair stands, standing balance, and gait speed, with 0-4 points assigned for each task and higher scores indicating better physical function.[18] For chair stands, participants were instructed to stand from a seated position in a straight-backed chair five times as quickly as possible with arms crossed over the chest. Balance consisted of three progressively harder standing tasks: feet side-by-side, semi-tandem, and full-tandem. Participants were instructed to hold each position for 10 seconds. Usual gait speed in meters per second was measured over a 4-meter course and the faster of two trials was used in the analysis.[18] Walking aids were permitted. The scores of the three subtests were summed to generate a composite SPPB score, ranging from 0 to 12. We examined the SPPB scores both continuously and dichotomously, with composite score ≤6 and component score ≤2 used to define poor performance.[8]

Covariates

Sociodemographic characteristics including age, sex, race, and education were collected by interview. Height and weight were assessed using a stadiometer and a calibrated scale, respectively. Body mass index (BMI) was calculated as kilograms per meter squared (kg/m^2). Participants reported smoking status (never, former, or current) and chronic conditions including cardiovascular disease, high cholesterol, diabetes, stroke, arthritis, respiratory disease, kidney disease, liver disease, human immunodeficiency virus infection (HIV), and Parkinson's disease. Number of comorbidities were classified into one, two, or three or more conditions.

Statistical Analysis

Sociodemographic characteristics, health conditions, accelerometer metrics, and physical function variables for all participants, by study site, and by participant type (ARIC vs. de novo) were summarized using mean (SD) or frequency and percentage. Chi-square tests were used for categorical variables. When comparing these characteristics by study site, one-way analysis of variance (ANOVA) tests were used for continuous variables except for SPPB total and subscores, where Kruskal-Wallis tests were used. When comparing these characteristics by participant type, independent t-tests were used for continuous variables except for SPPB total and subscores where Mann-Whitney tests were used.

Sociodemographic and health characteristics were also compared by hearing impairment level (moderate or greater vs. mild) using independent t-tests for continuous variables and chi-square tests for categorical variables. Age- and sex-adjusted predicted marginal means of continuous variables for physical activity and physical function were further compared by hearing impairment to adjust for differences in age and sex distributions between groups.

Linear regression models were used to examine the association between hearing impairment and TAC, LTAC, active time, sedentary time, activity fragmentation, grip strength, and gait speed. Linearity and multicollinearity were checked using scatter plots of outcome variables versus predictor variables and variance inflation factor (VIF), respectively. Logistic regression models were used to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) of having poor performance on the SPPB (score ≤6) and its subtests (score ≤2) comparing participants with moderate or greater versus those with mild hearing impairment. Linear mixed effects models tested differences in TAC across four 6-hour time intervals of the day between participants with moderate or greater vs. mild hearing impairment. An unstructured correlation matrix was used to account for within-participant clustering of time intervals and restricted maximum likelihood (REML) estimation was applied to fit the models. Multivariable regression models were adjusted for age, sex, race, study site, education years, BMI, smoking status, and comorbidities.

Sensitivity analyses were conducted to investigate whether the results were robust after treating hearing as a continuous variable (per 10-dB HL). Linear regression models were used to estimate the beta coefficients of TAC, LTAC, active time, sedentary time, activity fragmentation, grip strength, and gait speed by each 10-dB higher in hearing level. Logistic regression models were used for dichotomous outcomes including SPPB tests and subtests. We additionally used partial proportional odds (PPO) models for SPPB total scores and continuous SPPB subscores to estimate the ORs of having lower scores by both dichotomous and continuous hearing measures.[19,20] We first tested the proportional odds assumptions for all independent variables in all models using Brant test and relaxed the parallel-lines constraint for independent variables in which proportional odds assumptions were violated.[19] SPPB total score was categorized into four groups for PPO models (group 1: score 1-3; group 2: score 4-6; group 3: score 7-9; group 4: score 10-12). The dichotomous hearing impairment variable meets the proportional odds assumptions for all dependent variables (SPPB total and subscores) **(Supplementary Table 4)**. The continuous hearing level variable meets the proportional odds assumptions for SPPB balance, gait speed, and total scores but not SPPB chair stand subscore **(Supplementary Table 6)**. Covariates in the models that did not meet the proporational odds assumptions are listed at the footnotes below Supplementary Table 4 and 6.

