Association between hearing aid use and all-cause and cause-specific dementia: an analysis of the UK Biobank cohort

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Summary

Background Dementia and hearing loss are both highly prevalent conditions among older adults. We aimed to examine the association between hearing aid use and risk of all-cause and cause-specific dementia among middle-aged and older-aged adults, and to explore the roles of mediators and moderators in their association.

Methods We used data from the UK Biobank, a population-based cohort study, which recruited adults aged 40–69 years between 2006 and 2010 across 22 centres in England, Scotland, and Wales. We used Cox proportional hazards models to estimate hazard ratios (HRs) and 95% CIs between self-reported hearing aid use status (hearing loss with or without hearing aids) at baseline and risk of dementia (all-cause dementia, Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia). Dementia diagnoses were ascertained using hospital records and death-register data. We also analysed the roles of mediators (self-reported social isolation, loneliness, and mood) and moderators (self-reported education and income, smoking, morbidity, and measured *APOE* allele status).

Findings After the exclusion of people who did not answer the question on hearing difficulties (n=25 081 [5·0%]) and those with dementia at baseline visit (n=283 [0·1%]), we included 437 704 people in the analyses. Compared with participants without hearing loss, people with hearing loss without hearing aids had an increased risk of all-cause dementia (HR 1·42 [95% CI 1·29–1·57]); we found no increased risk in people with hearing loss with hearing aids (1·04 [0·98–1·10]). The positive association of hearing aid use was observed in all-cause dementia and cause-specific dementia subtypes (Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia). The attributable risk proportion of dementia for hearing loss was estimated to be 29·1%. Of the total association between hearing aid use and all-cause dementia, 1·5% was mediated by reducing social isolation, 2·3% by reducing loneliness, and 7·1% by reducing depressed mood.

Interpretation In people with hearing loss, hearing aid use is associated with a risk of dementia of a similar level to that of people without hearing loss. With the postulation that up to 8% of dementia cases could be prevented with proper hearing loss management, our findings highlight the urgent need to take measures to address hearing loss to improve cognitive decline.

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Introduction

Dementia and hearing loss are both highly prevalent conditions among older adults. By 2050, dementia is predicted to affect 150 million people worldwide, contributing to 115·8 million disability-adjusted life-years.[1] The 2020 *Lancet* Commission reported that 12 modifiable risk factors account for around 40% of worldwide dementia cases, making addressing preventable risk factors crucial for the prevention of dementia.[1] Worldwide, hearing loss (≥20 dB) affects 10% of people aged 40–69 years, 30% in people aged over 65 years and 70–90% in people aged 85 years or older.[2–4] Research has shown an association between hearing loss and dementia, indicating hearing loss might be a potential modifiable risk factor for dementia.[5,6] Thus, remediation of hearing loss, such as through the use of hearing aids in middle-aged or older age people might be a potential way to reduce the risk of dementia.[7] Although studies have reported that hearing aid use is associated with improved cognitive function[8,9] and attenuated cognitive decline,[3] the effectiveness of hearing aid use on reducing the risk of dementia in a real-world context remains unclear. A few studies[10–12] have investigated the relationship between hearing aid use and dementia and yielded inconsistent findings. A retrospective cohort study in the USA found that hearing aid use was associated with delayed diagnosis of Alzheimer's disease among adults aged 66 years or older,[10] whereas other studies[11,12] did not observe a significant decreased risk with dementia in hearing-aid users compared with non-users or were based on small samples.

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Research in context

Evidence before this study

We searched PubMed and Web of Science from database inception up to Sept 1, 2022, using the terms "hearing aid(s)", "hearing intervention", "dementia", "Alzheimer's disease", "AD", "vascular dementia", "VD", "non-AD and VD", and "NAVD", with no language restrictions. We screened papers by title and abstract to identify relevant full-text reports. We also screened citation lists from these full-text reports to identify other relevant research. We found that previous evidence on the association between hearing aid use and dementia has been scarce (four related studies) and inconsistent. No study had examined the link between hearing aid use and cause-specific dementia, and mechanisms between them.

Added value of this study

We examined the association between hearing aid use and incident dementia (all-cause and cause-specific dementia of Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia), and the mechanisms that underpin these associations. Hearing loss was associated with an increased risk of dementia, and using hearing aids was associated with a risk of dementia of a similar level to that of people without hearing loss. The associations with hearing aid use were observed in all-cause dementia and cause-specific dementia. Analyses suggested that the observed association between hearing aid use and dementia risk reduction was mainly related to the so-called direct effects of hearing aid use, with measured indirect effects accounting for less than 8% for each possible mediator.

