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Investigating ethnic inequalities in hearing aid use in the UK: a cross-sectional study

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Abstract

Objective: To establish whether ethnic inequalities exist in levels of self-reported hearing difficulty and hearing aid use among middle-aged adults.

Design: Cross-sectional data from the UK Biobank resource.

Study sample: 164,786 participants aged 40-69 who answered hearing questions.

Results: After taking into account objectively assessed hearing performance and a corresponding correction for bias in non-native English speakers, as well as a range of correlates including demographic, socioeconomic, and health factors, ethnic inequalities were observed in both hearing aid use and self-reported hearing difficulty. There were lower levels of hearing aid use for people from Black African (OR 0.36, 95% CI 0.17-0.76), Black Caribbean (OR 0.37, 95% CI 0.22-0.64) and Indian (OR 0.59, 95% CI 0.41-0.85) ethnic groups, compared to the White British or Irish group. For equivalent levels of objectively assessed hearing, men from most ethnic minority groups, and women from Black African, Black Caribbean and Indian groups were less likely to report hearing difficulty than their White British or Irish counterparts.

Conclusions: For equivalent levels of hearing loss, use of hearing aids is lower among ethnic minority groups. Inequalities are partly due to lower levels of self reported hearing difficulty among minority groups. However, even when self reported hearing difficulty considered, hearing aid use remains lower among many ethnic minority groups. As reasons for low hearing aid use in ethnic minorities may differ between groups, potential reasons for low use including barriers to services, the effect of discrimination, and attitudes to hearing loss and hearing aid use, should be explored using culturally safe methodology with each major UK ethnic group.

Keywords

Hearing aids, hearing aid, ethnicity, inequalities, hearing health

Introduction

Hearing aids are provided free at the point of service via the United Kingdom (UK) National Health Service (NHS), but research documenting the correlates of hearing aid use has shown that people from ethnic minority groups in the UK are half as likely (OR 0.53, 95% CI 0.39-0.72) as White groups to use a hearing aid [1]. Uncorrected hearing loss is linked to social isolation, depression, cognitive decline and poorer quality of life [2]. Conversely, the use of a hearing aid improves quality of life, reduces social isolation and may mitigate cognitive decline [3]. Inequality in hearing aid use therefore may exacerbate the often-poorer quality of life and health outcomes experienced by people from ethnic minority groups. The dynamics of this inequality must be understood to remove the barriers to hearing aid use for people from ethnic minority groups and redress inequalities in uptake of hearing aids.

Research on hearing help-seeking and hearing aid uptake has tended to neglect ethnicity, meaning that there is little evidence to draw upon to explain the ethnic inequalities in this area. The available body of evidence on correlates of hearing aid use includes a number of reviews [4–6], and studies using UK data [1,7,8], yet only two studies among this entire body report results on ethnicity, and only one of these [1] uses UK data. While theories have been proposed concerning the influence of cultural factors on hearing help-seeking and hearing aid uptake (see [9] for a review), there is no direct evidence linking cultural factors to ethnic inequalities in hearing aid use. Multiple studies and reviews have found that the most important predictor of hearing aid use is self-reported hearing difficulty [1,4–7,10,11]. Although it is known that self-reported hearing difficulty does not explain ethnic inequalities in hearing aid use [1], the existence of ethnic inequalities in the acknowledgement and awareness of hearing difficulty are unknown.

Ethnic inequalities in health outcomes more widely are commonly seen in terms of the 'health disadvantage' reported among older people from ethnic minority groups, whereby poorer health outcomes are not explained by socioeconomic factors and known correlates of health [12]. Proposed explanations are that this disadvantage is the result of accumulation of risks, including poor healthcare experiences [13] or experiences of racism [14], across the life course [12]. An alternative explanation is that the limited nature of the socioeconomic measures included in many studies is unable to completely represent the socioeconomic disadvantage faced by ethnic minority populations [14,15]. To illustrate, although hearing aids are freely available on the NHS, it is conceivable that severe poverty and insecure employment may affect uptake of hearing aids, for example via cost of travel to appointments, or ability to attend appointments without fear of penalty from one's employer. An additional explanation, for those not born in the UK, is differences in the ability to negotiate the NHS system [16], a concept described as "newness" by Szczepura [17].

The existing research on ethnic inequalities in hearing aid use has been conducted using UK Biobank data [1]. The UK Biobank is a sample of over 500,000 people aged 40-69 collected between 2006-2010, representing the most complete dataset available for use in studies of ethnic inequalities in earlier hearing aid uptake. The aforementioned paper was conceived as a general exploration of the causal determinants of hearing aid use and found ethnic inequalities in the non-White cohort of the sample. The authors subsequently conducted an ethnic sub-group using a model with a reduced subset of predictors, containing only those predictors that were significant in the previous model. This study found significantly lower levels of hearing aid use in the Black African, Black Caribbean and Indian ethnic groups. It is of relevance to the present research to note that the existing study was conducted on a subsample of the UK Biobank (N=18,730) who had hearing impairment according to the Digit Triplet Test (DTT), a language-based measure of hearing. However, we recently reported that the DTT may over-estimate hearing loss for non-native English speakers [18], most of whom have ethnic minority status. This bias of the DTT against non-native English speakers introduces the possibility of over-estimation of ethnic inequalities in hearing aid use.

The present study extends the existing research in three ways. Firstly, through building a model specifically tailored to reliably identify ethnic inequalities, by including additional measures of socioeconomic position and corrections for bias in the DTT hearing measure. Secondly, by investigating whether ethnic inequalities exist in self-reported hearing difficulty. It is known that awareness of one's hearing difficulty is the best predictor of hearing aid use; as such, if ethnic differences exist here, it might help tailor approaches to rectify the inequalities in hearing aid use. Finally, to explore whether the mechanism for ethnic inequalities in hearing aid use is consistent across ethnic groups by testing whether the effect of selected predictors upon our hearing-related outcomes differs across ethnic groups.

We addressed the following research questions:

1. Are there ethnic inequalities in self-reported hearing difficulty?
2. Are there ethnic inequalities in hearing aid use after controlling for DTT bias and an extended range of socioeconomic measures?
3. Are there differences in the effect of predictors (e.g. age/sex/UK birth) on hearing aid use and self-reported hearing difficulty across ethnic groups?

Materials and Methods

Sample and design

We used the UK Biobank, a dataset comprising a very large and diverse sample of adults living in the United Kingdom aged 40-69 recruited between 2006 and 2010 [19]. Given that the average age of a first-time hearing aid user is 74 years old [20], and that people typically wait 10-15 years after noticing hearing problems before seeking help [20], the UK Biobank sample of 40-69 year olds is the ideal data set to examine barriers and facilitators to earlier hearing help-seeking and hearing aid uptake. Participation in the UK Biobank was governed by proximity to one of 25 test centres and being registered with the NHS [19]. Our sample was restricted to participants who had hearing test data collected, which occurred from 2009 onwards. While previous studies of hearing aid use have used a sample of participants who are candidates for hearing aid use by indication of having a mild or greater hearing loss [1], in the present study we use the full sample. This is to allow for the bias in the DTT (see Measures for more detail).

Measures

UK Biobank participants underwent a series of physical measurements, and completed a touchscreen questionnaire and brief verbal interview [19]. We included four hearing-related measures, and a range of correlates that we judged to be related to ethnicity, according to previous studies, or theory based on the literature. Some of these correlates are likely to be confounders of ethnicity, meaning variables associated with both the outcome and the "treatment" (in this case ethnicity), for example age, and socioeconomic-related variables. Other correlates may be directly related to the outcome, such as cognitive ability.

Hearing-related

Hearing aid use: This was determined from the UK Biobank by the question "Do you use a hearing aid most of the time?" (Yes/No/Prefer not to answer).

Hearing test (DTT): The DTT is a speech-in-noise test devised for screening hearing conditions [21]. The outcome of the test is a Speech Recognition Threshold (SRT), the signal-to-noise ratio in decibels averaged across eight sets of triplets [21], where lower scores indicate better hearing. In the present research, the DTT is treated as a continuous measure.

Self-reported hearing difficulty (Awareness stage): Participants were asked "Do you have any difficulty with your hearing?" (*Yes / No / I am completely deaf / Do not know / Prefer not to answer), and* "Do you find it difficult to follow a conversation if there is background noise (such as TV, radio, children playing)?" (*Yes / No / Do not know / Prefer not to answer).* Participants were classified as being in the Awareness stage if they answered "Yes" to either of these questions.

Tinnitus: As tinnitus is a predictor of hearing aid use [1], and levels of tinnitus may vary by ethnic group [22], we included a measure for tinnitus. Participants were asked "Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that lasts for more than five minutes at a time?" *(Yes, now most or all of the time / Yes, now a lot of the time / Yes, now some of the time / Yes, but not now, but have in the past / No, never / Do not know / Prefer not to answer).* The measure was coded into i) currently experiencing, or having previously experienced, tinnitus or ii) having never had tinnitus.

For all hearing-related variables, we excluded participants responding "Prefer not to answer". Respondents who stated they were completely deaf or used a cochlear implant were also excluded. Participants responding "no" to all questions were assumed to have normal hearing, characterised by the "Pre-hearing loss" group in figure 1.

Correlates of hearing aid use

Age: Hearing loss is known to have strong dependence on age [23], which in some studies has been reflected in levels of hearing aid use [1,5].

Sex: Although sex is commonly not associated with hearing aid use [1,4], it is included in the present research to permit testing of sex differences across ethnic groups.

Socio-economic status: Although the literature linking socioeconomic status with hearing aid use is mixed [1,4,24], one study has reported a strong link between socioeconomic position and self-reported hearing difficulty [8]. We included variables for income quintile and area-level of deprivation. The area-level measure used was the Townsend score, which was based on four variables from the 2001 UK Census: non-car ownership, overcrowded households, non-house ownership, and persons unemployed.

Education: The link between education and hearing aid use is mixed, but higher education may be linked to reduced uptake of hearing aids [4]. Participants were classified as having any formal qualification versus having none.

Employment: Employment status was characterised as employed, unemployed or other/ student/volunteering.

Health: The existence of other health problems has a mixed association with hearing aid use. Some studies have found a positive association between comorbidities and hearing aid use [10], whereas other studies have found that lower overall health status [1], and conditions such as hypertension and diabetes [7] can increase the risk of not using hearing aids. We included binary variables for diagnoses of diabetes, osteoarthritis and cardiovascular disorder (heart attack, stroke, angina, deep vein thrombosis or other related condition), which have been found to be related to hearing aid use by Fisher et al. [10]). The presence of all conditions was based on diagnosis from a doctor.

Self-rated health was dichotomised as "Excellent/Good" or "Fair/Poor". Respondents' BMI was classified as underweight (BMI <18.5), normal weight (BMI ≥18.5 and <25), overweight (BMI ≥25 and <30) or obese (BMI ≥30).

Ethnicity: We used an extended ethnic group classification, as shown in Appendix A Table 1. All Mixed ethnic groups were combined as the small sample sizes within each sub-groups meant that they would likely not have sufficient statistical power to demonstrate significant differences. Due to the small sample size for Black Other and Bangladeshi ethnic group, and the inability to combine them with other groups, these groups were excluded from the analysis. For the hearing-aid use analysis, there was a risk of unusably small sample sizes in the models that incorporated interactions with ethnicity. Accordingly, the 16 ethnicity categories in the data were initially collapsed into four groups (South Asian, Black, White and Mixed/Chinese/Other; see Appendix A Table 2). However, as will be seen in the Results section, these interactions did not improve model fit; as such, we returned to the extended ethnic group classification.