We further stratified the analytic sample to lower activity and higher activity groups based on the mean TAC. Linear and logistic regression models for both continuous and categorical hearing measures were conducted for each group separately.

All significance tests were conducted using two-sided tests with a significance level α set as 0.05. All data analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC) and Stata 14.1 (StataCorp LLC, College Station, TX). All figures were made using R (v. 4.2.2) package ggplot2.

Results

Among 977 participants in the ACHIEVE cohort, 887 participants had complete accelerometer data. After removing 41 participants with less than 3 valid days of wear time and one outlier for extremely high daily activity counts (>99th percentile and potential device error), the final analytic sample was 845 participants aged 76.6 (SD=4.0) years. Participants were recruited from Forsyth (n=212), Jackson (n=202), Minnesota (n=197), and Washington County (n=234) study sites. Over half (51.8%) of the participants were women and the majority (89.2%) of them were White. Fifty-six percent of participants (n=472) had mild hearing impairment, and 373 had moderate or greater hearing impairment. The average number of valid accelerometer days was 7.3 (SD=0.9). After removing typical sleep time (11pm to 5am), participants had an average of 1,894,202 total activity counts per day, 24% activity fragmentation, and 383 mins (6.4 hours) of active time/day. Among 838 participants with complete grip strength assessment, the average grip strength was 22.1 (SD=5.3) kg for women and 36.6 (8.2) kg for men. The average gait speed was 1.02 (SD=0.22) m/s among 841 participants with complete walking test. The average SPPB score among 827 participants was 10.0 (SD=2.01). The sample characteristics, daily activity quantities and patterns, and physical function outcomes by hearing impairment, study site, and participant type are shown in **Table 1, Supplementary Table 1, and Supplementary Table 2**, respectively. **Supplementary Figure 1** displays the plotted means and distribution of physical activity and physical function variables by study site.

Participants with moderate or greater hearing impairment had lower activity counts (i.e., TAC, LTAC), more fragmented patterns of activity (i.e., higher ASTP), and fewer active minutes and more sedentary minutes compared to those with mild hearing impairment

(**Table 1; Figure 1**). For physical function, older adults with moderate or greater hearing impairment had slower gait speed (1.00 vs. 1.04, p=0.006), and lower SPPB total score (9.65 vs. 10.27, p<0.001) and lower scores in balance and chair stands components compared to those with mild hearing impairment (p<0.05 for all; **Table 1**). We found similar results when comparing age- and sex-adjusted means of physical activity and physical function measures between participants with moderate or greater vs. mild hearing impairment (**Supplementary Table 3**).

Unadjusted linear regression models showed that compared to participants with mild hearing impairment, those with moderate or greater hearing impairment had 123,465 fewer activity counts per day, 0.07 fewer LTAC, 1.2% higher fragmentation of activity patterns, 22 fewer minutes spent in active states, and 0.04 m/s slower gait speed (p<0.01 for all; **Table 2, Model 1**). These associations were diminished after adjusting for covariates. In the fully adjusted model, participants with moderate or greater hearing impairment had over double the odds of having a low SPPB balance subscore (≤2) compared to those with mild hearing impairment (OR=2.17, 95% CI=1.29-3.67, p=0.004; **Table 2, Model 3**). Using PPO models, moderate or greater hearing impairment was associated with 81% greater odds of having lower SPPB balance scores in the fully adjusted model (OR=1.81, 95% CI=1.25-2.64, p=0.002; **Supplementary Table 4**). The significant association between hearing impairment and SPPB total score was attenuated after adjusting for education, BMI, smoking status, and comorbidities.