Implications of all the available evidence

In people with hearing loss, hearing aid use could reduce risk of dementia. With the suggestion that up to 8·2% of dementia cases could be prevented with hearing loss prevention, our findings might have important clinical and public health implications. If causality is established hearing aids could present a minimally invasive, cost-effective intervention to mitigate all or at least some of the effect of hearing loss on dementia.

Knowledge gaps still exist in the association of hearing aid use and the risk of dementia. First, limited by sample size, previous studies have focused on cognitive function without examining the association of hearing aid use with specific types of dementia, including Alzheimer's disease, vascular dementia, and other types of dementia.[7] Also, the mechanisms by which hearing aid use reduces the risk of dementia remain unclear. Besides the biological plausibility that better hearing might reduce cognitive load and alleviate sensory deprivation, hearing aids might also help to improve understanding spoken communication, therefore relieving loneliness, potentially depressive symptoms, and enhancing social interaction, thereby reducing the risk of dementia.[13,14]

See Online for appendix

In this study we aimed to assess whether hearing aid use was associated with decreased risk of dementia (all-cause dementia, Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia) in people with hearing loss, using people without hearing loss as reference. We also examined the mediation effect of loneliness, isolation, depressed mood, and the interaction of socioeconomic status, smoking, morbidity status, and *APOE ε4* allele status in their association.

Methods

Study design and participants

UK Biobank is a prospective population-based cohort, which recruited over 500 000 volunteers aged 40–69 years between 2006 and 2010, who lived within 10 miles of the 35 assesment centres. Individuals were invited to attend one of the 22 centres across England, Scotland, and Wales for baseline assessment. Written informed consent was obtained for collection of questionnaire and biological data. UK Biobank was undertaken with ethical approval from the UK North West Multi-Centre Research Ethics Committee (11/NW/0382). This research was done under UK Biobank application number 68369. We used a prospective design limiting analyses to participants without dementia at baseline. This study is reported as per STROBE guidelines (appendix pp 25–27).

Exposure and outcome

Information on presence of hearing loss and hearing aid use were extracted from the Touchscreen questionnaire. Hearing loss status was collected via a self-report question: "Do you have any difficulty with your hearing?" with optional responses of "yes", "no", or "I am completely deaf". We categorised hearing loss status into two groups: without hearing loss ("no" responses) or with hearing loss ("yes" or "I am completely deaf" responses). Hearing aid use status was collected via a self-reported question: "Do you use a hearing aid most of the time?" with optional responses of "yes" or "no". Before speech-in-noise tests were introduced in 2009, people who reported having hearing loss (n=51 438) were asked hearing aid use status. From 2009 onwards, all participants (n=226 046) who joined the UK Biobank were asked about their hearing aid use status. Participants who were completely deaf (n=130) were not asked hearing aid use status and were classified into the hearing loss without hearing aids group.

Dementia diagnoses were ascertained using hospital inpatient records (Hospital Episode Statistics for England, Morbidity Records for Scotland, and the Patient Episode Database for Wales) and death register data

(National Health Service [NHS] Digital, NHS Central Register, and National Records) as per the algorithmically defined dementia outcomes[15] listed in category 47. The outcome variable was incident all-cause dementia, including dementia subtypes of Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia. The International Classification of Diseases 10th revision (ICD-10) codes F00, F01, F02, F03, G30, G310, G311, G318, and ICD-9 code 290 were used to identify participants with all-cause dementia if one or more of these codes were recorded as a primary or secondary diagnosis in the health records. Incident Alzheimer's disease was defined by ICD-10 codes F00 (including atypical or mixed type), G30, and ICD-9 code 290. Incident vascular dementia was defined by ICD-10 code F01. Incident non-Alzheimer's disease non-vascular dementia was defined by ICD-10 codes F02, F03, G310, G311, and G318. Outcome adjudication for incident dementia was done by the UK Biobank Outcome Adjudication team.

