Hearing in middle age: a population snapshot of 40-69 year olds in the UK

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Objective: To report population-based prevalence of hearing impairment based on speech recognition in noise testing in a large and inclusive sample of UK adults aged 40 to 69 years. The present study is the first to report such data. Prevalence of tinnitus and use of hearing aids is also reported.

Design: The research was conducted using the UK Biobank resource. The better-ear unaided speech reception threshold was measured adaptively using the Digit Triplet Test (n = 164,770). Self-report data on tinnitus, hearing aid use, noise exposure as well as demographic variables were collected.

Results: Overall, 10.7% of adults (95%CI 10.5-10.9%) had significant hearing impairment. Prevalence of tinnitus was 16.9% (95%CI 16.6-17.1%) and hearing aid use was 2.0% (95%CI 1.9-2.1%). Odds of hearing impairment increased with age, with a history of work- and

music-related noise exposure, for lower socioeconomic background and for ethnic minority backgrounds. Males were at no higher risk of hearing impairment than females.

Conclusion: Around 1 in 10 adults aged 40 to 69 years have substantial hearing impairment. The reasons for excess risk of hearing impairment particularly for those from low socioeconomic and ethnic minority backgrounds require identification, as this represents a serious health inequality. The underutilization of hearing aids has altered little since the 1980s, and is a major cause for concern.

INTRODUCTION

Hearing loss represents a substantial burden on society (Mathers et al. 2006) and on individuals in terms of reduced emotional, social and physical well-being (Arlinger 2003; Chia et al. 2007; Dalton et al. 2003; Gopinath, Wang, et al. 2009; Mulrow, Aguilar, Endicott, Velez, et al. 1990; Strawbridge et al. 2000). Good hearing across the life course is vital in terms of people's ability to carry out everyday activities at home, at work and at leisure. To date, the epidemiology of hearing has primarily focused on hearing loss, or sensitivity measured by detection of very quiet pure tones of varying frequencies (Agrawal et al. 2008; Cruickshanks et al. 1998; Davis 1989; Gates et al. 1990; Mościcki et al. 1985; D. H. Wilson et al. 1999). Measures of hearing loss, however, are poor predictors of hearing disability (i.e. the impact of hearing difficulties in daily life), with correlations between measures of disability and loss ranging between 0.3 and 0.6 depending on the type of disability measure and range of hearing loss (Anderson et al. 1995; Koike et al. 1994; Lutman et al. 1987; Meijer et al. 2003; Newman et al. 1990).

In order to better index hearing problems that impact on daily life, use of speech recognition tests as a supplement to tests of hearing sensitivity has been advocated in clinical audiology (Arlinger et al. 2009; Kramer et al. 1996). In the present paper, we refer to poor performance on tests of speech recognition as 'hearing impairment'. As listening in noise is a key function of hearing, and difficulty hearing in noise is the most common complaint by people with hearing loss, speech recognition testing in noise arguably provides a more ecologically valid measure of hearing than detection of tones in a quiet environment

(Arlinger et al. 2009). The present study provides estimates of the prevalence of hearing impairment in the general UK population based on speech-in-noise testing using the Digit Triplet Test (DTT; Smits, Kapetyn & Houtgast, 2004). Because the DTT correlates with measures of hearing sensitivity (PTA; r = 0.77; Smits et al. 2004) and with other speech recognition measures (such as with Plomp and Mimpen's (1979) Sentences in Noise; r = 0.85; Smits et al. 2004), it may be regarded as being both an indirect index of hearing loss and a measure of hearing impairment.

There has been a surge of interest in speech recognition testing in large-scale screening for clinical audiological services in the UK and Europe, Australia and the US (Meyers et al. 2011; Vlaming et al. 2011; Watson et al. 2012). Despite this interest and an extensive body of lab-based research in speech recognition, very little population-based research has been reported. We identified only three studies. The first included male participants aged 20 to 64 years recruited from an engineering firm, and older male and female participants up to 89 years recruited from nursing homes, with a total sample size of 212 (Plomp et al. 1979). The second study did not report any demographic information other than the age of the 75 participants in the study, which ranged between 20 to 79 years (R. H. Wilson et al. 2002). The third included 1086 adults aged over 60 years in the Netherlands (Smits et al. 2006). The levels of self-reported hearing problems in the study sample were similar to those in the population-based sample from which the study sample was drawn. However, no other information on the comparability of the study sample to the general Dutch population was reported. All three studies suggested worse speech recognition in noise with age, particularly after the age of 50-60 years. For all studies, the generalizability of the results is uncertain, and only limited descriptions of the prevalence of hearing impairment according to demographic variables were possible.

The study utilised the UK Biobank resource (Collins 2012), in which 164,770 participants completed the DTT. To our knowledge no previous study has reported prevalence data for hearing impairment with a sample of this large size and wide coverage. The primary aim of the study was to provide an objective current estimate of the burden associated with hearing difficulties among UK adults aged 40 to 69 years. Secondary aims were to document associated demographics as well as prevalence of tinnitus and hearing aid use.