Migration: A measure for whether participants were born in the UK was included, to represent the influence of migration history [17]. There are clear differences in hearing aid uptake around the world, with western countries having higher levels of hearing aid use compared with developing countries [9]. While this could have an effect for migrants to the UK, it would not necessarily be expected that their ,... As such we tested an interaction

Social activities: Studies of hearing aid use often consider the effect of social participation on hearing aid acquisition [1,10]. Participants were categorised as being socially active if they reported attending a sports club or gym, pub or social club, adult education class, or other group activity (except religious groups, below).

Religiosity: A variable for attending a religious group was included separately from the social activities above, to test the often-repeated claim about fatalism playing a role in ethnic differences in uptake of services. [25,26].

Household members: Family members can influence seeking a hearing aid [27,28] and living alone has been associated with lower levels of hearing aid use [1], so we characterised household living arrangements as: "Lives alone", "Lives with family", "Lives with unrelated people".

Neuroticism: This personality trait has been linked with seeking out, and subsequent satisfaction with, hearing aids [29]. As such, a score for neuroticism was included, derived from responses to 12 neurotic behaviour domains and combined by Smith et al. [30], where higher scores indicate more neuroticism.

Noise exposure: Hearing aid use has been linked to historical noise exposure [31]. As such, binary variables indicating previous exposure to loud music or to noisy work environments were included.

Cognitive ability: A study by Fisher et al. [10] reported an association between cognitive ability and hearing aid use. We included a measure created using a factor analysis of three tests: pairs matching, reaction time and fluid intelligence [1,3]. The fluid intelligence test consisted of 13 questions assessing logic and reasoning ability. The language proficiency questions were excluded from the fluid intelligence test as they were used in the language ability measure below. The pairs matching tests required participants to remember the position of pairs of cards, displayed in one round of 3 pairs and one round of 6 pairs. We used the total number of matching errors across both rounds. The reaction time test was based on 12 rounds of the card game "Snap"; we used the mean time to correctly identify matches. The factor analysis was conducted in the *factanal* package in R, with Varimax rotation. It should be noted that the study by Fisher et al. used a series of cognitive exams and the Diagnostic and Statistical Manual of Mental Disorders criteria for mild cognitive impairment; as such, our measure is less thorough and consequently may not reflect cognitive ability as accurately.

Language ability: The Digit Triplet Test (DTT) has been found to be biased by language proficiency [18]. This is problematic for our study, as ethnicity, and particularly immigration history, are also predictors of language proficiency. To control for these potentially confounding effects, language proficiency was included in our models. The measures available to gauge language proficiency in the UK Biobank are limited to two language-based questions included in the Fluid Intelligence (FI) assessment: *1) "Stop means the same as?" (Pause/Close/Cease/Break/Rest); 2) "Bud is to Flower as Child is to?" (Grow/Develop/Improve/Adult /Old).* To create our variable, respondents were given one point for each correct answer.

Data analysis

We used logistic regression modelling for both outcome variables, conducted using R version 3.5.1. Categorical variables were dummy-coded; continuous variables (age, DTT, Townsend deprivation, cognitive score) were mean-centred.

Several multiplicative interactions were included in the models. As a bias mitigation measure, we included a two-way interaction between the DTT score and language. This allowed for DTT to be a stronger predictor of hearing aid use at higher language scores. It should be noted that language has also been identified as a barrier in accurate self-reporting of health, including the clinical interview [32]. This means that while language proficiency will correct for bias in the DTT, it will also confound with direct effects on hearing aid use. This was mitigated to some extent by interacting the DTT with the language test; however, the effects will likely not be completely separated. It has been suggested that the extent to which hearing loss is seen as a normal part of the ageing process may have a cultural dimension, as such we also included an interaction between age and ethnicity to allow for potential differences in how hearing loss is perceived [33]. As highlighted, there is stigma surrounding hearing aid use [5,33]. Other research investigating stigmatised conditions and self-image has found differences across the intersection of ethnicity and gender [34], therefore this interaction was also evaluated.

Tinnitus is a predictor of hearing aid use [1], and levels of tinnitus may vary by ethnic group [22]. As such, the strength of tinnitus as a predictor for hearing aid use might vary by ethnic group, so an interaction of tinnitus and ethnic group was included.

As the interaction effects for the hearing-aid use model did not improve model fit (see Appendix B), interaction terms were not included in the final models. Given this, the limitation of small cell size that prevented the use of detailed ethnic group categories no longer applied. Consequently, models for both awareness and hearing-aid use were run using detailed ethnic group. Although these post-hoc model modifications risked inflating model fit and increasing the family-wise error rate, we felt these risks were acknowledged and outweighed by the resulting simplicity of interpretation of the models.

Missingness in the dataset was less than 5% for all variables, except income, for which 13.9% of responses were missing. Cases with missing data for ethnicity and DTT were excluded from the analysis, as these were considered to be key variables. We conducted multiple imputation of the missing data using the *mice* library in R, which employs a Markov Chain Monte Carlo method [35]. Results from 10 iterations and 10 imputations were combined using Rubin's rules for calculating estimates and variances in multiply-imputed datasets [36]. As the UK Biobank is not considered to be a representative sample (but is thought to be suitable for measures of disease-exposure relationships) [19], no analytical methods were employed to account for sampling strategy.

The predictor variables were introduced into the model in the following hierarchical sequence:

1. Sociodemographic and living situation
2. Health-related and history of exposure to noise
3. Hearing-related (DTT and tinnitus)
4. Hearing-related (self-reported, for Hearing-aid use model only)
5. Interaction terms

Results

164,786 participants with hearing test data were included in the study (Appendix A Table 1). Levels of self-reported hearing difficulty ranged from 9.8% in the Black African group, to 28.3% in the White British or Irish group. Hearing aids were used by 2.8% of the White British or Irish population, representing the ethnic group with the highest proportion of hearing aid use. Levels of hearing aid use varied from 0.6% to 2.3% in the remaining ethnic groups.

Hearing-aid use

In a model correcting for DTT bias, known correlates of hearing aid use and self-reported hearing difficulty, lower levels of hearing aid use were seen among people from Black African (OR 0.36, 95% CI 0.17-0.77, $p=0.008$), Black Caribbean (OR 0.38, 95% CI 0.22-0.65, $p<.001$) and Indian (OR 0.60, 95% CI 0.41-0.86, $p=0.006$) ethnic groups (see Table 4). Higher levels of language ability were associated with lower levels of hearing aid use (OR 0.75, 95% CI 0.67-0.84 per question correct, $p<.001$). Income was associated with higher hearing aid usage in the 4th (OR 0.80, 95% CI 0.70-0.92, $p=0.002$) and 5th quintiles (OR 0.71, 95% CI 0.55-0.92, $p=0.008$). Townsend deprivation, education and having private healthcare had no significant effect.

Higher levels of hearing aid use were associated with self-reported hearing difficulty (OR 35.80, 95% CI 29.06-44.10, $p<.001$), self-reported hearing difficulty in noisy environments (OR 3.92, 95% CI 3.39-4.55, $p<.001$), lower hearing acuity according to the DTT test (OR 1.17, 95% CI 1.14-1.21 per dB SRT, $p<.001$), and currently experiencing, or previously having experienced, tinnitus (OR 1.42, 95% CI 1.32-1.52, $p<.001$). Other health variables did not have an effect, except osteoarthritis (OR 1.23, 95% CI 1.13-1.33, $p<.001$). Cognitive ability had no effect on hearing aid use, but higher neuroticism scores were associated with lower levels of hearing aid use (OR 0.98, 95% CI 0.96-0.99 per scale point, $p=0.001$). Loud occupational noise exposure was associated with higher levels of hearing aid use (OR 1.13, 95% CI 1.05-1.23, $p=0.002$).

For both models, no differences were observed between ethnic minority people born in the UK, and those born outside the UK. Additionally, for both models the interaction between DTT and language score was significant; this showed that at lower language scores, the DTT is not as strong a predictor of self-reported hearing difficulty or hearing aid use, likely because a low DTT score has been affected by language proficiency as well as hearing acuity.

Self reported hearing difficulties

Ethnic inequalities were observed in self-reported hearing difficulty (see Table 1). Women from Black African (OR 0.60, 95% CI 0.50-0.73, *p<.001*), and Black Caribbean (OR 0.61, 95% CI 0.53-0.69, *p<.001*) ethnic groups were less likely than White British or Irish women to self-report hearing difficulty in the model of best fit *m4* (see Table 1). Black African (OR 0.75, 95% CI 0.58-0.95, *p=0.019*) and Black Caribbean (OR 0.59, 95% CI 0.48-0.72, *p<.001*) men were also less likely to self-report hearing difficulty than the White British or Irish group (see Appendix C). Men from most of the ethnic minority groups (Asian Other, Black African, Black Caribbean, Bangladeshi, Indian. Chinese, Mixed, Other, White Other) were less likely to report hearing difficulty than White British or Irish men. Ethnic differences were not always consistent across sex: women from the Chinese (OR 1.27, 95% CI 1.02-1.60, *p=0.034*) and White Other (OR 1.11, 95% CI 1.02-1.21, *p=0.013*) groups were more likely to report hearing difficulty than White British or Irish women, but men from these groups (Chinese OR 0.47, 95% CI 0.32-0.68, *p<.001*; White Other OR 0.83, 95% CI 0.74-0.94, *p=0.002*) were less likely to report hearing difficulty than White British or Irish men.

Men in general were more likely to self-report hearing difficulty (OR 1.46, 95% CI 1.42-1.50, *p<.001*), as were those of older age (OR 1.04, 95% CI 1.04-1.04 per year, *p<.001*). Degree-educated participants were more likely to report hearing difficulty (OR 1.12, 95% CI 1.09-1.15, *p<.001*). Income affected awareness of hearing difficulty, with those from the 2nd – 5th highest income quintiles being more likely to be aware of hearing difficulty than those in the lowest quintile. Townsend deprivation did not affect awareness of hearing difficulty. Retirees were less likely to report hearing difficulty (OR 0.94, 95% CI 0.92-0.97, *p<.001*), as were those who lived alone (OR 0.87, 95% CI 0.85-0.90, *p<.001*).

Lower hearing acuity according to the DTT test (OR 1.10, 95% CI 1.08-1.13 per dB SRT, *p<.001*) and currently experiencing, or previously having experienced, tinnitus (OR 2.49, 95% CI 2.43-2.56, *p<.001*) were both associated with greater levels of self-reported hearing difficulty. A "poor" or "fair" health rating was associated with self-reporting hearing difficulty (OR 1.20, 95% CI 1.17-1.23, *p<.001*). Osteoarthritis was associated with higher levels of self-reported hearing difficulty (OR 1.14, 95% CI 1.11-1.18, *p<.001*). Overweight (OR 1.04, 95% CI 1.01-1.06, *p=0.005*) or obesity (1.05, 95% CI 1.02-1.08, *p=0.003*) was associated with higher levels of self-reported hearing difficulty. Cognitive ability was negatively associated with self-reported hearing difficulty (OR 0.93, 95% CI 0.91-0.95 per factor point, *p<.001*). Neuroticism score (OR 1.09, 95% CI 1.08-1.09 per scale point, *p<.001*) and exposure to occupational noise (OR 1.57, 95% CI 1.53-1.62, *p<.001*) or loud music (OR 1.47, 95% CI 1.42-1.52, *p<.001*) were all strongly associated with higher levels of self-reported hearing difficulty.

