Title page

Hearing impairment and incident physician diagnosed dementia: findings from the English Longitudinal Study of Ageing.

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Abstract

Purpose: To investigate if hearing-loss is associated with dementia in a representative sample of adults aged over 50 years in England.

Methods: We analysed data from the English Longitudinal Study of Ageing. Cross-sectional associations between both self-reported (n=7,865) and objective hearing measures (n=6,902) and dementia were examined using multinomial-logistic regression. Additionally, we modelled the longitudinal association between self-reported hearing reported at wave 2 (2004) and cumulative-physician-diagnosed dementia up to wave 7 (2015) using Cox (proportional-hazards) regression.

Results: After adjustment for potential confounders, in cross-sectional analysis, participants who had either self-reported and objective moderate- and poor-hearing were more likely to have a dementia diagnosis compared with individuals who had normal-hearing (self-reported:OR:1.6, 95% CI:1.1-2.4 and 2.6, 95% CI:1.7-3.9, objective:OR:1.6, 95% CI:1.0-2.8 and 4.4, 95% CI:1.9-9.9 respectively). Longitudinally, the hazard of developing dementia was 1.39 (95% CI:1.0-1.9) and 1.57 (95% CI:1.1-2.0) higher in individuals who reported moderate- and poor-hearing respectively.

Conclusion: Older adults with hearing-loss are at higher risk of dementia than those with normal-hearing. Our findings are consistent with the rationale that correction of hearing-loss could help delay the onset of dementia, or that hearing-loss itself could serve as a risk indicator for cognitive decline. The public health implications are considerable as over 3-million UK-adults aged over 50 years currently have hearing-loss.

Keywords: Hearing loss-Dementia-Aging

Introduction

The global estimate of individuals living with dementia was 46.8 million in 2015, with around 800,000 residing in the United Kingdom (UK) and 676,000 living in England (1). The estimated economic cost of dementia in the UK is approximately £23 billion per annum, which is predicted to increase threefold by 2040 (1). Additionally, the overwhelming social impact on individuals with dementia and their families has contributed to dementia becoming a public health priority (2–4).

A number of modifiable risk factors for dementia have been identified including social interactions, physical activity and type 2 diabetes (5). There is also evidence that hearing loss could be a potential risk factor (6–8). As with dementia, the risk of hearing loss increases with age. Over 3 million adults aged over 50 years and older in the UK were estimated to have hearing loss in 2011, despite the fact that reporting or diagnosing these conditions is challenging (9). The Health Survey for England found that only 26% of individuals with moderate or severe objective hearing-loss had previously had a formal hearing test, and that 60% of individuals over the age of 55 years who could have improved hearing with a hearing aid, had never used one (10).

Previous longitudinal epidemiological studies conducted in the USA and Wales have provided evidence for hearing loss being independently associated with dementia (6-7,11-12). Because these studies, however, have either focused on adults over the age of 70 years (11), only included men in their analysis (6), not included the use of hearing aids as a confounding factor (6,12), had a relatively small sample size (7), or had no objective hearing measure (12). We therefore aimed to investigate if both subjective and objective measures of hearing-loss were independently associated with dementia using cross-sectional and longitudinal analysis in a representative sample of adults aged over 50 years and older in England.

Methods

Study Population

We used data from a cohort of men and women, aged over 50 years and older, from the English Longitudinal Study of Ageing (ELSA) (13). ELSA is a panel study which was set up in 2002 as a parallel study design to the Health and Retirement Study in the USA (13). Face to face interviews and tests have been carried out at two-year intervals (waves 1-7) to obtain information regarding socio-economic circumstances, physical and mental health and cognitive function in adults as they progress into their retirement.