PARTICIPANTS AND METHODS

UK Biobank was established for investigations of the genetic, environmental and lifestyle causes of diseases of middle and older age. Recruitment was carried out via the UK National Health Service and aimed to be as inclusive and representative as possible of the population. Stratification and over-sampling were employed to maintain comparability with demographic statistics based on the 2001 UK Census (Office for National Statistics 2005). Overall, 9.2 million invitations were sent to recruit 503,325 participants over the course of 2006-2010, giving a response rate of 5.47%. Table 1 shows sex, ethnicity and Townsend deprivation index score (a proxy measure of socioeconomic status; see below) for the UK Biobank sample aged 40 to 69 years and for the corresponding section of the UK population as reported in the 2001 UK Census. The UK Biobank contains a slightly higher proportion of females, people of White ethnicity and people living in less deprived areas than the general population. As data collection proceeded, additional measures were included for a subset of participants. Data were obtained from 164,770 participants for the hearing measure (Digit Triplet Test). Different numbers of participants completed self-report questions (dependent on when the question was included in the measurement protocol and contingent on responses to earlier questions), and the size of each sub-sample for each question is reported in Appendix A.

Table 1. Participants in the UK Biobank versus 2001 UK Census data for sex, age, ethnicity and socio-economic status. Sex and ethnicity are shown as percentages while socio-economic status is reported as average Townsend deprivation index score (with standard deviation).

		UK Biobank	UK Census 2001
Sex	Male	45.6	49.2
Age group (years)	40-44	10.4	20.1
	45-49	13.2	18.0
	50-54	15.3	19.3
	55-59	18.2	16.3
	60-64	24.3	13.8
	65-69	18.7	12.5
Ethnicity	White	94.1	91.3
	Mixed	0.6	1.3
	Asian or Asian British	2.0	4.4
	Black or Black British	1.6	2.2
	Chinese	0.3	0.4
	Other ethnic group	0.9	0.4
	Prefer not to answer	0.3	-
	Missing data	0.2	-
Socioeconomic status	Mean Townsend score* (SD)	-1.3 (3.1)	0.7 (4.2)

*Lower Townsend scores indicate less deprivation

Volunteers attended an assessment centre and gave informed consent. They completed an assessment of approximately 90 minutes duration which included a computerised questionnaire (on lifestyle, environment and medical history) and physical measures including hearing testing. Information on the procedure and the additional data collected can be found elsewhere (http://www.ukbiobank.ac.uk/).

Data on sex and ethnicity (2001 UK Census categories) and the area of residence translated to Townsend deprivation score were collected for each participant. The Townsend deprivation scheme is widely used in health studies as a proxy for socioeconomic status, and is applicable across the UK's constituent countries (Norman 2010). It comprises four input variables on unemployment, non-car ownership, non-home ownership and household overcrowding which are used to allocate a score to a small area geography[1]. Each variable is expressed as a z-score relative to the national level which are then summed, equally weighted, to give a single deprivation score for each area. Lower Townsend scores represent

[1] Electoral wards in England, Wales and Northern Ireland, postal sectors in Scotland

areas associated with less deprived socioeconomic status. Self-report questions on tinnitus, hearing aid use, amount of music- and work-related noise exposure are tabled in Table 2. Tinnitus identification was based on self-report of ringing or buzzing in the head or one or both ears that lasts for more than five minutes at a time and is currently experienced at least some of the time.

Table 2. Self-report questions and the size of subsample for each question. Response options are shown in brackets.

Question	Number of respondents in the subsample (n)
Do you get or have you had noises (such as ringing or buzzing) in your head or in one or both ears that lasts for more than five minutes at a time? *(Yes, now most or all of the time; Yes, now a lot of the time; Yes, now some of the time; Yes, not now, but have in the past; No, never; Do not know; Prefer not to answer)*	171,736
Do you use a hearing aid most of the time? *(Yes; No; Prefer not to answer)*	164,770
Have you ever worked in a noisy place where you had to shout to be heard? *(Yes, for more than 5 years; Yes, for around 1-5 years; Yes, for less than a year; No; Do not know; Prefer not to answer)*	171,736
Have you ever listened to music for more than 3 hours per week at a volume which you would need to shout to be heard or, if wearing headphones, someone else would need to shout for you to hear them? *(Yes, for more than 5 years; Yes, for around 1-5 years; Yes, for less than a year; No; Do not know; Prefer not to answer)*	171,736