Some significant interactions were seen between ethnicity and age, non-UK birth and tinnitus (see Appendix C), such as lower levels of awareness for the non-UK born cohort in the Asian Other (OR 0.40, 95% CI 0.17-0.95 in the fully-specified model *m7, p=0.044*) and White Other (OR 0.86, 95%

CI 0.74-1.00 in *m7, p=0.045*) groups. However, these interactions were generally weak: the models containing these interactions had worse fit than the model containing only the interaction between ethnicity and sex.

Model fit

In the self reported hearing difficulties models, *m0* represents the model controlling for age, sex, ethnicity and UK birth. Model *m1* also corrects for socioeconomic and living situation variables, *m2* adds health-related variables and history of exposure to noise, *m3* adds other hearing-related variables, and *m4* onwards introduce interaction terms (see Appendix C). In the hearing aid use analysis, models *m0* to *m3* are as per the self-reported hearing difficulty analysis; whereas model *m4* includes a variable for self-reported hearing difficulty.

Model fit statistics for the logistic regression models can be seen in tables 3 and 4. Model fit was assessed according to the Bayesian Information Criterion (BIC), and log likelihood. BIC and Likelihood Ratio Tests (LRTs) were calculated according to the mean results across the 10 model imputations. The model of "best fit" is that whose predicted values most closely match the observed values, when taken across each participant. LRT tests the hypothesis that additional parameters in a model are not redundant, whereas BIC is a test of improved fit that penalises model complexity, to avoid "overfitting" of the data. We report the LRT for reference, but use the BIC for selecting the model of best fit. Among the hearing-aid use models, *m4* was the best fit. This is not surprising given the strong link between self-reported hearing health and hearing aid use. Among the Awareness models, the best fit was *m3*, the final model before interactions. Introducing interactions significantly improved Log-Likelihood score, suggesting the parameters were not redundant, but resulted in poorer BIC scores; albeit only slightly poorer in the case of model *m4*.

Table 1: Coefficients from self-reported hearing difficulty (Awareness) model

	m0 (OR) OR (95% CI)	***m1 (OR)*** OR (95% CI)	***m2 (OR)*** OR (95% CI)	***m3 (OR) ±*** OR (95% CI)	***m4 (OR)*** OR (95% CI)
(Intercept)	0.55 [0.54-0.56]***	0.55 [0.53-0.56]***	0.26 [0.25-0.28]***	0.21 [0.20-0.23]***	0.21 [0.20-0.22]***
Age	1.04 [1.04-1.04]***	1.04 [1.03-1.04]***	1.05 [1.05-1.05]***	1.04 [1.04-1.04]***	1.04 [1.04-1.04]***
Sex: Male	1.58 [1.55-1.61]***	1.59 [1.55-1.62]***	1.42 [1.38-1.45]***	1.41 [1.38-1.44]***	1.46 [1.42-1.50]***
Ethnicity: Indian	0.99 [0.91-1.08]	0.93 [0.86-1.02]	0.95 [0.87-1.04]	0.90 [0.82-0.99]*	1.07 [0.95-1.21]
Ethnicity: Pakistani	1.04 [0.88-1.22]	0.92 [0.78-1.08]	0.97 [0.81-1.15]	0.90 [0.75-1.08]	1.03 [0.77-1.37]
Ethnicity: Chinese	0.94 [0.79-1.12]	0.90 [0.75-1.07]	1.05 [0.88-1.26]	0.97 [0.81-1.17]	1.27 [1.02-1.60]*
Ethnicity: Asian Other	0.99 [0.86-1.14]	0.91 [0.79-1.05]	0.97 [0.83-1.12]	0.88 [0.76-1.03]	1.23 [0.99-1.53]
Ethnicity: Black African	0.61 [0.54-0.69]***	0.52 [0.46-0.59]***	0.60 [0.53-0.69]***	0.52 [0.45-0.60]***	0.60 [0.50-0.73]***
Ethnicity: Black Caribbean	0.59 [0.53-0.65]***	0.54 [0.49-0.59]***	0.54 [0.49-0.60]***	0.49 [0.45-0.55]***	0.61 [0.53-0.69]***
Ethnicity: Mixed	0.93 [0.82-1.05]	0.89 [0.79-1.01]	0.88 [0.77-1.00]*	0.85 [0.75-0.97]*	0.95 [0.81-1.12]
Ethnicity: Other	0.90 [0.81-1.00]*	0.82 [0.73-0.91]***	0.86 [0.77-0.96]**	0.80 [0.71-0.89]***	0.89 [0.77-1.02]
Ethnicity: White Other	1.09 [1.02-1.16]*	1.07 [1.00-1.14]*	1.06 [0.99-1.14]	1.03 [0.96-1.11]	1.11 [1.02-1.21]*
Born outside UK	0.97 [0.92-1.03]	0.96 [0.91-1.02]	1.02 [0.96-1.08]	0.97 [0.91-1.03]	0.97 [0.91-1.02]
Income: 2nd quintile		0.97 [0.95-1.00]	1.02 [0.99-1.05]	1.04 [1.01-1.08]**	1.04 [1.01-1.07]**
Income: 3rd quintile		0.94 [0.91-0.96]***	1.04 [1.00-1.07]*	1.07 [1.04-1.11]***	1.07 [1.04-1.11]***
Income: 4th quintile		0.88 [0.85-0.91]***	1.03 [0.99-1.07]	1.09 [1.05-1.13]***	1.08 [1.04-1.13]***
Income: 5th quintile		0.77 [0.73-0.81]***	1.01 [0.95-1.06]	1.09 [1.03-1.15]**	1.09 [1.03-1.15]**
Townsend area deprivation score		1.02 [1.01-1.02]***	1.00 [1.00-1.01]	1.00 [1.00-1.00]	1.00 [1.00-1.00]
Education: Degree/prof qual or equiv.		1.13 [1.10-1.16]***	1.14 [1.11-1.17]***	1.12 [1.09-1.15]***	1.12 [1.09-1.15]***
Education: None		1.17 [1.13-1.21]***	1.06 [1.02-1.10]**	1.01 [0.97-1.05]	1.01 [0.97-1.05]
Cognitive score		1.01 [0.99-1.02]	0.96 [0.94-0.97]***	0.93 [0.91-0.95]***	0.93 [0.91-0.95]***
Employment: Other		1.20 [1.16-1.25]***	1.04 [1.00-1.09]*	0.99 [0.95-1.03]	0.99 [0.95-1.03]
Employment: Retired		0.97 [0.94-1.00]*	0.96 [0.93-0.99]**	0.94 [0.92-0.97]***	0.94 [0.92-0.97]***
Attends 1 or more social activities		0.97 [0.96-0.99]***	1.00 [0.99-1.01]	1.01 [1.00-1.03]	1.01 [1.00-1.03]
Attends religious group		1.12 [1.07-1.17]***	1.09 [1.04-1.15]***	1.05 [1.00-1.10]	1.05 [1.00-1.10]
Relations: Live alone		0.89 [0.87-0.91]***	0.88 [0.85-0.90]***	0.87 [0.85-0.90]***	0.87 [0.85-0.90]***
Relations: Lives with non-relations		0.90 [0.82-1.00]*	0.89 [0.80-0.98]*	0.90 [0.81-1.00]	0.90 [0.81-1.00]
Health rating: Poor or fair			1.26 [1.23-1.29]***	1.20 [1.17-1.24]***	1.20 [1.17-1.23]***
BMI: Underweight			1.07 [0.92-1.24]	1.07 [0.91-1.25]	1.06 [0.91-1.24]
BMI: Overweight			1.03 [1.00-1.06]*	1.04 [1.01-1.07]**	1.04 [1.01-1.06]**
BMI: Obese			1.04 [1.01-1.07]**	1.05 [1.02-1.08]***	1.05 [1.02-1.08]**
Cardiovascular disease			1.05 [1.01-1.09]**	1.03 [0.99-1.07]	1.03 [0.99-1.07]
Diabetes			0.96 [0.92-1.01]	0.97 [0.92-1.01]	0.97 [0.92-1.02]
Osteoarthritis			1.19 [1.15-1.23]***	1.14 [1.10-1.18]***	1.14 [1.11-1.18]***
Neuroticism score			1.10 [1.09-1.10]***	1.09 [1.08-1.09]***	1.09 [1.08-1.09]***
Noise exposure: work environment			1.74 [1.69-1.78]***	1.58 [1.54-1.62]***	1.57 [1.53-1.62]***
Noise exposure: loud music			1.61 [1.56-1.67]***	1.47 [1.42-1.52]***	1.47 [1.42-1.52]***
DTT (SRT minimum score)				1.10 [1.08-1.13]***	1.10 [1.08-1.13]***
Language Score: Correct responses				1.03 [0.99-1.07]	1.03 [0.99-1.07]
Interaction: DTT and Language Score				1.05 [1.01-1.08]**	1.05 [1.01-1.08]**
Tinnitus				2.50 [2.43-2.56]***	2.49 [2.43-2.56]***
Interaction: born outside UK/ethnicity					See Appendix C
Interaction:Age/ethnicity					See Appendix C
Interaction: Sex/ethnicity					See Appendix C
Interaction: Tinnitus/ethnicity					See Appendix C
Model fit statistics					
BIC	216,104	215,699	203,124	195,509	195,520
Log Likelihood	-107,974	-107,687	-101,340	-97,509	-97,460