Outcome measures

To define dementia, we used a three way assessment protocol as described previously by Khondoker et al (14). The primary criterion was a doctor diagnosis of dementia as reported by participants or informants in waves 1-7 (14). Secondly, carers completed an adapted short form Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) for individuals who were not able to respond themselves (14). The carers were asked to compare the present functional performance of the participant with 2 years before, instead of the 10 year interval in the standard measure (15). Consistent with previous work, we defined those with a cut-off of 3.5 with dementia as the IQCODE has both a high specificity (0.84) and sensitivity (0.82) at this cut-off (14,16). Finally, we also defined dementia as such if individuals were receiving prescriptions for anticholinesterase inhibitors, NMDA receptor antagonists or other relevant medication (galantamine, rivastigmine, memantine, donepezil, or tacrine (17,18). Many people with dementia do not have a formal diagnosis (19). These analyses should therefore be regarded as a measure of physician-diagnosed dementia and not complete incident dementia.

Exposure measures

Self-reported hearing

Participants were asked to rate their hearing from 1-5 (1=excellent, 5=poor) in waves 1-7 (20). If an individual had a hearing aid, they were asked to rate their hearing based on when they were using their hearing aid (20). We used self-reported hearing at wave 2 (longitudinal analysis) and wave 7 (cross-sectional analysis). There were originally 5 self-reported hearing groups (excellent, very good, good, fair and poor hearing) and we combined fair and poor, and excellent and very good, to create three categories for analysis (normal, moderate difficulties and poor hearing) (10,20).

Objective hearing test

A hearing screening device, the HearCheck Screener™ manufactured by Siemens, was used to obtain objective hearing scores for participants at wave 7. This device has been validated and previously used in the Health Survey for England in 2014 (10). Hearing loss was measured using the Decibel Hearing Level (dbHL) which is the increase of decibels in order for a person to hear a sound at a certain frequency for at least 50% of the time (10). The test involves the presentation of six increasing volumes of sounds at different frequency levels and participants indicate which tones they can hear (10,21). Both ears were tested in a

quiet environment and hearing aids were removed before the test (10). The HearCheck test was not carried out with people who had either a cochlear implant or ear infection (10). Individuals were classified with hearing loss if they could only hear mid-frequency sounds at dbHL of 20 and high frequency sounds at 35 dbHL. Responses were originally categorised into 4 groups (good hearing, moderate loss, severe loss and profound loss). For the current study, the lower two (severe and profound loss) were combined, resulting in three groups (normal, moderate difficulties and poor hearing)

Other independent variables

We classified age into four categories (50-59, 60-69, 60-79, and 80 years of age and over). Economic status was defined using quintiles of non-pension wealth (1=low, 5=high) as calculated by Institute for Fiscal Studies (13). We divided participants' highest educational qualifications into three groups; no formal qualification, intermediate and higher education. Ethnicity was divided into White and non-White. Smoking was categorised into three groups; never smoked, ex-smoker and current smoker. The following variables were binary: use of hearing aid, diabetes, hypertension, and history of stroke (22).

Statistical analysis

The socio-demographic and clinical risk profiles were summarised by self-reported (waves 2 and 7) and objective hearing categories (wave 7). Chi-square tests were performed to ascertain if there were significant differences in the distribution of socio-demographic and clinical categories between hearing groups. For the cross-sectional analyses of self-reported and objective hearing impairments, odds ratios and 95% confidence intervals of diagnosed dementia at wave 7 were calculated, with normal hearing as the reference group. Separate analyses were carried out on self-reported and objective hearing impairment. We decided *a priori* on the basis of the existing literature that age, gender, ethnicity, wealth, education and hearing aid use were possible confounders (7,11,23). Additionally, we adjusted for the following cardiovascular risk factors; smoking status, diabetes, hypertension and stroke. We used a forward stepwise approach and performed likelihood ratio tests and Akaike information criterion to select the model of best fit (24,25).

