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Relationships Among Measures of Physical Activity and Hearing in African Americans: The Jackson Heart Study

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Objectives/Hypothesis: To evaluate the relationships among measures of physical activity and hearing in the Jackson Heart Study.

Study Design: Prospective cohort study.

Methods: We assessed hearing on 1,221 Jackson Heart Study participants who also had validated physical activity questionnaire data on file. Hearing thresholds were measured across frequency octaves from 250 to 8,000 Hz, and various frequency pure-tone averages (PTAs) were constructed, including PTA4 (average of 500, 1,000, 2,000, and 4,000 Hz), PTA-high (average of 4,000 and 8,000 Hz), PTA-mid (average of 1,000 and 2,000 Hz), and PTA-low (average of 250 and 500 Hz). Hearing loss was defined for pure tones and pure-tone averages as >25 dB HL in either ear and averaged between the ears. Associations between physical activity and hearing were estimated using linear regression, reporting changes in decibel hearing level, and logistic regression, reporting odds ratios (OR) of hearing loss.

Results: Physical activity exhibited a statistically significant but small inverse relationship with PTA4, −0.20 dB HL per doubling of activity (95% confidence interval [CI]: −0.35, −0.04; $P = .016$), as well as with PTA-low and pure tones at 250, 2,000, and 4,000 Hz in adjusted models. Multivariable logistic regression modeling supported a decrease in the odds of high-frequency hearing loss among participants who reported at least some moderate weekly physical activity (PTA-high, OR: 0.69 [95% CI: 0.52, 0.92]; $P = .011$ and 4000 Hz, OR: 0.75 [95% CI: 0.57, 0.99]; $P = .044$).

Conclusions: Our study provides further evidence that physical activity is related to better hearing; however, the clinical significance of this relationship cannot be estimated given the nature of the cross-sectional study design.

Key Words: Presbycusis, hearing, pure-tone average, exercise, physical activity, cardiovascular, cardio-metabolic, obesity, waist circumference.

Level of Evidence: 2b

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INTRODUCTION

As part of a heart healthy lifestyle, the American Heart Association recommends at least 150 minutes of moderate to vigorous, or 75 minutes of vigorous, physical activity (PA) per week.[1] Regular PA has clearly been shown to decrease cardiometabolic risk by decreasing levels of circulating inflammatory markers,[2] improving insulin sensitivity,[3] decreasing body fat,[4] and improving blood lipid profiles.[5] Additionally, regular PA is thought to be protective of neurocognitive,[6–8] as well as peripheral[9] and central,[10] auditory function.

In relation to peripheral auditory function, there is a growing body of literature that links this to measures of general cardiovascular fitness and levels of weekly PA. For example, there is evidence that temporary threshold shifts in hearing that occur from loud noise exposure are reduced in amplitude and duration in physically fit individuals.[11–15] Two studies have shown a statistically significant, negative correlation among measures of physical fitness and hearing threshold levels.[9,16] In a study by Hutchinson et al., the investigators found that individuals in an older age group who had low cardiovascular fitness profiles had significantly ($P < .05$) worse hearing at 2,000 Hz and 4,000 Hz compared to their fit, age-matched peers.[9] In a convenience sample of 154 subjects, Alessio et al. showed that participants over 50 years of age with low cardiovascular fitness had worse hearing at 2 kHz, 3 kHz, and 4 kHz compared to a high cardiovascular fitness group.[16] Additionally, Loprinzi et al.[17] found a significant ($P < .05$) correlation between an estimation of cardiorespiratory fitness and pure-tone hearing thresholds in data from the NHANES (National Health and Nutrition Examination Survey) cohort. In an epidemiological cohort study of 3,285 participants in Beaver Dam, Wisconsin,

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Nash et al.[18] found a correlation between several cardiovascular risk factors and hearing with covariate adjustment for age and sex. They observed an odds ratio (OR) of 0.77 (95% confidence interval [CI]: 0.6, 0.99) of hearing loss for those with enough regular PA "to work up a sweat at least once a week" compared to those who did not. Hearing loss was defined as a pure-tone average >25 dB HL in either ear. This suggests that the risk of hearing loss is lessened (OR < 1.0) by a measurable extent in more active individuals.