Digit Triplet Test

The Digit Triplet Test (DTT) is a speech-in-noise test originally developed in Dutch (Smits et al. 2004) for reliable large scale hearing screening (Vlaming et al. 2011). Telephone and internet-based versions of the DTT for adult hearing screening have been implemented in the Netherlands, United Kingdom, Australia, Poland, Switzerland, Germany, France and the USA (Watson et al. 2012). The English speech materials for the UK Biobank DTT were developed at the University of Southampton (Hall 2006). The DTT is described elsewhere (http://biobank.ctsu.ox.ac.uk/crystal/label.cgi?id=100049). Briefly, fifteen sets of three monosyllabic digits (e.g. 1-5-8) were presented via circumaural headphones (Sennheiser HD-25). Each ear was tested separately with the order of testing randomised across participants. Participants first set the volume of the stimuli to a comfortable level. Digit triplets were then presented in a background of noise shaped to match the spectrum of the speech stimuli. Noise levels varied adaptively after each triplet to estimate the SNR for 50% correct recognition of the three digits via touchscreen response. The recognition threshold was taken as the mean SNR for the last eight triplets. Testing of each ear took around 4 minutes. Lower (more negative) scores correspond to better performance. In the present study, hearing disability was based on 'better ear' performance (i.e. the ear with the lower recognition threshold) categorised with reference to a group consisted of 20 volunteers with normal hearing aged 18 to 29 years who performed the UK Biobank version of the DTT tested by the first author. Normal hearing was defined as pure tone audiometric thresholds <25 dB HL between 250 Hz and 8,000 Hz bilaterally. For the normative group, mean speech reception threshold in the better ear was -8.00 dB SNR, SD = 1.24. Performance categories were based on those used by the UK telephone hearing screening version of the DTT (http://www.actiononhearingloss.org.uk/). Cut-off scores were thus 'Normal'; SRT < -5.5 dB, 'Insufficient'; -5.5 dB to -3.5 dB and 'Poor'; SRT > -3.5 dB[2].

Data analysis

All analyses were performed in Stata version 12.1. Within each subsample, iterative proportional fitting was used (IPF, or raking; *ipfweight* command in Stata) in each age category to adjust the subsample margins to known population margins of sex, ethnicity and socioeconomic status from the 2001 UK Census. For the overall age category (40-69 year-olds), age was included as an additional weighting variable. With respect to socioeconomic status, deciles of deprivation weighted for each five year age-group using 2001 UK Census data were linked to each participant. This allowed for the Biobank sample being selective of people living in slightly less deprived circumstances and that the distribution of people

[2] To facilitate comparability, the category names ('insufficient' and 'poor') are the same as those used in previous publications concerning the DTT (Hall 2006; Smits et al. 2004; Vlaming et al. 2011). The cut-off for the 'insufficient' category is performance lower than -2 standard deviations with respect to the normative sample while the 'poor' category is defined by a further 2 dB step, which corresponds to an increase of hearing threshold level of around 10 dB (Smits et al. 2004; Vlaming et al. 2011).

across differently deprived areas varies by age. As different subsets of participants completed each measure, the weights were calculated separately within subsamples based on whether the respective outcome variable was observed. This assumes that missing data may be ignored because the reason for missing data is not systematically related to the outcome variable. Missing data were primarily accounted for by the inclusion of measures at different points over the course of data collection, and this was unrelated to the hearing status of participants. The IPF procedure performs a stepwise adjustment of survey sampling weights until the difference between the observed subsample margins and the known population margins across sex, ethnicity and socioeconomic status is less than a specified tolerance, which was set at 0.2%. Convergence of the IPF procedure was achieved within 10 iterations for all subsamples and age categories. The subsamples were weighted and the crosstabulations performed to generate the population prevalence estimates. Multinomial logistic regression was used to model the effects of age, sex, socioeconomic status, work- and music-related noise exposure and ethnicity on hearing difficulties.

RESULTS

Prevalence data are presented graphically. For numerical values, see the Supplementary Data files. Figure 1 shows that the prevalence of hearing difficulties increases with age, with an acceleration in prevalence beginning in the 55-59 year-old age group. The proportional increase in hearing difficulties between the youngest and the oldest age group was 3.9-fold.

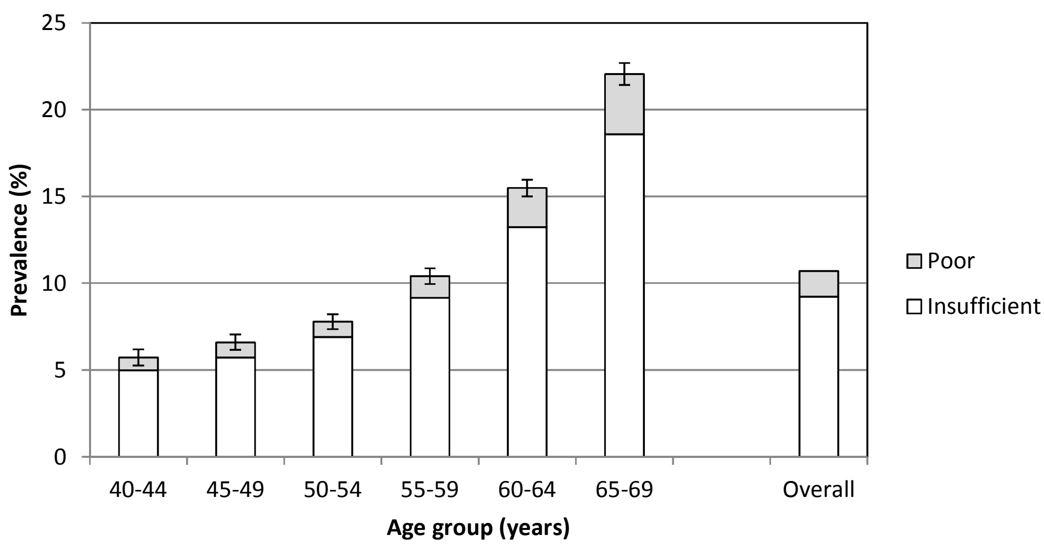

Fig. 1. Prevalence (%) of hearing disability based on Digit Triplet Test performance in the better ear by age group. Error bars show the 95% confidence interval for performance outside the normal range (insufficient/poor).

