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Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England

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Keywords: hearing loss; hearing aids; surveys; epidemiology; social inequalities

Strengths and limitations

- Estimates of the burden of hearing loss, the use of hearing aids among persons with hearing loss, and their associations with socioeconomic status, are rarely available from nationally-representative health examination surveys.
- We used data from a screening audiometry device to estimate the prevalence of hearing loss. The prevalence of current hearing aid use was estimated among persons with hearing loss.
- The associations between different markers of socioeconomic status and hearing were examined after adjustment for a wide range of confounders such as age, exposure to work-related noise, and risk factors for cardiovascular disease.
- Exclusion of persons from the study due to difficulties in interviewer-participant communication through conditions such as deafness means that our estimates are likely to underestimate the true prevalence of hearing loss among community-dwelling middle-aged and older adults.

ABSTRACT

Background: Hearing loss impacts on cognitive, social and physical functioning. Both hearing loss and hearing aid use vary across population subgroups. We examined whether objectively measured hearing loss, and reported hearing aid use among persons with hearing loss, were associated with different markers of socioeconomic status (SES) in a nationally-representative sample of community-dwelling middle-aged and older adults.

Methods: Hearing was measured using an audiometric screening device in the Health Survey for England 2014 (3292 participants aged 45 years and over). Hearing loss was defined as ≥35dBHL at 3.0 kHz in the better-hearing ear. Using sex-specific logistic regression modelling, we evaluated the associations between SES and hearing after adjustment for potential confounders.

Results: 26% of men and 20% of women aged 45 years and over had hearing loss. Hearing loss was higher among men in the lowest SES groups. For example, the multivariable-adjusted odds of hearing loss were almost twice as high for those in the lowest versus the highest income tertile [Odds Ratio (OR): 1.77; 95% CI: 1.15, 2.74]. Among those with hearing loss, 30% of men and 27% of women were currently using a hearing aid. Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the middle (OR: 0.50; 95% CI: 0.25, 0.99) and the lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. SES was not associated with hearing outcomes among women.

Conclusions: Whilst the burden of hearing loss fell highest among persons in the lowest SES groups, hearing aid use was demonstrably lower. Initiatives to detect hearing loss early and increase the uptake and the use of hearing aids may provide substantial public health benefits and reduce socioeconomic inequalities in health.

INTRODUCTION

Hearing loss is well known to impact on cognitive, social and physical functioning.[1-3] It can be congenital, but most is acquired and is sensorineural and irreversible in nature.[4] Preventing hearing loss requires understanding its aetiology and risk factors.[5] Epidemiological studies have shown that hearing loss increases with age[6-8] and increases with the duration of exposure to work-related noise. It is higher among men [6-8], higher among persons with cardiovascular disease risk factors, and is inversely associated with socioeconomic status (SES).[6-9] Early detection and hearing aid use may be effective at ameliorating the impact of hearing loss.[10] However, levels of hearing aid use among persons most likely to benefit are low, especially among persons in the lowest SES groups.

Based on the UK National Study of Hearing conducted in four cities in the early 1980s, 16% of adults aged 17-80years had a bilateral, and 25% had a unilateral or bilateral, hearing loss.[11] Uptake and use of hearing aids was low, with uptake being 10-30% among persons with hearing loss, and up to 25% of hearing aid owners never using them.[12] To provide up-to-date estimates of the burden of hearing loss, the Health Survey for England 2014 included, for the first time in a nationally-representative sample of the population, valid screening audiometry data. The aim of this study was to estimate the prevalence of (1) hearing loss, and (2) current hearing aid use (among persons with hearing loss), in this sample of community-dwelling middle-aged and older adults across population subgroups defined by demographics, work-related noise exposure, and by the presence of cardiovascular disease risk factors. We also examined the associations between SES and hearing.

METHODS

Study population

The present study used data from the Health Survey for England (HSE). The HSE is an annual, nationally-representative cross-sectional survey of the non-institutionalised general population. Multistage stratified probability sampling is used with postcode sectors as the primary sampling unit and the Postcode Address File as the sampling frame for households. Details about the HSE are described elsewhere.[13] Interview and nurse-visit response rates were 55% and 37%, respectively. Participants gave verbal consent to be interviewed, visited by a nurse, participate in a hearing test, and have blood pressure and anthropometric measurements taken, and gave written consent for blood sampling. Ethical approval was obtained from the Oxford A Research Ethics Committee (12/SC/0317).

All participants (aged 16 years and over) who had a nurse-visit were eligible for the hearing test, excluding those with a cochlear implant or with a current ear infection (Figure 1). Participants aged 16-44 years were excluded due to hearing loss being comparatively rare (*n*=46). In addition, a number of persons would have been excluded if interviewer-participant communication difficulties through conditions such as deafness were sufficient to prevent inclusion in the study. The final analytical sample was 3292 participants.

(Figure 1 here)

Objective hearing test

Hearing was measured using an audiometric screening device (HearCheck screener, Siemens, Erlangen, Germany) in participants' own homes. Two evaluation studies comparing the results of the screener to pure tone audiometry showed good sensitivity (range: 78% to 92%) and acceptable to good specificity (62% to 95%).[14;15] This handheld device produced a series of three sounds of decreasing volume at 1.0 kHz (55dBHL, 35dBHL and 20dBHL) and then at 3.0 kHz (75dBHL, 55dBHL and 35dBHL). Both ears were tested, starting with the left. Participants were instructed to indicate when they heard a noise by raising their finger. If an

irregular pattern was found (a combination of responses indicating that quieter sounds were heard but louder ones were not), the test was repeated at least 60s later for that ear. Participants with an irregular pattern at the first test, but a regular pattern at the second test, were included in the analyses. Further details of the testing procedures are available elsewhere.[16]

Outcomes

Hearing loss

Hearing loss was defined as ≥35dBHL at 3.0 kHz in the better-hearing ear, the level at which intervention has been shown to be definitely beneficial.[17] Hearing loss was subdivided into two mutually exclusive categories: (1) 'moderate loss' : >35dBHL to 54dBHL (tone not heard at 35dBHL, but heard at 55dBHL and at 75dBHL), and (2) 'moderately severe or severe loss' : >55dBHL (tone not heard at 35dBHL and at 55dBHL, but the tone may, or may not, have been heard at 75dBHL). Prevalence estimates were multiplied by the 2014 household population to estimate the number of people with hearing loss.[18]

Hearing aid use

As part of the main interview, participants were asked if they ever wore a hearing aid nowadays: those who reported that they did not were asked whether they had ever tried one.

Markers of socioeconomic status

Tertiles of equivalised household income, quintiles of the area-based Index of Multiple Deprivation (IMD 2010: Q1 least deprived; Q5 most deprived)[19], and the highest formal educational attainment (degree or higher, below degree, no qualifications) were chosen as related, but different, markers of SES. Broader categories of SES were used for the analysis of hearing aid use – among persons with hearing loss - due to smaller sample sizes.

Covariates

Covariates were grouped into: (1) demographic characteristics (age, region), (2) exposure to work-related noise, and (3) risk factors for cardiovascular disease (cigarette smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity). Modifiable risk factors for cardiovascular disease are well-known to be independently associated with hearing impairment[20;21], and potentially confound the associations between SES and hearing loss. Age-at-interview was categorized into four groups (45-54, 55-64, 65-74, and 75+ years). Government Office Region was grouped into North, Midlands, London, and South. Duration of exposure to work-related noise was established by asking participants whether they had ever worked in a place that was so noisy that you had to shout to be heard (response categories: 'no', 'yes, for less than 1 year', 'yes, for at least 1 year but less than 5 years', and 'yes, for 5 years or longer'). Cigarette smoking status categories were current, ex-regular and never. Single measurements of height and weight were taken by trained interviewers using standard protocols. Body mass index (BMI) was computed as weight in kilogrammes (kg) divided by height in metres squared (m^2): participants were classified as normal-weight (18.5-24.9kg/m^2), overweight (25.0-29.9kg/m^2), or obese (≥30.0kg/m^2). We used two indicators of hyperglycaemia: self-reported physician diagnosis of diabetes, and a raised glycated haemoglobin (HbA_{1C} ≥48mmol/mol) irrespective of diagnosis. Hypertension was defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg and/or current use of medication taken for the purposes of lowering blood pressure. Total cholesterol was measured in non-fasting blood samples. Dyslipidaemia was defined as total cholesterol ≥5.0mmol/L and/or current use of lipid-lowering medication. Based on the Short-Form International Physical Activity Questionnaire (IPAQ), participants spending <30 minutes per week in moderate-to-vigorous physical activity were classed as physically inactive.[22] Broader categories of these covariates were used in some cases for the analysis of hearing aid use due to smaller sample sizes.

Statistical analysis

All analyses were sex-specific. Hearing loss prevalence (overall and by severity) was estimated among the overall population and as stratified by demographic characteristics, exposure to work-related noise, CVD risk factors, and SES. Prevalence estimates were directly age-standardised within sex to the English household population using the four age-groups described above. Differences in the prevalence of hearing loss across groups were evaluated using the chi-square χ^2 test. This analysis was repeated to estimate the prevalence of current hearing aid use among those participants with hearing loss.

Logistic regression modelling was used to evaluate the association between SES and hearing loss after adjustment for demographics, exposure to work-related noise, and CVD risk factors. Associations were summarised using Odds Ratios (OR) with 95% Confidence Intervals (CI). We decided a priori to run separate models for the three indicators of SES rather than estimate a single model to avoid multicollinearity. Two sequential models were fitted. SES and hearing loss associations were age-adjusted (Model A), and then further adjusted for region, exposure to work-related noise, and CVD risk factors (Model B). SES was entered in the models as a categorical variable, with the highest status group as the reference category. We repeated the analyses to evaluate the association between SES and current hearing aid use, with an additional adjustment for the severity of hearing loss. All analyses accounted for the complex survey design, incorporating the nurse-visit weight which accounted for individual non-participation and preserved the national representativeness of the sample. Data set preparation was performed in SPSS V.20.0 (SPSS IBM Inc., Chicago, Illinois, USA). Statistical analysis was conducted using Stata V13.1 (College Station, Texas, USA). The HSE 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk).

RESULTS

Compared to participants with data collected from the nurse-visit stage, participants interviewed in the survey but without data from the nurse visit were more likely to be in the lowest income tertile (P=0.002), had no formal educational qualifications (P<0.001), resided in the most deprived IMD quintile (P<0.001), and currently smoked cigarettes (P=0.011) (Supplementary Table 1).

Hearing loss

Table 1 shows the age-standardised estimates of the prevalence of hearing loss. For simplicity, we present only estimates by age, duration of exposure to work-related noise, and each indicator of socioeconomic status in the main text, with the estimates for region and each CVD risk factor available as Supplementary data. Overall, 26% of men and 20% of women aged 45 years and over had hearing loss defined as ≥35dBHL at 3.0 kHz in the better-hearing ear (n=769/3292), equivalent to 5.2million persons. The prevalence of 'moderate' loss (15% men, 12% women) exceeded that of 'moderately severe or severe' loss (11% and 7%). Hearing loss increased monotonically with age, reaching 67% of men and 58% of women aged 75+ years. Only among men in the oldest age-group did the prevalence of 'moderately severe or severe' loss (39%) exceed that of 'moderate' loss (29%). Among men, hearing loss was higher among those exposed to work-related noise for ≥5 years (P<0.001), in the lowest income tertile (P=0.005), residing in areas of higher deprivation (P=0.011), and with no formal educational qualifications (P<0.001). Patterns among women were similar, yet typically weaker. Of the risk factors for cardiovascular disease, hearing loss was higher among men and women with doctor-diagnosed diabetes, with elevated Hb1Ac irrespective of diagnosis, and among women classed as physically inactive (Supplementary Table 2).

(Table 1 here)

Figure 2 shows the associations between SES and hearing loss (expressed as odds ratios) after age (Model A) and additional adjustment for region, duration of exposure to work-related noise, and CVD risk factors (Model B). Among men, the multivariable-adjusted associations were partly attenuated: nevertheless, the multivariable-adjusted odds of hearing loss showed a strong socioeconomic gradient. The odds of hearing loss were almost twice as high for men in the lowest versus the highest income tertile (OR: 1.77; 95% CI: 1.15, 2.74) and were over twice as high for men with no formal educational qualifications versus those with at least a degree (OR: 2.35; 95% CI: 1.54, 3.59). For women, SES was not significantly associated with hearing loss.

(Figure 2 here)

Current hearing aid use

Among participants with hearing loss, 30% of men and 27% of women wore hearing aids nowadays (*n*=264/769; Table 2). Lower proportions had tried hearing aids in the past, but not currently (7% men, 10% women) (data not shown). Current use for persons with 'moderately severe or severe' loss (53% men, 47% women) exceeded that for persons with 'moderate' loss (18% men, 19% women). Use increased monotonically with age but was confined to the minority, reaching close to 40% for participants aged 75+ years.

(Table 2 here)

Differences in hearing aid utilisation by population subgroups were typically minor, with the exception of lower use among women classed as physically inactive (Supplementary Table 3). Lower use among participants reporting doctor-diagnosed diabetes was also noteworthy. Figure 3 shows the associations between SES and current hearing aid use after age- (Model A) and full-adjustment (Model B). Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the

middle (OR: 0.50; 95% CI: 0.25, 0.99) and lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. Area deprivation and educational attainment was associated with hearing aid use in the same direction, yet typically more weakly. For women, SES was not associated with hearing aid use.

(Figure 3 here)

DISCUSSION

In this nationally-representative sample of community-dwelling persons aged 45 years and over, more than one in four persons had a level of hearing loss that would benefit from hearing aid use. However, less than one in three persons with hearing loss reported using a hearing aid nowadays, suggesting a significant level of unmet need. The burden of hearing loss fell highest among persons in the lowest SES groups, especially among men, suggesting hearing loss as a source of socioeconomic inequalities in health. Even after adjustment for the severity of hearing loss, hearing aid use was evidently lower for men in the middle- and low-income groups compared with their high-income counterparts.

Comparisons with previous studies are difficult due to differences in the age-range of participants.[6] Considerable heterogeneity also exists in the definition and the measurement of hearing loss.[23] The WHO defines adult disabling hearing impairment as a permanent unaided hearing threshold for the better-hearing ear of ≥41dBHL (averaged over 0.5, 1.0, 2.0 and 4.0 kHz).[24] Using this definition, disabling hearing loss was estimated to affect 360 million people worldwide in 2012 (more than 5% of the global population).[25] The Global Burden of Disease Hearing Loss Expert Group uses a threshold of >35dBHL for all age-groups, and equates "unilateral hearing impairment" with "bilateral mild hearing impairment".[7] The estimated global prevalence of hearing loss using this alternative definition was 12% for males and 10% for females aged ≥15 in 2008.[7] Analysis of HSE 2014 data by the same

authors of the present study found that 13% of adults (14% men, 12% women) had loss of ≥35dBHL at 3.0 kHz in the better-hearing ear.[16] Our findings of differences in the burden of hearing loss agree with other population-based studies in which the prevalence of hearing loss was higher for men than women[6-8 8;26-29], increased monotonically with age[6-8 11 26-28 30;31], increased with longer exposure to occupational noise[6-8], co-existed with CVD risk factors such as diabetes[6;8;21;31;32], and was higher in the lowest SES groups [6;27;28;30;31;33], especially for men.[9] In contrast to other studies[6;8;31;32], hearing loss did not vary in the present study by current smoking status.

Other studies have shown similar or lower levels of hearing aid use among persons with hearing loss. Using the Digit Triplet Test, 21.5% of UK Biobank participants aged 40-69years with 'poor' speech recognition in noise testing reported using a hearing aid.[30] Based on the 1999-2006 US National Health and Nutrition Examination Survey, hearing aid use among participants aged 50+ years with hearing loss was 14.2%.[34] Our findings of subgroup differences in levels of hearing aid use are consistent with other studies which showed that use increases with age [34;35] and with the severity of hearing loss.[34;36] Our finding of lower utilisation among men in the lowest SES groups, independent of the severity of hearing loss, is also consistent with other studies.[30;35-38]

Associations between SES and hearing loss likely involve multiple simultaneous pathways [27] including other concomitant factors of lower SES such as educational and employment factors (including exposure to work-related noise), and modifiable lifestyle factors.[8] While occupational noise is now limited and generally well-controlled in the UK[39], past exposure may have had serious long-term consequences for hearing in middle- and older-age. It remains unclear whether hearing loss is a driver of low SES or whether low SES is a driver of hearing loss.[27] The diabetes-hearing loss associations found in our study are in agreement with a recent meta-analysis.[40] Greater atrophy of the stria vascularis is a potential biologic

mechanism for this association.[21;40-43] Finally, this study confirms the low level of current hearing aid use, especially among men in the lowest SES groups. Previous studies have demonstrated non-financial barriers to uptake and use, with self-recognition of hearing problems being the strongest factor.[44] Low take-up and use are typically attributed to a perception of hearing loss being an inconsequential part of ageing.[34] Although treatment and hearing aid provision is financially supported in the UK through the National Health Service, persons in the lower SES groups use specialist health services less frequently than those in higher SES groups.[45]

The main strength of this study was the use of valid screening audiometry data within a nationally-representative health examination survey. Objectively-measured hearing loss data overcomes the under-estimation of socioeconomic inequalities in health that are typically associated with self-reports.[46] Other analyses of HSE 2014 showed that socioeconomic inequalities in hearing were most apparent using objective but not self-report data[16], partly reflecting differences in levels of expectations, and differences in levels of awareness of adverse health conditions[47]. This study also has a number of limitations. Differences in the propensity to respond at the nurse-visit may have weakened the sample's representativeness and reduced the generalizability of our findings, but the use of statistical weights to account for the biases in individual participation would have mitigated this to a considerable extent. The estimates of hearing loss prevalence are conservative due to the exclusion of: (1) the institutionalised population, (2) individuals with a cochlear implant or with a current ear infection, and (3) the exclusion of an unknown number of individuals with conditions such as deafness that were judged to impede interviewer-participant communication. The relatively small number of participants with hearing loss may have resulted in our analyses of hearing aid use to be underpowered to detect differences among subgroups. For the same reason, we were unable to examine differences in utilisation among subgroups stratified by the severity

of hearing loss. Insufficient numbers meant that we were unable to provide separate reliable estimates for minority ethnic groups. Our findings could have been influenced by unmeasured confounders such as the duration of exposure to non-occupational noise. Lastly, since we utilised cross-sectional data, we could not establish the direction of the observed associations, and we cannot establish causality.