To date, the published research has clearly established that there is a measurable correlation between PA level and peripheral auditory function; however, there is some inconsistency among the published study designs. There is at present no standard PA measure that is being used, and it remains unclear which unmeasured confounders are affecting statistical models. To further investigate the suspected relationship between these variables, we analyzed extensive PA and pure-tone auditory data obtained from an African-American cardiovascular study cohort (i.e., the Jackson Heart Study [JHS]), which is based in the Jackson, Mississippi metropolitan area. We suspected that an increased level of PA would have a statistically significant, inverse relationship with pure-tone hearing thresholds.

MATERIALS AND METHODS

The study protocol was approved by the institutional review boards of the participating institutions: the University of Mississippi Medical Center, Jackson State University, and Tougaloo College. All of the participants provided written informed consent.

Study Sample

The JHS is a prospective, population-based, longitudinal study aimed at identification of factors that influence the development and worsening of cardiovascular disease in African Americans. The JHS enrolled a cohort of 5,301 African-American participants from the Jackson, Mississippi metropolitan area, between the ages of 21 and 94 years of age, between September 2000 and March 2004.[19] Demographic and health information was collected during a series of home interviews and clinical examinations that took place during three exam periods: exam 1 (2000–2004), exam 2 (2005–2008), and exam 3 (2009–2012). The data presented in this report were obtained from a sample of 1,221 individuals participating in the JHS cohort with PA data from exam 1 and who underwent hearing evaluations in an ancillary study coinciding with exam 2.

Physical Activity Assessment

A PA questionnaire, which was derived from modifications to the Baecke/Atherosclerosis Risk in Communities PA survey,[20,21] was administered by home interview. Questions involved assessment of the type, frequency, and intensity of PA for the prior 12 months. The questionnaire was validated with repeat testing, 24-hour accelerometer counts, and 3 days of pedometer counts.[22,23]

Metabolic Equivalent of Task (MET) levels for each named activity were taken from the most current version of the national Compendium of Physical Activity. [21,24] Activities identified as either vigorous (>6 METs) or moderate (3–6 METs) contributed to all participants' PA score for the purpose of our analysis. To account for skewness and to make the data more interpretable for inferential statistical analysis, the continuous PA variable was transformed to a logarithm base 2, yielding regression estimates per doubling of PA. For dichotomous analyses, each participant was scored as having achieved one of two levels of PA. "Any" activity was defined as greater than 0 minutes/week of moderate or vigorous activity, and "no" activity was defined as equal to 0 minutes/week of moderate or vigorous PA.

Audiological Assessment

All participants in the study were volunteers from the JHS cohort. Data obtained from individuals who presented with occluded ear canals, middle ear disorders with conductive hearing losses, or had known histories of hearing loss related to head injury, radiotherapy, or chemotherapy, were removed from analysis. Reported noise exposure was used as an adjustment variable in statistical modeling.