	N	Without hearing loss	Hearing loss		Dementia (n=5380)
			Hearing loss without hearing aids	Hearing loss with hearing aids	
Hearing					
Without hearing loss	325882	..	..	..	3015 (0·93%)
Hearing loss without hearing aid use	98730	..	..	..	2645 (2·68%)
Hearing loss with hearing aid use	13092	..	..	..	170 (1·30%)
Age at baseline, years					
40–49	102116	85726 (83·95%)	15658 (15·33%)	732 (0·72%)	100 (0·10%)
50–59	167409	126521 (75·58%)	37656 (22·49%)	3232 (1·93%)	844 (0·50%)
60–69	168179	113635 (67·57%)	45416 (27·00%)	9128 (5·43%)	4886 (2·91%)
Sex					
Female	235249	185361 (78·79%)	44076 (18·74%)	5812 (2·47%)	2749 (1·17%)
Male	202455	140521 (69·41%)	54654 (27·00%)	7280 (3·60%)	3081 (1·52%)
Ethnicity					
White	416131	307905 (73·99%)	95487 (22·95%)	12739 (3·06%)	5592 (1·34%)
Asian or Asian British	8327	6830 (82·02%)	1338 (16·07%)	159 (1·91%)	83 (1·00%)
Black or Black British	6135	5437 (88·62%)	643 (10·48%)	55 (0·90%)	85 (1·39%)
Other	7111	5710 (80·30%)	1262 (17·75%)	139 (1·95%)	70 (0·98%)
Education, years					
≤10	215501	156979 (72·84%)	50766 (23·56%)	7756 (3·60%)	3658 (1·70%)
11–12	52271	40097 (76·71%)	10942 (20·93%)	1232 (2·36%)	572 (1·09%)
>12	169932	128806 (75·80%)	37022 (21·79%)	4104 (2·42%)	1600 (0·94%)
Income levels					
Level 1 (<£18 000)	97236	69244 (71·21%)	23601 (24·27%)	4391 (4·52%)	2406 (2·47%)
Level 2 (£8000–30 999)	106630	77600 (72·78%)	25206 (23·64%)	3824 (3·59%)	1608 (1·51%)
Level 3 (£31 000–52 000)	113589	85513 (75·28%)	25245 (22·22%)	2831 (2·49%)	1005 (0·88%)
Level 4 (>£52 000)	120249	93525 (77·78%)	24678 (20·52%)	2046 (1·70%)	811 (0·67%)
Townsend deprivation index quartile					
Q1 (least deprived)	112182	84228 (75·08%)	24758 (22·07%)	3196 (2·85%)	1362 (1·21%)
Q2	110060	81916 (74·43%)	24794 (22·53%)	3350 (3·04%)	1384 (1·26%)
Q3	109650	81494 (74·32%)	24873 (22·68%)	3283 (2·99%)	1398 (1·27%)
Q4 (most deprived)	105812	78244 (73·95%)	24305 (22·97%)	3263 (3·08%)	1686 (1·59%)
BMI, kg/m²					
<18·5	2209	1784 (80·76%)	373 (16·89%)	52 (2·35%)	40 (1·81%)
≥18·5 to <25·0	143832	111686 (77·65%)	28785 (20·01%)	3361 (2·34%)	1714 (1·19%)
≥25·0 to <30·0	186713	136967 (73·36%)	43822 (23·47%)	5924 (3·17%)	2479 (1·33%)
≥30·0	104950	75445 (71·89%)	25750 (24·54%)	3755 (3·58%)	1597 (1·52%)
Smoking status					
Never	239864	184460 (76·90%)	49236 (20·53%)	6168 (2·57%)	2682 (1·12%)
Past	152767	107936 (70·65%)	39099 (25·59%)	5732 (3·75%)	2538 (1·66%)
Current	45073	33486 (74·29%)	10395 (23·06%)	1192 (2·64%)	610 (1·35%)

(Table 1 continues on next page)