In conclusion, hearing loss is highly prevalent, affecting more than one in four men and more than one in five women. However, less than one in three persons with hearing loss reported using a hearing aid nowadays, suggesting a significant level of unmet need. Whilst the burden of hearing loss falls highest among persons in the lowest SES groups, use of hearing aids is demonstrably lower. Initiatives to detect hearing loss early, and the increased uptake of hearing aids, may provide substantial public health benefits and reduce socioeconomic inequalities in health.

Data sharing agreement

The Health Survey for England 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk). Statistical code is available from the corresponding author at s.scholes@ucl.ac.uk.

Contributors

SS, JB, AD and JM were responsible for developing the design of the study.
SS was responsible for conducting the analyses, interpreting the results, and drafting the manuscript. SS, JB, AD and JM critically revised the manuscript. All authors have read and approved the final manuscript.

Table 1 Age-standardised prevalence (%) and standard error (SE) of hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Males					Females				
	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§
N	1485	425	244	181		1807	344	217	127	
All	1485	26.2 (1.2)	15.2 (1.0)	11.0 (0.9)	-	1807	19.6 (1.0)	12.2 (0.8)	7.4 (0.7)	
Age-group:										
45-54	420	8.0 (1.5)	7.0 (1.4)	1.0 (0.5)	<0.001	560	3.1 (0.9)	2.3 (0.7)	0.7 (0.4)	<0.001
55-64	401	17.0 (2.0)	10.9 (1.7)	6.1 (1.2)		446	10.6 (1.6)	8.6 (1.4)	2.0 (0.7)	
65-74	402	37.0 (2.5)	23.8 (2.2)	13.3 (2.0)		476	20.4 (1.8)	14.5 (1.6)	5.9 (1.1)	
75+	262	67.3 (3.2)	28.6 (2.8)	38.7 (3.1)		325	57.9 (2.9)	30.6 (2.5)	27.3 (2.6)	
Duration of work-related noise exposure:										
None	819	22.2 (1.6)	13.4 (1.3)	8.9 (1.2)	<0.001	1468	18.6 (1.1)	12.1 (0.9)	6.5 (0.7)	0.091
Less than 5 years	226	24.6 (2.9)	11.1 (2.3)	13.5 (2.4)		128	18.8 (3.8)	10.8 (3.0)	7.9 (2.7)	
5+ years	434	35.1 (2.5)	21.5 (2.1)	13.6 (1.7)		210	25.4 (3.0)	13.6 (2.4)	11.8 (2.2)	
Income tertiles:										
Highest	491	21.3 (2.5)	13.1 (2.0)	8.2 (1.7)	0.005	484	16.5 (2.3)	11.0 (1.9)	5.5 (1.4)	0.413
Middle	458	28.6 (2.2)	16.7 (1.9)	12.0 (1.5)		562	19.3 (1.8)	11.9 (1.4)	7.4 (1.2)	
Lowest	305	32.9 (2.8)	19.8 (2.2)	13.1 (2.0)		417	20.1 (1.9)	13.1 (1.6)	7.0 (1.2)	
Index of Multiple Deprivation quintiles:										
Least deprived	369	21.4 (2.2)	11.0 (1.8)	10.3 (1.7)	0.011	448	18.6 (2.1)	11.4 (1.5)	7.2 (1.4)	0.077
2	340	23.0 (2.4)	13.2 (1.8)	9.8 (1.7)		407	17.6 (1.7)	11.5 (1.5)	6.1 (1.2)	
3	311	27.2 (2.7)	17.1 (2.3)	10.1 (1.8)		392	17.5 (2.1)	10.9 (1.7)	6.6 (1.5)	
4	255	32.6 (2.9)	18.2 (2.5)	14.4 (2.2)		312	19.8 (2.6)	10.6 (2.1)	9.2 (1.7)	
Most deprived	210	30.2 (3.3)	18.0 (2.6)	12.2 (2.6)		248	26.3 (2.7)	18.4 (2.4)	7.9 (1.7)	
Education status:										
Degree or higher	344	20.1 (2.6)	12.3 (2.1)	7.8 (1.7)	<0.001	309	14.5 (3.5)	7.8 (2.2)	6.7 (2.5)	0.070
Below degree	733	23.2 (1.8)	12.8 (1.3)	10.4 (1.4)		941	18.4 (1.6)	12.1 (1.2)	6.4 (1.1)	
No qualifications	407	40.1 (3.0)	26.5 (2.9)	13.7 (1.7)		555	23.6 (2.1)	14.7 (1.8)	8.9 (1.1)	

* Hearing loss: ≥35dBHL at 3.0 kHz (tone not heard at 35dBHL).
† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but heard at 55 and at 75dBHL).
‡ Moderately severe or severe loss: >55 dBHL (tone not heard at 35 and at 55dBHL, but may or may not have heard the tone at 75dBHL).
§ P-values are for comparison across groups with respect to hearing loss (χ^2 test)

Table 2 Age-standardized prevalence (%) and standard error (SE) of hearing aid use among persons with hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Men			Women		
	N	Hearing aid use % (SE)	*P-value*[*]	N	Hearing aid use % (SE)	*P-value*[*]
N	425	29.7 (3.1)		344	26.9 (3.3)	
Severity of loss:						
Moderate[†]	244	17.8 (3.2)	<0.001	217	19.1 (3.5)	0.002
Moderate to severe[‡]	181	52.9 (6.3)		127	47.1 (8.7)	
Age-group:						
45-64	101	25.4 (4.6)	0.056	63	21.2 (5.1)	0.035
65-74	147	34.3 (4.3)		94	31.4 (4.9)	
75+	177	40.2 (3.7)		187	39.1 (3.7)	
Duration of work-related noise exposure:						
None	250	26.1 (3.9)	0.234	287	25.3 (3.6)	0.296
Some	173	33.5 (4.9)		56	35.5 (9.4)	
Income tertiles:						
Highest	84	36.0 (6.5)	0.548	54	24.7 (6.5)	0.900
Middle	149	31.2 (5.5)		105	28.6 (5.8)	
Lowest	118	26.0 (6.1)		90	26.0 (7.0)	
Index of Multiple Deprivation quintiles:						
Least deprived 1 & 2	179	29.8 (5.3)	0.812	158	29.1 (5.2)	0.615
Quintile 3	101	33.5 (8.0)		66	29.3 (6.6)	
Most deprived 4 & 5	145	27.9 (4.6)		120	22.6 (5.6)	
Education status:						
O level or above	227	32.3 (4.2)	0.354	151	28.0 (4.3)	0.654
No qualifications	198	26.3 (4.6)		192	24.7 (5.6)	

[*] P-values are for comparison across groups with respect to hearing aid use (χ^2 test).
[†] Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but tone heard at 55 and 75dBHL).
[‡] Moderately severe or severe loss: >55dBHL (tone not heard at 35 and 55dBHL, but may or may not have heard the tone at 75dBHL).

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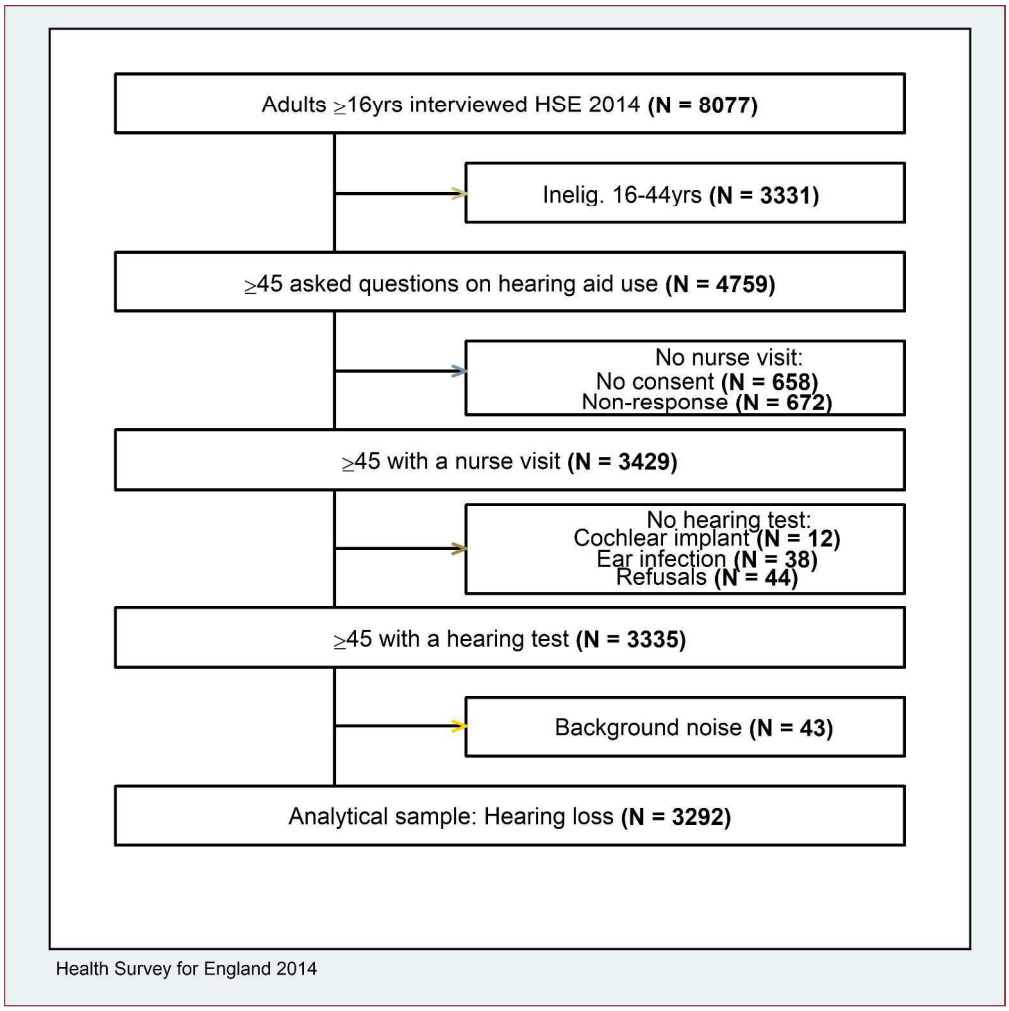

Selection of Study Participants, Health Survey for England 2014

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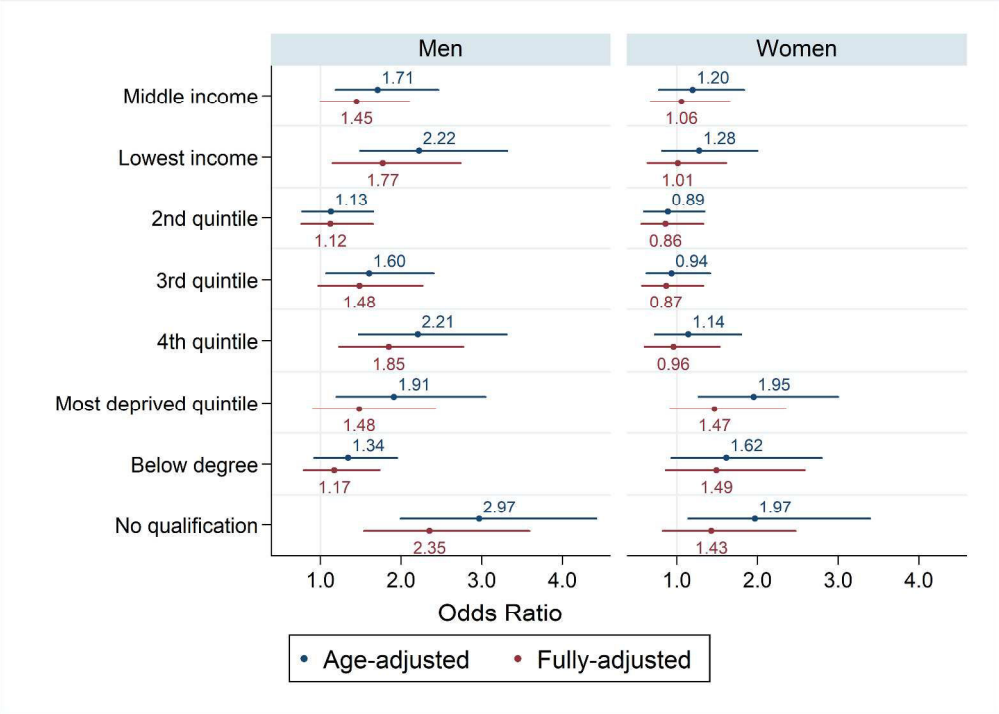

Associations between socioeconomic status and hearing loss in middle-aged and older adults. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (most affluent), and highest educational attainment (degree or higher). Lines represent Odds Ratio (outcome = hearing loss) and its 95% confidence interval. Model A: adjusted for age. Model B: adjusted for: age, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

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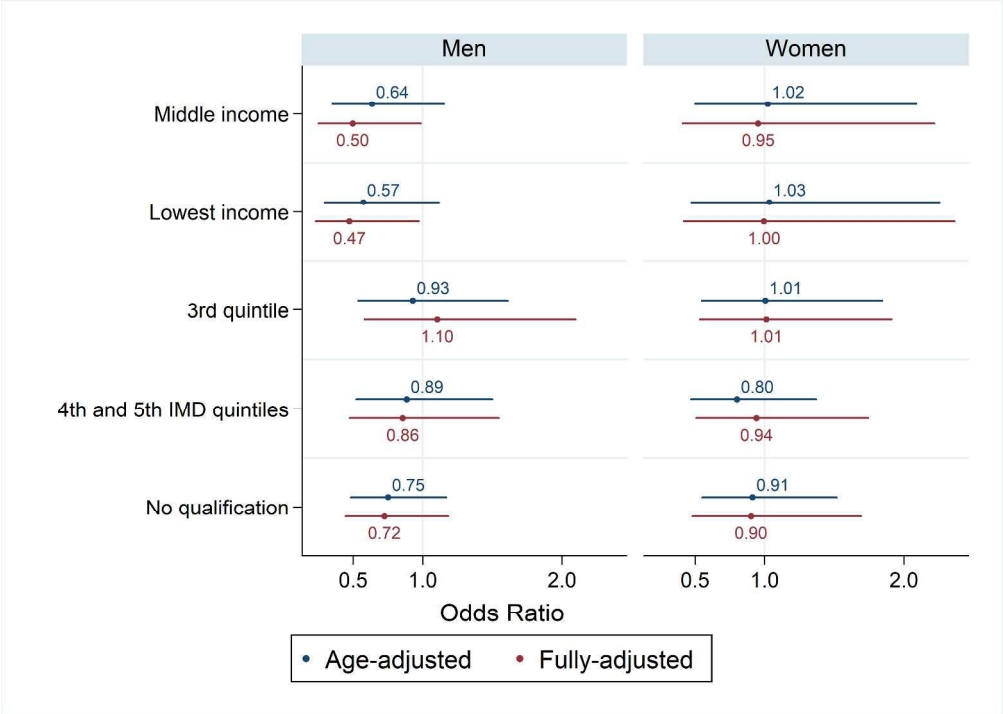

Associations between socioeconomic status and current hearing aid use in middle-aged and older adults with hearing loss.
Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (least deprived Q1 and Q2), and highest educational attainment (O level or above). Lines represent Odds Ratio (outcome = hearing aid use) and its 95% confidence interval. Model A: adjusted for age. Model B: adjusted for: age, severity of hearing loss, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

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Supplementary Tables

Scholes S, Biddulph J, Davis AC and Mindell JS. Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England. *Submitted to BMJ Open.*

Supplementary Table 1 Characteristics of participants aged 45+ with main interview with and without nurse visit

	No nurse visit	Nurse visit	*P*-value
N	**1,330**	**3,429**	
Age in years: mean (SD)	62.4 (12.4)	63.0 (11.7)	0.129
Age (%):			
45-54	34.7	29.8	*<0.001*
55-64	24.7	25.7	
65-74	20.8	26.6	
75+	19.8	18.0	
Sex (%):			
Males	46.2	45.1	0.502
Females	53.8	54.9	
Region (%):			
North	37.3	31.7	*<0.001*
Midlands	27.0	30.6	
London	11.0	8.0	
South	24.7	29.8	
Occupational noise exposure (%):			
None	71.9	69.3	*0.004*
Less than 5 years	7.7	10.9	
5 years or more	20.4	19.8	
Missing (*n*=16)			
Income tertiles (%):			
Highest	35.2	35.5	*0.002*
Middle	32.3	37.5	
Lowest	32.4	27.0	
Missing (*n*=1013)			
Index of Multiple Deprivation (%):			
Least deprived	19.9	24.5	*<0.001*
2nd	22.0	22.5	
3rd	18.4	21.3	
4th	19.3	17.6	
Most deprived	20.3	14.1	
Education (%):			
Degree	17.3	19.7	*<0.001*
Below degree	46.2	50.8	
No qualifications	36.6	29.5	
Missing (*n*=23)			
Smoking status (%):			
Never	52.4	54.1	*0.011*
Former	30.6	32.3	
Current	17.0	13.6	
Missing (*n*=15)			
BMI (%):			
Normal	25.1	27.6	*0.291*
Overweight	42.4	41.2	
Obese	32.6	31.2	

Missing (*n*=691)			
Doctor-diagnosed diabetes (%):			
No	89.5	89.6	*0.886*
Yes	10.5	10.4	
Missing (*n*=1)			
Hearing difficulty (%):			
None	68.7	60.4	<0.001
Slight	15.5	22.9	
Moderate	7.6	8.8	
Great	8.3	8.0	
Missing (*n*=26)			
Hearing aid use (%):			
Current	10.1	9.5	0.748
Used but not nowadays	3.1	3.3	
Never used	86.8	87.2	
Missing (*n*=9)			

Abbreviations: BMI: body mass index; SD: standard deviation

Notes: Analysis is unweighted. Data are presented as mean and standard deviation (SD) for continuous variables; and as the column (%) for categorical variables. *P*-values are based on t-test for continuous variables and the chi-square test χ^2 for categorical variables (excluding missing data on covariates).