Audiometry was performed with insert earphones (ER-3A type; GN Otometrics, Taastrup, Denmark) on a two-channel diagnostic audiometer (Madsen Conera; GN Otometrics, Schaumburg, IL), calibrated yearly to American National Standards Institute (ANSI) specifications for diagnostic audiometers.[25] All participants were evaluated in a commercially available test room, which met the ANSI standards for permissible ambient noise.[26] Assessment of middle ear compliance and pressure were assessed with a conventional tympanometer (Madsen Capella, GN Otometrics).[27,28] Pure-tone audiometric testing was performed in accordance with procedures recommended by the American Speech-Language-Hearing Association.[29] Thresholds were determined for octaves from 250 Hz to 8,000 Hz by air conduction and for octaves from 500 Hz to 4,000 Hz by bone conduction. Several different pure-tone averages (PTAs) were used in this study. PTA3, the average of thresholds at frequencies 500, 1,000, and 2,000 Hz was used as a crosscheck with the speech recognition threshold (SRT) as an estimate of pure-tone testing reliability. SRT and PTA3 agreement within 10 dB HL was considered acceptable reliability. The addition of a fourth frequency (4,000 Hz) to the PTA3 was used as a clinical estimate of functional impairment in statistical analyses.[30] Other PTAs were used for analyses, including: 1) PTA-high (the average of 4,000 and 8,000 Hz), 2) PTA-mid (the average of 1,000 and 2,000 Hz), and 3) PTA-low (the average of 250 and 500 Hz). For this study, hearing loss was defined for individual frequencies and PTAs as >25 dB HL.

Risk Factors and Covariate Assessment

Risk factors and covariates were measured at exam 2 (2007–2009). Body mass index (BMI) was defined as weight (in kilograms) divided by the square of height (in meters). Obesity was defined by BMI of at least 30 kg/m^2. As an estimate of adiposity in linear statistical models, waist circumference (WC) in centimeters was used. Alcohol consumption was assessed by validated food questionnaires and collected during the face-to-face encounters by trained interviewers.[31] Participants were considered current tobacco users if they had smoked, used chewing tobacco or nicotine gum, or were wearing a nicotine patch at the time of interview. Noise exposure was determined by a "yes" or "no" response to the question: Have you been exposed to loud noise that may have affected your hearing?

Statistical Analyses

Potential nonlinear relationships between measures of PA and hearing were diagnosed using adjusted component plus residual plots and locally weighted scatterplot smoothing

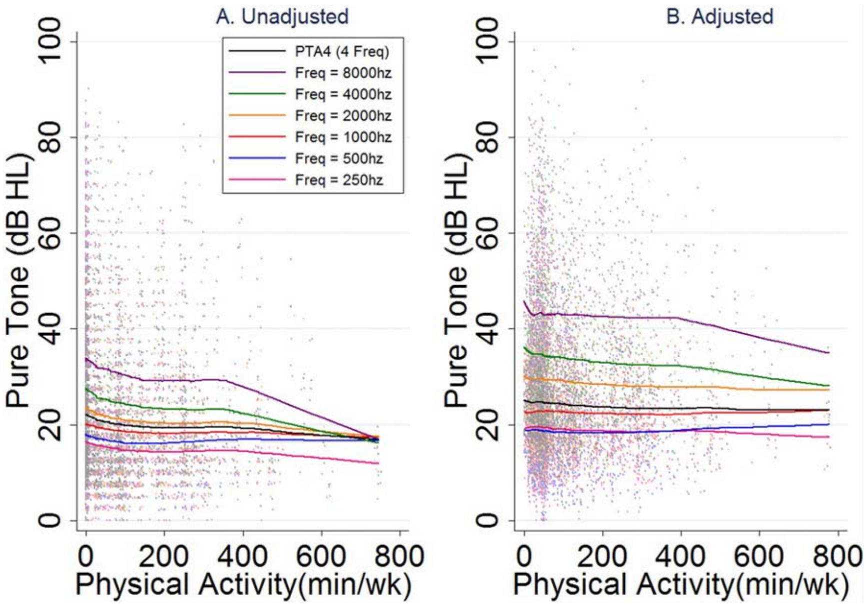

Fig. 1. (A) Scatter plot showing pure-tone threshold in decibel hearing level against reported physical activity time in minutes per week. Results shown are for all test frequencies and the four-frequency pure-tone average (PTA4). Data are unadjusted. (B) Scatter plot showing pure-tone threshold in decibel hearing level against reported physical activity time in minutes per week. Results shown are for all test frequencies and the PTA4. Data are adjusted for age, sex, tobacco use, and alcohol consumption.

techniques. Once linearity among variables was established, the primary analyses employed linear regression models to estimate associations between PA and PTAs, and each individual frequency measure. Logistic regression was used to estimate the OR of associations between PA and dichotomized hearing loss variables (>25 dB).