** p < .05, ** p < .01, *** p <.001, ± denotes model of best fit*

Table 2: Coefficients from hearing aid use model (Hearing-aid use)

	m0 (OR) OR (95% CI)	***m1 (OR)*** OR (95% CI)	***m2 (OR)*** OR (95% CI)	***m3 (OR)*** OR (95% CI)	***m4 (OR) ±*** OR (95% CI)
(Intercept)	0.02 [0.01-0.02]***	0.02 [0.01-0.02]***	0.01 [0.01-0.01]***	0.01 [0.01-0.01]***	0.00 [0.00- 0.00]***
Age	1.11 [1.10-1.11]***	1.09 [1.08-1.09]***	1.09 [1.08-1.10]***	1.08 [1.07-1.08]***	1.04 [1.04- 1.05]***
Sex: Male	1.44 [1.36-1.53]***	1.52 [1.43-1.62]***	1.22 [1.14-1.31]***	1.13 [1.05-1.22]***	0.96 [0.89- 1.03]
Ethnicity: Indian	0.83 [0.60-1.14]	0.66 [0.48-0.92]*	0.65 [0.46-0.90]*	0.47 [0.33-0.67]***	0.60 [0.41- 0.86]**
Ethnicity: Pakistani	1.41 [0.83-2.41]	0.99 [0.58-1.69]	0.99 [0.56-1.72]	0.66 [0.36-1.21]	0.91 [0.48- 1.70]
Ethnicity: Chinese	0.65 [0.30-1.41]	0.58 [0.27-1.26]	0.68 [0.32-1.48]	0.50 [0.22-1.14]	0.63 [0.27- 1.49]
Ethnicity: Asian Other	0.90 [0.54-1.52]	0.73 [0.43-1.23]	0.78 [0.46-1.31]	0.45 [0.26-0.80]**	0.72 [0.40- 1.29]
Ethnicity: Black African	0.42 [0.22-0.80]**	0.27 [0.14-0.52]***	0.28 [0.14-0.56]***	0.14 [0.07-0.29]***	0.36 [0.17- 0.77]**
Ethnicity: Black Caribbean	0.46 [0.29-0.74]***	0.35 [0.22-0.56]***	0.32 [0.19-0.52]***	0.21 [0.12-0.35]***	0.38 [0.22- 0.65]***
Ethnicity: Mixed	0.69 [0.41-1.19]	0.62 [0.36-1.06]	0.57 [0.33-1.00]*	0.49 [0.27-0.87]*	0.60 [0.33- 1.08]
Ethnicity: Other	0.97 [0.66-1.41]	0.76 [0.52-1.12]	0.78 [0.52-1.15]	0.53 [0.35-0.81]**	0.79 [0.51- 1.23]
Ethnicity: White Other	1.03 [0.83-1.28]	1.04 [0.83-1.30]	1.02 [0.81-1.27]	0.91 [0.72-1.16]	0.91 [0.71- 1.16]
Born outside UK?	1.15 [0.95-1.40]	1.11 [0.91-1.35]	1.04 [0.85-1.27]	1.20 [0.97-1.48]	1.10 [0.89- 1.37]
Income: 2nd quintile		0.96 [0.89-1.04]	1.03 [0.95-1.11]	1.10 [1.01-1.19]*	1.07 [0.98- 1.17]
Income: 3rd quintile		0.80 [0.73-0.88]***	0.91 [0.82-1.00]	0.98 [0.89-1.09]	0.94 [0.85- 1.04]
Income: 4th quintile		0.64 [0.56-0.72]***	0.74 [0.65-0.84]***	0.83 [0.73-0.95]**	0.80 [0.70- 0.92]**
Income: 5th quintile		0.48 [0.38-0.61]***	0.60 [0.47-0.77]***	0.72 [0.57-0.93]*	0.71 [0.55- 0.92]**
Townsend area deprivation score		1.02 [1.01-1.03]***	1.01 [1.00-1.02]	0.99 [0.98-1.01]	1.00 [0.99- 1.01]
Education: Degree/prof. qual./equiv.		1.14 [1.05-1.23]**	1.12 [1.03-1.22]**	1.11 [1.02-1.21]*	1.03 [0.95- 1.13]
Education: None		1.35 [1.23-1.49]***	1.20 [1.09-1.32]***	1.05 [0.94-1.16]	1.03 [0.93- 1.15]
Has private healthcare		0.92 [0.86-0.99]*	0.93 [0.86-1.00]	0.95 [0.88-1.03]	0.95 [0.88- 1.03]
Cognitive score		1.05 [1.00-1.11]	1.02 [0.96-1.07]	0.90 [0.85-0.95]***	0.95 [0.89- 1.01]
Employment: Other		1.55 [1.38-1.75]***	1.32 [1.17-1.50]***	1.22 [1.08-1.39]**	1.22 [1.07- 1.39]**
Employment: Retired		1.25 [1.15-1.36]***	1.23 [1.13-1.34]***	1.21 [1.11-1.32]***	1.26 [1.15- 1.38]***
No. social activities		0.96 [0.92-1.00]*	0.97 [0.94-1.02]	1.00 [0.96-1.04]	0.98 [0.94- 1.02]
Attends religious group		1.49 [1.29-1.71]***	1.49 [1.29-1.73]***	1.42 [1.22-1.65]***	1.46 [1.25- 1.71]***
Relations: Live alone		0.75 [0.69-0.82]***	0.76 [0.69-0.82]***	0.74 [0.67-0.80]***	0.80 [0.73- 0.87]***
Relations: Lives with non-relations		0.74 [0.52-1.05]	0.76 [0.53-1.08]	0.77 [0.53-1.12]	0.87 [0.59- 1.28]
Health rating: Poor or fair			1.20 [1.11-1.29]***	1.11 [1.03-1.20]**	0.99 [0.91- 1.07]
BMI: Underweight			1.11 [0.69-1.78]	1.03 [0.63-1.71]	1.12 [0.67- 1.87]
BMI: Overweight			1.02 [0.95-1.11]	1.04 [0.96-1.12]	1.00 [0.92- 1.09]
BMI: Obese			1.10 [1.01-1.20]*	1.10 [1.01-1.20]*	1.05 [0.95- 1.15]
Cardiovascular disease			1.08 [0.99-1.18]	1.05 [0.96-1.15]	1.04 [0.94- 1.14]
Diabetes			1.10 [0.98-1.23]	1.10 [0.98-1.24]	1.11 [0.98- 1.26]
Osteoarthritis			1.34 [1.25-1.45]***	1.29 [1.19-1.40]***	1.23 [1.13- 1.33]***
Neuroticism score			1.03 [1.01-1.04]***	1.01 [1.00-1.02]	0.98 [0.96- 0.99]***
Noise exposure: work environment			1.86 [1.73-1.99]***	1.57 [1.45-1.69]***	1.13 [1.05- 1.23]**
Noise exposure: loud music			1.40 [1.27-1.54]***	1.22 [1.10-1.35]***	0.98 [0.88- 1.08]
DTT (SRT minimum score)				1.21 [1.18-1.25]***	1.17 [1.14- 1.21]***
Language Score: Correct responses				0.79 [0.70-0.88]***	0.75 [0.67- 0.84]***
Interaction: DTT and Language Score				1.10 [1.06-1.15]***	1.09 [1.06- 1.13]***
Tinnitus				2.73 [2.55-2.92]***	1.42 [1.32- 1.52]***
Self-reported hearing difficulty					35.80 [29.06-44.10]***
Self-reported h/diff in noisy env.					3.92 [3.39- 4.55]***
Model fit statistics					
BIC	38,298	38,050	36,391	33,388	26,468
Log Likelihood	-19,071	-18,857	-17,968	-16,442	-12,970

** p < .05, ** p < .01, *** p <.001, ± denotes model of best fit*

Discussion

Are there ethnic inequalities in hearing aid use after controlling for DTT bias and an extended range of socioeconomic measures?

Among people with similar levels of both objectively assessed hearing function and self-reported hearing difficulty, pronounced ethnic inequalities in hearing aid use were observed for people from Black African, Black Caribbean and Indian ethnic groups. Black African and Black Caribbean groups were nearly 3 times less likely to use a hearing aid than White/Irish groups. These inequalities persisted after controlling for bias in the DTT by using a measure of language ability. For those with higher language ability, the DTT was a stronger predictor of hearing aid use. One explanation for this is that for those with lower language ability, a poorer DTT result may not reflect poorer hearing acuity but lower language ability, and so is not linked to hearing aid acquisition.

The additional measures of socioeconomic status we included in our model did not explain the ethnic inequalities in hearing aid use. Greater income was associated with reductions in hearing aid use, suggesting that access to hearing aid services may not generally be dependent on financial security, an observation that may be expected in the UK given the free provision of hearing aids on the NHS. Having private healthcare also did not affect hearing aid use, although not all private health policies cover hearing aid provision. Area-level deprivation, education and number of social activities did not affect hearing aid use.

It is conceivable that, despite our efforts to more accurately capture socioeconomic status, our model has not been able to fully correct for the effect of social and material disadvantage accumulated across the lifecourse by many people in ethnic minority groups. Measures of socioeconomic status are often crude, and may mask ethnic differences in income [14]. There is a body of evidence in the United States concerning racial non-equivalence of socioeconomic status indicators, whereby the often-used measures of socioeconomic status are "relevant, but limited" indicators of social inequality [15]. Furthermore, socioeconomic disadvantage experienced by previous generations could affect the health of the next, an example being in the case of low birthweight; this disadvantage would not be picked up by the socioeconomic measures used in the present research [14].

In the UK, the evidence linking socioeconomic status and hearing aid use is mixed [1,8,37]. While hearing aids are free on the NHS, market research has shown higher levels of satisfaction with private hearing aid providers, particularly in the domains of satisfaction with the device itself, waiting times, continuity of care, ease of booking appointments and follow-up service [38]. Although no evidence exists on inequalities in access to NHS hearing services, lack of trust is a known obstacle in the patient/audiologist relationship [11], and patient satisfaction is lower among patients from ethnic minority backgrounds [13]. Additionally, there appear to be barriers to access among some ethnic minority groups for other health services and procedures, such as referrals to secondary care [16], and mental health services [39]. However, in our study, having private healthcare did not affect levels of hearing aid use. One explanation for this is that the barriers to access may be driven by the relationship between patient and healthcare provider, rather than waiting lists and difficulty arranging appointments. Qualitative work investigating barriers to services faced by ethnic minority people has revealed themes such as insensitivity towards ethnic minority patients' needs, discrimination, cultural naivety and poor communication [40].

Are there ethnic inequalities in self-reported hearing difficulty?

There were ethnic inequalities in self-reported hearing difficulty, with Black African and Black Caribbean men and women less likely to report hearing difficulty than White British or Irish men or women. Men from the Bangladeshi, Indian, Chinese, Asian Other, Mixed, Other and White Other ethnic groups were also less likely than White British or Irish men to report hearing difficulty. Self-reported hearing difficulty is the primary determinant of hearing aid use, and our models show that lower levels of self-reported hearing difficulty partially explain relatively low hearing aid use among ethnic minority groups (Table 2, *m3* Vs *m4*). However, severe inequalities in hearing aid use persisted after corrections for self-reported hearing difficulty, DTT bias and known correlates of hearing aid use including demographic, socioeconomic and health factors.

Those in the lowest income quintile were significantly less likely to be aware of having a hearing difficulty, suggesting there may be value in measures to improve awareness of hearing impairment among those on the lowest incomes.

This results from these two research questions suggest that while hearing aid use inequalities are partially driven by differences in awareness of hearing difficulty, there may be further drivers of inequalities in addition to the demographic, socioeconomic, and health factors already accounted for.

Are there differences in the effect of predictors (e.g. age/sex/UK birth) on hearing aid use and self-reported hearing difficulty across ethnic groups?