We used Cox proportional hazards regression to model the association between self-reported hearing (wave 2) and cumulative diagnosed dementia (wave 3 to 7 from July 2005 to June 2015). We applied inverse probability weighting to control for non-response bias (22,26). Individuals who had been diagnosed with dementia in wave 2 were excluded. The

time to dementia was measured in years from the beginning of wave 2. Date of dementia diagnosis was used if known; if not known, we used the midpoint date between waves of data collection. We censored individuals who were known to have died or left the study. Mortality data for ELSA were available up to February 2013. If an individual dropped out of the study between waves, we used the last interview date for the censor date. We used the Schoenfeld residual test to test the proportional-hazards assumption of the models (27).

Sensitivity analysis

In order to examine if the self-report and objective measures had independent effects on risk of dementia, we included both measures in one model. Additionally, we excluded individuals who wore hearing aids in the sensitivity analysis because the self-report measure was based on hearing aid use whereas the objective measure was not.
All data were analysed using STATA Statistical Software (version 14) (Stata Corp LP, College Station, Texas).

Results

Cross-sectional analyses

In total, 95% (7,865/8,253) of the participants in wave 7 rated their hearing, with a fifth (23.1%, n=1,771) reporting poor and a third (34.7%, n=2,669) moderate hearing difficulties. Self-reported hearing difficulties were associated with greater age, male gender, lower wealth and education, hearing aid use, a history of stroke and a co-morbidity of either diabetes or hypertension (**Error! Reference source not found.**).

Insert Table 1

Some 84% (6,902/8,253) of the participants had a HearCheck test in wave 7 (Table 2). Compared with the self-reported hearing categories, fewer individuals were categorised into the poor objective hearing group (5.2% vs 23.1%), but a similar proportion (33.5% vs 34.7%) were in the moderate hearing group. Objective hearing difficulties were associated with a similar set of demographic and clinical factors as in the case of self-reported hearing (Table 2).

Insert Table 2

Dementia was associated with worse self-reported and objective hearing (Table 3). After adjustment for confounders, participants in the moderate and poor self-reported hearing groups were 1.6 (95% CI: 1.05-2.37) and 2.6 (95% CI: 1.74-3.93) times more likely to have a dementia diagnosis compared with individuals who had normal hearing. Similarly, those in

the moderate and poor hearing groups for the HearCheck test were 1.6 (95% CI: 0.93-2.84) and 4.4 (95% CI: 1.94-9.91) times more likely to have a diagnosis of dementia. Increased age, hypertension and previous stroke were risk factors for dementia diagnosis, whereas greater wealth, intermediate and higher education and using a hearing aid seemed to have protective effects. (Table 3)

Insert Table 3

Longitudinal analyses

Of the 8,780 core members in wave 2, a fifth (22%, n=1,933) reported poor hearing and a third (31.6%, n=2,774) moderate hearing difficulties. Self-reported hearing difficulties was associated with greater age, male-gender, lower wealth and education, hearing aid use, a co-morbidity of hypertension and a history of a stroke (Table 4).

Insert Table 4

There were 269 incident cases of diagnosed dementia between wave 2 and the end of wave 7 (June 2015). During the mean follow-up period of 11 years, individuals in the moderate and poor hearing groups were at increased risk of developing dementia compared with the normal hearing group, with hazard ratios of 1.39 (95% CI: 1.01-1.92) and 1.57 (1.12-2.02) respectively. Both increasing age and the presence of diabetes also emerged as significant independent risk factors. (Table 5)

Insert table 5

Sensitivity analysis

There was a fair agreement between the objective and self-reported hearing measures (κ=0.262, 95% CI 0.257-0.269). The association between objective hearing and physician diagnosed dementia remained significant for the poor hearing group when including self-reported hearing in the model. In contrast the association between self-reported hearing difficulties weakened and became non-insignificant. (**Supplementary Table 1**). The associations did not change when we excluded individuals who used a hearing aid.

Discussion

Our study supports the evidence that both moderate and poor objective and self-reported hearing are both associated with physician-diagnosed dementia in a representative sample of English older adults (mean age 70 ±9.5 years) cross-sectionally. Longitudinal analysis over an 11 year period showed that the incidence was 39% and 57% higher in

individuals with moderate and poor self-reported hearing compared with individuals with normal hearing after adjusting for multiple covariates.