Supplementary Table 2 Age-standardised prevalence (%) and standard error (SE) of hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Males					Females				
	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§
Region:										
North	485	26.7 (2.1)	14.9 (1.7)	11.8 (1.6)	0.618	556	20.2 (1.6)	13.0 (1.4)	7.2 (1.1)	0.322
Midlands	454	28.0 (2.1)	16.9 (1.6)	11.1 (1.7)		558	21.6 (1.7)	13.0 (1.4)	8.6 (1.2)	
London	113	21.9 (5.1)	14.1 (4.0)	7.8 (3.6)		142	15.6 (3.5)	9.4 (2.8)	6.2 (2.5)	
South	433	25.4 (2.3)	14.0 (1.8)	11.4 (1.6)		551	18.1 (1.8)	11.3 (1.3)	6.8 (1.2)	
Smoking status:										
Never smoked	709	24.9 (1.8)	14.0 (1.4)	10.9 (1.3)	0.102	1083	19.1 (1.3)	11.5 (1.0)	7.6 (0.9)	0.290
Ex-regular	559	26.0 (1.9)	15.1 (1.5)	10.9 (1.2)		494	17.6 (1.6)	11.0 (1.3)	6.6 (1.1)	
Current smoker	217	32.9 (4.1)	17.1 (3.1)	15.8 (3.8)		230	23.0 (3.4)	14.9 (2.8)	8.1 (2.6)	
BMI:										
Normal	297	27.1 (3.2)	16.3 (2.4)	10.8 (2.4)	0.529	535	15.6 (1.7)	7.3 (1.1)	8.4 (1.4)	0.135
Overweight	658	24.0 (1.7)	13.6 (1.4)	10.4 (1.1)		565	20.3 (1.7)	13.0 (1.5)	7.4 (1.1)	
Obese	401	26.9 (2.2)	16.4 (1.8)	10.5 (1.7)		519	19.7 (1.9)	15.0 (1.7)	4.6 (1.1)	
Diagnosed diabetes:										
No	1294	24.2 (1.3)	13.7 (1.0)	10.6 (1.0)	<0.001	1652	18.4 (1.0)	11.0 (0.8)	7.4 (0.7)	0.005
Yes	191	40.4 (3.9)	26.2 (3.5)	14.2 (2.5)		154	28.8 (4.0)	21.2 (3.7)	7.6 (1.9)	
Raised Hb1Ac:										
No	981	23.6 (1.4)	13.1 (1.1)	10.6 (1.1)	<0.001	1189	17.9 (1.2)	10.7 (0.9)	7.2 (0.9)	0.025
Yes	140	39.8 (4.3)	25.5 (4.0)	14.3 (2.9)		114	27.1 (4.4)	17.0 (3.6)	10.1 (3.0)	
Hypertension:										
No	630	27.7 (2.0)	17.4 (1.7)	10.3 (1.6)	0.752	906	18.6 (1.6)	11.7 (1.3)	6.9 (1.1)	0.133
Yes	640	26.8 (1.9)	14.5 (1.5)	12.4 (1.3)		707	22.0 (1.6)	13.8 (1.3)	8.2 (1.0)	
Dyslipidaemia:										
No	483	29.7 (2.3)	17.0 (2.0)	12.7 (1.5)	0.031	389	22.0 (2.1)	13.5 (1.7)	8.5 (1.5)	0.098
Yes	637	23.2 (2.1)	13.2 (1.5)	10.0 (1.7)		915	17.8 (1.5)	10.9 (1.2)	6.8 (1.0)	
Physically inactive:										
No	838	24.1 (1.7)	14.3 (1.3)	9.9 (1.3)	0.180	875	16.0 (1.5)	10.8 (1.3)	5.2 (1.0)	0.028
Yes	437	27.7 (2.2)	16.0 (1.7)	11.7 (1.5)		649	20.9 (1.6)	13.4 (1.3)	7.4 (1.0)	

[*] Hearing loss: ≥35dBHL at 3.0 kHz (tone not heard at 35dBHL).
[†] Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but heard at 55 and at 75dBHL).
[‡] Moderately severe or severe loss: >55 dBHL (tone not heard at 35 and at 55dBHL, but may or may not have heard the tone at 75dBHL).
[§] P-values are for comparison across groups with respect to hearing loss (χ^2 test)

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Supplementary Table 3 Age-standardized prevalence (%) and standard error (SE) of hearing aid use among persons with hearing loss, persons aged 45 years and over, HSE 2014

	Men			Women		
	N	**Hearing aid use % (SE)**	***P-value*** *	**N**	**Hearing aid use % (SE)**	***P-value*** *
Smoking status:						
Never smoked	182	35.3 (4.1)	0.452	202	32.7 (4.2)	0.849
Ex-regular	189	28.4 (3.8)		96	31.1 (5.9)	
Current smoker	54	27.5 (7.6)		46	27.4 (8.0)	
BMI:						
Normal	72	27.2 (6.7)	0.789	72	36.2 (8.1)	0.362
Overweight	181	30.7 (5.5)		112	23.5 (4.9)	
Obese	113	33.5 (5.5)		90	25.9 (6.0)	
Diagnosed diabetes:						
No	338	32.5 (3.6)	0.101	287	29.6 (3.8)	0.077
Yes	87	20.5 (5.6)		56	13.5 (6.4)	
Raised Hb1Ac:						
No	234	30.2 (4.0)	0.510	184	31.4 (4.5)	0.194
Yes	62	24.3 (7.5)		35	17.4 (8.3)	
Hypertension:						
No	159	30.7 (4.6)	0.761	113	30.1 (5.2)	0.803
Yes	223	28.7 (4.8)		201	28.4 (4.9)	
Dyslipidaemia:						
No	172	29.0 (4.8)	0.910	88	24.7 (7.6)	0.584
Yes	126	28.2 (5.2)		132	29.8 (4.9)	
Physically inactive:						
No	182	30.3 (4.5)	0.628	99	36.6 (5.6)	0.003
Yes	162	26.8 (5.4)		162	15.8 (3.9)	

* P-values are for comparison across groups with respect to hearing aid use (χ^2 test).

STROBE Statement—checklist of items that should be included in reports of observational studies

Scholes S, Biddulph J, Davis AC, Mindell JS. Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England. Submitted to BMJ Open.

		Recommendation	Author response
1	**Title / abstract**	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Yes. The title of our submitted manuscript is: "Socioeconomic differences in hearing among middle-aged and older adults: **cross-sectional analyses** using the Health Survey for England".
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Yes
2	**Introduction**	Explain the scientific background and rationale for the investigation being reported	Yes. The background and rationale for our study are outlined in the Introduction (1st and 2nd paragraphs, respectively).
3		State specific objectives, including any prespecified hypotheses	Yes. The primary and secondary aims are outlined in the second paragraph of the Introduction. We did not have any pre-specified hypotheses.
4	Methods	*Study design*: Present key elements of study design early in the paper	Yes. The first sentence of the Methods Section states that the present study uses data from the Health Survey for England, an annual nationally-representative cross-sectional survey of the non-institutionalised general population.
5		*Setting:* Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Yes. The study setting is outlined in the first paragraph of the Methods Section.
6		*Participants (cross-sectional study):* Give the eligibility criteria, and the sources and methods of selection of participants	Yes. The participants in this study (including eligibility criteria) are described in the 1st and 2nd paragraphs of the Methods section. Figure 1 is a flowchart which shows the derivation of the analytical sample used to estimate the prevalence of hearing loss.
7		*Variables*: Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Yes. The key variables for this study (hearing outcomes; markers of socioeconomic status (SES), and various potential confounders of the SES-hearing associations) are clearly defined under the appropriate heading (hearing loss, socioeconomic status, and covariates)
8		*Data sources / measurement*: For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment	Yes, sources of details and methods of assessment are outlined under the appropriate heading (hearing loss, socioeconomic status, and covariates).

		methods if there is more than one group	
9		*Bias* Describe any efforts to address potential sources of bias	We discussed the potential source of bias through missing data as a result of: (1) survey non-response (main interview and nurse visit); and (2) interviewer-participant communication difficulties through conditions such as deafness. The appropriate non-response weights archived with the data were used in all analyses. Potential bias arising from both potential sources of missing data is discussed in the section on Study limitations (see Checklist Item No. 19).
10		*Study size*: Explain how the study size was arrived at.	Yes, Figure 1 shows the derivation of the analytical sample. We explain in the Methods section that participants aged 16-44 years were excluded due to hearing loss being comparatively rare. We explain that the analysis of hearing aid use was carried out only on the subset of participants with hearing loss.
11		Quantitative variables: Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Yes.
12		*Statistical methods*: (*a*) Describe all statistical methods, including those used to control for confounding; (*b*) Describe any methods used to examine subgroups and interactions; (*c*) Explain how missing data were addressed; (d) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy; (e) *Describe any sensitivity analyses*	*(a)* Yes. Firstly, prevalence estimates across subgroups were age-standardised within sex to the 2014 English household population. Secondly, a fully-adjusted model was used to examine the SES-hearing associations. Potential confounders adjusted for in the modelling included age, duration of work-related exposure, and CVD risk factors. Severity of hearing loss was adjusted for in the analysis of hearing aid use. *(b)* Yes, the chi-square test was used to test subgroup differences in hearing outcomes. *(c)Missing data:* analyses were weighted by the nurse-visit weight: this accounts for individual non-participation and preserves the national representativeness of the sample. *(d) Sampling strategy:* the weighting and clustering of participants within PSUs were accounted for by using design-based inference (the complex survey module in Stata). *(e) Sensitivity analyses:* N/A
13	**Results**	*Participants: (a)* Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in	Yes, Reasons for exclusion at each stage of the study are shown in the flow diagram (**Figure 1**).

		the study, completing follow-up, and analysed; *(b)* Give reasons for non-participation at each stage; *(c)* Consider use of a flow diagram	
14		*Descriptive data: (a)* Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; *(b)* Indicate number of participants with missing data for each variable of interest	Yes, Supplementary Table 1 shows the characteristics of participants aged 45+ with main interview data with and without nurse visit data (including the number of participants with missing data for each variable of interest).
15		*Outcome data*: Report numbers of outcome events or summary measures	Yes, we outline the number of participants with hearing loss (769/3292) and the number of participants with hearing loss reporting current use of a hearing aid (264/769). Prevalence estimates are set out in Table 1 (hearing loss) and Table 2 (current hearing aid use).
16		*Main results*: (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included; (*b*) Report category boundaries when continuous variables were categorized; (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	We present odds ratios (and accompanying 95% CIs) for the SES-hearing associations in both age-adjusted and fully-adjusted models in Figures 2 and 3. The estimates are displayed graphically to avoid lengthy tables. The legends for Figures 2 and 3 make clear which confounders were adjusted for. In the Methods Section we explain that modifiable risk factors for CVD such as diabetes have been independently associated with hearing impairment and are also possible confounders for any observed associations between SES and hearing.
17		*Other analyses*: Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Yes, the analysis of current hearing aid use is based on the subset of participants with objectively measured hearing loss.
18	**Discussion**	*Key results:* Summarise key results with reference to study objectives	Yes, we summarise the key results with reference to the study objectives in the first paragraph of the Discussion.
19		*Limitations:* Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Yes, the limitations of the study are outlined in the Discussion. Limitations include missing data (accounted for by the use of non-response weighting), the small number of participants with hearing loss, and the unknown influence of unmeasured confounders. We state that since this study utilises cross-sectional data, we could not establish the direction of the observed associations, and we cannot establish causality.
20		Interpretation: Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	Yes, in the Discussion we present a cautious overall interpretation of the main findings.

		analyses, results from similar studies, and other relevant evidence	
21		*Generalisability:* Discuss the generalisability (external validity) of the study results	Yes
22	**Other Information**	*Funding:* Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	The Health Survey for England 2014 was funded by NHS Digital. This particular study received no funding.

BMJ Open

Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England

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Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England

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Keywords: hearing loss; hearing aids; surveys; epidemiology; social inequalities

Strengths and limitations

- Estimates of the burden of hearing loss, the use of hearing aids among persons with hearing loss, and their associations with socioeconomic status, are rarely available from nationally-representative health examination surveys.
- We used data from a screening audiometry device to estimate the prevalence of hearing loss. The prevalence of current hearing aid use was estimated among persons with hearing loss.
- The associations between different markers of socioeconomic status and hearing were examined after adjustment for a wide range of confounders such as age, exposure to work-related noise, and risk factors for cardiovascular disease.
- Exclusion of persons from the study due to difficulties in interviewer-participant communication through conditions such as deafness means that our estimates are likely to underestimate the true prevalence of hearing loss among community-dwelling middle-aged and older adults.

ABSTRACT

Background: Hearing loss impacts on cognitive, social and physical functioning. Both hearing loss and hearing aid use vary across population subgroups. We examined whether hearing loss, and reported current hearing aid use among persons with hearing loss, were associated with different markers of socioeconomic status (SES) in a nationally-representative sample of community-dwelling middle-aged and older adults.

Methods: Hearing was measured using an audiometric screening device in the Health Survey for England 2014 (3292 participants aged 45 years and over). Hearing loss was defined as >35dBHL at 3.0 kHz in the better-hearing ear. Using sex-specific logistic regression modelling, we evaluated the associations between SES and hearing after adjustment for potential confounders.

Results: 26% of men and 20% of women aged 45 years and over had hearing loss. Hearing loss was higher among men in the lowest SES groups. For example, the multivariable-adjusted odds of hearing loss were almost twice as high for those in the lowest versus the highest income tertile [Odds Ratio (OR): 1.77; 95% CI: 1.15, 2.74]. Among those with hearing loss, 30% of men and 27% of women were currently using a hearing aid. Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the middle (OR: 0.50; 95% CI: 0.25, 0.99) and the lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. Associations between SES and hearing were weaker or null among women.

Conclusions: Whilst the burden of hearing loss fell highest among men in the lowest SES groups, current hearing aid use was demonstrably lower. Initiatives to detect hearing loss early and increase the uptake and the use of hearing aids may provide substantial public health benefits and reduce socioeconomic inequalities in health.

INTRODUCTION

Hearing loss is well known to impact on cognitive, social and physical functioning.[1-3] It can be congenital, but most is acquired and is sensorineural and irreversible in nature.[4] Preventing hearing loss requires understanding its aetiology and risk factors.[5] Epidemiological studies have shown that hearing loss increases with age[6-8] and increases with the duration of exposure to work-related noise.[8] It is higher among men[6-8], higher among persons with cardiovascular disease (CVD) risk factors[6;8-11], and is inversely associated with socioeconomic status (SES).[6-8;12] Early detection and hearing aid use may be effective at ameliorating the impact of hearing loss.[13] However, levels of hearing aid use among persons most likely to benefit are low[14-17], especially among persons with hearing loss in the lowest SES groups.[14;18-20]

Based on the UK National Study of Hearing conducted in four cities in the early 1980s, 16% of adults aged 17-80 years had a bilateral, and 25% had a unilateral or bilateral, hearing loss.[21] Uptake and use of hearing aids was low, with uptake being 10-30% among persons with hearing loss, and up to 25% of hearing aid owners never using them.[22] To provide up-to-date estimates of the burden of hearing loss, the Health Survey for England (HSE) 2014 included, for the first time in a nationally-representative sample of the population, valid screening audiometry data. The aim of this study was to estimate the prevalence of (1) hearing loss, and (2) current hearing aid use (among persons with hearing loss), in this sample of community-dwelling middle-aged and older adults across population subgroups defined by demographics, work-related noise exposure, and by the presence of CVD risk factors. We also examined the associations between SES and hearing.

METHODS

Study population

The present study used data from the HSE. The HSE is an annual, nationally-representative cross-sectional survey of the non-institutionalised general population of all ages. A maximum of two children per household contributed to the 2014 survey. In households with more than two children, two were randomly selected using the Kish grid method.[23] Multistage stratified probability sampling is used with postcode sectors as the primary sampling unit and the Postcode Address File as the sampling frame for households. Details about the HSE are described elsewhere.[23] Interview and nurse-visit response rates were 55% and 37%, respectively. Participants gave verbal consent to be interviewed, visited by a nurse, participate in a hearing test, and have blood pressure and anthropometric measurements taken, and gave written consent for blood sampling. Ethical approval was obtained from the Oxford A Research Ethics Committee (12/SC/0317).

Overall, 8077 participants aged 16+ years were interviewed, including questions on the use of hearing aids (see below). All participants aged 16+ years who had a nurse-visit were eligible for the hearing test, excluding those with a cochlear implant or with a current ear infection (Figure 1). Participants aged 16-44 years were excluded due to hearing loss being comparatively rare (n=46). In addition, a number of persons would have been excluded if interviewer-participant communication difficulties through conditions such as deafness were sufficient to prevent inclusion in the study. The final analytical sample was 3292 participants.

(Figure 1 here)

Hearing test

Hearing was measured using an audiometric screening device (HearCheck screener, Siemens, Erlangen, Germany) in participants' own homes. Two evaluation studies comparing the results of the screener to pure tone audiometry showed good sensitivity (range: 78% to 92%) and acceptable to good specificity (62% to 95%).[24;25] This handheld device produced a series

of three sounds of decreasing volume at 1.0 kHz (55dBHL, 35dBHL and 20dBHL) and then at 3.0 kHz (75dBHL, 55dBHL and 35dBHL). Both ears were tested, starting with the left. Participants were instructed to indicate when they heard a noise by raising their finger. If an irregular pattern was found (a combination of responses indicating that quieter sounds were heard but louder ones were not), the test was repeated at least 60s later for that ear. Participants with an irregular pattern at the first test, but a regular pattern at the second test, were included in the analyses. Further details of the testing procedures are available elsewhere.[17]

Outcomes

Hearing loss

Hearing loss was defined as >35dBHL at 3.0 kHz in the better-hearing ear, the level at which intervention has been shown to be definitely beneficial.[26] More specifically, a comparison of different screen programmes conducted as part of the NHS Health Technology Assessment Programme showed that the combination of >35dBHL at 3.0 kHz was the best predictor (in terms of the d-prime statistic: a combination of good sensitivity and low false alarm rate) for the ability of persons to gain the greatest benefit from hearing aids.[26] Hearing loss of >35dBHL at 3.0 kHz had 88% sensitivity and 10% false alarm rate.[26] Hearing loss was subdivided into two mutually exclusive categories: (1) 'moderate loss' : >35dBHL to 54dBHL (tone not heard at 35dBHL, but heard at 55dBHL and at 75dBHL), and (2) 'moderately severe or severe loss' : >55dBHL (tone not heard at 35dBHL and at 55dBHL, but the tone may, or may not, have been heard at 75dBHL). Prevalence estimates were multiplied by the 2014 household population to estimate the number of people with hearing loss.[27]

Current hearing aid use

As part of the main interview, all participants were asked if they ever wore a hearing aid nowadays: those who answered negatively were asked whether they had ever tried one. Current hearing aid use, for the purposes of the present study, consisted of those participants who answered positively to the question about use of a hearing aid nowadays. Participants classed as not currently using a hearing aid consisted of those who had tried hearing aids in the past but did not use a hearing aid nowadays, and those who had never tried a hearing aid.