Our models that employed interactions to investigate how the effects of age, sex, UK birth and tinnitus upon hearing aid use varied by ethnic group were not an improvement over the models without interactions. As such, the effect of age, sex and tinnitus upon hearing aid use did not vary by ethnic group. Importantly, we found no difference in hearing aid use between ethnic minority people born in the UK, and ethnic minority people born elsewhere. Although there is evidence that inequalities may spring from differences in the ability to negotiate the NHS system among those who were not born in the UK [16], a concept described as "newness" by Szczepura [17], our findings suggest that newness did not play a role in ethnic inequalities in hearing aid use, supporting the considerable body of evidence showing that health behaviours of migrants often change to match those of the host country following an acculturation period [41]. A related concept often considered by research discussing ethnic differences in the use of hearing aids is cultural beliefs. In our models, attending a religious group had no effect on awareness of hearing difficulty, and increased the likelihood of hearing aid use, contrary to the literature on the negative effects of religious fatalism on healthcare seeking [25,26] (but consistent with the positive association between social activities and hearing aid use observed elsewhere [10]). The available data did not permit us to further explore the effect of beliefs. While there are many psychological factors known to affect uptake of hearing aids including acceptance of hearing loss, awareness of having a hearing difficulty, and use of coping mechanisms [4], there is no research available that would suggest that these factors vary across ethnic groups. Research into cross-cultural differences in hearing aid uptake has considered factors as the tendency towards either collectivism or individualism in the patient's country of origin [9]. However, in the latter case, the ethnic groups identified as being at risk for healthcare underuse due to having a more collectivist outlook (i.e. Pakistan, Bangladesh, China) [42] generally do not correspond to those groups identified as being at risk of lower levels of hearing aid use in the UK (i.e. Black African, Black Caribbean and Indian) [1]. As such, we can find no evidence that cultural differences affect hearing aid use.

Although the self-reported hearing difficulty models employing interactions did not improve model fit, we found evidence that the impact of sex upon self-reported hearing difficulty varied across ethnic groups. In general, self-reported hearing difficulty was more common among men. Men were also more likely to use a hearing aid, until self-reported hearing difficulty was taken into account, at which point differences were attenuated. It is of note there do not appear to be sex differences in hearing impairment, according to a study using the UK Biobank sample [23]. The sex differences in self-reported hearing health varied across ethnic groups, as evidenced by significant interaction effects between sex and ethnicity. Predicted probabilities for these interactions can be seen in Appendix D. Lower levels of awareness were consistent across sexes for the Black African and Black Caribbean groups; however, for many ethnic groups only men had lower levels of awareness. Additionally, Chinese and White Other women were more likely to report hearing difficulty, while Chinese and White Other men were less likely to do so.

Strengths and Limitations

This is the first study of the UK Biobank to take into account the bias of the DTT in estimates of hearing difficulty and hearing aid use, so as to present an unbiased estimate of ethnic inequalities in hearing aid use. This study confirms that ethnic inequalities in hearing aid use hold when bias in the DTT is corrected for, and that ethnic group is in fact among the most important predictors of hearing aid use. It is also the first study to report ethnic differences in the awareness of hearing difficulty, demonstrating that ethnic inequalities present themselves early in the journey through hearing health.

However, there were some limitations to the study. Firstly, as language proficiency was determined using just two language questions, there could be a degree of measurement error in the assessment of language ability; however, it should be noted that language (and its interaction with the DTT) had a relatively strong effect. Secondly, an estimated 20% of people who have hearing aids do not wear them [43]. As such, when interpreting the present results in relation to hearing aid *use* (versus ownership) it is important to note that there are likely around 20% of individuals in our sample who were previously hearing aid users, but no longer wear their device.

In addition, the UK Biobank data have some limitations. Firstly, the UK Biobank sample is not representative of the UK; however, the UK Biobank is thought to be generalisable for disease-exposure relationships [19]. Furthermore, the limitations of the UK Biobank data make it impossible to draw firm conclusions as to the drivers of ethnic inequalities in hearing aid use. Despite these elements, until improved data are collected, the UK Biobank remains the most viable dataset for studies of ethnic inequalities in hearing aid use. Finally, the UK Biobank data were collected over a decade ago, meaning that they cannot account for health inequality initiatives that have been implemented since this time, such as NHS England's Equality Delivery System, which was introduced in July 2011.

Conclusion

A stark finding in the present research is that ethnicity is one of the best predictors of hearing aid use. From the wider literature, it is apparent that ethnic inequalities in health, particularly in stigmatised conditions, have complex mechanisms. The absence of sufficient data in the present research to account for the myriad forms of social and material disadvantage experienced by people from ethnic minority groups should not be taken as proof that ethnic inequalities in hearing aid use have cultural, attitudinal or biological roots. Rather, ethnicity itself may not be the most salient driver of these inequalities, but the circumstances that ethnic minority people find themselves in that may lead to inequalities.

There are limitations in data available to investigate ethnic inequalities in hearing health and hearing aid use. The UK Biobank measures include hospital admissions and GP records, but these sources do not capture referrals to hearing services or provision of hearing aids. Other UK health surveys do not have sufficient ethnic minority sample size to conduct a reliable statistical analysis [44]; while the poor coverage and inconsistent coding of ethnicity in English NHS health service datasets precludes their use [45]. Reliable, standardised clinical recording of hearing service use and ethnicity would allow for identification of inequalities in hearing service use, and allow barriers to be identified and addressed. In addition to leveraging routine clinical data, inequalities in hearing health and outcomes observed here could be explored through qualitative work that listens to and documents the experiences of ethnic minority people in terms of barriers to service, the effect of discrimination, and attitudes to hearing loss and hearing aid use. These data may then inform steps to eradicate inequality and facilitate sufficient hearing for everyone to achieve their goals in life.

Declarations and ethics statements

Ethical approval

The UK Biobank received ethical approval from the National Health Service Research Ethics Service North West (11/NW/0382).

Informed consent from participants

Explicit consent for secondary analyses such as the one reported here, was obtained from participants in the UK Biobank.

Data availability statement

Data are available in a public, open access repository. The UK Biobank data are held in an open access resource available to researchers via the procedure described at https://ukbiobank.ac.uk/enable-your-research.

Consent to publish statement / form

Not required.

Competing interests

None declared.

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Author contributions

All authors made substantial contributions to the conception and design of the study, and interpretation of results. HT also analysed the data and drafted the manuscript. PD, DK, NS and PN also critically revised the manuscript. All authors approved the final version and agree to be accountable for all aspects of the work.

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Appendix A: Descriptive Statistics

Table 1: Descriptive statistics for the 165,554 UK Biobank participants having hearing test data, split by ethnic group (values are N (%) unless stated otherwise)