Tinnitus shows a pattern of increase with age (Figure 2), although this follows a more gradual linear pattern than for DTT performance. The proportional increase in tinnitus between the youngest and oldest age groups was 2-fold. Hearing aid use (Figure 3) was 2.0% overall, and usage accelerated with age (a 7.4-fold increase between youngest and oldest age groups). Among the 'poor' category of hearing, only 21.5% reported using a hearing aid and those with hearing aids had significantly lower (less deprived) Townsend levels than those without (-0.63 versus 0.15; $t(3150) = 5.42$, $p < 0.001$).

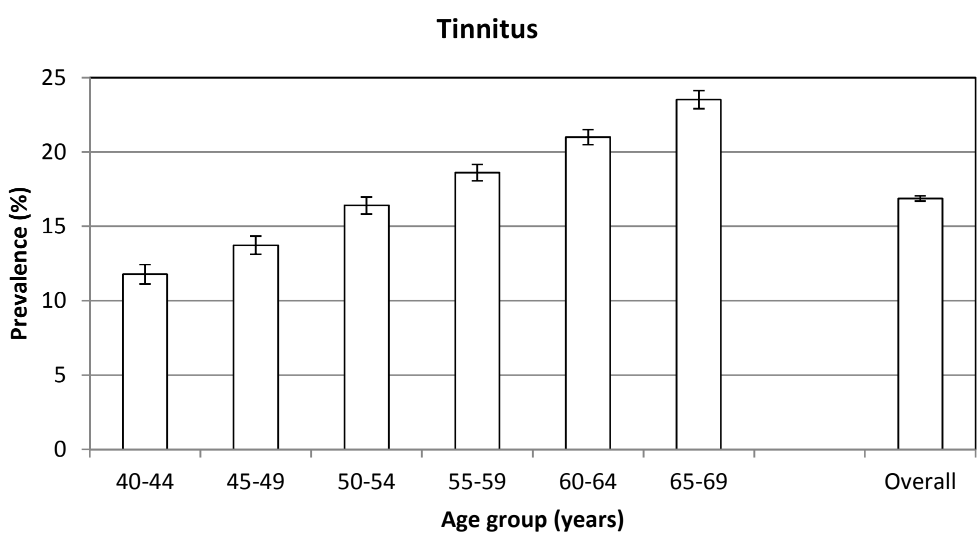

Fig. 2. Prevalence (%) of self-reported tinnitus by age group. Tinnitus identification was based on self-report of ringing or buzzing in the head or one or both ears that lasts for more than five minutes at a time and is currently experienced at least some of the time. Error bars show the 95% confidence interval.

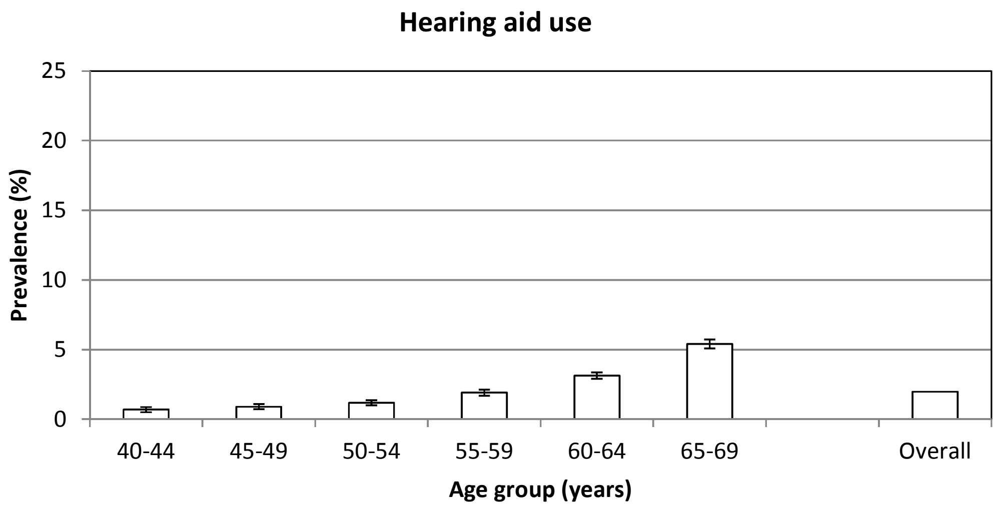

Fig. 3. Prevalence (%) of self-reported hearing aid use by age group. Error bars show the 95% confidence interval.