Comparison with other studies

The Health and Retirement Study (HRS) which has a similar profile to ELSA also examined self-reported hearing and dementia cross-sectionally and found that 44% of participants who reported fair to poor hearing had probable dementia (28). The HRS analysis focused on the last two years of life rather than a more prolonged period, and their definition of probable dementia was based on an algorithmic analysis of cognitive function rather than physician diagnoses (28,29).

Our findings build on previous longitudinal studies conducted in the USA and Wales, which found increased hazard ratios of developing dementia in individuals with moderate and severe hearing loss (6-7,12,22). Lin *et al* prospectively analysed 639 older adults (>65 years) from the Baltimore Longitudinal Study of Aging over 11.9 years (7). They found that not only was objective hearing loss independently associated with incident dementia, but that risk also increased log-linearly with the severity of hearing loss (mild hearing loss HR: 1.89, 95% CI: 1.00-3.58, moderate hearing loss HR: 3.00, 95% CI:1.43-6.30 and severe hearing loss, HR: 4.94 , 95% CI:1.09-22.40) (7). The confidence interval for the severe hearing loss category was large, probably because of the small number of cases in that category (n=6). Deal *et al* tracked older adults (n=1,889, 70-79 years) from the Health, Ageing and Body Composition study for 9 years and the results suggested that individuals with moderate/severe objective hearing impairment had a higher rate of developing dementia than those whose hearing was normal (HR: 1.55, 95% CI: 1.10-2.19). Older men from the Caerphilly Study in Wales (n=1,057) were followed for 17 years and results showed an association between objective auditory threshold and dementia (OR: 2.67, 95% CI: 1.38-5.18). Unlike the other previous studies, they only included males in their analysis (6). Finally, the Cache County Study on Memory, Health, and Aging in the USA (n=4,545) followed older adults (> 65 years) for 13 years and also found that hearing loss was an independent risk factor for developing dementia (12). However, the identification of hearing loss was questionable since it was based on interviewer ratings that were not a mandatory part of the assessment protocol

The previous studies of objective hearing loss used a Pure Tone Audiometry (PTA) test, whereas we used self-reported hearing measures in our longitudinal analyses (6-7,11). We did however find a significant positive association between the self-reported and objective HearCheck test measure in wave 7. Additionally PTA and HearCheck tests are

comparable with similar sensitivities (89% compared with 94%) and specificities (87% and 82%) (30). However, when self-reported and objective measures were entered into the same models competitively, associations between objective hearing loss and dementia were more robust.

Strengths and limitations

A unique strength of using ELSA is that it involves a large national sample of resident English men and women aged over 50 years and older. The dataset includes repeated measures of chronic conditions and therefore we were able to capture cumulative physician-diagnosed dementia cases and analyse time to dementia diagnosis. The dataset also had measures of both self-report and objective hearing measures at wave 7 which we were able to compare in the presence of potential other covariate measures.

There are also several limitations to these analyses. Firstly, in comparison with population estimates, there were fewer dementia cases in this study (31,32). This is primarily due to the identification of dementia on the basis of physician diagnoses, since it is thought that only around half of people living with dementia, have had a formal diagnosis (33). We therefore also included dementia cases based on IQCODE above 3.5 (15,29,34). Attrition bias is also relevant (27), though we allowed for this by using probability weights for non-responders (22,26).

Secondly, only self-reported hearing measures were available in ELSA for longitudinal analysis, where objective measures would be desirable. The comparison between subjective and objective measures of hearing loss was also challenging, as only the self-reported hearing was based on hearing aid use. However we found that the two measures had a significant positive association. Additionally, we included the use of a hearing aid as a confounder in our analysis.