Though it is well established in the literature that age, sex, and noise exposure are risk factors for hearing impairment, there is emerging evidence that tobacco use[32] and increased adiposity[32] are also risks. Additionally, there is evidence that alcohol consumption may be either protective of[33] or detrimental to[34] hearing. For this reason, two adjustment models were examined containing covariates suspected of being in the causal pathway: model 1 with adjustments for age, gender, tobacco use, and alcohol consumption, and model 2 with additional adjustments for WC and reported noise exposure. The Stata 13 software package (StataCorp, LP, College Station, TX) was used for analyses.

RESULTS

The study group was comprised entirely of African Americans who were predominantly female (70%) with an average age of 60.18 years. The average BMI of the group was 32 (standard deviation [SD] = 6.82), with an average waist circumference of 102 cm (40.16 inches, SD = 15.39 cm). Over half of the study participants (58%) were obese, defined as a BMI >30. Only 11% of the participants were considered normal or underweight, based on BMI <25. Nearly 70% (68.80) of the participants had hypertension, whereas 30% had diabetes, with 36% of the participants exhibiting no, 31% exhibiting only one, and 18% exhibiting two or more cardiometabolic risk factors, concurrently. Only 6% of participants reported tobacco use; however, 47% of participants reported alcohol consumption. The average time per week spent performing moderate or vigorous PA was 68.56 minutes (SD = 108.87), with 46.9% of participants reporting only light or no PA in a typical week. Hearing loss in both ears, in only one ear, and averaged between the ears was present in 20.80%, 9.53%, and 26.93% of participants, respectively. Seventy-one percent of participants reported noise exposure they estimate might have affected their hearing.

Figure 1 is a scatter plot showing mean air-conducted thresholds (decibels hearing level) for frequency octaves 250 Hz to 8,000 Hz and PTA4, averaged between the ears, given as a function of any PA time per week in minutes. Figure 1A is unadjusted, whereas Figure 1B is adjusted for age, sex, tobacco use, and alcohol consumption. Smooth fitted lines were applied showing a slight, inverse relationship between any PA time per week and pure-tone thresholds. The relationship appears stronger when looking at the low (250 Hz) and the high (4,000 Hz and 8,000 Hz) frequencies, though less so for adjusted compared to unadjusted models. Inverse relationships between any PA time per week and hearing thresholds appear potentially more pronounced with PA levels around 400 minutes per week and above, but limited participants reported such high activity. Differences between participants reporting >400 minutes per week versus <150 minutes per week were borderline supported only for 8,000 Hz ($P = .050$).

Table I shows results from multiple linear regression modeling between hearing level (decibel hearing level) as a continuous dependent variable on the log of PA time in minutes (continuous predictor variable) and on any PA as a binary predictor (1 = any moderate or vigorous PA, 0 = no moderate or vigorous PA). Model 1 is adjusted for age, sex, tobacco use, and alcohol consumption. Model 2 is adjusted for age, sex, tobacco use, alcohol consumption, as well as waist circumference and reported noise exposure. Values on the left half of the table represent change in decibel hearing level per doubling in PA (minutes). Values on the right half of the table represent change in decibel hearing level when comparing any to no PA. We note that whether PA is represented as a continuous or a categorical variable for model 2, there is a statistically significant ($P < .05$) inverse relationship between reported PA and decibel

TABLE I.
Multiple Linear Regression of Pure Tones.