Markers of socioeconomic status

Tertiles of equivalised household income, quintiles of the area-based Index of Multiple Deprivation (IMD 2010: Q1 least deprived; Q5 most deprived)[28], and the highest formal educational attainment (degree or higher, below degree, no qualifications) were chosen as related, but different, markers of SES. Broader categories of SES were used for the analysis of current hearing aid use among persons with hearing loss due to smaller sample sizes. The IMD 2010 quintiles were recoded into three categories: Q1 and Q2 (least deprived); Q3; and Q4 and Q5 (most deprived). Educational status was recoded into two categories: O level and above, and no qualifications.

Covariates

Covariates were grouped into: (1) demographic characteristics (age, region), (2) exposure to work-related noise, and (3) risk factors for CVD (cigarette smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity). Modifiable risk factors for CVD are well-known to be independently associated with hearing impairment[11;29], and potentially confound the associations between SES and hearing loss. Age-at-interview was categorized into four groups (45-54, 55-64, 65-74, and 75+ years). Government Office Region was grouped into North, Midlands, London, and South. Duration of exposure to work-related noise was established by asking participants whether they had ever worked in a

place that was so noisy that you had to shout to be heard (response categories: 'no', 'yes, for less than 1 year', 'yes, for at least 1 year but less than 5 years', and 'yes, for 5 years or longer'). Cigarette smoking status categories were current, ex-regular and never. Single measurements of height and weight were taken by trained interviewers using standard protocols. Body mass index (BMI) was computed as weight in kilogrammes (kg) divided by height in metres squared (m^2): participants were classified as normal-weight (18.5-24.9kg/m^2), overweight (25.0-29.9kg/m^2), or obese (≥30.0kg/m^2). We used two indicators of hyperglycaemia: self-reported physician diagnosis of diabetes, and raised glycated haemoglobin (HbA1c ≥48mmol/mol) irrespective of diagnosis. Hypertension was defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg and/or current use of medication taken for the purposes of lowering blood pressure. Total cholesterol was measured in non-fasting blood samples. Dyslipidaemia was defined as total cholesterol ≥5.0mmol/L and/or current use of lipid-lowering medication. Based on the Short-Form International Physical Activity Questionnaire (IPAQ), participants spending <30 minutes per week in moderate-to-vigorous physical activity were classed as physically inactive.[30] Broader categories of these covariates were used in some cases for the analysis of current hearing aid use due to smaller sample sizes. Age-at-interview was recoded into three categories: 45-64; 65-74; and 75+ years. Duration of exposure to work-related noise was dichotomised into none and at least some exposure to loud noise.

Statistical analysis

All analyses were sex-specific. Hearing loss prevalence (overall and by severity) was estimated among the overall population and as stratified by demographic characteristics, exposure to work-related noise, CVD risk factors, and SES. Prevalence estimates were directly age-standardised within sex to the English household population using the four age-groups described above. Differences in the prevalence of hearing loss across groups were

evaluated using the chi-square χ^2 test. This analysis was repeated to estimate the prevalence of current hearing aid use among those participants with hearing loss.

Logistic regression modelling was used to evaluate the association between SES and hearing loss after adjustment for demographics, exposure to work-related noise, and CVD risk factors. Associations were summarised using Odds Ratios (OR) with 95% Confidence Intervals (CI). We decided a priori to run separate models for the three indicators of SES rather than estimate a single model to avoid multicollinearity. Two sequential models were fitted. SES and hearing loss associations were age-adjusted (Model A), and then further adjusted for region, exposure to work-related noise, and CVD risk factors (Model B). To maximise power age was entered in the models as a continuous variable. SES was entered in the models as a categorical variable, with the highest status group as the reference category. We repeated the analyses to evaluate the association between SES and current hearing aid use, with an additional adjustment for the severity of hearing loss. All analyses accounted for the complex survey design, incorporating the nurse-visit weight which accounted for individual non-participation and preserved the national representativeness of the sample. Data set preparation was performed in SPSS V.20.0 (SPSS IBM Inc., Chicago, Illinois, USA). Statistical analysis was conducted using Stata V13.1 (College Station, Texas, USA). The HSE 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk).

RESULTS

Compared to participants with data collected from the nurse-visit stage, participants interviewed in the survey but without data from the nurse-visit were more likely to be in the lowest income tertile (P=0.002), to have no formal educational qualifications (P<0.001), to reside in the most deprived IMD quintile (P<0.001), and to be current cigarette smokers (P=0.011) (Supplementary Table 1).

Hearing loss

Table 1 shows the age-standardised estimates of the prevalence of hearing loss. For simplicity, we present only estimates by age, duration of exposure to work-related noise, and each indicator of SES in the main text, with the estimates for region and for each CVD risk factor available as Supplementary data. Overall, 26% of men and 20% of women aged 45+ years had hearing loss defined as >35dBHL at 3.0 kHz in the better-hearing ear (*n*=769/3292), equivalent to 5.2 million persons. The prevalence of 'moderate' loss (15% men, 12% women) exceeded that of 'moderately severe or severe' loss (11% men, 7% women). Hearing loss increased monotonically with age, reaching 67% of men and 58% of women aged 75+ years. Only among men in the oldest age-group did the prevalence of 'moderately severe or severe' loss (39%) exceed that of 'moderate' loss (29%). Among men, hearing loss was higher among those exposed to work-related noise for ≥5 years ($P<0.001$), in the lowest income tertile ($P=0.005$), residing in areas of higher deprivation ($P=0.011$), and with no formal educational qualifications ($P<0.001$). Patterns among women were similar but the differences in the prevalence of hearing loss across the SES groups only reached marginal statistical significance ($P=0.077$ and $P=0.070$ for IMD and for educational status, respectively). Of the risk factors for CVD, hearing loss was higher among men and women with doctor-diagnosed diabetes ($P<0.001$ men; $P=0.005$ women), with elevated Hb1Ac irrespective of diagnosis ($P<0.001$ men; $P=0.025$ women), and among women classed as physically inactive ($P=0.028$) (Supplementary Table 2).

(Table 1 here)

Figure 2 shows the associations between SES and hearing loss (expressed as odds ratios) after age (Model A) and additional adjustment for region, duration of exposure to work-related noise, and CVD risk factors (Model B). Among men, the multivariable-adjusted associations were partly attenuated: nevertheless, the multivariable-adjusted odds of hearing loss showed a

strong socioeconomic gradient. The odds of hearing loss were almost twice as high for men in the lowest versus the highest income tertile (OR: 1.77; 95% CI: 1.15, 2.74) and were over twice as high for men with no formal educational qualifications versus those with at least a degree (OR: 2.35; 95% CI: 1.54, 3.59). For women, SES was marginally significantly associated with hearing loss. For example, the odds of hearing loss were 1.4 times higher for women with no formal educational qualifications versus those with at least a degree (OR: 1.43, 95% CI: 0.83, 2.48).

(Figure 2 here)

Current hearing aid use

Among participants with hearing loss, 30% of men and 27% of women wore hearing aids nowadays (*n*=264/769; Table 2). Lower proportions had tried hearing aids in the past but did not use a hearing aid nowadays (7% men, 10% women): higher proportions had never tried a hearing aid (63% men, 64% women) (data not shown). Current use of a hearing aid for persons with 'moderately severe or severe' loss (53% men, 47% women) exceeded that for persons with 'moderate' loss (18% men, 19% women) ($p<0.001$ men; $p=0.004$ women). Current hearing aid use increased monotonically with age but was confined to the minority, reaching close to 40% for participants aged 75+ years.

(Table 2 here)

Differences in current hearing aid use by population subgroups were typically minor ($p>0.05$), with the exception of lower use of a hearing aid nowadays among women classed as physically inactive ($p=0.003$) (Supplementary Table 3). Lower use among participants reporting doctor-diagnosed diabetes (n=143/768) was marginally statistically significant ($p=0.101$ men; $p=0.077$ women). Figure 3 shows the associations between SES and current

hearing aid use after age- (Model A) and full-adjustment (Model B). Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the middle (OR: 0.50; 95% CI: 0.25, 0.99) and the lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. Among men, area deprivation (as measured by IMD) and highest educational attainment were associated with current hearing aid use in the same direction (i.e. lower levels of use in the lower SES groups) but the odds ratios did not reach statistical significance. For women, SES was not associated with current hearing aid use.

(Figure 3 here)

DISCUSSION

In this nationally-representative sample of community-dwelling persons aged 45 years and over, more than one in four persons had a level of hearing loss that would benefit from hearing aid use. However, less than one in three persons with hearing loss reported using a hearing aid nowadays, suggesting a significant level of unmet need. The burden of hearing loss fell highest among persons in the lowest SES groups, especially among men, suggesting hearing loss as a source of socioeconomic inequalities in health. Even after adjustment for the severity of hearing loss, hearing aid use was evidently lower for men in the middle- and low-income groups compared with their high-income counterparts.

Comparisons with previous studies are difficult due to differences in the age-range of participants.[6] Considerable heterogeneity also exists in the definition and the measurement of hearing loss.[31] The WHO defines adult disabling hearing impairment as a permanent unaided hearing threshold for the better-hearing ear of ≥41dBHL (averaged over 0.5, 1.0, 2.0 and 4.0 kHz).[32] Using this definition, disabling hearing loss was estimated to affect 360 million people worldwide in 2012 (more than 5% of the global population).[33] The Global Burden of Disease Hearing Loss Expert Group uses a threshold of >35dBHL for all age-groups, and

equates “unilateral hearing impairment” with “bilateral mild hearing impairment”.[7] The estimated global prevalence of hearing loss using this alternative definition was 12% for males and 10% for females aged ≥15 in 2008.[7] Analysis of HSE 2014 data by the same authors of the present study found that 13% of adults (14% men, 12% women) had loss of >35dBHL at 3.0 kHz in the better-hearing ear.[17] Our findings of differences in the burden of hearing loss agree with other population-based studies in which the prevalence of hearing loss was higher for men than women[6-8;34-37], increased monotonically with age[6-9;21;34-36;38], increased with longer exposure to occupational noise[8], co-existed with CVD risk factors such as diabetes[6;8-11], and was higher in the lowest SES groups [6;9;35;36;38;39], especially for men.[12] In contrast to other studies[6;8-10], hearing loss did not vary in the present study by current smoking status.

Other studies have shown similar or lower levels of hearing aid use among persons with hearing loss. Using the Digit Triplet Test, 21.5% of UK Biobank participants aged 40-69 years with ‘poor’ speech recognition in noise testing reported using a hearing aid.[38] Based on the 1999-2006 US National Health and Nutrition Examination Survey, hearing aid use among participants aged 50+ years with hearing loss was 14.2%.[15] Our findings of subgroup differences in levels of hearing aid use are consistent with other studies which showed that use increases with age[15;40] and with the severity of hearing loss.[15;19] Our finding of lower utilisation among men in the lowest SES groups, independent of the severity of hearing loss, is also consistent with other studies.[18;19;38;40;41]

Associations between SES and hearing loss likely involve multiple simultaneous pathways [35] including other concomitant factors of lower SES such as educational and employment factors (including exposure to work-related noise), and modifiable lifestyle factors.[8] While occupational noise is now limited and generally well-controlled in the UK[42], past exposure may have had serious long-term consequences for hearing in middle- and older-age.

It remains unclear the extent to which hearing loss is a driver of low SES or whether low SES is a driver of hearing loss.[35] First, analysis in Finland showed that hearing loss early in life – with its detrimental impact on educational attainment in adolescence – can be a driver of low SES in young adulthood through fewer opportunities for entering into higher education and through more frequent spells of unemployment.[43] Secondly, longitudinal studies have suggested low SES to be a key driver of hearing loss in middle-to-older age through factors such as working in jobs with a greater potential for exposure to damaging levels of noise. For example, analysis of the Beaver Dam Eye Study showed that the development of incident hearing loss was more likely among participants with lower levels of educational attainment and among those participants who worked in industrial occupations versus management and professional positions.[37;44]

The diabetes-hearing loss associations found in our study are in agreement with a recent meta-analysis.[45] Explanations for the association between diabetes and hearing loss include the microvascular and neuropathic complications that affect diabetics in multiple organ systems which may also affect the inner ear.[46;47] This study confirms the low level of current hearing aid use, especially among men in the lowest SES groups. Previous studies have demonstrated non-financial barriers to uptake and use, with self-recognition of hearing problems being the strongest factor.[48] Low take-up and use are typically attributed to a perception of hearing loss being an expected consequence of ageing. Non-audiological drivers for older adults with hearing impairment consulting a health professional and/or to use hearing aids included a positive attitude to hearing aids (their own and from significant others) and self-efficacy about hearing aids (e.g. placement and battery removal).[49] Although treatment and hearing aid provision is financially supported in the UK through the National Health Service, persons in the lower SES groups use specialist health services less frequently than those in higher SES groups.[50]

The main strength of this study was the use of valid screening audiometry data within a nationally-representative health examination survey. Data from a hearing test overcomes the under-estimation of socioeconomic inequalities in health that are typically associated with self-reports.[51] Other analyses of HSE 2014 showed that socioeconomic inequalities in hearing were most apparent using the data from the audiometric screening device but not from the self-report data[17], partly reflecting differences in levels of expectations, and differences in levels of awareness of adverse health conditions.[52] This study also has a number of limitations. Differences in the propensity to respond at the nurse-visit may have weakened the sample's representativeness and reduced the generalizability of our findings, but the use of statistical weights to account for the biases in individual participation would have mitigated this to a considerable extent. The estimates of hearing loss prevalence are conservative due to the exclusion of: (1) the institutionalised population, (2) individuals with a cochlear implant or with a current ear infection, and (3) the exclusion of an unknown number of individuals with conditions such as deafness that were judged to impede interviewer-participant communication. The relatively small number of participants with hearing loss may have resulted in our analyses of current hearing aid use to be underpowered to detect differences among subgroups. For the same reason, we were unable to examine differences in utilisation among subgroups stratified by the severity of hearing loss. Insufficient numbers meant that we were unable to provide separate reliable estimates for minority ethnic groups. Our findings could have been influenced by unmeasured confounders such as the duration of exposure to non-occupational noise. Lastly, since we utilised cross-sectional data, we were unable to assess the temporal relationship between SES and hearing, and so could not establish causality.

In conclusion, hearing loss is highly prevalent, affecting more than one in four men and affecting one in five women. However, less than one in three persons with hearing loss

reported using a hearing aid nowadays, suggesting a significant level of unmet need. Whilst the burden of hearing loss falls highest among persons, but especially men, in the lowest SES groups, use of hearing aids is demonstrably lower. Initiatives to detect hearing loss early, and the increased uptake of hearing aids, may provide substantial public health benefits and reduce socioeconomic inequalities in health.

Contributors

SS, JB, AD and JM were responsible for developing the design of the study.
SS was responsible for conducting the analyses, interpreting the results, and drafting the manuscript. SS, JB, AD and JM critically revised the manuscript. All authors have read and approved the final manuscript.

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Competing Interests

None.

Data sharing

The Health Survey for England 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk). Statistical code is available from the corresponding author at s.scholes@ucl.ac.uk

Table 1 Age-standardised prevalence (%) and standard error (SE) of hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Males					Females				
	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§
N	1485	425	244	181		1807	344	217	127	
All	1485	26.2 (1.2)	15.2 (1.0)	11.0 (0.9)	-	1807	19.6 (1.0)	12.2 (0.8)	7.4 (0.7)	
Age-group:										
45-54	420	8.0 (1.5)	7.0 (1.4)	1.0 (0.5)	<0.001	560	3.1 (0.9)	2.3 (0.7)	0.7 (0.4)	<0.001
55-64	401	17.0 (2.0)	10.9 (1.7)	6.1 (1.2)		446	10.6 (1.6)	8.6 (1.4)	2.0 (0.7)	
65-74	402	37.0 (2.5)	23.8 (2.2)	13.3 (2.0)		476	20.4 (1.8)	14.5 (1.6)	5.9 (1.1)	
75+	262	67.3 (3.2)	28.6 (2.8)	38.7 (3.1)		325	57.9 (2.9)	30.6 (2.5)	27.3 (2.6)	
Duration of work-related noise exposure:										
None	819	22.2 (1.6)	13.4 (1.3)	8.9 (1.2)	<0.001	1468	18.6 (1.1)	12.1 (0.9)	6.5 (0.7)	0.091
Less than 5 years	226	24.6 (2.9)	11.1 (2.3)	13.5 (2.4)		128	18.8 (3.8)	10.8 (3.0)	7.9 (2.7)	
5+ years	434	35.1 (2.5)	21.5 (2.1)	13.6 (1.7)		210	25.4 (3.0)	13.6 (2.4)	11.8 (2.2)	
Income tertiles:										
Highest	491	21.3 (2.5)	13.1 (2.0)	8.2 (1.7)	0.005	484	16.5 (2.3)	11.0 (1.9)	5.5 (1.4)	0.413
Middle	458	28.6 (2.2)	16.7 (1.9)	12.0 (1.5)		562	19.3 (1.8)	11.9 (1.4)	7.4 (1.2)	
Lowest	305	32.9 (2.8)	19.8 (2.2)	13.1 (2.0)		417	20.1 (1.9)	13.1 (1.6)	7.0 (1.2)	
Index of Multiple Deprivation quintiles:										
Least deprived	369	21.4 (2.2)	11.0 (1.8)	10.3 (1.7)	0.011	448	18.6 (2.1)	11.4 (1.5)	7.2 (1.4)	0.077
2	340	23.0 (2.4)	13.2 (1.8)	9.8 (1.7)		407	17.6 (1.7)	11.5 (1.5)	6.1 (1.2)	
3	311	27.2 (2.7)	17.1 (2.3)	10.1 (1.8)		392	17.5 (2.1)	10.9 (1.7)	6.6 (1.5)	
4	255	32.6 (2.9)	18.2 (2.5)	14.4 (2.2)		312	19.8 (2.6)	10.6 (2.1)	9.2 (1.7)	
Most deprived	210	30.2 (3.3)	18.0 (2.6)	12.2 (2.6)		248	26.3 (2.7)	18.4 (2.4)	7.9 (1.7)	
Education status:										
Degree or higher	344	20.1 (2.6)	12.3 (2.1)	7.8 (1.7)	<0.001	309	14.5 (3.5)	7.8 (2.2)	6.7 (2.5)	0.070
Below degree	733	23.2 (1.8)	12.8 (1.3)	10.4 (1.4)		941	18.4 (1.6)	12.1 (1.2)	6.4 (1.1)	
No qualifications	407	40.1 (3.0)	26.5 (2.9)	13.7 (1.7)		555	23.6 (2.1)	14.7 (1.8)	8.9 (1.1)	

* Hearing loss: >35dBHL at 3.0 kHz (tone not heard at 35dBHL).
† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but heard at 55 and at 75dBHL).