Similar patterns of diurnal physical activity were observed for participants with moderate or greater hearing impairment and mild hearing impairment, with a rapid increase in activity in the morning, a gradual decline in the afternoon, and a steeper decline in the night (**Figure 2**). However, linear mixed effects models showed that participants with moderate or greater hearing impairment had more activity counts overnight (12:00am to 05:59am) and fewer activity counts in the afternoon (12:00pm to 05:59pm) compared to those with mild hearing impairment in the fully adjusted model (**Table 3**).

Sensitivity analyses indicated that when hearing was modeled continuously, each 10-dB increase in PTA hearing level (i.e., worse hearing) was associated with 64% greater odds of having a low SPPB balance score (≤2) (OR=1.64, 95% CI=1.16-2.34, p=0.006; **Supplementary Table 5).** We found similar results using PPO models; for every 10-dB worse in hearing level, participants had 53% greater odds of having lower SPPB balance scores in the fully adjusted model (OR=1.53, 95% CI=1.17-2.00, p=0.002; **Supplementary Table 6**). Each 10-dB higher in PTA hearing level was also associated with 44% greater odds of having a a higher SPPB chair stand subscore (1-4) compared to those with score 0 in the fully adjusted model (OR=1.44, 95% CI=1.02-2.03, p=0.041; **Supplementary Table 6**). Analysis stratified by mean TAC showed that participants with moderate or greater hearing impairment had over three times the odds of having a low SPPB balance subscore compared to those with mild hearing impairment (OR=3.79, 95% CI=1.40-10.26, p=0.009) only in the higher activity group. Using the continuous hearing measure, we found that every 10-dB worse in hearing level was associated with 2.5 times greater odds of having a low SPPB balance score (OR=2.49, 95% CI=1.23-5.03, p=0.011) and 3.6 times greater odds of having a low SPPB total score (OR=3.62, 95% CI=1.10-11.94, p=0.035) in the higher activity group (**Supplementary Table 7**). We did not find significant associations of hearing impairment with daily activity and physical function in the lower activity group.

Discussion

This study found that older adults with worse hearing function had altered activity patterns and poorer physical functioning, particularly in balance performance. These findings were robust after adjusting for demographics, health conditions, and health behaviors. Our study suggests that greater hearing impairment may impact daily activities, especially during the afternoon, and balance control which may lead to falls, mobility limitations, and in the long run, become a threat to maintaining independence.[21] Collectively, this work provides novel insights into the relationship between hearing impairment and physical activity and functioning and provides a basis for future longitudinal analyses.

The association between hearing impairment and physical activity have been investigated in previous studies. Gispen and colleagues found that individuals with moderate or greater hearing impairment had lower levels of physical activity among a group of adults aged 70 and older enrolled in NHANES (2005-2006).[9] These results were evident using both self-reported and accelerometer-measured physical activity data. Kuo and colleagues found that poorer hearing function (higher PTA hearing level) was associated with less time spent in light-intensity and moderate-to-vigorous physical activity, more time spent in sedentary behaviors, and a more fragmented physical activity pattern among 291 adults aged 60-69 enrolled in the NHANES.[22] Significant differences in these physical activity measures were also observed between participants with vs. without hearing impairment. The current study adds to these findings by exploring activity quantities and patterns in adults aged 70 and older across the hearing impairment spectrum. Although we found a significant association between severity of hearing impairment and activity quantities and patterns in the model adjusted for demographics, this association was diminished after further adjustment for health characteristics and behaviors, which might be due to homogeneity of the ACHIEVE cohort. Specifically, all participants enrolled in the ACHIEVE study had hearing impairment and the reference group is those with mild hearing impairment in statistical models, which is associated with a lower variation of exposure compared to other studies. Longitudinal studies are needed to explore whether hearing impairment leads to more fragmented activity patterns that differ by time of day, which may be a precursor to poor functional outcomes.[12]

Consistent with other study findings, we demonstrated an association between hearing and physical function, particularly balance control. Previous studies found that older adults with hearing impairment had poorer physical function, slower gait speed, reduced walking endurance, and greater difficulties in activities of daily living (ADLs).[4,5,8] Similarly, we found that participants with moderate or greater hearing impairment had greater odds of having a low SPPB balance subscore compared to mild hearing impairment. Continuous hearing level was also associated with SPPB total score in the higher activity group. These results add to the literature suggesting that older adults with hearing impairment may be at greater risk for impaired balance, mobility limitations, and disability. Further, our findings suggest that for older adults who are already active, the severity of hearing impairment may be an important factor impacting the maintenance of physical functioning, particularly balance control.