	Predictor: Log Transformed Physical Activity Time, min				Predictor: Any Physical Activity (Binary Variable)			
	MVR Model 1* Change in Pure Tone(95% CI)	P Value	MVR Model 2† Change in Pure Tone (95% CI)	P Value	MVR Model 1* Change in Pure Tone (95% CI)	P Value	MVR Model 2† Change in Pure Tone (95% CI)	P Value
PTA4	−0.22 (−0.38, −0.06)	.007‡	−0.20 (−0.35, −0.04)	.016‡	−1.45 (−2.53, −0.38)	.008‡	−1.27 (−2.35, −0.20)	.020‡
PTA-low (250–500 Hz)	−0.18 (−0.33, −0.03)	.022‡	−0.16 (−0.31, −0.01)	.039‡	−1.32 (−2.33, −0.30)	.011‡	−1.20 (−2.22, −0.17)	.022‡
PTA-Mid (1 kHz–2 kHz)	−0.19 (−0.36, −0.02)	.031‡	−0.16 (−0.33, 0.01)	.061	−1.23 (−2.38, −0.08)	.036‡	−1.04 (−2.20, 0.11)	.077
PTA-High (4 kHz–8 kHz)	−0.23 (−0.47, 0.00)	.050‡	−0.23 (−0.46, 0.00)	.053	−1.56 (−3.13,0.02)	.052	−1.46 (−3.03, 0.11)	.069
250Hz	−0.20 (−0.36, −0.04)	.012‡	−0.19 (−0.34, −0.03)	.021‡	−1.29 (−2.34, −0.24)	.017‡	−1.18 (−2.25, −0.12)	.030‡
500 Hz	−0.15 (−0.31, 0.01)	.065	−0.13 (−0.29, 0.03)	.108	−1.24 (−2.31, −0.18)	.022	−1.11 (−2.19, −0.04)	.043‡
1,000 Hz	−0.12 (−0.29, 0.05)	.164	−0.10 (−0.27, 0.07)	.254	−0.92 (−2.05, 0.20)	.108	−0.77 (−1.91, 0.36)	.183
2,000 Hz	−0.24 (−0.44, −0.04)	.020‡	−0.21 (−0.41, −0.01)	.040‡	−1.40 (−2.75, −0.06)	.040‡	−1.17 (−2.52, 0.17)	.087
4,000 Hz	−0.33 (−0.56, −0.10)	.004‡	−0.31 (−0.54, −0.09)	.007‡	−2.01 (−3.54, −0.47)	.011‡	−1.79 (−3.32, −0.27)	.021‡
8,000 Hz	−0.20 (−0.48, 0.09)	.175	−0.21 (−0.49, 0.08)	.154	−1.54 (−3.45, 0.38)	.116	−1.54 (−3.47, 0.39)	.118

Results from multiple linear regression modeling between hearing level (decibel hearing level) as a continuous dependent variable on the log of physical activity time in minutes (continuous predictor variable) and on any physical activity as a binary predictor (1 = any moderate or vigorous physical activity; 0 = no moderate or vigorous physical activity). Values are presented in decibel hearing level.

*Model 1: adjusted for age, sex, tobacco use, and alcohol consumption.

†Model 2: adjusted for age, sex, tobacco use, alcohol consumption, waist circumference, and reported noise exposure.

‡Statistically significant.

CI = confidence interval; Log = logarithm base 2; MVR = multivariable regression; PTA = pure-tone average; PTA4 = four-frequency average of pure tones 500, 1,000, 2,000, and 4,000 Hz.

hearing level for individual low (250 Hz) and high (4,000 Hz) frequencies, as well as for the PTA4 and PTA-low.