Table 3 shows odds ratios derived from multivariable logistic regression modelling of the main effects for the prevalence of hearing difficulties on the Digit Triplet Test. The main effects of six factors were tested including age, sex, socioeconomic status, work- and music-related noise exposure and ethnicity. Increasing age was associated with higher risk of hearing difficulties. Those from a low socioeconomic background and those with a history of work-related noise exposure were also more likely to have hearing difficulties. Music-related noise exposure showed an inconsistent pattern; exposure for more than 5 years was associated with a small but significant increased risk of hearing impairment, exposure between 1 and 5 years was not associated with increased risk, but shorter duration exposure (<1 year) was. Female sex was associated with small increased odds for 'insufficient' speech reception threshold, while sex was not a significant factor for 'poor' performance. Comparison of mean performance between males and females suggested no significant difference the speech reception threshold in younger age groups (40-44 year-olds: males -7.82 dB, females -6.76 dB; $t(17136) = -2.3$ $p = 0.29$) while females tended to have slightly better mean performance in the oldest age groups (65-69 year-olds: males -6.65 dB, females -6.79 dB; $t(32242) = 6.0$ $p<0.001$). Non-white ethnicity was associated with increased risk. Logistic models were re-run to provide odds ratios for ethnic sub-groups compared to White British for hearing difficulties (insufficient or poor; see Supplemental

Tables). Ethnicities at highest risk were Bangladeshi, Black African, Pakistani, Black Other and Asian Other (ORs 5.0 to 7.1, $p < 0.001$).

Table 3. The odds ratios from the multivariable logistic models fitted to the prevalence of better-ear hearing disability based on Digit Triplet Test performance.

Factor		Odds ratio (95% confidence interval) Insufficient	Poor
Age	40-44	-	-
	45-49	1.2*** (1.1 - 1.3)	1.2 (1.0 – 1.5)
	50-54	1.5*** (1.4 - 1.7)	1.5*** (1.2 – 1.8)
	55-59	2.2*** (2.0 - 2.4)	2.4*** (1.9 – 2.9)
	60-64	3.3*** (3.1 - 3.6)	3.9*** (2.3 – 4.7)
	65-69	5.2*** (4.9 – 5.7)	7.5*** (6.2 – 9.0)
Sex	Female	-	-
	Male	0.9*** (0.8 - 0.9)	1.0 (0.9-1.1)
Ethnicity	White	-	-
	Non-white	3.2***(3.1 – 3.4)	5.4** (4.9 – 5.9)
Socio-economic status	Medium-high socioeconomic status (>-1SD)	-	-
	Low socioeconomic status (<-1SD)†	1.5*** (1.4 - 1.6)	2.0*** (1.8 – 2.2)
Work noise exposure	No exposure	-	-
	Yes, for more than 5 years	1.5*** (1.4 - 1.6)	2.4*** (2.1 – 2.6)
	Yes, for around 1-5 years	1.3*** (1.1 - 1.4)	1.5*** (1.3 – 1.7)
	Yes, for less than a year	1.1 (1.0 - 1.1)	1.1 (1.0 – 1.4)
Music noise exposure	No exposure	-	-
	Yes, for more than 5 years	1.1* (1.0-1.2)	1.2* (1.0 – 1.4)
	Yes, for around 1-5 years	1.0 (1.0 – 1.1)	1.2 (1.0 – 1.4)
	Yes, for less than a year	1.0 (0.9 -1.1)	1.4*** (1.2 – 1.7)

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

† Low socioeconomic status was defined as a Townsend deprivation index score lower than 1 standard deviation (SD) below the mean with reference to the general population of 40 to 69 year-olds; i.e. the most deprived 15% of the population.

DISCUSSION

Overall 10.7% of adults had a hearing impairment based on speech recognition in noise measured with the DTT. This impairment may be expected to impact on both home and work life. Prevalence increased with age particularly after the mid-50s, consistent with earlier studies (Plomp and Mimpen 1979; Smits et al. 2006; R. H. Wilson and Strouse 2002). The proportion of adults who reported tinnitus (16.9%) was comparable to a previous estimate which used a somewhat similar measure (15.1% of those aged 41 to 70 years; Davis 1995). Prevalence of tinnitus also increased with age, although the proportional increase in tinnitus was smaller than for hearing impairment.

In the present study and in numerous previous ones, increasing age was strongly associated with hearing loss, although recent observations suggest that hearing loss may be delayed and/or the severity of hearing loss with age may be moderated (Hoffman et al. 2012; Zhan et al. 2009). Alterations in environmental, lifestyle or other modifiable risks may explain a lower prevalence of hearing loss in younger birth cohorts (Zhan et al. 2011). Given the substantial burden of hearing loss with aging, the possibility of preventing or postponing hearing loss is extremely appealing.