Possible causal mechanisms

There are three possible mechanisms supporting hearing-loss as a cause of dementia; increased cognitive burden, changes in brain structure and function and increased social isolation. Firstly, increased cognitive burden or the *"effortfulness hypothesis"* was demonstrated by both McCoy *et al* and Tun *et al* in older adults (66-81 years) (34-35). Although the numbers of older adults with hearing impairment were relatively small (n=12 and n=24), their findings suggested that older individuals with hearing-loss had both poorer recall and reduced secondary task performance (35,36). Sound signals become more

distorted in individuals with hearing-loss, especially in the high frequency range, leading to an increased effort in perceiving sound (35,36). The extra cognitive load on those with hearing-loss could be at the expense of encoding and processing speech into memory (35,36).

Secondly, decreased sensory input and processing may lead to changes in brain structure and function (6–8). Evidence from cross-sectional studies suggests that hearing impairment is associated with a reduction in the cortical volume of the primary auditory cortex in the temporal lobe and variable white matter fibres (37). The evidence was strengthened by neuroimaging data from participants enrolled in the neuroimaging sub-study of the Baltimore Longitudinal Study for Ageing, showing that hearing impairment in older adults was associated with an increased rate of decline of the whole brain volume, particularly in the right temporal lobe which is responsible for processing of speech (38). The majority of individuals (n=126, 58-86 years old) with hearing impairment were in the mild hearing category.

Finally, decreased interaction and intellectual stimulation has been associated with dementia in prospective studies (38-39). Social gatherings may become more challenging for individuals with hearing impairment as they use more cognitive resources to process speech which may increase withdrawal from social activities. Wang *et al* examined Swedish older adults prospectively (n=776, >75 years old), and the results suggested that individuals who participated less in social, mental or physical activity had a higher risk of developing dementia (39). Furthermore, cross-sectional and prospective studies have shown an independent association between hearing loss and social isolation (41). Social isolation may therefore be a mediator on the causal pathway of dementia through which hearing impairment might act (41).

Clinical implications

Is hearing-loss an indicator of early stages of dementia and a preventable risk factor, or is dementia an indicator of hearing-loss? There is an opposing argument of the direction of association between hearing and dementia, however either pathway could have major public health implications.

In the UK, approximately four million people with hearing impairment delay seeking medical help (42). Unlike eye tests, individuals seem to be more reluctant to have hearing tests possibly due to the stigma associated with hearing-loss, which could be reduced by a screening programme (42). One study of hearing screening for older adults showed a positive benefit to cost ratio (43). Consequently, the Department of Health have developed

an action plan on hearing which includes awareness, early detection and treatment for hearing loss (44).

Hearing aids could help with the treatment of hearing loss and possibly decrease social isolation, although they need to be acceptable and effective. The quality of hearing aids seems to have improved and 70% of older adults reported being fairly satisfied with their hearing aid in the Health Survey for England (10). Individuals who were tested at a younger age, benefitted more from their hearing aid as they had more time to adapt (42). Together with detection and treatment, hearing loss could also be an early indicator for testing for cognitive decline and dementia.

Conclusion

In conclusion, our study supports the hypothesis that older adults with hearing-loss have a higher rate of developing dementia. We also found that hearing aid use had a protective effect cross-sectionally. Our findings suggest that treatment of hearing loss with hearing aids could help delay the onset of dementia. The public health implications are substantial as over 3 million UK adults aged over 50 years and older currently have hearing-loss. Further studies are still needed to confirm the possible biological and social mechanisms involved and a large prospective study to examine treatment of hearing loss.

Ethical approval

Ethical approval for all the ELSA waves was granted from the National Research and Ethics Committee (http://www.nres.npsa.nhs.uk/).