	Score or category N (% within category)									
Predictor	**Asian Indian**	**Asian Pakistani**	**Asian Other**	**Chinese**	**Black African**	**Black Caribbean**	**Mixed**	**Other**	**White British or Irish**	**White Other**
N	3,448	681	952	616	1,631	2,602	1,252	2,006	145,054	6,218
40-44	565 (16.4)	199 (29.2)	178 (18.7)	88 (14.3)	404 (24.8)	427 (16.4)	272 (21.7)	375 (18.7)	13,412 (9.2)	1,068 (17.2)
45-49	588 (17.1)	116 (17.0)	166 (17.4)	121 (19.6)	380 (23.3)	648 (24.9)	313 (25.0)	390 (19.4)	17,049 (11.8)	980 (15.8)
50-54	643 (18.6)	124 (18.2)	160 (16.8)	106 (17.2)	327 (20.0)	570 (21.9)	234 (18.7)	359 (17.9)	20,618 (14.2)	980 (15.8)
55-59	625 (18.1)	96 (14.1)	157 (16.5)	143 (23.2)	218 (13.4)	391 (15.0)	162 (12.9)	348 (17.3)	25,278 (17.4)	1,022 (16.4)
60-64	579 (16.8)	65 (9.5)	161 (16.9)	94 (15.3)	183 (11.2)	284 (10.9)	161 (12.9)	320 (16.0)	38,226 (26.4)	1,239 (19.9)
65+	448 (13.0)	81 (11.9)	130 (13.7)	64 (10.4)	119 (7.3)	282 (10.8)	110 (8.8)	214 (10.7)	30,471 (21.0)	929 (14.9)
Female	1,687 (48.9)	265 (38.9)	422 (44.3)	404 (65.6)	842 (51.6)	1,677 (64.5)	789 (63.0)	1,206 (60.1)	78,426 (54.1)	3,934 (63.3)
Male	1,761 (51.1)	416 (61.1)	530 (55.7)	212 (34.4)	789 (48.4)	925 (35.5)	463 (37.0)	800 (39.9)	66,628 (45.9)	2,284 (36.7)
Born in UK	399 (11.7)	105 (15.7)	43 (4.7)	43 (7.0)	173 (10.8)	1,121 (43.3)	789 (63.3)	303 (15.3)	141,999 (97.9)	1,810 (29.2)
Born outside UK	3,019 (88.3)	565 (84.3)	875 (95.3)	571 (93.0)	1,429 (89.2)	1,468 (56.7)	458 (36.7)	1,681 (84.7)	3,036 (2.1)	4,389 (70.8)
Does not use hearing aid	3,392 (98.4)	665 (97.7)	935 (98.2)	609 (98.9)	1,621 (99.4)	2,582 (99.2)	1,238 (98.9)	1,972 (98.3)	140,956 (97.2)	6,088 (97.9)
Uses hearing aid	56 (1.6)	16 (2.3)	17 (1.8)	7 (1.1)	10 (0.6)	20 (0.8)	14 (1.1)	34 (1.7)	4,098 (2.8)	130 (2.1)
Mean SRT score (DTT)	-6.3	-6.1	-5.9	-6.7	-5.7	-6.7	-7.3	-6.2	-7.4	-6.9
No self-reported hearing difficulty	2,594 (80.2)	521 (81.5)	745 (82.7)	493 (85.6)	1,413 (90.2)	2,078 (85.6)	954 (80.9)	1,557 (83.2)	98,268 (71.7)	4,417 (75.9)
Self-reported hearing difficulty	642 (19.8)	118 (18.5)	156 (17.3)	83 (14.4)	153 (9.8)	350 (14.4)	225 (19.1)	314 (16.8)	38,760 (28.3)	1,403 (24.1)
No self-reported h/diff (noisy env.)	2,099 (63.8)	429 (65.3)	582 (63.3)	391 (67.1)	1,224 (77.1)	2,011 (79.3)	835 (69.1)	1,306 (68.0)	88,734 (62.7)	3,840 (63.7)
Self-reported h/diff (noisy env.)	1,191 (36.2)	228 (34.7)	338 (36.7)	192 (32.9)	363 (22.9)	526 (20.7)	374 (30.9)	615 (32.0)	52,871 (37.3)	2,187 (36.3)
No tinnitus	2,411 (74.4)	459 (72.2)	655 (73.9)	411 (70.6)	1,160 (76.4)	1,754 (70.5)	847 (69.3)	1,382 (73.0)	101,308 (71.1)	4,379 (72.7)
Tinnitus	830 (25.6)	177 (27.8)	231 (26.1)	171 (29.4)	359 (23.6)	735 (29.5)	375 (30.7)	511 (27.0)	41,206 (28.9)	1,646 (27.3)
Household income: Lowest quint.	603 (22.8)	215 (41.3)	233 (31.5)	108 (22.0)	432 (33.3)	579 (28.0)	239 (22.7)	505 (33.1)	27,243 (21.6)	1,028 (19.2)
H/h income: 2nd quintile	690 (26.1)	119 (22.8)	195 (26.4)	114 (23.2)	372 (28.6)	600 (29.0)	223 (21.2)	380 (24.9)	32,292 (25.6)	1,120 (21.0)
H/h income: 3rd quintile	624 (23.6)	89 (17.1)	166 (22.4)	151 (30.8)	306 (23.6)	542 (26.2)	269 (25.5)	346 (22.7)	32,983 (26.2)	1,318 (24.7)
H/h income: 4th quintile	556 (21.1)	70 (13.4)	113 (15.3)	84 (17.1)	158 (12.2)	317 (15.3)	237 (22.5)	224 (14.7)	26,135 (20.7)	1,318 (24.7)
H/h income: Highest quintile	167 (6.3)	28 (5.4)	33 (4.5)	34 (6.9)	31 (2.4)	30 (1.5)	86 (8.2)	70 (4.6)	7,334 (5.8)	560 (10.5)
Mean Townsend score	0.1	1	0.6	-0.5	2.8	1.8	0.3	1.2	-1.4	-0.1
Education: A-Levels/GCSE/CSE	896 (27.0)	175 (27.1)	235 (25.7)	112 (18.8)	210 (13.2)	597 (23.6)	301 (24.5)	339 (17.3)	33,545 (23.3)	1,001 (16.3)
Education: Deg./Prof Qual/Other	2,056 (61.9)	360 (55.8)	576 (63.0)	431 (72.4)	1,269 (79.6)	1,569 (62.0)	800 (65.0)	1,375 (70.2)	87,954 (61.1)	4,731 (77.0)
Education: None	370 (11.1)	110 (17.1)	103 (11.3)	52 (8.7)	116 (7.3)	366 (14.5)	129 (10.5)	245 (12.5)	22,475 (15.6)	414 (6.7)
Private healthcare: No	2,442 (72.3)	552 (83.6)	659 (71.1)	420 (69.5)	1,351 (84.4)	2,047 (79.9)	886 (71.5)	1,482 (75.2)	101,099 (70.2)	3,788 (61.4)
Private healthcare: Yes	937 (27.7)	108 (16.4)	268 (28.9)	184 (30.5)	250 (15.6)	514 (20.1)	353 (28.5)	489 (24.8)	43,003 (29.8)	2,377 (38.6)
Mean cognitive score	0.4	0.6	0.6	0.3	0.8	0.5	0.1	0.5	0	0.1
Mean % correct language resp	64.3	54.8	60.8	71.2	56.8	62.7	76.9	60.7	84.9	78
Employment: Employed	2,253 (66.0)	393 (59.2)	576 (61.7)	394 (64.3)	1,101 (68.6)	1,802 (69.6)	855 (69.2)	1,189 (60.6)	79,510 (55.1)	3,974 (64.5)
Employment: other	461 (13.5)	176 (26.5)	179 (19.2)	93 (15.2)	351 (21.9)	386 (14.9)	202 (16.4)	439 (22.4)	12,043 (8.3)	759 (12.3)
Employment: Retired	699 (20.5)	95 (14.3)	178 (19.1)	126 (20.6)	154 (9.6)	401 (15.5)	178 (14.4)	335 (17.1)	52,770 (36.6)	1,427 (23.2)
Health rating: good/excellent	2,053 (60.0)	335 (49.8)	536 (57.4)	423 (69.2)	1,128 (70.3)	1,508 (58.3)	832 (66.8)	1,231 (62.7)	106,151 (73.4)	4,558 (73.8)
Health rating: fair/poor	1,367 (40.0)	338 (50.2)	397 (42.6)	188 (30.8)	477 (29.7)	1,078 (41.7)	413 (33.2)	732 (37.3)	38,522 (26.6)	1,620 (26.2)
BMI: Underweight	23 (0.7)	2 (0.3)	9 (1.0)	9 (1.5)	0 (0.0)	2 (0.1)	11 (0.9)	20 (1.0)	667 (0.5)	42 (0.7)
BMI: Normal weight	1,148 (34.0)	162 (24.8)	323 (34.8)	354 (58.8)	249 (16.0)	496 (19.7)	461 (37.6)	569 (29.3)	47,256 (33.3)	2,365 (38.9)
BMI: Obese	703 (20.8)	193 (29.6)	175 (18.8)	39 (6.5)	678 (43.5)	987 (39.3)	298 (24.3)	543 (27.9)	34,810 (24.6)	1,354 (22.3)
BMI: Overweight	1,506 (44.6)	296 (45.3)	422 (45.4)	200 (33.2)	633 (40.6)	1,027 (40.9)	455 (37.1)	812 (41.8)	58,998 (41.6)	2,312 (38.1)
Cardiovascular disorder: No	3,108 (90.4)	579 (86.0)	863 (90.7)	591 (96.6)	1,508 (92.7)	2,368 (91.2)	1,156 (92.5)	1,853 (92.6)	130,532 (90.0)	5,659 (91.2)
Cardiovascular disorder: Yes	330 (9.6)	94 (14.0)	89 (9.3)	21 (3.4)	118 (7.3)	228 (8.8)	94 (7.5)	149 (7.4)	14,439 (10.0)	547 (8.8)
Diabetes: No	2,878 (84.0)	532 (79.2)	761 (80.8)	576 (94.0)	1,443 (88.9)	2,313 (89.1)	1,164 (93.4)	1,769 (88.9)	137,520 (95.0)	5,935 (95.7)
Diabetes: Yes	549 (16.0)	140 (20.8)	181 (19.2)	37 (6.0)	180 (11.1)	283 (10.9)	82 (6.6)	221 (11.1)	7,286 (5.0)	265 (4.3)
Osteoarthritis: No	3,073 (89.1)	595 (87.4)	849 (89.2)	580 (94.2)	1,515 (92.9)	2,295 (88.2)	1,117 (89.2)	1,781 (88.8)	122,584 (84.5)	5,492 (88.3)
Osteoarthritis: Yes	375 (10.9)	86 (12.6)	103 (10.8)	36 (5.8)	116 (7.1)	307 (11.8)	135 (10.8)	225 (11.2)	22,470 (15.5)	726 (11.7)
Mean neuroticism score	4.4	4.5	3.9	3.4	3.4	3.7	4.4	4.3	4.1	4.1
Noise exposure: No	2,685 (79.8)	513 (78.1)	738 (80.8)	526 (86.9)	1,286 (81.0)	2,024 (79.0)	982 (79.4)	1,609 (82.2)	110,209 (76.6)	4,977 (81.0)
Noise exposure: Yes	678 (20.2)	144 (21.9)	175 (19.2)	79 (13.1)	302 (19.0)	538 (21.0)	254 (20.6)	349 (17.8)	33,640 (23.4)	1,169 (19.0)
Music exposure: No	3,007 (90.3)	585 (89.9)	812 (88.3)	561 (93.3)	1,357 (85.6)	1,987 (78.0)	954 (78.3)	1,698 (87.2)	125,684 (87.8)	5,196 (85.1)
Music exposure: Yes	322 (9.7)	66 (10.1)	108 (11.7)	40 (6.7)	228 (14.4)	561 (22.0)	265 (21.7)	250 (12.8)	17,452 (12.2)	913 (14.9)
Mean number of social activities	1.4	1.3	1.4	1.2	2.4	1.6	1.3	1.5	1.3	1.3
Attends religious group: No	2,364 (70.2)	484 (72.2)	667 (71.0)	488 (80.7)	579 (35.7)	1,745 (67.5)	1,023 (82.2)	1,388 (70.1)	124,453 (86.0)	5,216 (84.3)
Attends religious group: Yes	1,002 (29.8)	186 (27.8)	273 (29.0)	117 (19.3)	1,045 (64.3)	840 (32.5)	221 (17.8)	593 (29.9)	20,239 (14.0)	970 (15.7)
Lives with family	3,036 (89.8)	618 (92.9)	788 (84.5)	519 (85.9)	1,286 (80.4)	1,754 (69.3)	949 (77.2)	1,543 (78.7)	115,854 (80.3)	4,653 (75.6)
Lives alone	304 (9.0)	43 (6.5)	111 (11.9)	70 (11.6)	243 (15.2)	734 (29.0)	261 (21.2)	354 (18.1)	27,124 (18.8)	1,282 (20.8)
Lives with unrelated people	40 (1.2)	4 (0.6)	33 (3.5)	15 (2.5)	70 (4.4)	43 (1.7)	19 (1.5)	64 (3.3)	1,292 (0.9)	219 (3.6)

Table 1: Descriptive statistics for the 165,554 UK Biobank participants having hearing test data, split by ethnic group (values are N (%) unless stated otherwise)