The association between socioeconomic status and hearing has been observed in several studies in addition to the present one (Davis 1989; Sixt et al. 1997). Low socioeconomic status is associated with a range of modifiable lifestyle factors such as smoking, poor diet, insufficient exercise and excessive alcohol intake (Poortinga 2007). All of these factors have been independently associated with higher risk of hearing loss (Cruickshanks et al. 2010), and this may explain the association of low socioeconomic status with hearing loss. Noise exposure is a particular risk for hearing loss, and low socioeconomic status is also associated with occupations involving high levels of noise exposure (Lutman et al. 1994; Lutman et al. 1991). Interestingly, in a study by Davis and colleagues (Davis et al. 2008), after controlling for occupation-related noise exposure, smoking and drinking, the effect of current socioeconomic status on hearing still accounted for up to 64% of variance in hearing thresholds. Further, socioeconomic status during childhood accounted for an even higher proportion. The authors concluded that adult susceptibility to hearing impairment is likely to be determined by socioeconomic status-mediated experiences in childhood. Early childhood and pre-natal experiences have been associated with a range of adult health outcomes, particularly cardio-vascular ones (Barker 2004). Several studies also suggest an association between early childhood experiences (such as birth weight, weight gain and parental smoking) with risk of adult hearing loss (Barrenäs et al. 2005; Power et al. 2007; Sayer et al. 1998). Understanding and moderating the risk associated with low socioeconomic status and adult hearing loss may involve attention to the experiences of childhood.

In the present study, work-related noise exposure was associated with poor hearing, in line with previous research (Cruickshanks et al. 2010). Music-related noise exposure was inconsistently associated with poor hearing; exposure over 5 years or less than 1 year's duration were associated with poor hearing, but exposure between 1 to 5 years was not. If this is a reliable finding, one possible explanation may be that respondents reporting exposure of less than 1 year's duration had few, but highly damaging exposures over a short period (for example, one or two very loud rock concerts). Reliable measurement of music-related noise exposure is a challenge, although these data suggest that music-related exposure poses a risk to hearing similar to established risks for occupational noise.

Male sex was associated with slightly reduced risk of 'insufficient' category of hearing difficulties, with no significant association between sex and the 'poor' category of hearing difficulties. This was unexpected. Previous studies indicated that males are at increased risk of hearing impairment (Agrawal et al. 2008; Cruickshanks et al. 1998; Gopinath, Rochtchina, et al. 2009), although in the UK National Study of Hearing, males had only slightly increased odds of mild to moderate hearing impairment, and sex was not significantly associated with severe hearing impairment (Davis 1989). The present study included participants up to the age of 69 years only. However, it is unlikely that the exclusion of older adults may account for the lack of more substantial sex differences in hearing because in previous studies, as these are already apparent by middle age. These contradictory findings might perhaps be due to differences in un-modelled confounding factors associated with male sex in the different populations across studies. That male sex is not a consistent risk factor might suggest that the excess risks to hearing associated with male sex are modifiable (Cruickshanks et al. 2012). Evidence for the modifiability of excess risk associated with male sex include the observation that in the US Health Aging and Body Composition Study, sex differences disappeared after multivariable adjustment which included lifestyle factors (such as smoking and work-related noise exposure) (Helzner et al. 2005). There are also reports of reduced sex differences in hearing loss in younger age cohorts (in the US National Health and Nutrition Examination Survey; Hoffman et al. 2012, and in studies of successive generations of participants in the Beaver Dam studies; Zhan et al. 2009). Previous studies that utilized older age cohorts may therefore have over-estimated the magnitude of sex differences in hearing, due to cohort-specific experiences of males (for example, noise exposure associated with military service in the Second World War and employment in 'traditional' manufacturing and farming industries with high levels of work-related noise exposure). Alternatively, the lack of sex differences in the present study may be due to a particular characteristic of the speech-in-noise measure. The high redundancy of the speech signal may mean that, as a test of speech recognition, the DTT is not sensitive to mild levels of hearing loss because recognition remains unaffected. This may result in men with typically mild losses not being differentiated from women with typically normal hearing. However, this does not explain why there remains no excess risk for male sex for more severe levels of hearing impairment. For further examination of male-female performance differences on the DTT, see Moore et al. (submitted).

Non-White ethnicity was associated with hearing impairment. Examination of risks associated with ethnic subgroups suggested that this association is driven by ethnic subgroups that are at very high risk for hearing difficulties; Bangladeshi, Black African, Black Other and Pakistani in particular. This was a surprising result, as previous research in the US suggested that non-White ethnicity is associated with reduced risk of hearing loss (Agrawal et al. 2008). This was suspected to be due to the protective effects of melanin against hearing loss in the cochlea (Barrenäs et al. 1991). The finding of higher risk for hearing loss in the present study does accord with findings of poorer general health within ethnic minorities in the UK, however (Department of Health 2001). The particular ethnic minorities associated with the poorest general health indices tended to be the same as those in the present study associated with poor hearing. Suggested reasons for the general health inequality of ethnic minorities centre on culture and lifestyle, socioeconomic factors, reduced uptake of services and biological susceptibility (Smith et al. 2000). In the case of hearing, it may be that in the UK, other risk factors outweigh the biological resilience of non-

White ethnicity. Elucidation of the reasons for the disproportionate risk of hearing impairment associated with ethnic subgroups would be a first step towards redressing this particular health inequality.