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Table 1: Descriptive statistics of dementia and self-reported hearing test (Wave 7)

			Self-reported hearing						
	Total cohort from wave 7 (n=7,685)		**Poor** (n=1,771, 23.1%)		**Moderate difficulties** (n=2,669, 34.7%)		**Normal** (n=3,242, 42.2%)		**p-value***
Characteristics	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	
Dementia									<0.001
	193	2.5	86	4.9	67	2.5	40	1.2	
Age-groups (years)									<0.001
50-59	937	12.2	131	7.4	287	10.8	519	16.0	
60-69	3,139	40.9	571	32.2	1,054	39.5	1512	46.6	
70-79	2,414	31.4	610	34.4	888	33.3	914	28.2	
80+	1,196	15.5	459	25.9	440	16.5	297	9.2	
Mean age=70 ±9.5									
Gender									<0.001
Females	4,302	55.9	786	43.4	1,479	55.4	2,054	63.4	
Wealth									<0.001
1 low	1,292	16.8	377	21.3	448	16.8	466	14.4	
2	1,384	18.0	368	20.8	479	17.9	535	16.5	
3	1,632	20.8	378	21.3	566	21.2	688	21.2	
4	1,694	22.4	339	19.1	595	22.3	760	23.4	
5 high	1,683	22.0	309	17.5	581	21.8	793	24.5	
Ethnicity									0.52
Non-white	261	3.4	51	2.9	105	3.9	105	3.2	
Education									<0.001
No qualifications	1,838	23.9	557	31.5	654	24.5	626	19.3	
Intermediate	3,100	40.3	658	37.2	1,055	39.5	1,386	42.8	
Higher	2,747	35.8	556	31.4	960	35.9	1,230	37.9	
Hearing aid									<0.001
Yes	1,041	13.6	557	31.4	354	13.3	130	4.1	
Diabetes									<0.001
Yes	1,070	13.9	329	18.6	352	13.2	389	12.0	
Hypertension									<0.001
Yes	3,836	49.9	1,006	56.8	1,362	51.1	1,006	56.8	
Stroke									<0.001
Yes	457	5.9	157	8.9	169	6.3	131	4.1	
Smoking status									0.17
Never smoked	6,773	88.1	1,566	88.4	2,364	88.6	2,840	87.6	
Ex-smoker	102	1.33	29	1.7	35	1.3	38	1.2	
Current	810	10.54	176	9.9	270	10.1	364	11.2	

Table 2: Descriptive statistics of dementia and objective hearing test (Wave 7)

	Total cohort from wave 7 (n= 6,902)		Objective hearing screening test						p-value
			Poor (n=359, 5.2%)		Moderate difficulties (n=2,314, 33.5%)		Normal (n=4,229, 61.3%)		
	N	%	N	%	N	%	N	%	
Dementia									<0.001
	76	1.1	16	4.4	34	1.5	26	0.6	
Age groups (years)									0.001
50-59	865	12.5	11	3.1	145	6.3	709	16.8	
60-69	2,865	41.5	38	10.6	690	29.8	2,137	50.5	
70-79	2,191	31.7	122	34.0	907	39.2	1,162	27.5	
80+	981	14.2	188	52.4	572	24.7	221	5.2	
Gender									<0.001
Females	3,880	56.2	184	51.3	1,198	52.0	2,498	59.1	
Wealth									0.001
1	1,128	16.3	109	30.4	447	19.3	572	13.5	
2	1,218	17.7	69	19.2	440	19.0	709	16.8	
3	1,450	21.0	86	24.0	465	20.1	899	21.3	
4	1,555	22.5	58	16.2	536	23.2	961	22.7	
5	1,551	22.5	37	10.3	426	18.4	1,088	25.7	
Ethnicity									0.183
Non-white	218	3.2	4	1.1	79	3.4	139	3.3	
Education									0.001
No qualifications	1,574	22.8	160	44.6	683	29.5	731	17.3	
Intermediate	2,814	40.77	118	32.9	919	39.7	1,777	42.0	
Higher	2,514	36.42	81	22.6	712	30.8	1,721	40.7	
Hearing aid									<0.001
Yes	896	13.0	260	72.4	536	23.2	100	2.4	
Diabetes									<0.001
Yes	931	13.5	64	17.8	378	16.3	489	11.6	
Hypertension									<0.001
Yes	3,368	48.8	223	62.1	1,270	54.9	1,875	44.3	
Stroke									<0.001
Yes	353	5.1	42	8.9	160	6.3	151	4.1	
Smoking status									0.170
Never smoked	6,097	88.3	325	90.5	2,059	89.0	3,713	87.8	
Ex-smoker	93	1.4	3	0.8	32	1.4	58	1.4	
Current	712	10.3	31	8.6	223	9.6	458	10.8	