‡ Moderately severe or severe loss: >55 dBHL (tone not heard at 35 and at 55dBHL, but may or may not have heard the tone at 75dBHL).
§ Prevalence of hearing loss (>35dBHL at 3.0 kHz in the better hearing ear) across the categories of each variable (age-group; duration of work-related noise exposure; income tertiles; Index of Multiple Deprivation quintiles; and highest educational attainment) were compared using the Chi-square (χ^2) tests. No adjustment to the p-values for multiple comparisons was made.

Table 2 Age-standardized prevalence (%) and standard error (SE) of hearing aid use among persons with hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Men			Women		
	N	Hearing aid use % (SE)	*P-value*[*]	N	Hearing aid use % (SE)	*P-value*[*]
N	425	29.7 (3.1)		344	26.9 (3.3)	
Severity of loss:						
Moderate[†]	244	17.8 (3.2)	<0.001	217	19.1 (3.5)	0.002
Moderate to severe[‡]	181	52.9 (6.3)		127	47.1 (8.7)	
Age-group:						
45-64	101	25.4 (4.6)	0.056	63	21.2 (5.1)	0.035
65-74	147	34.3 (4.3)		94	31.4 (4.9)	
75+	177	40.2 (3.7)		187	39.1 (3.7)	
Duration of work-related noise exposure:						
None	250	26.1 (3.9)	0.234	287	25.3 (3.6)	0.296
Some	173	33.5 (4.9)		56	35.5 (9.4)	
Income tertiles:						
Highest	84	36.0 (6.5)	0.548	54	24.7 (6.5)	0.900
Middle	149	31.2 (5.5)		105	28.6 (5.8)	
Lowest	118	26.0 (6.1)		90	26.0 (7.0)	
Index of Multiple Deprivation quintiles:						
Least deprived 1 & 2	179	29.8 (5.3)	0.812	158	29.1 (5.2)	0.615
Quintile 3	101	33.5 (8.0)		66	29.3 (6.6)	
Most deprived 4 & 5	145	27.9 (4.6)		120	22.6 (5.6)	
Education status:						
O level or above	227	32.3 (4.2)	0.354	151	28.0 (4.3)	0.654
No qualifications	198	26.3 (4.6)		192	24.7 (5.6)	

[*] Prevalence of current hearing aid use across the categories of each variable (age-group; duration of work-related noise exposure; income tertiles; Index of Multiple Deprivation

quintiles; and highest educational attainment) were compared using the Chi-square (χ^2) test. No adjustment to the p-values for multiple comparisons was made.

† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but tone heard at 55 and 75dBHL).

‡ Moderately severe or severe loss: >55dBHL (tone not heard at 35 and 55dBHL, but may or may not have heard the tone at 75dBHL).

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FIGURE 1 LEGEND

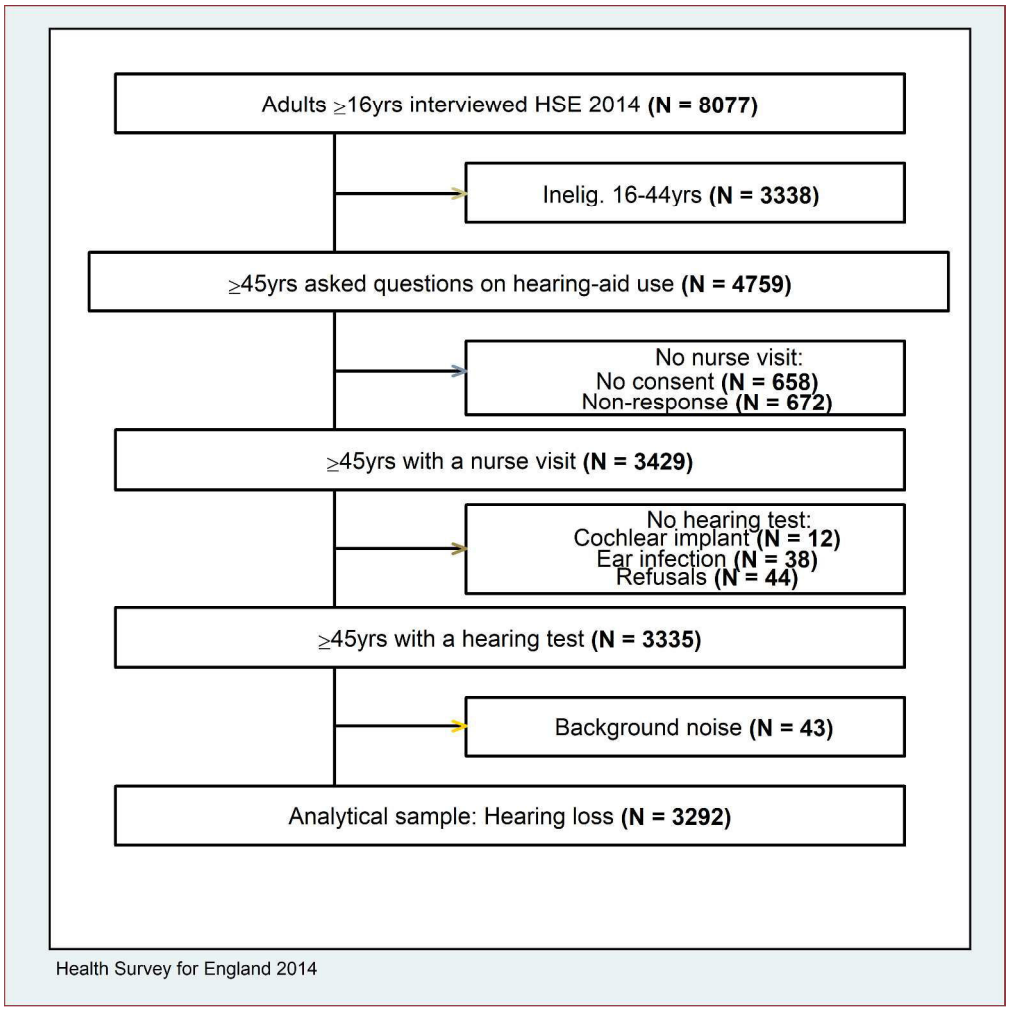
Selection of Study Participants, Health Survey for England 2014

FIGURE 2 LEGEND

Association between socioeconomic status (SES) and hearing loss in middle-aged and older adults. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (most affluent), and highest educational attainment (degree or higher). Lines represent Odds Ratio (outcome = hearing loss) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

FIGURE 3 LEGEND

Association between SES and current hearing aid use in middle-aged and older adults with hearing loss. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (least deprived Q1 and Q2), and highest educational attainment (O level and above). Lines represent Odds Ratio (outcome = hearing aid use) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, severity of hearing loss, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).



Selection of Study Participants, Health Survey for England 2014

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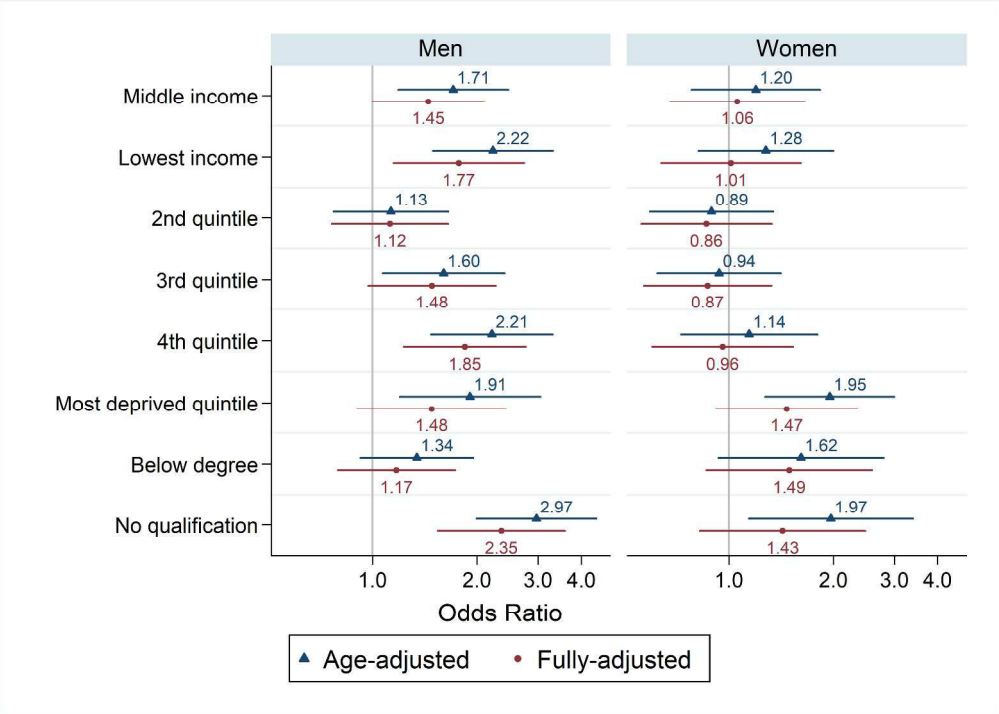
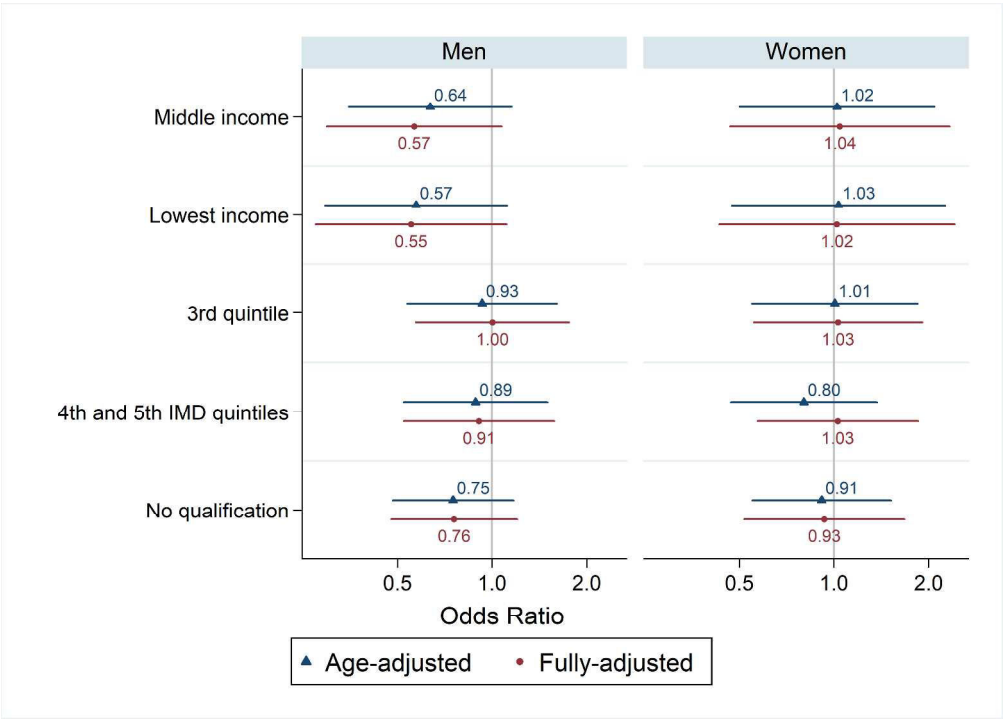


Associations between socioeconomic status (SES) and hearing loss in middle-aged and older adults. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (most affluent), and highest educational attainment (degree or higher). Lines represent Odds Ratio (outcome = hearing loss) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

350x250mm (300 x 300 DPI)



Associations between SES and current hearing aid use in middle-aged and older adults with hearing loss. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (least deprived Q1 and Q2), and highest educational attainment (O level or above). Lines represent Odds Ratio (outcome = hearing aid use) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, severity of hearing loss, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

350x250mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

Scholes S, Biddulph J, Davis AC, Mindell JS. Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England. Submitted to BMJ Open.

		Recommendation	Author response
1	**Title / abstract**	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Yes. The title of our submitted manuscript is: "Socioeconomic differences in hearing among middle-aged and older adults: **cross-sectional analyses** using the Health Survey for England".
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Yes
2	**Introduction**	Explain the scientific background and rationale for the investigation being reported	Yes. The background and rationale for our study are outlined in the Introduction (1st and 2nd paragraphs, respectively).
3		State specific objectives, including any prespecified hypotheses	Yes. The primary and secondary aims are outlined in the second paragraph of the Introduction. We did not have any pre-specified hypotheses.
4	Methods	*Study design*: Present key elements of study design early in the paper	Yes. The first sentence of the Methods Section states that the present study uses data from the Health Survey for England, an annual nationally-representative cross-sectional survey of the non-institutionalised general population.
5		*Setting:* Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Yes. The study setting is outlined in the first paragraph of the Methods Section.
6		*Participants (cross-sectional study):* Give the eligibility criteria, and the sources and methods of selection of participants	Yes. The participants in this study (including eligibility criteria) are described in the 1st and 2nd paragraphs of the Methods section. Figure 1 is a flowchart which shows the derivation of the analytical sample used to estimate the prevalence of hearing loss.
7		*Variables*: Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Yes. The key variables for this study (hearing outcomes; markers of socioeconomic status (SES), and various potential confounders of the SES-hearing associations) are clearly defined under the appropriate heading (hearing loss, socioeconomic status, and covariates)
8		*Data sources / measurement*: For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment	Yes, sources of details and methods of assessment are outlined under the appropriate heading (hearing loss, socioeconomic status, and covariates).

		methods if there is more than one group	
9		*Bias* Describe any efforts to address potential sources of bias	We discussed the potential source of bias through missing data as a result of: (1) survey non-response (main interview and nurse visit); and (2) interviewer-participant communication difficulties through conditions such as deafness. The appropriate non-response weights archived with the data were used in all analyses. Potential bias arising from both potential sources of missing data is discussed in the section on Study limitations (see Checklist Item No. 19).
10		*Study size*: Explain how the study size was arrived at.	Yes, Figure 1 shows the derivation of the analytical sample. We explain in the Methods section that participants aged 16-44 years were excluded due to hearing loss being comparatively rare. We explain that the analysis of hearing aid use was carried out only on the subset of participants with hearing loss.
11		Quantitative variables: Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Yes.
12		*Statistical methods*: (*a*) Describe all statistical methods, including those used to control for confounding; (*b*) Describe any methods used to examine subgroups and interactions; (*c*) Explain how missing data were addressed; (d) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy; (e) *Describe any sensitivity analyses*	*(a)* Yes. Firstly, prevalence estimates across subgroups were age-standardised within sex to the 2014 English household population. Secondly, a fully-adjusted model was used to examine the SES-hearing associations. Potential confounders adjusted for in the modelling included age, duration of work-related exposure, and CVD risk factors. Severity of hearing loss was adjusted for in the analysis of hearing aid use. *(b)* Yes, the chi-square test was used to test subgroup differences in hearing outcomes. *(c)Missing data:* analyses were weighted by the nurse-visit weight: this accounts for individual non-participation and preserves the national representativeness of the sample. *(d) Sampling strategy:* the weighting and clustering of participants within PSUs were accounted for by using design-based inference (the complex survey module in Stata). *(e) Sensitivity analyses:* N/A
13	**Results**	*Participants: (a)* Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in	Yes, Reasons for exclusion at each stage of the study are shown in the flow diagram (**Figure 1**).

		the study, completing follow-up, and analysed; *(b)* Give reasons for non-participation at each stage; *(c)* Consider use of a flow diagram	
14		*Descriptive data: (a)* Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; *(b)* Indicate number of participants with missing data for each variable of interest	Yes, Supplementary Table 1 shows the characteristics of participants aged 45+ with main interview data with and without nurse visit data (including the number of participants with missing data for each variable of interest).
15		*Outcome data*: Report numbers of outcome events or summary measures	Yes, we outline the number of participants with hearing loss (769/3292) and the number of participants with hearing loss reporting current use of a hearing aid (264/769). Prevalence estimates are set out in Table 1 (hearing loss) and Table 2 (current hearing aid use).
16		*Main results*: (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included; (*b*) Report category boundaries when continuous variables were categorized; (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	We present odds ratios (and accompanying 95% CIs) for the SES-hearing associations in both age-adjusted and fully-adjusted models in Figures 2 and 3. The estimates are displayed graphically to avoid lengthy tables. The legends for Figures 2 and 3 make clear which confounders were adjusted for. In the Methods Section we explain that modifiable risk factors for CVD such as diabetes have been independently associated with hearing impairment and are also possible confounders for any observed associations between SES and hearing.
17		*Other analyses*: Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Yes, the analysis of current hearing aid use is based on the subset of participants with objectively measured hearing loss.
18	**Discussion**	*Key results:* Summarise key results with reference to study objectives	Yes, we summarise the key results with reference to the study objectives in the first paragraph of the Discussion.
19		*Limitations:* Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Yes, the limitations of the study are outlined in the Discussion. Limitations include missing data (accounted for by the use of non-response weighting), the small number of participants with hearing loss, and the unknown influence of unmeasured confounders. We state that since this study utilises cross-sectional data, we could not establish the direction of the observed associations, and we cannot establish causality.
20		Interpretation: Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	Yes, in the Discussion we present a cautious overall interpretation of the main findings.

		analyses, results from similar studies, and other relevant evidence	
21		*Generalisability:* Discuss the generalisability (external validity) of the study results	Yes
22	**Other Information**	*Funding:* Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	The Health Survey for England 2014 was funded by NHS Digital. This particular study received no funding.