In the current study, 2.0% of 40 to 69 year-olds were regular hearing aid users. Hearing aid ownership among 41 to 70 year-olds in the early 1980s was estimated at 2.8% (Davis 1995). This represented a significant underutilization; 9.4% of 41 to 70 year-olds had a hearing loss severe enough to benefit from a hearing aid (better ear average ≥35 dB HL over 0.5, 1, 2, and 4 kHz). It is striking that despite significant advances in hearing aid technology and improvements in provision by the National Health Service, hearing aids remain significantly underutilized. Hearing loss is responsible for a substantial burden on society (Mathers and Loncar 2006), impacting on emotional, social and physical well-being (Arlinger 2003; Chia et al. 2007; Dalton et al. 2003; Gopinath, Wang, et al. 2009; Mulrow, Aguilar, Endicott, Velez, et al. 1990; Strawbridge et al. 2000). Hearing aids ameliorate these adverse outcomes (Appollonio et al. 1996; Chisolm et al. 2007; Kochkin et al. 2000; Mulrow, Aguilar, Endicott, Tuley, et al. 1990) and are currently the primary treatment for hearing loss. Continued underutilization of hearing aids is therefore a major public health problem. Both uptake and use of hearing aids is problematic; only around 10-30% of those with hearing loss obtain hearing aids and up to a quarter of hearing aid owners never use them (Chia et al. 2007; Davis 1989; Hartley et al. 2010; Popelka et al. 1998).

There is a large body of research into factors underlying poor hearing aid uptake and use (see McCormack and Fortnum 2013 and Vestergaard Knudsen et al. 2010 for reviews). Some studies have suggested that cost may be a barrier to hearing aid uptake (Chien et al. 2012), although this is unlikely to be a significant barrier in the UK where hearing aids are provided in a socialised health care setting where they are free at point of delivery. In the present study, for those with 'poor' speech recognition, hearing aid users were from less deprived areas than nonusers on average. As cost is not likely to be a strong factor, perhaps another factor associated with deprivation such as awareness of options for hearing rehabilitation may be an explanation. Additional factors that have been researched include motivation, expectation, attitude to hearing aids, hearing sensitivity, age, gender and the effect of counselling (McCormack and Fortnum 2013; Vestergaard Knudsen et al. 2010. The evidence for the importance of most of these factors is mixed. One reason may be that while some factors are associated with one aspect of obtaining and using hearing aids, they may not be associated with others. For example, external motivation is associated with initial help-seeking and uptake, but not with continued use and satisfaction. Self-recognition of hearing problems is the factor most consistently related with both hearing aid uptake and use (Vestergaard Knudsen et al. 2010), and self-reported disability tends to be a more reliable predictor of hearing aid use than audiometric threshold. However, self-report of significant hearing difficulties was common in the UK National Study of Hearing (Davis 1989), so this does not support low levels of self-identification of hearing difficulties as underpinning low hearing aid uptake and use generally. McCormack and Fortnum (2013) report insufficient hearing aid value (i.e. the hearing aid providing limited benefit) and uncomfortable fit as being most commonly reported reasons for low hearing aid use.

The association of specific factors with particular steps in the process of acquiring, acclimatizing to and using hearing aids suggests that strategies aimed at improving uptake should focus on the desired outcome (i.e. satisfaction and use), while being prepared to address likely barriers at each stage of the process (Vestergaard Knudsen et al. 2010). For example, Davis and colleagues tested the acceptability of adult hearing screening in those aged 55-74 years (Davis et al. 2007). Only around a quarter of those identified with hearing loss used hearing aids at the time of screening. Of those who did not use hearing aids but had significant hearing loss, hearing aids were accepted by ~70%. However, long-term use was generally low. This suggests that the model of hearing screening in this study was effective in boosting hearing aid uptake, but less good at ensuring continued use. Encouragingly, there is evidence that appropriate strategies may be employed to ensure high use and satisfaction in the long term. Bertoli et al (2009) reported relatively high rates of long-term hearing aid use and satisfaction in Switzerland (where only 3% of hearing aid owners were non-users). Bertoli et al ascribed this to the Swiss model of hearing aid provision, in which candidacy is based on the degree of social and emotional handicap due to hearing loss in addition to audiometric thresholds. The dispensing process also allows fitting and trial of different types of devices and provides on-going counselling after fitting. State health insurance covers most or all of the cost. A comprehensive strategy to boost initial help-seeking and uptake as well as long-term use and satisfaction may need to address particular barriers at each stage of the process of hearing aid adoption. Models of this process have been proposed (e.g. Kochkin 2007), although they remain to be empirically investigated. Clinical fitting and counselling are under-researched but potentially critical aspects of the adoption process (Vestergaard Knudsen et al. 2010), and this may be particularly relevant given recent moves in England to open hearing aid provision to commercial competition (the 'any qualified provider' scheme). In addition to the above suggestions, hearing aid use and uptake may be facilitated by i) making hearing care a 'lifestyle choice'. Currently in the UK, one must obtain a referral from a GP to attend a hospital-based audiology clinic, and this may contribute to the stigmatisation of hearing loss by an association with illness and infirmity. Removing the need for GP consultation and increasing accessibility of good quality audiology services may reduce the stigma associated with hearing aid use. (ii) Undertaking good quality trials of adult hearing screening and early hearing intervention that are based on models of hearing aid uptake and which include tests of the effectiveness of methods of improving hearing aid uptake and long-term use. Empirical data could then be used to address barriers to uptake and use. iii) Improving hearing aid technology to the level that it will significantly improve speech understanding in noise. If hearing aids provided near- or even super-normal listening performance, this may both remove the stigma associated with hearing aids and do away with dissatisfaction with performance, a major reason for non-use (Dillon 2013).