The potential underlying mechanisms between hearing impairment and physical function have been discussed in previous studies. First, due to the shared location for cochlear and vestibular systems, a damage in the inner ear may contribute to both hearing impairment and poor balance control.[23] Second, hearing impairment may lead to reduced physical functioning through increased cognitive load. It has been found that older adults with hearing impairment had poor performance in executive function tests which require attentional resources.[24,25] Third, older adults with hearing impairment experience depression and social isolation which can contribute to activity restrictions and accelerated decline in physical functioning.[6,26,27] Fourth, hearing and physical functioning may share the same causes such as cardiovascular risk factors.[28,29] Interestingly, our findings stratified by higher vs lower daily activity suggest that decrements in balance may be stronger among those with higher daily activity. Future longitudinal research is needed to better discern the temporal association of declines in physical activity and balance in older adults with hearing impairment.

Our study adds to these findings by using novel and informative measures to characterize patterns of daily activity measured by accelerometers. High activity fragmentation has been associated with poorer physical functioning and endurance, and greater mortality risk, over and above total daily activity.[30,31] Although our study did not find a significant association between hearing impairment and activity fragmentation in covariate-adjusted models, Kuo and colleagues demonstrated the link between poorer hearing function and a more fragmented activity pattern, suggesting that hearing impairment may interfere with the capacity and endurance to sustain prolonged activity.[22] It is possible that older adults with hearing impairment may stop more frequently while performing physical activity due to impaired balance and poor postural control.[32,33] For diurnal patterns of physical activity, our study extends prior findings by demonstrating that older adults with worse hearing function had fewer activity counts in the afternoon in adjusted models.[22,29] Collectively, these studies suggest diminished physiological capacity and reduced endurance among older adults with worse hearing function and reveal a need for longitudinal research to identify effective intervention strategies.

Several limitations should be noted. First, given the nature of a cross-sectional study, the temporality of the relationship between hearing impairment and physical activity cannot be demonstrated. Restrictions of physical activity participation may also contribute to hearing impairment in older adults. It has been found that higher physical activity is associated with reduced risk of hearing loss.[34] Future longitudinal studies are needed to explore the potential bidirectional association between hearing function and physical activity. Second, although accelerometers objectively record physical activity and minimize recall biases, the types of activities in which participants engage are undefined. Examining different types of physical activity in relation to hearing function may inform interventions to alleviate the impacts of hearing impairment on daily activities.

In conclusion, older adults with worse hearing function had shifted physical activity patterns and poor balance control. More severe hearing impairment may lead to physical activity restrictions, sedentary lifestyle, and poorer physical functioning, which increase the risk of developing mobility limitations and disability. Exercise programs tailored to older adults with different levels of hearing impairment are needed to promote physical activity and maintain physical functioning.

Acknowledgement

Members of the ACHIEVE Collaborative Research Group are listed at achievestudy.org. The Aging and Cognitive Health Evaluation in Elders (ACHIEVE) Study is supported by the National Institute on Aging (NIA) R01AG055426 and R01AG060502 with previous pilot study support from the NIA R34AG046548 and the Eleanor Schwartz Charitable Foundation, in collaboration with the Atherosclerosis Risk in Communities (ARIC) Study, supported by National Heart, Lung, and Blood Institute contracts (HHSN268201700001I, HHSN268201700002I, HHSN268201700003I, HHSN268201700005I, HHSN268201700004I). Neurocognitive data are collected by 2U01HL096812, 2U01HL096814, 2U01HL096899, 2U01HL096902, 2U01HL096917 from the NIH (NHLBI, NINDS, NIA and NIDCD), and with previous brain MRI examinations funded by R01HL70825 from the NHLBI. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The investigators thank the staff and participants of the ACHIEVE and ARIC studies for their important contributions and dedication to the study, Sonova / Phonak for in-kind donation of hearing technologies and training support of audiologists for the ACHIEVE study, and the members of the ACHIEVE DSMB (Doug Galasko, Julie Buring, Judy Dubno, Tom Greene, and Larry Lustig) for their guidance and insights during the course of the study.