Table 3: Unadjusted (U-OR) ad adjusted odds ratios (A-OR) for cross-sectional self-reported hearing and objective hearing test and dementia (Wave 7)

Self-reported hearing	Model 1			Model 2			**Objective hear-test**	Model 1			Model 2		
	U-OR	95% CI	p-value	A-OR	95% CI	p-value		U-OR	95% CI	p-value	A-OR	95% CI	p-value
Normal	1			1			Normal	1			1		
Moderate	2.06	1.39-3.06	<0.001	1.58	1.05-2.37	0.027	Moderate	2.41	1.44-4.03	0.001	1.62	0.93-2.84	0.091
Poor	4.08	2.79-5.97	<0.001	2.62	1.74-3.93	<0.001	Poor	7.54	4.01-14.2	<0.001	4.39	1.94-9.91	<0.001
Age group(years)													
50-59	1			1				1			1		
60-69	1.65	0.57-4.79	0.36	1.70	0.58-4.97	0.330		1.06	0.35-3.22	0.922	1.16	0.38-3.56	0.796
70-79	5.34	1.93-14.8	0.001	4.95	1.77-13.8	0.002		2.69	0.94-7.69	0.066	2.39	0.81-7.07	0.113
80+	24.58	9.03-66.9	0	21.23	7.67-58.7	<0.001		7.02	2.47-19.9	<0.001	4.55	1.49-13.1	0.008
Gender													
Females	1.12	0.84-1.50	0.43	0.93	0.66-1.26	0.657		1.13	0.71-1.79	0.597	1.04	0.64-1.68	0.643
Wealth													
1	1			1				1			1		
2	0.69	0.47-1.02	0.07	0.77	0.51-1.17	0.224		0.37	0.18-0.75	0.06	0.46	0.23-0.96	0.226
3	0.56	0.37-0.83	0.00	0.71	0.46-1.08	0.112		0.51	0.28-0.94	0.029	0.64	0.34-1.20	0.339
4	0.35	0.22-0.54	0.00	0.53	0.32-0.87	0.011		0.32	0.16-0.63	0.001	0.41	0.19-0.85	0.199
5	0.22	0.13-0.38	0.00	0.43	0.24-0.77	0.005		0.21	0.09-0.47	<0.001	0.33	0.14-0.78	0.139
Education													
No qualifications	1			1				1			1		
Intermediate	0.33	0.23-0.46	<0.001	0.54	0.38-0.78	0.001		0.38	0.21-0.66	0.001	0.63	0.35-1.10	0.106
Higher	0.29	0.20-0.42	<0.001	0.71	0.47-1.08	0.114		0.43	0.25-0.73	0.002	0.99	0.53-1.86	0.999
Hearing aid													
Yes	0.65	0.40-1.05	0.08	0.24	0.14-0.39	0.041		0.68	0.42-1.05	0.08	0.24	0.24-0.99	0.046
Hypertension													
Yes	2.59	1.89-3.56	<0.001	1.56	1.11-2.17	0.010		1.71	1.07-2.72	0.024	1.06	0.65-1.72	0.820
Stroke													
Yes	7.38	5.33-10.2	<0.001	4.04	2.83-5.76	<0.001		4.32	2.39-7.79	<0.001	2.48	1.34-4.61	0.004

Table 4. Descriptive statistics of dementia and self-reported hearing (Wave 2)