The most significant limitation of the current study is that, despite the large number of participants, the low response rate of 5.47% may have introduced unknown biases into prevalence estimates that may not be accounted for by the statistical weighting procedures used in this study. Representatives of the UK Biobank argued that despite the low response rate, the size and coverage of the sample allows generalizable associations between relevant risk factors and health outcomes (Allen et al. 2012). The size and coverage of the UK Biobank sample may also give confidence in the reliability of prevalence estimates reported here. Further, because the recruitment was for a general health study rather than a hearing study, it is unlikely that knowledge or concerns about hearing were important factors in the decision to participate. In the present study, recruitment bias was in favour of ethnically White, female and more affluent participants – all of which are associated with lower levels of hearing problems. One might expect that any residual or unknown bias might also result in under-estimates of the prevalence of hearing problems. The prevalence statistics reported in the present paper should therefore be regarded as being conservative estimates. Finally, the present paper was primarily concerned with examining patterns of association with hearing impairment and key demographic variables. Future work with this data set will involve detailed analysis of associations between life-style and health-related risk and protective factors and hearing impairment.

CONCLUSIONS

This is the first study to describe the prevalence of difficulties understanding speech in background noise in a large inclusive sample of UK adults aged 40 to 69 years. Older age, low socioeconomic background and ethnic minority backgrounds were associated with hearing difficulties, as was work- and music-related noise exposure. Hearing aids remain significantly underutilised despite improvements in technology and provision, and a high proportion of those who would benefit from treatment may not receive effective intervention. Possible reasons for low hearing aid uptake and use may include lack of recognition of difficulties, lack of awareness of treatment options, stigma associated with hearing aid use, insufficient hearing aid value (i.e. the hearing aid providing limited benefit) and uncomfortable fit.

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Supplemental tables

Table 1. Prevalence (%) of hearing disability in the better ear by age group.

	Digit Triplet Test (Better ear)					
Age group	Normal		Insufficient		Poor	
	Prevalence	95% CI	Prevalence	95% CI	Prevalence	95% CI
40-44	94.28	93.82-94.75	4.98	4.54-5.41	0.74	0.57-0.92
45-49	93.40	92.96-93.85	5.72	5.31-6.13	0.88	0.69-1.07
50-54	92.22	91.79-92.64	6.91	6.51-7.31	0.87	0.72-1.03
55-59	89.59	89.13-90.04	9.15	8.72-9.58	1.26	1.09-1.43
60-64	84.52	84.03-85.00	13.24	12.79-13.69	2.24	2.01-2.47
65-69	77.95	77.32-78.58	18.58	17.99-19.17	3.47	3.19-3.75
Overall	89.28	89.09-89.48	9.23	9.05-9.42	1.48	1.40-1.56

Table 2. Prevalence (%) of self-reported tinnitus and hearing aid use by age group.

	Hearing aid user		Tinnitus	
Age group	Prevalence	95% CI	Prevalence	95% CI
40-44	0.69	0.51 - 0.88	11.78	11.13 – 12.44
45-49	0.90	0.71 - 1.08	13.72	13.12 - 14.33
50-54	1.18	1.00 - 1.35	16.40	15.82 – 16.97
55-59	1.90	1.69 - 2.11	18.61	18.06 -19.16
60-64	3.13	2.90 - 3.36	20.99	20.49 – 21.50
65-69	5.40	5.07 - 5.73	23.52	22.92 – 24.12
Overall	1.97	1.88 - 2.05	16.88	16.64 – 17.12

Table 3. The odds ratios from the logistic models fitted to the prevalence of better-ear hearing disability (insufficient or poor) based on Digit Triplet Test performance for ethnic sub-groups.

Ethnic category	Odds Ratio	95% CI			n
White British	-				136581
Bangladeshi	7.1***	4.2	-	12.0	68
Black African	7.0***	6.3	-	7.9	1538
Pakistani	5.4***	4.5	-	6.4	633
Black other	5.3***	2.9	-	9.6	54
Asian other	5.0***	4.3	-	5.8	884
Other ethnicity	4.5***	4.0	-	5.0	1903
Indian	4.0***	3.7	-	4.4	3251
Don't know	3.5***	2.0	-	6.4	60
Chinese	3.2***	2.6	-	3.9	589
Black Caribbean	2.7***	2.4	-	3.0	2498
White other	2.3***	2.1	-	2.4	6027
Mixed other	1.7***	1.3	-	2.3	415
Prefer not to say	1.7***	1.3	-	2.1	560
Mixed Black African	1.6*	1.0	-	2.7	154
Mixed Asian	1.4*	1.0	-	2.0	353
White Irish	1.4***	1.3	-	1.5	4656
Mixed Caribbean	1.4	0.9	-	2.0	269

*** p < 0.001
** p < 0.01
* p < 0.05