Conflict of interest statement

FRL reports being a consultant to Frequency Therapeutics and Apple and being the director of a public health research center funded in part by a philanthropic gift from Cochlear Ltd to the Johns Hopkins Bloomberg School of Public Health. JB is entitled to equity and future royalties in MiDiagnostics. AAW, FRL, and JAS currently serve on the editorial board of JGMS. All other authors do not have conflict of interest to disclose.

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Table 1. Demographics, physical activity, and physical function by hearing impairment level for participants with accelerometer data (N=845) in the ACHIEVE study

Characteristic	All (N=845)	Hearing impairment Mild (n=472)	Hearing impairment Moderate or greater (n=373)	p-value
	Mean (SD) or n(%)			
Age (years)	76.62 (3.96)	76.18 (3.95)	77.17 (3.90)	**<0.001**
Female, n (%)	438 (51.83)	264 (55.93)	174 (46.65)	**0.007**
White, n (%)	754 (89.23)	424 (89.83)	330 (88.47)	0.527
Highest education attained, n (%)				**<0.001**
Eighth grade or some HS	29 (3.44)	8 (1.69)	21 (5.65)	
HS diploma or some college	365 (43.25)	184 (38.98)	181 (48.66)	
Bachelor's degree or higher	450 (53.32)	280 (59.32)	170 (45.70)	
Comorbid conditions reported, n (%)	2.37 (1.39)	2.25 (1.35)	2.52 (1.43)	**0.006**
BMI	28.84 (5.39)	28.59 (5.39)	29.15 (5.39)	0.129
Smoking, n (%)				0.423
Current	20 (2.37)	9 (1.91)	11 (2.95)	
Former	390 (46.15)	225 (47.67)	165 (44.24)	
Never	435 (51.48)	238 (50.42)	197 (52.82)	
Valid ActiGraph wear days	7.28 (0.87)	7.33 (0.90)	7.22 (0.83)	0.078
TAC (x1000 counts)	1894.20 (580.80)	1948.70 (587.23)	1825.24 (565.84)	**0.002**
LTAC	14.41 (0.32)	14.43 (0.32)	14.37 (0.32)	**0.002**
ASTP (%)	24.41 (6.23)	23.87 (6.16)	25.10 (6.25)	**0.004**
Active time (min/day)	382.76 (110.39)	392.69 (109.82)	370.20 (109.98)	**0.003**
Sedentary time (min/day)	697.24 (110.39)	687.31 (109.82)	709.80 (109.98)	**0.003**
Grip strength (kg)	29.16 (9.98)	28.59 (9.98)	29.88 (9.96)	0.064
Women (n=432)	22.14 (5.29)	22.17 (5.41)	22.09 (5.11)	0.886
Men (n=406)	36.64 (8.23)	36.70 (8.40)	36.57 (8.06)	0.881
Gait speed (m/s) (n=841)	1.02 (0.22)	1.04 (0.22)	1.00 (0.22)	**0.006**
SPPB chair stand subscore (n=835)	2.53 (1.29)	2.67 (1.24)	2.35 (1.32)	**<0.001**
≤2, n (%)	377 (45.15)	190 (40.69)	187 (50.82)	**<0.001**
SPPB balance subscore (n=837)	3.66 (0.79)	3.76 (0.66)	3.53 (0.92)	**<0.001**

≤2, n (%)	78 (9.32)	28 (6.00)	50 (13.51)	**<0.001**
SPPB gait speed subscore (n=841)	3.78 (0.54)	3.81 (0.50)	3.74 (0.59)	0.066
≤2, n (%)	35 (4.16)	18 (3.84)	17 (4.57)	0.059
SPPB total score (n=827)	10.00 (2.01)	10.27 (1.82)	9.65 (2.19)	**<0.001**
≤6, n (%)	54 (6.53)	22 (4.77)	32 (8.74)	**<0.001**

Note. BMI=body mass index. TAC=total activity counts. LTAC=logged total activity counts. ASTP=active-to-sedentary transition probability. SPPB=short physical performance battery.