BMJ Open

Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England

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Primary Subject Heading:	Ear, nose and throat/otolaryngology
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	hearing loss, hearing aids, EPIDEMIOLOGY, social inequalities

Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England

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Keywords: hearing loss; hearing aids; surveys; epidemiology; social inequalities

Strengths and limitations

- Estimates of the burden of hearing loss, the use of hearing aids among persons with hearing loss, and their associations with socioeconomic status, are rarely available from nationally-representative health examination surveys.
- We used data from a screening audiometry device to estimate the prevalence of hearing loss. The prevalence of current hearing aid use was estimated among persons with hearing loss.
- The associations between different markers of socioeconomic status and hearing were examined after adjustment for a wide range of confounders such as age, exposure to work-related noise, and risk factors for cardiovascular disease.
- Exclusion of persons from the study due to difficulties in interviewer-participant communication through conditions such as deafness means that our estimates are likely to underestimate the true prevalence of hearing loss among community-dwelling middle-aged and older adults.

ABSTRACT

Background: Hearing loss impacts on cognitive, social and physical functioning. Both hearing loss and hearing aid use vary across population subgroups. We examined whether hearing loss, and reported current hearing aid use among persons with hearing loss, were associated with different markers of socioeconomic status (SES) in a nationally-representative sample of community-dwelling middle-aged and older adults.

Methods: Hearing was measured using an audiometric screening device in the Health Survey for England 2014 (3292 participants aged 45 years and over). Hearing loss was defined as >35dBHL at 3.0 kHz in the better-hearing ear. Using sex-specific logistic regression modelling, we evaluated the associations between SES and hearing after adjustment for potential confounders.

Results: 26% of men and 20% of women aged 45 years and over had hearing loss. Hearing loss was higher among men in the lowest SES groups. For example, the multivariable-adjusted odds of hearing loss were almost twice as high for those in the lowest versus the highest income tertile [Odds Ratio (OR): 1.77; 95% CI: 1.15, 2.74]. Among those with hearing loss, 30% of men and 27% of women were currently using a hearing aid. Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the middle (OR: 0.50; 95% CI: 0.25, 0.99) and the lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. Associations between SES and hearing were weaker or null among women.

Conclusions: Whilst the burden of hearing loss fell highest among men in the lowest SES groups, current hearing aid use was demonstrably lower. Initiatives to detect hearing loss early and increase the uptake and the use of hearing aids may provide substantial public health benefits and reduce socioeconomic inequalities in health.

INTRODUCTION

Hearing loss is well known to impact on cognitive, social and physical functioning.[1-3] It can be congenital, but most is acquired and is sensorineural and irreversible in nature.[4] Preventing hearing loss requires understanding its aetiology and risk factors.[5] Epidemiological studies have shown that hearing loss increases with age[6-8] and increases with the duration of exposure to work-related noise.[8] It is higher among men[6-8], higher among persons with cardiovascular disease (CVD) risk factors[6;8-11], and is inversely associated with socioeconomic status (SES).[6-8;12] Early detection and hearing aid use may be effective at ameliorating the impact of hearing loss.[13] However, levels of hearing aid use among persons most likely to benefit are low[14-17], especially among persons with hearing loss in the lowest SES groups.[14;18-20]

Based on the UK National Study of Hearing conducted in four cities in the early 1980s, 16% of adults aged 17-80 years had a bilateral, and 25% had a unilateral or bilateral, hearing loss.[21] Uptake and use of hearing aids was low, with uptake being 10-30% among persons with hearing loss, and up to 25% of hearing aid owners never using them.[22] To provide up-to-date estimates of the burden of hearing loss, the Health Survey for England (HSE) 2014 included, for the first time in a nationally-representative sample of the population, valid screening audiometry data. The aim of this study was to estimate the prevalence of (1) hearing loss, and (2) current hearing aid use (among persons with hearing loss), in this sample of community-dwelling middle-aged and older adults across population subgroups defined by demographics, work-related noise exposure, and by the presence of CVD risk factors. We also examined the associations between SES and hearing.

METHODS

Study population

The present study used data from the HSE. The HSE is an annual, nationally-representative cross-sectional survey of the non-institutionalised general population of all ages. A maximum of two children per household contributed to the 2014 survey. In households with more than two children, two were randomly selected using the Kish grid method.[23] Multistage stratified probability sampling is used with postcode sectors as the primary sampling unit and the Postcode Address File as the sampling frame for households. Details about the HSE are described elsewhere.[23] Interview and nurse-visit response rates were 55% and 37%, respectively. Participants gave verbal consent to be interviewed, visited by a nurse, participate in a hearing test, and have blood pressure and anthropometric measurements taken, and gave written consent for blood sampling. Ethical approval was obtained from the Oxford A Research Ethics Committee (12/SC/0317).

Overall, 8077 participants aged 16+ years were interviewed, including questions on the use of hearing aids (see below). All participants aged 16+ years who had a nurse-visit were eligible for the hearing test, excluding those with a cochlear implant or with a current ear infection (Figure 1). Participants aged 16-44 years were excluded due to hearing loss being comparatively rare (n=46). In addition, a number of persons would have been excluded if interviewer-participant communication difficulties through conditions such as deafness were sufficient to prevent inclusion in the study. The final analytical sample was 3292 participants.

(Figure 1 here)

Hearing test

Hearing was measured using an audiometric screening device (HearCheck screener, Siemens, Erlangen, Germany) in participants' own homes. Two evaluation studies comparing the results of the screener to pure tone audiometry showed good sensitivity (range: 78% to 92%) and acceptable to good specificity (62% to 95%).[24;25] This handheld device produced a series

of three sounds of decreasing volume at 1.0 kHz (55dBHL, 35dBHL and 20dBHL) and then at 3.0 kHz (75dBHL, 55dBHL and 35dBHL). Both ears were tested, starting with the left. Participants were instructed to indicate when they heard a noise by raising their finger. If an irregular pattern was found (a combination of responses indicating that quieter sounds were heard but louder ones were not), the test was repeated at least 60s later for that ear. Participants with an irregular pattern at the first test, but a regular pattern at the second test, were included in the analyses. Further details of the testing procedures are available elsewhere.[17]

Outcomes

Hearing loss

Hearing loss was defined as >35dBHL at 3.0 kHz in the better-hearing ear, the level at which intervention has been shown to be definitely beneficial.[26] More specifically, a comparison of different screen programmes conducted as part of the NHS Health Technology Assessment Programme showed that hearing loss of >35dBHL at 3.0 kHz was the best predictor (in terms of the d-prime statistic: a combination of good sensitivity and low false alarm rate) for the ability of persons to gain the greatest benefit from hearing aids.[26] Hearing loss of >35dBHL at 3.0 kHz had 88% sensitivity and 10% false alarm rate.[26] Hearing loss was subdivided into two mutually exclusive categories: (1) 'moderate loss' : >35dBHL to 54dBHL (tone not heard at 35dBHL, but heard at 55dBHL and at 75dBHL), and (2) 'moderately severe or severe loss' : >55dBHL (tone not heard at 35dBHL and at 55dBHL, but the tone may, or may not, have been heard at 75dBHL). Prevalence estimates were multiplied by the 2014 household population to estimate the number of people with hearing loss.[27]

Current hearing aid use

As part of the main interview, all participants were asked if they ever wore a hearing aid nowadays: those who answered negatively were asked whether they had ever tried one. Current hearing aid use, for the purposes of the present study, consisted of those participants who answered positively to the question about use of a hearing aid nowadays. Participants classed as not currently using a hearing aid consisted of those who had tried hearing aids in the past but did not use a hearing aid nowadays, and those who had never tried a hearing aid.

Markers of socioeconomic status

Tertiles of equivalised household income, quintiles of the area-based Index of Multiple Deprivation (IMD 2010: Q1 least deprived; Q5 most deprived)[28], and the highest formal educational attainment (degree or higher, below degree, no qualifications) were chosen as related, but different, markers of SES. Broader categories of SES were used for the analysis of current hearing aid use among persons with hearing loss due to smaller sample sizes. The IMD 2010 quintiles were recoded into three categories: Q1 and Q2 (least deprived); Q3; and Q4 and Q5 (most deprived). Educational status was recoded into two categories: O level and above, and no qualifications.

Covariates

Covariates were grouped into: (1) demographic characteristics (age, region), (2) exposure to work-related noise, and (3) risk factors for CVD (cigarette smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity). Modifiable risk factors for CVD are well-known to be independently associated with hearing impairment[11;29], and potentially confound the associations between SES and hearing loss. Age-at-interview was categorized into four groups (45-54, 55-64, 65-74, and 75+ years). Government Office Region was grouped into North, Midlands, London, and South. Duration of exposure to work-related noise was established by asking participants whether they had ever worked in a

place that was so noisy that you had to shout to be heard (response categories: 'no', 'yes, for less than 1 year', 'yes, for at least 1 year but less than 5 years', and 'yes, for 5 years or longer'). Cigarette smoking status categories were current, ex-regular and never. Single measurements of height and weight were taken by trained interviewers using standard protocols. Body mass index (BMI) was computed as weight in kilogrammes (kg) divided by height in metres squared (m^2): participants were classified as normal-weight (18.5-24.9kg/m^2), overweight (25.0-29.9kg/m^2), or obese (≥30.0kg/m^2). We used two indicators of hyperglycaemia: self-reported physician diagnosis of diabetes, and raised glycated haemoglobin (HbA1c ≥48mmol/mol) irrespective of diagnosis. Hypertension was defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg and/or current use of medication taken for the purposes of lowering blood pressure. Total cholesterol was measured in non-fasting blood samples. Dyslipidaemia was defined as total cholesterol ≥5.0mmol/L and/or current use of lipid-lowering medication. Based on the Short-Form International Physical Activity Questionnaire (IPAQ), participants spending <30 minutes per week in moderate-to-vigorous physical activity were classed as physically inactive.[30] Broader categories of these covariates were used in some cases for the analysis of current hearing aid use due to smaller sample sizes. Age-at-interview was recoded into three categories: 45-64; 65-74; and 75+ years. Duration of exposure to work-related noise was dichotomised into none and at least some exposure to loud noise.

Statistical analysis

All analyses were sex-specific. Hearing loss prevalence (overall and by severity) was estimated among the overall population and as stratified by demographic characteristics, exposure to work-related noise, CVD risk factors, and SES. Prevalence estimates were directly age-standardised within sex to the English household population using the four age-groups described above. Differences in the prevalence of hearing loss across groups were

evaluated using the chi-square χ^2 test. This analysis was repeated to estimate the prevalence of current hearing aid use among those participants with hearing loss.

Logistic regression modelling was used to evaluate the association between SES and hearing loss after adjustment for demographics, exposure to work-related noise, and CVD risk factors. Associations were summarised using Odds Ratios (OR) with 95% Confidence Intervals (CI). We decided a priori to run separate models for the three indicators of SES rather than estimate a single model to avoid multicollinearity. Two sequential models were fitted. SES and hearing loss associations were age-adjusted (Model A), and then further adjusted for region, exposure to work-related noise, and CVD risk factors (Model B). To maximise power age was entered in the models as a continuous variable. SES was entered in the models as a categorical variable, with the highest status group as the reference category. We repeated the analyses to evaluate the association between SES and current hearing aid use, with an additional adjustment for the severity of hearing loss. All analyses accounted for the complex survey design, incorporating the nurse-visit weight which accounted for individual non-participation and preserved the national representativeness of the sample. Data set preparation was performed in SPSS V.20.0 (SPSS IBM Inc., Chicago, Illinois, USA). Statistical analysis was conducted using Stata V13.1 (College Station, Texas, USA). The HSE 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk).

RESULTS

Compared to participants with data collected from the nurse-visit stage, participants interviewed in the survey but without data from the nurse-visit were more likely to be in the lowest income tertile (P=0.002), to have no formal educational qualifications (P<0.001), to reside in the most deprived IMD quintile (P<0.001), and to be current cigarette smokers (P=0.011) (Supplementary Table 1).

Hearing loss

Table 1 shows the age-standardised estimates of the prevalence of hearing loss. For simplicity, we present only estimates by age, duration of exposure to work-related noise, and each indicator of SES in the main text, with the estimates for region and for each CVD risk factor available as Supplementary data. Overall, 26% of men and 20% of women aged 45+ years had hearing loss defined as >35dBHL at 3.0 kHz in the better-hearing ear (*n*=769/3292), equivalent to 5.2 million persons. The prevalence of 'moderate' loss (15% men, 12% women) exceeded that of 'moderately severe or severe' loss (11% men, 7% women). Hearing loss increased monotonically with age, reaching 67% of men and 58% of women aged 75+ years. Only among men in the oldest age-group did the prevalence of 'moderately severe or severe' loss (39%) exceed that of 'moderate' loss (29%). Among men, hearing loss was higher among those exposed to work-related noise for ≥5 years ($P<0.001$), in the lowest income tertile ($P=0.005$), residing in areas of higher deprivation ($P=0.011$), and with no formal educational qualifications ($P<0.001$). Patterns among women were similar but the differences in the prevalence of hearing loss across the SES groups did not reach statistical significance ($P=0.077$ and $P=0.070$ for IMD and for educational status, respectively). Of the risk factors for CVD, hearing loss was higher among men and women with doctor-diagnosed diabetes ($P<0.001$ men; $P=0.005$ women), with elevated Hb1Ac irrespective of diagnosis ($P<0.001$ men; $P=0.025$ women), and among women classed as physically inactive ($P=0.028$) (Supplementary Table 2).

(Table 1 here)

Figure 2 shows the associations between SES and hearing loss (expressed as odds ratios) after age (Model A) and additional adjustment for region, duration of exposure to work-related noise, and CVD risk factors (Model B). Among men, the multivariable-adjusted associations were partly attenuated: nevertheless, the multivariable-adjusted odds of hearing loss showed a

strong socioeconomic gradient. The odds of hearing loss were almost twice as high for men in the lowest versus the highest income tertile (OR: 1.77; 95% CI: 1.15, 2.74) and were over twice as high for men with no formal educational qualifications versus those with at least a degree (OR: 2.35; 95% CI: 1.54, 3.59). For women, the association between SES and hearing loss did not reach statistical significance. For example, the odds of hearing loss were 1.4 times higher for women with no formal educational qualifications versus those with at least a degree (OR: 1.43, 95% CI: 0.83, 2.48).

(Figure 2 here)

Current hearing aid use

Among participants with hearing loss, 30% of men and 27% of women wore hearing aids nowadays (*n*=264/769; Table 2). Lower proportions had tried hearing aids in the past but did not use a hearing aid nowadays (7% men, 10% women): higher proportions had never tried a hearing aid (63% men, 64% women) (data not shown). Current use of a hearing aid for persons with 'moderately severe or severe' loss (53% men, 47% women) exceeded that for persons with 'moderate' loss (18% men, 19% women) ($p<0.001$ men; $p=0.004$ women). Current hearing aid use increased monotonically with age but was confined to the minority, reaching close to 40% for participants aged 75+ years.

(Table 2 here)

Differences in current hearing aid use by population subgroups were typically minor ($p>0.05$), with the exception of lower use of a hearing aid nowadays among women classed as physically inactive ($p=0.003$) (Supplementary Table 3). Lower use among participants reporting doctor-diagnosed diabetes (n=143/768) did not reach statistical significance ($p=0.101$ men; $p=0.077$ women). Figure 3 shows the associations between SES and current

hearing aid use after age- (Model A) and full-adjustment (Model B). Compared with men in the highest income tertile, the multivariable-adjusted odds of using a hearing aid nowadays were lower for men in the middle (OR: 0.50; 95% CI: 0.25, 0.99) and the lowest (OR: 0.47; 95% CI: 0.23, 0.97) income tertiles. Among men, area deprivation (as measured by IMD) and highest educational attainment were associated with current hearing aid use in the same direction (i.e. lower levels of use in the lower SES groups) but the odds ratios did not reach statistical significance. For women, SES was not associated with current hearing aid use.

(Figure 3 here)

DISCUSSION

In this nationally-representative sample of community-dwelling persons aged 45 years and over, more than one in four persons had a level of hearing loss that would benefit from hearing aid use. However, less than one in three persons with hearing loss reported using a hearing aid nowadays, suggesting a significant level of unmet need. The burden of hearing loss fell highest among persons in the lowest SES groups, especially among men, suggesting hearing loss as a source of socioeconomic inequalities in health. Even after adjustment for the severity of hearing loss, hearing aid use was evidently lower for men in the middle- and low-income groups compared with their high-income counterparts.

Comparisons with previous studies are difficult due to differences in the age-range of participants.[6] Considerable heterogeneity also exists in the definition and the measurement of hearing loss.[31] The WHO defines adult disabling hearing impairment as a permanent unaided hearing threshold for the better-hearing ear of ≥41dBHL (averaged over 0.5, 1.0, 2.0 and 4.0 kHz).[32] Using this definition, disabling hearing loss was estimated to affect 360 million people worldwide in 2012 (more than 5% of the global population).[33] The Global Burden of Disease Hearing Loss Expert Group uses a threshold of >35dBHL for all age-groups, and

equates “unilateral hearing impairment” with “bilateral mild hearing impairment”.[7] The estimated global prevalence of hearing loss using this alternative definition was 12% for males and 10% for females aged ≥15 in 2008.[7] Analysis of HSE 2014 data by the same authors of the present study found that 13% of adults (14% men, 12% women) had loss of >35dBHL at 3.0 kHz in the better-hearing ear.[17] Our findings of differences in the burden of hearing loss agree with other population-based studies in which the prevalence of hearing loss was higher for men than women[6-8;34-37], increased monotonically with age[6-9;21;34-36;38], increased with longer exposure to occupational noise[8], co-existed with CVD risk factors such as diabetes[6;8-11], and was higher in the lowest SES groups [6;9;35;36;38;39], especially for men.[12] In contrast to other studies[6;8-10], hearing loss did not vary in the present study by current smoking status.