Table II is a display of results from logistic regression modeling between hearing level (decibel hearing level) as a categorical (1 = threshold >25 dB HL; 0 = threshold ≤25 dB HL), dependent variable on the log of PA time in minutes (continuous, predictor variable), and on PA as a categorical (1 = any moderate or vigorous physical, 0 = no moderate or vigorous PA) predictor variable. The OR is given for individual frequencies and PTAs. Hearing loss is defined as >25 dB HL, which is averaged between the two ears, except for PTA4-worse ear, where hearing loss is defined as PTA4 >25 dB HL in the ear with the most impairment. Values on the left half of the table represent OR of hearing loss for each one unit change in the log transformed PA time. Values on the right half of the table represent the OR of hearing loss with any compared to no PA. We note a similarity in these results, which show hearing loss as a categorical variable, to those displayed in Table I, which show hearing loss as a continuous variable. For both model 1 and 2, there is a statistically significant ($P < .05$), inverse relationship between reported PA and risk of hearing loss for 4,000 Hz and the PTA-high. However, in contrast to Table I, there is not a statistically significant relationship between reported PA and risk of hearing loss for 250 Hz and the PTA4 and PTA-low.

DISCUSSION

The results from our analyses supported the study hypothesis to a limited extent. We observed a trend of better hearing in the high frequencies (4,000 Hz and 8,000 Hz) and at a low frequency (250 Hz) among individuals who reported 400 or more minutes of regular PA per week. There was a significant difference ($P = .050$) in the hearing at 8,000 Hz between individuals who reported >400 minutes per week of PA compared to those who reported <150 minutes per week (Fig. 1).

With covariate adjustments, we observed statistically significant ($P < .05$) better hearing in physically active participants for the individual frequencies of 250 Hz and 4,000 Hz, and for the PTA4, in regression analysis (Table I). This result persisted when examining PA as both a continuous and a categorical value. For example, in Table I, we note that a 0.20 dB HL (95% CI: 0.35, 0.04; $P = .016$) improvement (i.e., lowering of threshold in decibel hearing level) occurs in the PTA4 per one-fold increase in PA time (model 2). Similarly, a 1.27 dB HL (95% CI: 2.35, 0.20; $P = .020$) difference in PTA4 is noted when comparing participants with any to those with no PA (also model 2). In Table II, we note that when looking at hearing as a categorical variable, participants were 31% (1–0.69 × 100, $P = .011$) less likely to have hearing loss for the PTA-high and 25% (1–0.75 × 100, $P = .044$) less likely to have hearing loss at 4,000 Hz (Model 2), if they had any compared to no PA.

Whether PA is actually protective of hearing cannot be estimated from our results; however, we did observe a statistically significant relationship between reported PA and decibel hearing level at select frequencies and PTAs,

TABLE II.
Multivariable Logistic Regression of Dichotomous Hearing Loss.

	Predictor: Log Transformed Physical Activity Time, min				Predictor: Any Physical Activity, Binary Variable			
	MVR Model 1* Odds Ratio (95% CI)	*P* Value	MVR Model 2† Odds Ratio (95% CI)	*P* Value	MVR Model 1* Odds Ratio (95% CI)	*P* Value	MVR Model 2† Odds Ratio (95% CI)	*P* Value
PTA4	0.96 (0.92, 1.01)	.088	0.97 (0.93, 1.01)	.176	0.77 (0.57, 1.03)	.076	0.81 (0.60, 1.09)	.160
PTA4, worse ear	0.96 (0.92, 1.00)	.071	0.97 (0.93, 1.01)	.136	0.75 (0.57, 1.00)	.050‡	0.79 (0.59, 1.05)	.105
PTA-low (250–500 Hz)	0.97 (0.92, 1.02)	.255	0.97 (0.92, 1.02)	.251	0.75 (0.53, 1.07)	.114	0.75 (0.53, 1.07)	.112
PTA-mid (1 kHz–2 kHz)	0.97 (0.93, 1.02)	.236	0.98 (0.94, 1.02)	.337	0.85 (0.64, 1.14)	.276	0.88 (0.66, 1.18)	.401
PTA-high (4 kHz–8 kHz)	0.95 (0.92, 0.99)	.028‡	0.96 (0.92, 1.00)	.038‡	0.68 (0.51, 0.90)	.007‡	0.69 (0.52, 0.92)	.011‡
250 Hz	0.96 (0.91, 1.02)	.182	0.96 (0.91, 1.02)	.178	0.75 (0.52, 1.08)	.119	0.75 (0.51, 1.08)	.122
500 Hz	1.00 (0.95, 1.05)	.956	1.00 (0.95, 1.05)	.988	0.92 (0.65, 1.29)	.616	0.91 (0.64, 1.28)	.585
1,000 Hz	0.98 (0.94, 1.03)	.465	0.99 (0.94, 1.03)	.543	0.85 (0.62, 1.15)	.290	0.86 (0.63, 1.18)	.344
2,000 Hz	0.96 (0.92, 1.00)	.074	0.97 (0.93, 1.01)	.146	0.79 (0.59, 1.04)	.096	0.83 (0.62, 1.10)	.193
4,000 Hz	0.95 (0.92, 0.99)	.026‡	0.96 (0.92, 1.00)	.056	0.72 (0.55, 0.94)	.018‡	0.75 (0.57, 0.99)	.044‡
8,000 Hz	0.99 (0.95,1.03)	.641	0.99 (0.95, 1.03)	.721	0.86 (0.66, 1.13)	.291	0.88 (0.67, 1.16)	.366