* Independent t-tests were used for continuous variables except for SPPB total score and subscores where Mann-Whitney tests were used. Chi-square tests were used for categorical variables.

Table 2. Physical activity and physical function by hearing impairment

Outcomes	Moderate or greater vs. Mild Hearing Impairment								
	Model 1			Model 2			Model 3		
	β	*95% CI*	*p*-value	β	*95% CI*	*p*-value	β	*95% CI*	*p*-value
TAC (x1000 counts)	-123.46	-202.05, -44.88	**0.002**	-69.41	-147.35, 8.53	0.081	-41.81	-116.69, 33.07	0.273
LTAC	-0.07	-0.11, -0.02	**0.002**	-0.04	-0.08, 0.004	0.072	-0.02	-0.07, 0.02	0.259
ASTP (%)	1.23	0.39, 2.07	**0.004**	0.68	-0.16, 1.53	0.111	0.47	-0.34, 1.28	0.258
Active time (min/day)	-22.49	-37.43, -7.55	**0.003**	-15.05	-30.09, -0.02	0.050	-10.89	-25.47, 3.70	0.143
Sedentary time (min/day)	22.49	7.55, 37.43	**0.003**	15.05	0.02, 30.09	0.050	10.89	-3.70, 25.47	0.143
Grip strength (kg)	1.29	-0.07, 2.65	0.064	0.03	-0.89, 0.95	0.949	0.07	-0.86, 0.99	0.889
Gait speed (m/s)	-0.04	-0.07, -0.01	**0.005**	-0.02	-0.05, 0.004	0.100	-0.005	-0.03, 0.02	0.676
	OR	*95% CI*	*p-value*	*OR*	*95% CI*	*p-value*	*OR*	*95% CI*	*p-value*
SPPB chair stand subscore ≤2	1.51	1.14-1.98	**0.004**	1.25	0.92-1.70	0.151	1.10	0.80-1.51	0.568
SPPB balance subscore ≤2	2.45	1.51-3.98	**<0.001**	2.39	1.45-3.95	**0.001**	2.17	1.29-3.67	**0.004**
SPPB gait speed subscore ≤2	1.20	0.61-2.36	0.598	1.05	0.51-2.17	0.900	0.83	0.37-1.87	0.648
SPPB total score ≤6	1.91	1.09-3.35	**0.024**	1.71	0.94-3.10	0.076	1.47	0.77-2.80	0.237

*Note***.** TAC=total activity counts. LTAC=logged total activity counts. ASTP=active-to-sedentary transition probability. SPPB=short physical performance battery. OR=odds ratio. CI=confidence interval.

Linear regression models used for physical activity, grip strength, and gait speed. Logistic regression models used for SPPB total score and subscores. Model 1 is the unadjusted model. Model 2 is adjusted for age, sex, race, and center. Model 3 is additionally adjusted for education, BMI, smoking status, and comorbidities.

Table 3. Interaction effect of 6-h time intervals and hearing impairment on total daily activity counts (TAC) for each time interval.

	TAC (x1000 counts)			
	12:00 am to 5:59 am	6:00 am to 11:59 am	12:00 pm to 5:59 pm	6:00 pm to 11:59 pm
	Beta Coefficient (*95% CI*)			
Model 1				
Hearing impairment				
Mild	Reference	Reference	Reference	Reference
Moderate or greater	13.16 (-9.96, 36.28)	-34.05 (-59.73, -8.37)**	-57.19 (-86.15, -28.24)***	-40.47 (-73.21, -7.74)*
Model 2				
Hearing impairment				
Mild	Reference	Reference	Reference	Reference
Moderate or greater	22.32 (-1.05, 45.70)	-24.89 (-50.62, 0.84)	-48.03 (-76.80, -19.26)**	-31.31 (-63.60, 0.98)
Model 3				
Hearing impairment				
Mild	Reference	Reference	Reference	Reference
Moderate or greater	28.44 (5.08, 51.81)*	-19.94 (-45.41, 5.53)	-42.20 (-70.46, -13.95)**	-25.31 (-56.85, 6.23)

Note. TAC=total activity counts. CI=confidence interval.