Other studies have shown similar or lower levels of hearing aid use among persons with hearing loss. Using the Digit Triplet Test, 21.5% of UK Biobank participants aged 40-69 years with ‘poor’ speech recognition in noise testing reported using a hearing aid.[38] Based on the 1999-2006 US National Health and Nutrition Examination Survey, hearing aid use among participants aged 50+ years with hearing loss was 14.2%.[15] Our findings of subgroup differences in levels of hearing aid use are consistent with other studies which showed that use increases with age[15;40] and with the severity of hearing loss.[15;19] Our finding of lower utilisation among men in the lowest SES groups, independent of the severity of hearing loss, is also consistent with other studies.[18;19;38;40;41]

Associations between SES and hearing loss likely involve multiple simultaneous pathways [35] including other concomitant factors of lower SES such as educational and employment factors (including exposure to work-related noise), and modifiable lifestyle factors.[8] While occupational noise is now limited and generally well-controlled in the UK[42], past exposure may have had serious long-term consequences for hearing in middle- and older-age.

It remains unclear the extent to which hearing loss is a driver of low SES or whether low SES is a driver of hearing loss.[35] First, analysis in Finland showed that hearing loss early in life – with its detrimental impact on educational attainment in adolescence – can be a driver of low SES in young adulthood through fewer opportunities for entering into higher education and through more frequent spells of unemployment.[43] Secondly, longitudinal studies have suggested low SES to be a key driver of hearing loss in middle-to-older age through factors such as working in jobs with a greater potential for exposure to damaging levels of noise. For example, analysis of the Beaver Dam Eye Study showed that the development of incident hearing loss was more likely among participants with lower levels of educational attainment and among those participants who worked in industrial occupations versus management and professional positions.[37;44]

The diabetes-hearing loss associations found in our study are in agreement with a recent meta-analysis.[45] Explanations for the association between diabetes and hearing loss include the microvascular and neuropathic complications that affect diabetics in multiple organ systems which may also affect the inner ear.[46;47] This study confirms the low level of current hearing aid use, especially among men in the lowest SES groups. Previous studies have demonstrated non-financial barriers to uptake and use, with self-recognition of hearing problems being the strongest factor.[48] Low take-up and use are typically attributed to a perception of hearing loss being an expected consequence of ageing. Non-audiological drivers for older adults with hearing impairment consulting a health professional and/or to use hearing aids included a positive attitude to hearing aids (their own and from significant others) and self-efficacy about hearing aids (e.g. placement and battery removal).[49] Although treatment and hearing aid provision is financially supported in the UK through the National Health Service, persons in the lower SES groups use specialist health services less frequently than those in higher SES groups.[50]

The main strength of this study was the use of valid screening audiometry data within a nationally-representative health examination survey. Data from a hearing test overcomes the under-estimation of socioeconomic inequalities in health that are typically associated with self-reports.[51] Other analyses of HSE 2014 showed that socioeconomic inequalities in hearing were most apparent using the data from the audiometric screening device but not from the self-report data[17], partly reflecting differences in levels of expectations, and differences in levels of awareness of adverse health conditions.[52] This study also has a number of limitations. Differences in the propensity to respond at the nurse-visit may have weakened the sample's representativeness and reduced the generalizability of our findings, but the use of statistical weights to account for the biases in individual participation would have mitigated this to a considerable extent. The estimates of hearing loss prevalence are conservative due to the exclusion of: (1) the institutionalised population, (2) individuals with a cochlear implant or with a current ear infection, and (3) the exclusion of an unknown number of individuals with conditions such as deafness that were judged to impede interviewer-participant communication. The relatively small number of participants with hearing loss may have resulted in our analyses of current hearing aid use to be underpowered to detect differences among subgroups. For the same reason, we were unable to examine differences in utilisation among subgroups stratified by the severity of hearing loss. Insufficient numbers meant that we were unable to provide separate reliable estimates for minority ethnic groups. Our findings could have been influenced by unmeasured confounders such as the duration of exposure to non-occupational noise. Lastly, since we utilised cross-sectional data, we were unable to assess the temporal relationship between SES and hearing, and so could not establish causality.

In conclusion, hearing loss is highly prevalent, affecting more than one in four men and affecting one in five women. However, less than one in three persons with hearing loss

reported using a hearing aid nowadays, suggesting a significant level of unmet need. Whilst the burden of hearing loss falls highest among persons, but especially men, in the lowest SES groups, use of hearing aids is demonstrably lower. Initiatives to detect hearing loss early, and the increased uptake of hearing aids, may provide substantial public health benefits and reduce socioeconomic inequalities in health.

Contributors

SS, JB, AD and JM were responsible for developing the design of the study.
SS was responsible for conducting the analyses, interpreting the results, and drafting the manuscript. SS, JB, AD and JM critically revised the manuscript. All authors have read and approved the final manuscript.

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Competing Interests

None.

Data sharing

The Health Survey for England 2014 dataset is available via the UK Data Service (http://www.ukdataservice.ac.uk). Statistical code is available from the corresponding author at s.scholes@ucl.ac.uk

Table 1 Age-standardised prevalence (%) and standard error (SE) of hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Males					Females				
	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§
N	1485	425	244	181		1807	344	217	127	
All	1485	26.2 (1.2)	15.2 (1.0)	11.0 (0.9)	-	1807	19.6 (1.0)	12.2 (0.8)	7.4 (0.7)	
Age-group:										
45-54	420	8.0 (1.5)	7.0 (1.4)	1.0 (0.5)	<0.001	560	3.1 (0.9)	2.3 (0.7)	0.7 (0.4)	<0.001
55-64	401	17.0 (2.0)	10.9 (1.7)	6.1 (1.2)		446	10.6 (1.6)	8.6 (1.4)	2.0 (0.7)	
65-74	402	37.0 (2.5)	23.8 (2.2)	13.3 (2.0)		476	20.4 (1.8)	14.5 (1.6)	5.9 (1.1)	
75+	262	67.3 (3.2)	28.6 (2.8)	38.7 (3.1)		325	57.9 (2.9)	30.6 (2.5)	27.3 (2.6)	
Duration of work-related noise exposure:										
None	819	22.2 (1.6)	13.4 (1.3)	8.9 (1.2)	<0.001	1468	18.6 (1.1)	12.1 (0.9)	6.5 (0.7)	0.091
Less than 5 years	226	24.6 (2.9)	11.1 (2.3)	13.5 (2.4)		128	18.8 (3.8)	10.8 (3.0)	7.9 (2.7)	
5+ years	434	35.1 (2.5)	21.5 (2.1)	13.6 (1.7)		210	25.4 (3.0)	13.6 (2.4)	11.8 (2.2)	
Income tertiles:										
Highest	491	21.3 (2.5)	13.1 (2.0)	8.2 (1.7)	0.005	484	16.5 (2.3)	11.0 (1.9)	5.5 (1.4)	0.413
Middle	458	28.6 (2.2)	16.7 (1.9)	12.0 (1.5)		562	19.3 (1.8)	11.9 (1.4)	7.4 (1.2)	
Lowest	305	32.9 (2.8)	19.8 (2.2)	13.1 (2.0)		417	20.1 (1.9)	13.1 (1.6)	7.0 (1.2)	
Index of Multiple Deprivation quintiles:										
Least deprived	369	21.4 (2.2)	11.0 (1.8)	10.3 (1.7)	0.011	448	18.6 (2.1)	11.4 (1.5)	7.2 (1.4)	0.077
2	340	23.0 (2.4)	13.2 (1.8)	9.8 (1.7)		407	17.6 (1.7)	11.5 (1.5)	6.1 (1.2)	
3	311	27.2 (2.7)	17.1 (2.3)	10.1 (1.8)		392	17.5 (2.1)	10.9 (1.7)	6.6 (1.5)	
4	255	32.6 (2.9)	18.2 (2.5)	14.4 (2.2)		312	19.8 (2.6)	10.6 (2.1)	9.2 (1.7)	
Most deprived	210	30.2 (3.3)	18.0 (2.6)	12.2 (2.6)		248	26.3 (2.7)	18.4 (2.4)	7.9 (1.7)	
Education status:										
Degree or higher	344	20.1 (2.6)	12.3 (2.1)	7.8 (1.7)	<0.001	309	14.5 (3.5)	7.8 (2.2)	6.7 (2.5)	0.070
Below degree	733	23.2 (1.8)	12.8 (1.3)	10.4 (1.4)		941	18.4 (1.6)	12.1 (1.2)	6.4 (1.1)	
No qualifications	407	40.1 (3.0)	26.5 (2.9)	13.7 (1.7)		555	23.6 (2.1)	14.7 (1.8)	8.9 (1.1)	

* Hearing loss: >35dBHL at 3.0 kHz (tone not heard at 35dBHL).
† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but heard at 55 and at 75dBHL).

‡ Moderately severe or severe loss: >55 dBHL (tone not heard at 35 and at 55dBHL, but may or may not have heard the tone at 75dBHL).
§ Prevalence of hearing loss (>35dBHL at 3.0 kHz in the better hearing ear) across the categories of each variable (age-group; duration of work-related noise exposure; income tertiles; Index of Multiple Deprivation quintiles; and highest educational attainment) were compared using the Chi-square (χ^2) tests. No adjustment to the p-values for multiple comparisons was made.

Table 2 Age-standardized prevalence (%) and standard error (SE) of hearing aid use among persons with hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Men			Women		
	N	Hearing aid use % (SE)	*P-value*[*]	N	Hearing aid use % (SE)	*P-value*[*]
N	425	29.7 (3.1)		344	26.9 (3.3)	
Severity of loss:						
Moderate[†]	244	17.8 (3.2)	<0.001	217	19.1 (3.5)	0.002
Moderate to severe[‡]	181	52.9 (6.3)		127	47.1 (8.7)	
Age-group:						
45-64	101	25.4 (4.6)	0.056	63	21.2 (5.1)	0.035
65-74	147	34.3 (4.3)		94	31.4 (4.9)	
75+	177	40.2 (3.7)		187	39.1 (3.7)	
Duration of work-related noise exposure:						
None	250	26.1 (3.9)	0.234	287	25.3 (3.6)	0.296
Some	173	33.5 (4.9)		56	35.5 (9.4)	
Income tertiles:						
Highest	84	36.0 (6.5)	0.548	54	24.7 (6.5)	0.900
Middle	149	31.2 (5.5)		105	28.6 (5.8)	
Lowest	118	26.0 (6.1)		90	26.0 (7.0)	
Index of Multiple Deprivation quintiles:						
Least deprived 1 & 2	179	29.8 (5.3)	0.812	158	29.1 (5.2)	0.615
Quintile 3	101	33.5 (8.0)		66	29.3 (6.6)	
Most deprived 4 & 5	145	27.9 (4.6)		120	22.6 (5.6)	
Education status:						
O level or above	227	32.3 (4.2)	0.354	151	28.0 (4.3)	0.654
No qualifications	198	26.3 (4.6)		192	24.7 (5.6)	

[*] Prevalence of current hearing aid use across the categories of each variable (age-group; duration of work-related noise exposure; income tertiles; Index of Multiple Deprivation

quintiles; and highest educational attainment) were compared using the Chi-square (χ^2) test. No adjustment to the p-values for multiple comparisons was made.

† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but tone heard at 55 and 75dBHL).

‡ Moderately severe or severe loss: >55dBHL (tone not heard at 35 and 55dBHL, but may or may not have heard the tone at 75dBHL).

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FIGURE 1 LEGEND

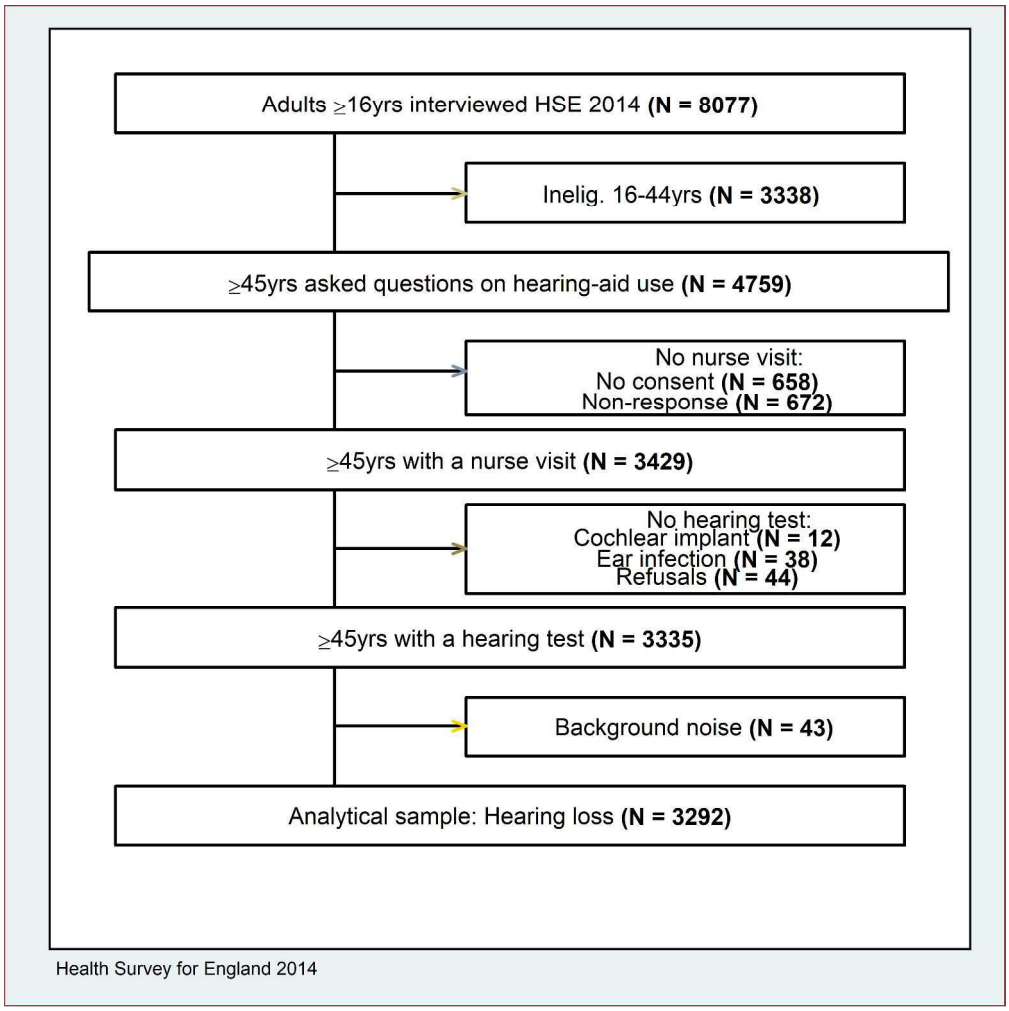
Selection of Study Participants, Health Survey for England 2014

FIGURE 2 LEGEND

Association between socioeconomic status (SES) and hearing loss in middle-aged and older adults. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (most affluent), and highest educational attainment (degree or higher). Lines represent Odds Ratio (outcome = hearing loss) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

FIGURE 3 LEGEND

Association between SES and current hearing aid use in middle-aged and older adults with hearing loss. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (least deprived Q1 and Q2), and highest educational attainment (O level and above). Lines represent Odds Ratio (outcome = hearing aid use) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, severity of hearing loss, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).