	Total cohort from wave 2 (n=8,780)		Self-reported hearing						
			Poor (n=1,933, 22.0%)		Moderate difficulties (n=2,774, 31.6%)		Normal (n=4,073, 46.4%)		p-value*
	N	%	N	%	N	%	N	%	
Age groups (years)									
50-59	2,597	29.6	371	19.2	772	27.8	1,454	35.7	<0.0001
60-69	2,874	32.7	537	27.8	941	33.9	1,396	34.3	
70-79	2,188	24.9	599	31.0	694	25.0	895	22.0	
80+	1,121	12.8	426	22.0	367	13.2	328	8.1	
Gender									
Females	4,831	55.0	848	43.9	1,468	52.9	2,515	61.7	<0.0001
Wealth									
1 low	1,583	18.3	445	23.0	475	17.1	663	16.3	<0.0001
2	1,724	19.9	459	23.7	523	18.9	742	18.2	
3	1,741	20.1	372	19.2	557	20.1	812	19.9	
4	1,773	20.5	334	17.3	579	20.9	860	21.1	
5 high	1,840	21.2	303	15.7	605	21.8	932	22.9	
Ethnicity									
Non-white	206	2.4	52	2.7	55	2.0	99	2.4	0.256
Education									
No qualifications	3,487	39.6	912	47.2	1,080	38.9	1,476	36.2	<0.0001
Intermediate	3,219	36.6	647	33.5	997	35.9	1,565	38.4	
Higher	2,100	23.9	371	19.2	693	25.0	1,029	25.3	
Hearing aid									
Yes	561	6.5	385	19.9	143	5.2	41	1.0	<0.0001
Diabetes									
Yes	248	2.8	72	3.7	76	2.7	100	2.5	0.020
Hypertension									
Yes	1,079	12.3	273	14.1	362	13.0	444	10.9	0.001
Stroke									
Yes	142	1.6	55	2.8	43	1.6	44	1.1	<0.0001
Smoking status									
Current smoker	1329	15.1	304	15.7	412	14.9	613	15.1	0.697

Table.5. Hazard ratios of self-reported hearing at wave 2 and cumulative dementia (Waves 3-7)

	No dementia (n=8,382)		Dementia (n=269)		Hazard ratio	95% CI	p-value
Self-reported hearing							
Normal	3,921	46.8	85	32.0	1		
Moderate	2,645	31.6	90	33.1	1.39	1.01-1.92	0.042
Poor	1,816	21.7	94	34.9	1.57	1.12-2.02	0.009
Age							
50-59	2,520	30.1	19	7.3	1		
60-69	2,795	33.4	45	16.7	2.06	1.19-3.66	0.010
70-79	2,062	24.6	101	36.7	6.44	3.86-10.73	<0.001
80+	1,005	12.0	108	39.3	18.29	10.63-31.48	<0.001
Gender							
Males	3,791	45.2	103	37.5	1		
Females	4,591	54.8	172	62.5	1.09	0.84-1.41	0.520
Wealth							
1	1,525	18.2	55	21.5	1		
2	1,650	19.7	69	24.7	1.34	0.97-2.11	0.068
3	1,688	20.2	53	18.9	1.06	0.75-1.71	0.566
4	1,725	20.6	48	18.2	1.08	0.71-1.71	0.664
5	1,794	21.4	44	16.7	1.04	0.67-1.87	0.650
Education							
No qualifications	3,295	39.3	142	52.4	1		
Intermediate	3,082	36.7	79	30.2	0.78	0.56-1.03	0.077
Higher	2,005	23.9	48	17.5	0.79	0.53-1.16	0.223
Hearing aid							
No	7,850	93.7	238	87.3	1		
Yes	532	6.3	31	12.7	0.99	0.61-1.42	0.736
Hypertension							
No	7,354	87.7	228	85.1	1		
Yes	1,028	12.3	41	14.9	1.01	0.68-1.52	0.94
Stroke/s							
No	8,249	98.4	262	98.1	1		
Yes	133	1.6	7	1.1	0.82	0.33-1.57	0.407
Diabetes							
No	8,150	97.3	253	94.18	1		
Yes	230	2.7	16	5.82	2.39	1.35-4.57	0.003