Hearing loss is defined as >25 dB HL averaged between the two ears, except for the row labeled "PTA4-worse ear," where hearing loss is defined as PTA4 >25 dB HL in the worse ear. Results from logistic regression modeling between hearing level (decibel hearing level) as a categorical (1 = threshold >25 dB HL; 0 = threshold ≤25 dB HL), dependent variable on the log of physical activity time in minutes (continuous, predictor variable), and on physical activity as a categorical (1 = any moderate or vigorous physical activity; 0 = no moderate or vigorous physical activity) predictor variable. Values are reported as odds ratio of hearing loss and confidence interval.

*Model 1: adjusted for age, sex, tobacco use, and alcohol consumption.

†Model 2: adjusted for age, sex, tobacco use, alcohol consumption, waist circumference, and reported noise exposure.

‡Statistically significant.

CI, confidence interval; Log = logarithm base 2; MVR = multivariable regression; PTA = pure-tone average; PTA4 = four-frequency average of pure tones 500, 1,000, 2,000, and 4,000 Hz.

which is affected by the level of covariate adjustment (model 1 vs. model 2) and whether the variables are analyzed as continuous or categorical data. Comparisons between participants who reported no and those who reported any PA are potentially at risk of unmeasured confounders between these two likely very different groups.

Our results are consistent with aspects of the published research. In particular, our results support previous findings by Hutchinson et al.,[9] as we observed statistically significant ($P = .021$) better hearing at 4,000 Hz in individuals who reported any moderate or vigorous PA compared to those who did not. This result persisted after adjustment for age, sex, tobacco use, alcohol consumption, waist circumference, and reported noise exposure. We note, however, that the regression coefficients that were observed are essentially weak, despite the level of statistical significance. This may indicate that the impact of PA on hearing may have more implications on a population rather than individual scale.

Our study involved certain limitations that may affect the generalization of results. Firstly, our study sample was from an entirely African-American cohort. In some ways this is a strength in terms of limiting inherent variation among racial groups, but it can also be a limitation when attempting to make comparisons to the more diverse general population. In terms of PA measurements, equal weight was given to vigorous (>6 METs) activity as was given to moderate activity (3–6 METs). This may discount the benefits of vigorous-only PA on hearing. Conversely, we did not analyze light activity, defined as PA <3 METs, which would include slow-paced, light housework, or slow walking.[24] Lastly, our study was limited by the cross-sectional design, such that PA and hearing were measured at different points in time, which can weaken the observed associations between measured variables.

CONCLUSION

Our study provides further evidence that PA is related to better hearing; however, the clinical/causal significance of this relationship cannot be estimated given the nature of the cross-sectional study design. Longitudinal studies that involve repeated measures of hearing, PA, and cardiometabolic risks need to be conducted to further elucidate the strength of the relationships among these measured variables.

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