Selection of Study Participants, Health Survey for England 2014

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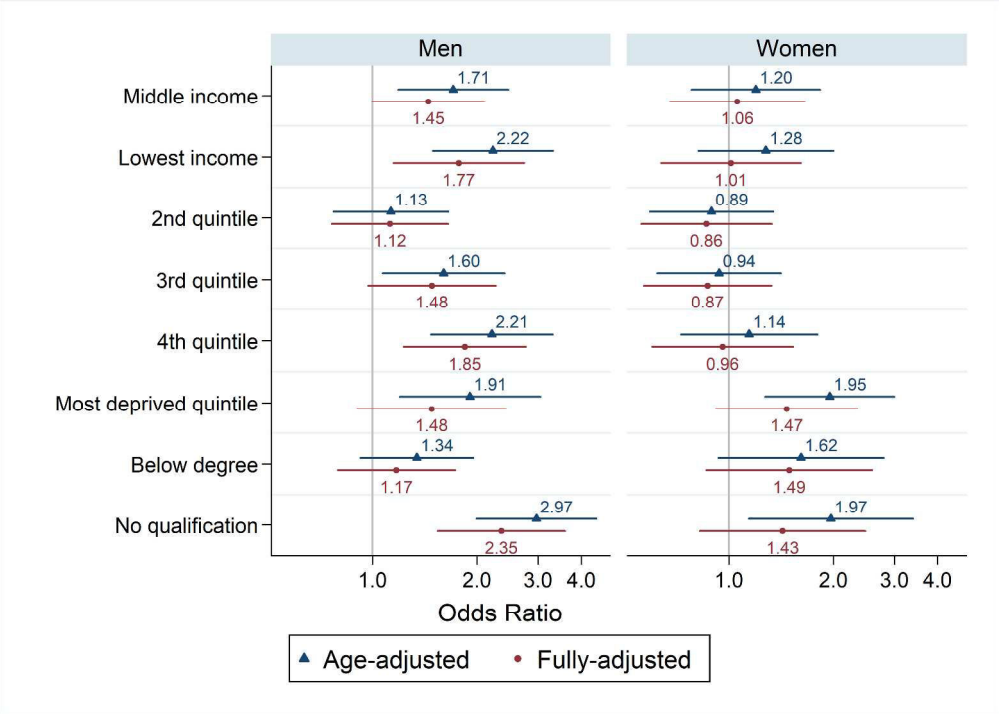

Associations between socioeconomic status (SES) and hearing loss in middle-aged and older adults. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (most affluent), and highest educational attainment (degree or higher). Lines represent Odds Ratio (outcome = hearing loss) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

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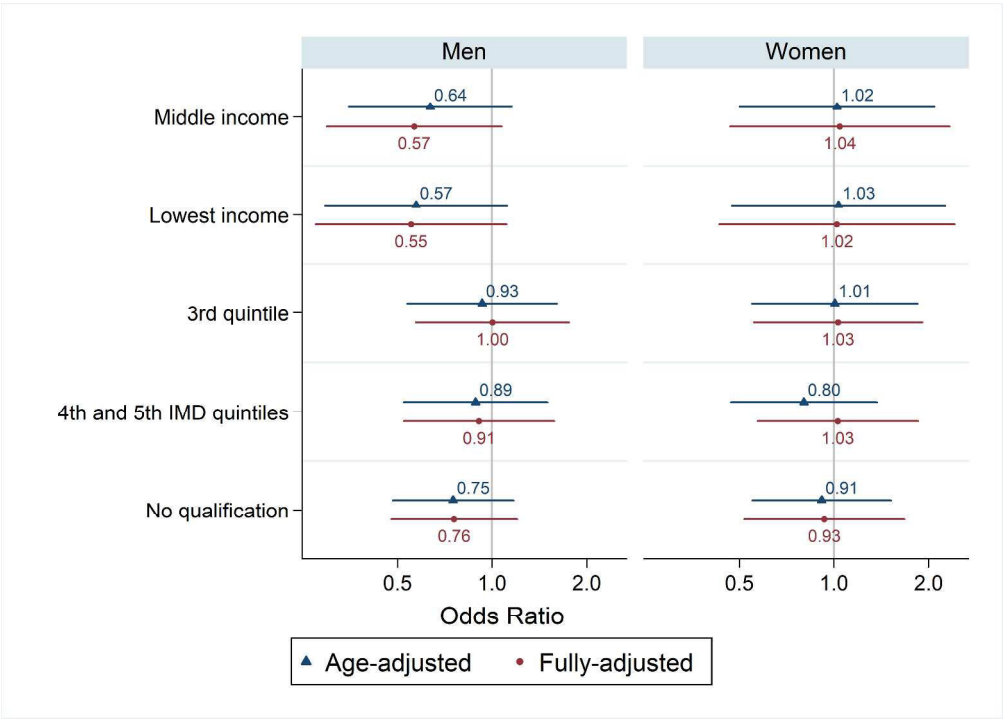

Associations between SES and current hearing aid use in middle-aged and older adults with hearing loss. Indicators of SES were: equivalised household income tertiles (highest tertile as reference), Index of Multiple Deprivation quintiles (least deprived Q1 and Q2), and highest educational attainment (O level or above). Lines represent Odds Ratio (outcome = hearing aid use) and its 95% confidence interval. Model A (triangles): adjusted for age. Model B (circles): adjusted for: age, severity of hearing loss, exposure to work-related noise, region, and CVD risk factors (smoking, body mass index, diabetes, hypertension, dyslipidaemia, and physical inactivity).

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Supplementary Tables

Scholes S, Biddulph J, Davis AC and Mindell JS. Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England. *Submitted to BMJ Open.*

Supplementary Table 1 Characteristics of participants aged 45+ with main interview with and without nurse visit

	No nurse visit	Nurse visit	*P*-value
N	**1,330**	**3,429**	
Age in years: mean (SD)	62.4 (12.4)	63.0 (11.7)	0.129
Age (%):			
45-54	34.7	29.8	*<0.001*
55-64	24.7	25.7	
65-74	20.8	26.6	
75+	19.8	18.0	
Sex (%):			
Males	46.2	45.1	0.502
Females	53.8	54.9	
Region (%):			
North	37.3	31.7	*<0.001*
Midlands	27.0	30.6	
London	11.0	8.0	
South	24.7	29.8	
Occupational noise exposure (%):			
None	71.4	69.1	*0.004*
Less than 5 years	7.6	10.9	
5 years or more	20.3	19.8	
Missing	0.7	0.2	
Income tertiles (%):			
Highest	24.6	29.2	*0.002*
Middle	22.6	30.9	
Lowest	22.6	22.2	
Missing	30.2	17.8	
Index of Multiple Deprivation (%):			
Least deprived	19.9	24.5	*<0.001*
2nd	22.0	22.5	
3rd	18.4	21.3	
4th	19.3	17.6	
Most deprived	20.3	14.1	
Education (%):			
Degree	17.0	19.7	*<0.001*
Below degree	45.5	50.7	
No qualifications	36.0	29.5	
Missing	1.5	0.1	
Smoking status (%):			
Never	51.8	54.1	*0.011*
Former	30.2	32.3	
Current	16.8	13.6	
Missing	1.1	0.0	
BMI (%):			
Normal	18.3	24.9	*0.291*
Overweight	31.1	37.2	
Obese	23.8	28.2	

Missing	26.8	9.8	
Doctor-diagnosed diabetes (%):			
No	89.5	89.6	*0.886*
Yes	10.5	10.4	
Missing	0.0	0.0	
Hearing difficulty (%):			
None	68.2	60.0	<0.001
Slight	15.4	22.7	
Moderate	7.5	8.7	
Great	8.2	8.0	
Missing	0.7	0.5	
Hearing aid use (%):			
Current	10.1	9.5	0.748
Used but not nowadays	3.1	3.3	
Never used	86.3	87.1	
Missing	0.5	0.1	

Abbreviations: BMI: body mass index; SD: standard deviation

Notes: Analysis is unweighted. Data are presented as mean and standard deviation (SD) for continuous variables; and as the column (%) for categorical variables. *P*-values are based on the t-test for continuous variables and the chi-square test χ^2 for categorical variables (excluding missing data on covariates) for the comparison of differences in the covariates between the two groups of participants (with and without nurse-visit data). No adjustment for multiple comparisons was performed.

Supplementary Table 2 Age-standardised prevalence (%) and standard error (SE) of hearing loss, persons aged 45 years and over, HSE 2014

Characteristics	Males					Females				
	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§	n	Hearing loss % (SE)*	Moderate % (SE)†	Moderate to severe % (SE)‡	*P-value*§
Region:										
North	485	26.7 (2.1)	14.9 (1.7)	11.8 (1.6)	0.618	556	20.2 (1.6)	13.0 (1.4)	7.2 (1.1)	0.322
Midlands	454	28.0 (2.1)	16.9 (1.6)	11.1 (1.7)		558	21.6 (1.7)	13.0 (1.4)	8.6 (1.2)	
London	113	21.9 (5.1)	14.1 (4.0)	7.8 (3.6)		142	15.6 (3.5)	9.4 (2.8)	6.2 (2.5)	
South	433	25.4 (2.3)	14.0 (1.8)	11.4 (1.6)		551	18.1 (1.8)	11.3 (1.3)	6.8 (1.2)	
Smoking status:										
Never smoked	709	24.9 (1.8)	14.0 (1.4)	10.9 (1.3)	0.102	1083	19.1 (1.3)	11.5 (1.0)	7.6 (0.9)	0.290
Ex-regular	559	26.0 (1.9)	15.1 (1.5)	10.9 (1.2)		494	17.6 (1.6)	11.0 (1.3)	6.6 (1.1)	
Current smoker	217	32.9 (4.1)	17.1 (3.1)	15.8 (3.8)		230	23.0 (3.4)	14.9 (2.8)	8.1 (2.6)	
BMI:										
Normal	297	27.1 (3.2)	16.3 (2.4)	10.8 (2.4)	0.529	535	15.6 (1.7)	7.3 (1.1)	8.4 (1.4)	0.135
Overweight	658	24.0 (1.7)	13.6 (1.4)	10.4 (1.1)		565	20.3 (1.7)	13.0 (1.5)	7.4 (1.1)	
Obese	401	26.9 (2.2)	16.4 (1.8)	10.5 (1.7)		519	19.7 (1.9)	15.0 (1.7)	4.6 (1.1)	
Diagnosed diabetes:										
No	1294	24.2 (1.3)	13.7 (1.0)	10.6 (1.0)	<0.001	1652	18.4 (1.0)	11.0 (0.8)	7.4 (0.7)	0.005
Yes	191	40.4 (3.9)	26.2 (3.5)	14.2 (2.5)		154	28.8 (4.0)	21.2 (3.7)	7.6 (1.9)	
Raised Hb1Ac:										
No	981	23.6 (1.4)	13.1 (1.1)	10.6 (1.1)	<0.001	1189	17.9 (1.2)	10.7 (0.9)	7.2 (0.9)	0.025
Yes	140	39.8 (4.3)	25.5 (4.0)	14.3 (2.9)		114	27.1 (4.4)	17.0 (3.6)	10.1 (3.0)	
Hypertension:										
No	630	27.7 (2.0)	17.4 (1.7)	10.3 (1.6)	0.752	906	18.6 (1.6)	11.7 (1.3)	6.9 (1.1)	0.133
Yes	640	26.8 (1.9)	14.5 (1.5)	12.4 (1.3)		707	22.0 (1.6)	13.8 (1.3)	8.2 (1.0)	
Dyslipidaemia:										
No	483	29.7 (2.3)	17.0 (2.0)	12.7 (1.5)	0.031	389	22.0 (2.1)	13.5 (1.7)	8.5 (1.5)	0.098
Yes	637	23.2 (2.1)	13.2 (1.5)	10.0 (1.7)		915	17.8 (1.5)	10.9 (1.2)	6.8 (1.0)	

Physically inactive:										
No	838	24.1 (1.7)	14.3 (1.3)	9.9 (1.3)	0.180	875	16.0 (1.5)	10.8 (1.3)	5.2 (1.0)	0.028
Yes	437	27.7 (2.2)	16.0 (1.7)	11.7 (1.5)		649	20.9 (1.6)	13.4 (1.3)	7.4 (1.0)	

* Hearing loss: >35dBHL at 3.0 kHz (tone not heard at 35dBHL).
† Moderate loss: >35 to 54dBHL (tone not heard at 35dBHL, but heard at 55 and at 75dBHL).
‡ Moderately severe or severe loss: >55 dBHL (tone not heard at 35 and at 55dBHL, but may or may not have heard the tone at 75dBHL).
§ Prevalence of hearing loss (>35dBHL at 3.0 kHz in the better hearing ear) across the categories of each variable (region; smoking status; BMI; diagnosed diabetes; Hb1Ac; hypertension; dyslipidaemia; physical activity) were compared using the Chi-square (χ^2) tests. No adjustment to the p-values for multiple comparisons was made.

Supplementary Table 3 Age-standardized prevalence (%) and standard error (SE) of hearing aid use among persons with hearing loss, persons aged 45 years and over, HSE 2014

	Men			Women		
	N	**Hearing aid use % (SE)**	***P-value****	**N**	**Hearing aid use % (SE)**	***P-value****
Smoking status:						
Never smoked	182	35.3 (4.1)	0.452	202	32.7 (4.2)	0.849
Ex-regular	189	28.4 (3.8)		96	31.1 (5.9)	
Current smoker	54	27.5 (7.6)		46	27.4 (8.0)	
BMI:						
Normal	72	27.2 (6.7)	0.789	72	36.2 (8.1)	0.362
Overweight	181	30.7 (5.5)		112	23.5 (4.9)	
Obese	113	33.5 (5.5)		90	25.9 (6.0)	
Diagnosed diabetes:						
No	338	32.5 (3.6)	0.101	287	29.6 (3.8)	0.077
Yes	87	20.5 (5.6)		56	13.5 (6.4)	
Raised Hb1Ac:						
No	234	30.2 (4.0)	0.510	184	31.4 (4.5)	0.194
Yes	62	24.3 (7.5)		35	17.4 (8.3)	
Hypertension:						
No	159	30.7 (4.6)	0.761	113	30.1 (5.2)	0.803
Yes	223	28.7 (4.8)		201	28.4 (4.9)	
Dyslipidaemia:						
No	172	29.0 (4.8)	0.910	88	24.7 (7.6)	0.584
Yes	126	28.2 (5.2)		132	29.8 (4.9)	
Physically inactive:						
No	182	30.3 (4.5)	0.628	99	36.6 (5.6)	0.003
Yes	162	26.8 (5.4)		162	15.8 (3.9)	

* Prevalence of current hearing aid use across the categories of each variable (region; smoking status; BMI; diagnosed diabetes; Hb1Ac; hypertension; dyslipidaemia; physical activity) were compared using the Chi-square (χ^2) test. No adjustment to the p-values for multiple comparisons was made

STROBE Statement—checklist of items that should be included in reports of observational studies

Scholes S, Biddulph J, Davis AC, Mindell JS. Socioeconomic differences in hearing among middle-aged and older adults: cross-sectional analyses using the Health Survey for England. Submitted to BMJ Open.

		Recommendation	Author response
1	**Title / abstract**	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Yes. The title of our submitted manuscript is: "Socioeconomic differences in hearing among middle-aged and older adults: **cross-sectional analyses** using the Health Survey for England".
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Yes
2	**Introduction**	Explain the scientific background and rationale for the investigation being reported	Yes. The background and rationale for our study are outlined in the Introduction (1st and 2nd paragraphs, respectively).
3		State specific objectives, including any prespecified hypotheses	Yes. The primary and secondary aims are outlined in the second paragraph of the Introduction. We did not have any pre-specified hypotheses.
4	Methods	*Study design*: Present key elements of study design early in the paper	Yes. The first sentence of the Methods Section states that the present study uses data from the Health Survey for England, an annual nationally-representative cross-sectional survey of the non-institutionalised general population.
5		*Setting:* Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Yes. The study setting is outlined in the first paragraph of the Methods Section.
6		*Participants (cross-sectional study):* Give the eligibility criteria, and the sources and methods of selection of participants	Yes. The participants in this study (including eligibility criteria) are described in the 1st and 2nd paragraphs of the Methods section. Figure 1 is a flowchart which shows the derivation of the analytical sample used to estimate the prevalence of hearing loss.
7		*Variables*: Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Yes. The key variables for this study (hearing outcomes; markers of socioeconomic status (SES), and various potential confounders of the SES-hearing associations) are clearly defined under the appropriate heading (hearing loss, socioeconomic status, and covariates)
8		*Data sources / measurement*: For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment	Yes, sources of details and methods of assessment are outlined under the appropriate heading (hearing loss, socioeconomic status, and covariates).

		methods if there is more than one group	
9		*Bias* Describe any efforts to address potential sources of bias	We discussed the potential source of bias through missing data as a result of: (1) survey non-response (main interview and nurse visit); and (2) interviewer-participant communication difficulties through conditions such as deafness. The appropriate non-response weights archived with the data were used in all analyses. Potential bias arising from both potential sources of missing data is discussed in the section on Study limitations (see Checklist Item No. 19).
10		*Study size*: Explain how the study size was arrived at.	Yes, Figure 1 shows the derivation of the analytical sample. We explain in the Methods section that participants aged 16-44 years were excluded due to hearing loss being comparatively rare. We explain that the analysis of hearing aid use was carried out only on the subset of participants with hearing loss.
11		Quantitative variables: Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Yes.
12		*Statistical methods*: (*a*) Describe all statistical methods, including those used to control for confounding; (*b*) Describe any methods used to examine subgroups and interactions; (*c*) Explain how missing data were addressed; (d) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy; (e) *Describe any sensitivity analyses*	*(a)* Yes. Firstly, prevalence estimates across subgroups were age-standardised within sex to the 2014 English household population. Secondly, a fully-adjusted model was used to examine the SES-hearing associations. Potential confounders adjusted for in the modelling included age, duration of work-related exposure, and CVD risk factors. Severity of hearing loss was adjusted for in the analysis of hearing aid use. *(b)* Yes, the chi-square test was used to test subgroup differences in hearing outcomes. *(c)Missing data:* analyses were weighted by the nurse-visit weight: this accounts for individual non-participation and preserves the national representativeness of the sample. *(d) Sampling strategy:* the weighting and clustering of participants within PSUs were accounted for by using design-based inference (the complex survey module in Stata). *(e) Sensitivity analyses:* N/A
13	**Results**	*Participants: (a)* Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in	Yes, Reasons for exclusion at each stage of the study are shown in the flow diagram (**Figure 1**).

		the study, completing follow-up, and analysed; *(b)* Give reasons for non-participation at each stage; *(c)* Consider use of a flow diagram	
14		*Descriptive data: (a)* Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders; *(b)* Indicate number of participants with missing data for each variable of interest	Yes, Supplementary Table 1 shows the characteristics of participants aged 45+ with main interview data with and without nurse visit data (including the number of participants with missing data for each variable of interest).
15		*Outcome data*: Report numbers of outcome events or summary measures	Yes, we outline the number of participants with hearing loss (769/3292) and the number of participants with hearing loss reporting current use of a hearing aid (264/769). Prevalence estimates are set out in Table 1 (hearing loss) and Table 2 (current hearing aid use).
16		*Main results*: (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included; (*b*) Report category boundaries when continuous variables were categorized; (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	We present odds ratios (and accompanying 95% CIs) for the SES-hearing associations in both age-adjusted and fully-adjusted models in Figures 2 and 3. The estimates are displayed graphically to avoid lengthy tables. The legends for Figures 2 and 3 make clear which confounders were adjusted for. In the Methods Section we explain that modifiable risk factors for CVD such as diabetes have been independently associated with hearing impairment and are also possible confounders for any observed associations between SES and hearing.
17		*Other analyses*: Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Yes, the analysis of current hearing aid use is based on the subset of participants with objectively measured hearing loss.
18	**Discussion**	*Key results:* Summarise key results with reference to study objectives	Yes, we summarise the key results with reference to the study objectives in the first paragraph of the Discussion.
19		*Limitations:* Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Yes, the limitations of the study are outlined in the Discussion. Limitations include missing data (accounted for by the use of non-response weighting), the small number of participants with hearing loss, and the unknown influence of unmeasured confounders. We state that since this study utilises cross-sectional data, we could not establish the direction of the observed associations, and we cannot establish causality.
20		Interpretation: Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	Yes, in the Discussion we present a cautious overall interpretation of the main findings.

		analyses, results from similar studies, and other relevant evidence	
21		*Generalisability:* Discuss the generalisability (external validity) of the study results	Yes
22	**Other Information**	*Funding:* Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	The Health Survey for England 2014 was funded by NHS Digital. This particular study received no funding.