	Score or category N (% within category)			
Predictor	**Black**	**Chinese/Mixed/Other**	**South Asian**	**White**
N	4,301	3,874	5,183	151,428
40-44	845 (19.6)	735 (19.0)	976 (18.8)	14,495 (9.6)
45-49	1,040 (24.2)	824 (21.3)	890 (17.2)	18,046 (11.9)
50-54	910 (21.2)	699 (18.0)	938 (18.1)	21,620 (14.3)
55-59	618 (14.4)	653 (16.9)	886 (17.1)	26,328 (17.4)
60-64	475 (11.0)	575 (14.8)	821 (15.8)	39,504 (26.1)
65+	413 (9.6)	388 (10.0)	672 (13.0)	31,435 (20.8)
Female	2,567 (59.7)	2,399 (61.9)	2,416 (46.6)	82,433 (54.4)
Male	1,734 (40.3)	1,475 (38.1)	2,767 (53.4)	68,995 (45.6)
Born in UK	1,319 (31.0)	1,135 (29.5)	558 (10.9)	143,950 (95.1)
Born outside UK	2,938 (69.0)	2,710 (70.5)	4,546 (89.1)	7,433 (4.9)
Does not use hearing aid	4,271 (99.3)	3,819 (98.6)	5,093 (98.3)	147,194 (97.2)
Uses hearing aid	30 (0.7)	55 (1.4)	90 (1.7)	4,234 (2.8)
Mean SRT score (DTT)	-6.3	-6.7	-6.2	-7.4
No self-reported hearing difficulty	3,539 (87.2)	3,004 (82.8)	3,940 (81.0)	102,785 (71.9)
Self-reported hearing difficulty	520 (12.8)	622 (17.2)	927 (19.0)	40,207 (28.1)
No self-reported hearing difficulty (noisy environments)	3,277 (78.2)	2,532 (68.2)	3,169 (63.9)	92,657 (62.7)
Self-reported hearing difficulty (noisy environments)	913 (21.8)	1,181 (31.8)	1,792 (36.1)	55,121 (37.3)
No Tinnitus	2,957 (72.6)	2,640 (71.4)	3,592 (74.0)	105,784 (71.1)
Tinnitus	1,116 (27.4)	1,057 (28.6)	1,262 (26.0)	42,901 (28.9)
Household income: Lowest quintile	1,035 (30.3)	852 (27.8)	1,089 (27.4)	28,310 (21.5)
Household income: 2nd quintile	982 (28.7)	717 (23.4)	1,013 (25.5)	33,438 (25.4)
Household income: 3rd quintile	859 (25.1)	766 (25.0)	891 (22.4)	34,318 (26.1)
Household income: 4th quintile	482 (14.1)	545 (17.8)	748 (18.8)	27,465 (20.9)
Household income: Highest quintile	63 (1.8)	190 (6.2)	229 (5.8)	7,896 (6.0)
Mean Townsend score	2.2	0.6	0.3	-1.3
Education: A-Levels/GCSE/CSE	817 (19.5)	752 (19.9)	1,321 (26.5)	34,568 (23.0)
Education: Deg./Prof Qual/Other	2,880 (68.7)	2,606 (68.9)	3,049 (61.3)	92,769 (61.7)
Education: None	494 (11.8)	426 (11.3)	607 (12.2)	22,930 (15.3)
Private healthcare: No	3,449 (81.6)	2,788 (73.1)	3,735 (73.8)	105,004 (69.8)
Private healthcare: Yes	780 (18.4)	1,026 (26.9)	1,329 (26.2)	45,413 (30.2)
Mean cognitive score	0.6	0.3	0.5	0
Mean % correct language responses	60.5	68	62.3	84.6
Employment: Employed	2,942 (69.0)	2,438 (64.0)	3,278 (64.1)	83,566 (55.5)
Employment: other	748 (17.6)	734 (19.3)	844 (16.5)	12,828 (8.5)
Employment: Retired	572 (13.4)	639 (16.8)	988 (19.3)	54,242 (36.0)
Health rating: good/excellent	2,680 (62.9)	2,486 (65.1)	2,965 (57.9)	110,798 (73.4)
Health rating: fair/poor	1,578 (37.1)	1,333 (34.9)	2,159 (42.1)	40,206 (26.6)
BMI: Underweight	3 (0.1)	40 (1.1)	35 (0.7)	709 (0.5)
BMI: Normal weight	761 (18.4)	1,384 (36.7)	1,678 (33.2)	49,663 (33.6)
BMI: Obese	1,688 (40.8)	880 (23.3)	1,087 (21.5)	36,221 (24.5)
BMI: Overweight	1,687 (40.8)	1,467 (38.9)	2,261 (44.7)	61,365 (41.5)
Cardiovascular disorder: No	3,932 (91.7)	3,600 (93.2)	4,639 (89.8)	136,319 (90.1)
Cardiovascular disorder: Yes	358 (8.3)	264 (6.8)	526 (10.2)	15,014 (9.9)
Diabetes: No	3,815 (89.0)	3,509 (91.2)	4,246 (82.6)	143,589 (95.0)
Diabetes: Yes	471 (11.0)	340 (8.8)	895 (17.4)	7,573 (5.0)
Osteoarthritis: No	3,863 (89.8)	3,478 (89.8)	4,604 (88.8)	128,201 (84.7)
Osteoarthritis: Yes	438 (10.2)	396 (10.2)	579 (11.2)	23,227 (15.3)
Mean neuroticism score	3.6	4.2	4.3	4.1
Noise exposure: No	3,365 (79.8)	3,117 (82.0)	4,015 (79.9)	115,292 (76.8)
Noise exposure: Yes	850 (20.2)	682 (18.0)	1,011 (20.1)	34,853 (23.2)
Music exposure: No	3,401 (81.0)	3,213 (85.3)	4,491 (89.9)	131,005 (87.7)
Music exposure: Yes	798 (19.0)	555 (14.7)	503 (10.1)	18,392 (12.3)
Mean number of social activities	1.9	1.4	1.4	1.3
Attends religious group: No	2,364 (55.3)	2,899 (75.7)	3,587 (70.7)	129,799 (85.9)
Attends religious group: Yes	1,911 (44.7)	931 (24.3)	1,487 (29.3)	21,229 (14.1)
Lives with family	3,083 (73.5)	3,011 (79.4)	4,528 (89.2)	120,616 (80.1)
Lives alone	997 (23.8)	685 (18.1)	469 (9.2)	28,445 (18.9)
Lives with unrelated people	115 (2.7)	98 (2.6)	80 (1.6)	1,512 (1.0)

Appendix B: Hearing-aid use model (interactions)

	m0 (OR) OR (95% CI)	***m1 (OR)*** OR (95% CI)	***m2 (OR)*** OR (95% CI)	***m3 (OR)*** OR (95% CI)	***m4 (OR)*** OR (95% CI)	***m5 (OR)*** OR (95% CI)	***m6 (OR)*** OR (95% CI)
(Intercept)	0.02 [0.01-0.02]***	0.02 [0.01-0.02]***	0.01 [0.01-0.01]***	0.01 [0.01-0.01]***	0.01 [0.01-0.01]***	0.00 [0.00-0.00]***	0.00 [0.00-0.00]***
Age	1.11 [1.10-1.11]***	1.09 [1.08-1.09]***	1.09 [1.08-1.10]***	1.08 [1.07-1.08]***	1.08 [1.07-1.09]***	1.04 [1.04-1.05]***	1.05 [1.04-1.05]***
Sex: Male	1.44 [1.35-1.53]***	1.52 [1.43-1.62]***	1.22 [1.13-1.31]***	1.13 [1.05-1.22]***	1.13 [1.05-1.22]***	0.96 [0.89-1.03]	0.95 [0.88-1.03]
Ethnicity: Asian	0.88 [0.68-1.14]	0.69 [0.53-0.90]**	0.70 [0.53-0.91]**	0.52 [0.40-0.70]***	0.52 [0.32-0.84]**	0.69 [0.52-0.93]*	0.75 [0.46-1.23]
Ethnicity: Black	0.43 [0.29-0.63]***	0.31 [0.21-0.45]***	0.29 [0.19-0.44]***	0.19 [0.12-0.29]***	0.17 [0.07-0.37]***	0.36 [0.23-0.56]***	0.33 [0.14-0.78]*
Ethnicity: Other	0.82 [0.61-1.09]	0.68 [0.51-0.91]**	0.69 [0.51-0.93]*	0.54 [0.39-0.75]***	0.39 [0.22-0.71]**	0.73 [0.52-1.02]	0.57 [0.31-1.06]
Born outside UK?	1.13 [0.96-1.31]	1.08 [0.92-1.27]	1.02 [0.87-1.20]	1.26 [1.06-1.49]**	1.17 [0.99-1.39]	1.15 [0.97-1.37]	1.10 [0.92-1.32]
Income: 2nd quintile		0.96 [0.89-1.04]	1.03 [0.95-1.11]	1.10 [1.01-1.20]*	1.10 [1.01-1.20]*	1.07 [0.98-1.17]	1.07 [0.98-1.17]
Income: 3rd quintile		0.80 [0.73-0.88]***	0.91 [0.82-1.00]	0.99 [0.89-1.09]	0.99 [0.89-1.09]	0.94 [0.85-1.04]	0.94 [0.85-1.05]
Income: 4th quintile		0.64 [0.56-0.72]***	0.74 [0.65-0.85]***	0.84 [0.74-0.96]**	0.84 [0.74-0.96]*	0.81 [0.71-0.93]**	0.82 [0.71-0.93]**
Income: 5th quintile		0.48 [0.38-0.61]***	0.60 [0.47-0.77]***	0.73 [0.57-0.93]*	0.73 [0.57-0.94]*	0.71 [0.55-0.92]**	0.71 [0.55-0.92]**
Townsend area deprivation score		1.02 [1.01-1.03]***	1.01 [1.00-1.02]	0.99 [0.98-1.01]	0.99 [0.98-1.01]	1.00 [0.99-1.01]	1.00 [0.99-1.01]
Education: Degree/prof. qual./equiv.		1.14 [1.05-1.24]**	1.13 [1.03-1.22]**	1.11 [1.02-1.21]*	1.11 [1.02-1.21]*	1.03 [0.94-1.13]	1.03 [0.94-1.13]
Education: None		1.35 [1.23-1.49]***	1.20 [1.09-1.32]***	1.05 [0.94-1.16]	1.04 [0.94-1.16]	1.03 [0.92-1.14]	1.02 [0.92-1.14]
Has private healthcare		0.92 [0.85-0.99]*	0.93 [0.86-1.00]	0.95 [0.88-1.03]	0.95 [0.88-1.02]	0.95 [0.88-1.03]	0.95 [0.88-1.03]
Cognitive score		1.05 [1.00-1.11]	1.02 [0.96-1.07]	0.90 [0.85-0.95]***	0.90 [0.85-0.95]***	0.95 [0.90-1.01]	0.95 [0.90-1.01]
Employment: Other		1.55 [1.38-1.75]***	1.32 [1.17-1.50]***	1.23 [1.08-1.40]**	1.22 [1.07-1.39]**	1.22 [1.07-1.40]**	1.22 [1.07-1.40]**
Employment: Retired		1.25 [1.15-1.36]***	1.23 [1.13-1.34]***	1.21 [1.11-1.33]***	1.21 [1.10-1.32]***	1.27 [1.16-1.39]***	1.26 [1.15-1.38]***
Attends 1 or more social activities		0.96 [0.92-0.99]*	0.97 [0.93-1.01]	1.00 [0.95-1.04]	0.99 [0.95-1.04]	0.98 [0.94-1.02]	0.98 [0.94-1.02]
Attends religious group		1.49 [1.29-1.71]***	1.50 [1.30-1.73]***	1.42 [1.22-1.65]***	1.42 [1.22-1.65]***	1.47 [1.26-1.72]***	1.48 [1.26-1.72]***
Relations: Live alone		0.75 [0.69-0.82]***	0.76 [0.70-0.82]***	0.74 [0.67-0.80]***	0.74 [0.67-0.80]***	0.80 [0.73-0.87]***	0.80 [0.73-0.87]***
Relations: Lives with non-relations		0.73 [0.51-1.05]	0.75 [0.52-1.08]	0.76 [0.52-1.11]	0.76 [0.52-1.10]	0.87 [0.59-1.28]	0.86 [0.58-1.27]
Health rating: Poor or fair			1.20 [1.11-1.29]***	1.12 [1.03-1.20]**	1.12 [1.03-1.20]**	0.99 [0.91-1.07]	0.99 [0.92-1.07]
BMI: Underweight			1.10 [0.68-1.78]	1.03 [0.62-1.71]	1.03 [0.62-1.70]	1.12 [0.67-1.87]	1.12 [0.67-1.87]
BMI: Overweight			1.02 [0.95-1.11]	1.04 [0.96-1.12]	1.04 [0.96-1.12]	1.00 [0.92-1.09]	1.00 [0.92-1.09]
BMI: Obese			1.10 [1.01-1.20]*	1.10 [1.01-1.21]*	1.10 [1.01-1.21]*	1.05 [0.96-1.15]	1.05 [0.96-1.15]
Cardiovascular disease			1.08 [0.99-1.18]	1.05 [0.96-1.15]	1.05 [0.96-1.15]	1.04 [0.94-1.14]	1.04 [0.94-1.14]
Diabetes			1.09 [0.97-1.22]	1.09 [0.97-1.23]	1.10 [0.98-1.24]	1.11 [0.98-1.25]	1.11 [0.98-1.26]
Osteoarthritis			1.34 [1.24-1.45]***	1.29 [1.19-1.39]***	1.29 [1.19-1.39]***	1.22 [1.13-1.33]***	1.22 [1.13-1.33]***
Neuroticism score			1.03 [1.02-1.04]***	1.01 [1.00-1.02]	1.01 [1.00-1.02]	0.98 [0.96-0.99]***	0.98 [0.96-0.99]***
Noise exposure: work environment			1.86 [1.73-2.00]***	1.57 [1.45-1.69]***	1.57 [1.46-1.69]***	1.13 [1.05-1.22]**	1.13 [1.05-1.23]***
Noise exposure: loud music			1.40 [1.27-1.54]***	1.23 [1.11-1.35]***	1.23 [1.11-1.36]***	0.98 [0.88-1.08]	0.98 [0.89-1.08]
DTT (SRT minimum score)				1.21 [1.18-1.24]***	1.21 [1.19-1.24]***	1.17 [1.14-1.20]***	1.18 [1.15-1.20]***
Language Score: Correct responses				0.77 [0.69-0.86]***	0.77 [0.69-0.86]***	0.74 [0.66-0.82]***	0.74 [0.66-0.83]***
Interaction: DTT and Language Score				1.11 [1.08-1.14]***	1.11 [1.08-1.14]***	1.10 [1.06-1.13]***	1.10 [1.06-1.13]***
Tinnitus				2.73 [2.55-2.92]***	2.72 [2.54-2.91]***	1.42 [1.32-1.52]***	1.42 [1.33-1.53]***
Interaction: born outside UK/Asian eth.					1.48 [0.49-4.47]		1.56 [0.50-4.83]
Interaction: born outside UK/Black eth.					3.30 [1.03-10.57]*		2.11 [0.62-7.17]
Interaction: born outside UK/Other eth.					1.44 [0.74-2.81]		0.95 [0.47-1.92]
Interaction: Age and Asian ethnicity					0.97 [0.94-1.00]		0.97 [0.94-1.00]
Interaction: Age and Black ethnicity					1.03 [0.97-1.09]		1.01 [0.95-1.07]
Interaction: Age and Other ethnicity					0.95 [0.91-0.98]**		0.93 [0.90-0.97]***
Interaction: Sex and Asian ethnicity					1.04 [0.65-1.67]		1.23 [0.75-2.00]
Interaction: Sex and Black ethnicity					0.67 [0.29-1.56]		1.28 [0.55-2.99]
Interaction: Sex and Other ethnicity					0.96 [0.53-1.72]		1.06 [0.57-1.95]
Interaction: Tinnitus and Asian eth.					0.94 [0.58-1.50]		0.70 [0.43-1.14]
Interaction: Tinnitus and Black eth.					0.93 [0.39-2.22]		0.70 [0.29-1.70]
Interaction: Tinnitus and Other eth.					1.48 [0.79-2.75]		1.49 [0.79-2.83]
Self-reported hearing difficulty						35.34 [28.73-43.47]***	35.53 [28.88-43.71]***
Self-reported h/diff in noisy env.						3.96 [3.41-4.59]***	3.96 [3.42-4.59]***
Model fit statistics							
BIC	38,294	38,043	36,384	33,369	33,491	26,438	26,557
Log Likelihood	-19,105	-18,889	-18,000	-16,469	-16,458	-12,991	-12,979
Nagelkerke Pseudo R2	0.07	0.08	0.13	0.21	0.21	0.39	0.39