Linear mixed effects model 1 is the unadjusted model. Model 2 is adjusted for age, sex, race, and center; Model 3 is additionally adjusted for education, BMI, smoking status, and comorbidities.

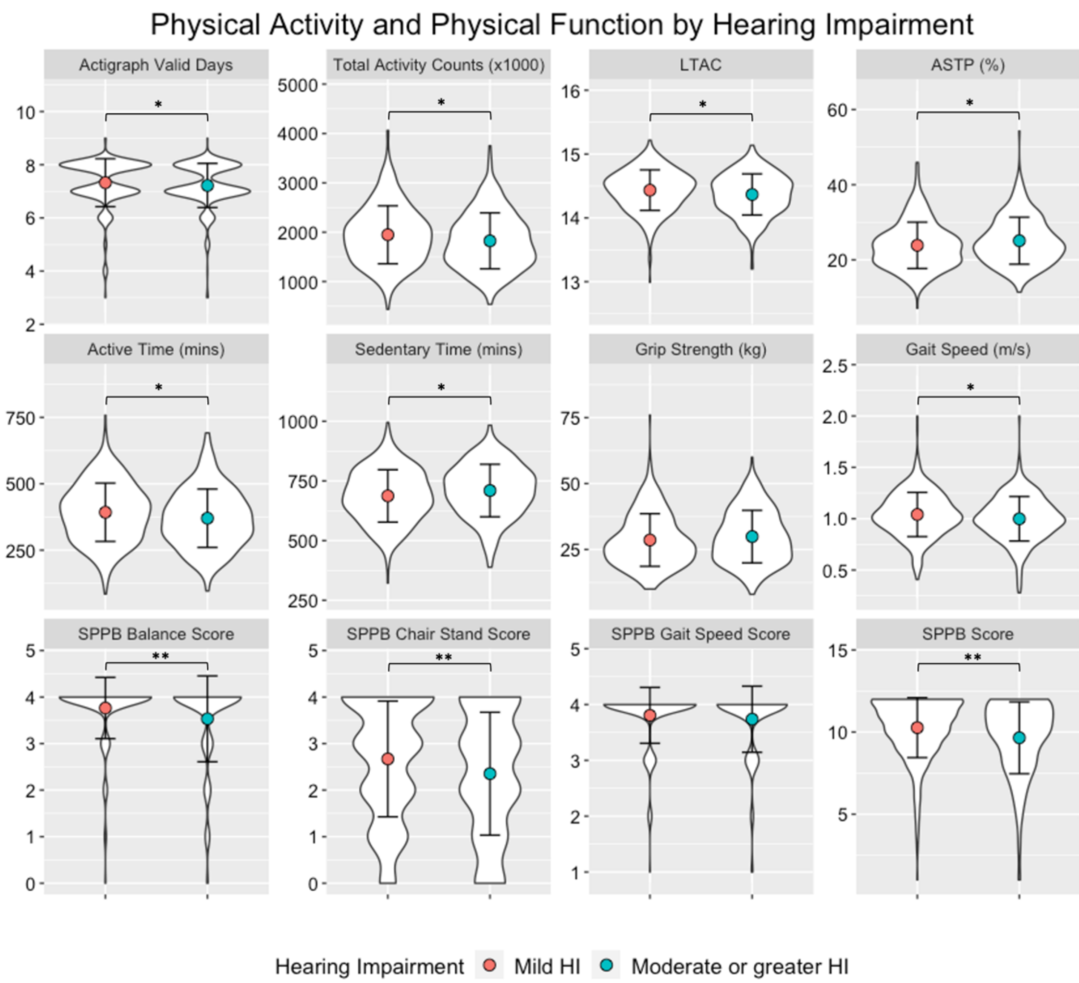
*p<.05, **p<.01, ***p<.001 for the difference between participants with mild and moderate or greater hearing level.