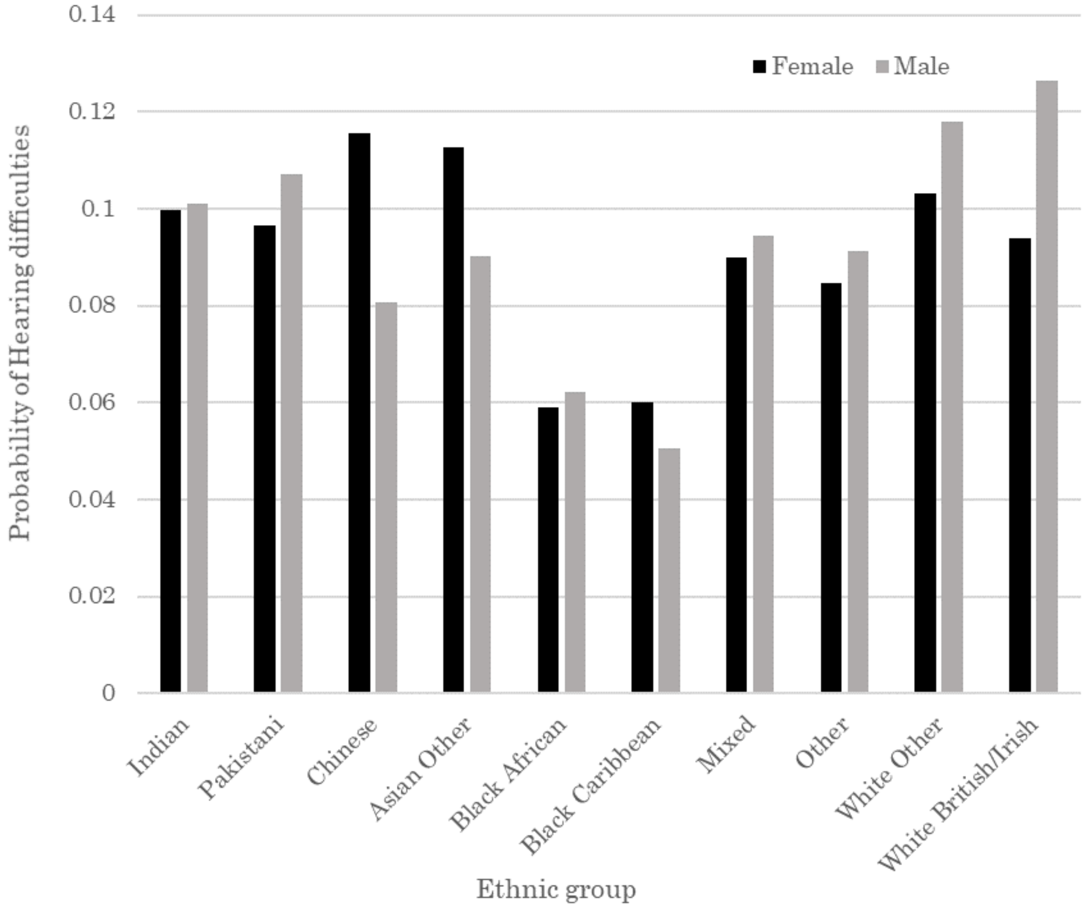
** p < .05, ** p < .01, *** p <.001*

Appendix C: Interactions from self-reported hearing difficulty model

	m4 (OR) OR (95% CI)	*m5 (OR)* OR (95% CI)	*m6 (OR)* OR (95% CI)	*m7 (OR)* OR (95% CI)
Interaction: Sex and Indian ethnicity	0.72 [0.62-0.84]***	0.72 [0.62-0.84]***	0.72 [0.62-0.84]***	0.72 [0.62-0.83]***
Interaction: Sex and Pakistani ethnicity	0.80 [0.56-1.14]	0.80 [0.56-1.14]	0.80 [0.56-1.14]	0.80 [0.56-1.15]
Interaction: Sex and Chinese eth.	0.47 [0.32-0.68]***	0.47 [0.32-0.69]***	0.47 [0.32-0.69]***	0.48 [0.33-0.69]***
Interaction: Sex and Asian Other ethnicity	0.55 [0.41-0.73]***	0.55 [0.41-0.73]***	0.56 [0.42-0.74]***	0.55 [0.42-0.73]***
Interaction: Sex and Black African ethnicity	0.75 [0.58-0.95]*	0.74 [0.58-0.94]*	0.73 [0.57-0.93]*	0.73 [0.57-0.93]*
Interaction: Sex and Black Caribbean ethnicity	0.59 [0.48-0.72]***	0.60 [0.49-0.74]***	0.60 [0.49-0.73]***	0.60 [0.49-0.73]***
Interaction: Sex and Mixed eth.	0.75 [0.57-0.97]*	0.75 [0.58-0.98]*	0.76 [0.59-0.99]*	0.76 [0.59-0.98]*
Interaction: Sex and Other eth.	0.77 [0.63-0.95]*	0.77 [0.63-0.95]*	0.77 [0.63-0.95]*	0.77 [0.63-0.95]*
Interaction: Sex and White Other eth.	0.83 [0.74-0.94]**	0.83 [0.74-0.94]**	0.82 [0.73-0.92]***	0.82 [0.73-0.92]***
Interaction: Age and Indian ethnicity		0.99 [0.98-1.00]	0.99 [0.98-1.00]*	0.99 [0.98-1.00]*
Interaction: Age and Pakistani ethnicity		0.99 [0.97-1.01]	0.99 [0.97-1.01]	0.99 [0.97-1.01]
Interaction: Age and Chinese eth.		0.99 [0.97-1.01]	0.99 [0.96-1.01]	0.99 [0.97-1.01]
Interaction: Age and Asian Other ethnicity		0.99 [0.97-1.01]	0.99 [0.98-1.01]	0.99 [0.98-1.01]
Interaction: Age and African ethnicity		0.99 [0.97-1.00]	0.99 [0.97-1.00]	0.99 [0.97-1.00]
Interaction: Age and Caribbean ethnicity		0.98 [0.96-0.99]***	0.98 [0.97-1.00]	0.98 [0.97-1.00]
Interaction: Age and Mixed eth.		0.98 [0.97-1.00]	0.98 [0.97-1.00]*	0.98 [0.97-1.00]*
Interaction: Age and Other eth.		1.00 [0.98-1.01]	1.00 [0.98-1.01]	1.00 [0.98-1.01]
Interaction: Age and White Other eth.		1.00 [0.99-1.00]	1.00 [0.99-1.00]	1.00 [0.99-1.00]
Interaction: born outside UK/Indian eth.			1.32 [0.98-1.76]	1.32 [0.98-1.76]
Interaction: born outside UK/Pakistani eth.			0.92 [0.54-1.56]	0.91 [0.54-1.55]
Interaction: born outside UK/Chinese eth.			0.94 [0.45-1.95]	0.92 [0.44-1.91]
Interaction: born outside UK/Asian Other eth.			0.41 [0.17-0.98]	0.40 [0.17-0.95]*
Interaction: born outside UK/African eth.			1.12 [0.72-1.75]	1.12 [0.72-1.74]
Interaction: born outside UK/Caribbean eth.			0.77 [0.58-1.02]	0.77 [0.58-1.02]
Interaction: born outside UK/Mixed eth.			1.08 [0.81-1.44]	1.08 [0.81-1.43]
Interaction: born outside UK/Other eth.			0.76 [0.57-1.01]	0.76 [0.57-1.02]
Interaction: born outside UK/White Other eth.			0.86 [0.74-1.00]*	0.86 [0.74-1.00]*
Interaction: Tinnitus and Indian ethnicity				0.97 [0.81-1.17]
Interaction: Tinnitus and Pakistani ethnicity				1.04 [0.71-1.52]
Interaction: Tinnitus and Chinese eth.				0.87 [0.59-1.27]
Interaction: Tinnitus and Asian Other ethnicity				0.72 [0.52-1.01]
Interaction: Tinnitus and African ethnicity				0.92 [0.70-1.20]
Interaction: Tinnitus and Caribbean ethnicity				1.04 [0.85-1.27]
Interaction: Tinnitus and Mixed eth.				0.69 [0.53-0.91]**
Interaction: Tinnitus and Other eth.				0.90 [0.72-1.12]
Interaction: Tinnitus and White Other eth.				0.98 [0.86-1.11]
Model fit statistics				
BIC	195,520	195,601	195,685	195,779
Log Likelihood	-97,460	-97,447	-97,435	-97,428
Nagelkerke Pseudo R2	0.21	0.21	0.21	0.21

** p < .05, ** p < .01, *** p <.001*

Appendix D: Predicted probability of self-reported hearing difficulty, interaction of ethnicity and sex



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