Figure Legend.

Figure 1. Means of physical activity and physical function variables by hearing impairment. Independent t-tests for physical activity, gait speed, and grip strength. Mann-Whitney tests for Actigraph valid days and SPPB (Short Physical Performance Battery) total and subscores. *$p<0.01$. **$p<0.001$.

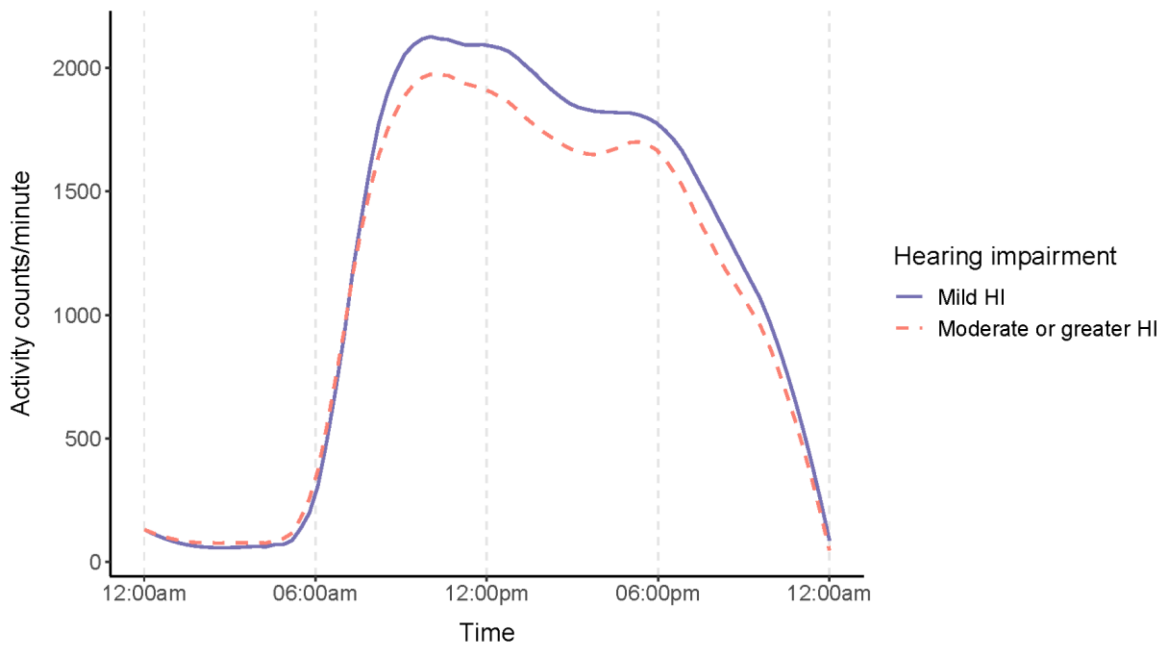
Figure 2. Smoothed 24-hour median activity counts per minute comparing participants with mild and moderate hearing impairment. Loess smooth method with a span of 0.2 was used for the figure.

Figure 1



Physical Activity and Physical Function by Hearing Impairment
Actigraph Valid Days
Total Activity Counts (x1000)
LTAC
ASTP (%)
Active Time (mins)
Sedentary Time (mins)
Grip Strength (kg)
Gait Speed (m/s)
SPPB Balance Score
SPPB Chair Stand Score
SPPB Gait Speed Score
SPPB Score
Hearing Impairment
Mild HI
Moderate or greater HI

Figure 2


Activity counts/minute
2000
1500
1000
500
0
12:00am
06:00am
12:00pm
06:00pm
12:00am
Time
Hearing impairment
Mild HI
Moderate or greater HI