	N	Without hearing loss	Hearing loss		Dementia (n=5380)
			Hearing loss without hearing aids	Hearing loss with hearing aids	
(Continued from previous page)					
Alcohol intake					
Daily or almost daily	91308	66213 (72·52%)	22388 (24·52%)	2707 (2·96%)	1226 (1·34%)
3–4 times a week	103199	77038 (74·65%)	23457 (22·73%)	2704 (2·62%)	1116 (1·08%)
1–2 times a week	113241	85044 (75·10%)	24868 (21·96%)	3329 (2·94%)	1290 (1·14%)
Occasionally	96732	72547 (75·00%)	21100 (21·81%)	3085 (3·19%)	1407 (1·45%)
Never	33224	25040 (75·37%)	6917 (20·82%)	1267 (3·81%)	791 (2·38%)
Diabetes					
No	414534	310090 (74·80%)	92598 (22·34%)	11846 (2·86%)	5002 (1·21%)
Yes	23170	15792 (68·16%)	6132 (26·47%)	1246 (5·38%)	828 (3·57%)
Hypertension					
No	315995	240179 (76·01%)	67739 (21·44%)	8077 (2·56%)	3229 (1·02%)
Yes	121709	85703 (70·42%)	30991 (25·46%)	5015 (4·12%)	2601 (2·14%)
Cardiovascular disease					
No	412442	309908 (75·14%)	91151 (22·10%)	11383 (2·76%)	4783 (1·16%)
Yes	25262	15974 (63·23%)	7579 (30·00%)	1709 (6·77%)	1047 (4·14%)
Social isolation					
No	232863	173451 (74·49%)	52420 (22·51%)	6992 (3·00%)	2765 (1·19%)
Yes	204841	152431 (74·41%)	46310 (22·61%)	6100 (2·98%)	3065 (1·50%)
Loneliness					
No	360238	271011 (75·23%)	78690 (21·84%)	10537 (2·93%)	4588 (1·27%)
Yes	77466	54871 (70·83%)	20040 (25·87%)	2555 (3·30%)	1242 (1·60%)
Depressed mood					
Several days or not at all	416744	311277 (74·69%)	93143 (22·35%)	12324 (2·96%)	5433 (1·30%)
More than half the days	12799	9085 (70·98%)	3283 (25·65%)	431 (3·37%)	232 (1·81%)
Nearly every day	8161	5520 (67·64%)	2304 (28·23%)	337 (4·13%)	165 (2·02%)
APOE e4					
0	332189	247153 (74·40%)	75107 (22·61%)	9929 (2·99%)	3216 (0·97%)
1	96738	72167 (74·60%)	21688 (22·42%)	2883 (2·98%)	2065 (2·13%)
2	8777	6562 (74·76%)	1935 (22·05%)	280 (3·19%)	549 (6·25%)

Data are n or n (%).

Table 1: **Characteristics of participants by hearing loss, hearing aid usage, and dementia status**

Covariates

We included the following factors in the analyses as covariates according to evidence from previous studies:[3,9,16] age at baseline, ethnicity, years of education, income levels, smoking status, alcohol intake, BMI, hypertension status, diabetes status, insulin use status, cardiovascular disease status, *APOE e4* status, social isolation, loneliness, and depressed mood. Ethnicity was categorised as White, Asian or Asian British, Black or Black British, and other. Years of education was categorised as 10 years or fewer, 11–12 years, or more than 12 years. Annual household income level was divided into four categories as level 1 (<£18 000), level 2 (£18 000–30 999), level 3 (£31 000–51 999), and level 4 (>£52 000). Townsend deprivation index, which reflects area-level socioeconomic status, was based on participants' residential postcode at recruitment and categorised on the basis of quartiles; higher values indicate greater levels of deprivation. Smoking status was categorised as current, former, or never smokers. Alcohol intake was categorised as daily, 3–4 times per week, 1–2 times per week, occasionally, and never. Physical activity level was categorised as low, moderate, and high. Measured BMI was categorised according to WHO criteria as less than 18·5 kg/m², 18·5–24·9 kg/m², 25·0–29·9 kg/m², and 30 kg/m² or greater. Prevalent hypertension, diabetes, and cardiovascular disease as present or absent based on self-report at baseline were categorised as yes or no. Insulin use status was self-reported and was divided into use or not use. *APOE* allele status was based on two single nucleotide polymorphisms: rs7412 and rs429358. The number of *APOE e4* alleles in each person was categorised as none (e2/e2, e2/e3, or e3/e3 haplotypes), one (e3/e4 and occasionally e2/e4 haplotypes), and two (e4/e4 haplotypes). Social isolation was quantified using a composite score previously

	Model 1		Model 2		Model 3		Model 4	
	HR (95% CI)	AR%	HR (95% CI)	AR%	HR (95% CI)	AR%	HR (95% CI)	AR%
People without hearing loss	1·00	..	1·00	..	1·00	..	1·00	..
People with hearing loss								
Without hearing aids	1·56 (1·41–1·72)	35·90%	1·47 (1·33–1·63)	31·97%	1·46 (1·32–1·62)	31·51%	1·42 (1·28–1·57)	29·08%
With hearing aids	1·06 (0·99–1·12)	NA	1·03 (0·97–1·10)	NA	1·03 (0·97–1·10)	NA	1·04 (0·98–1·10)	NA
Women with hearing loss								
Without hearing aids	1·62 (1·39–1·89)	38·27%	1·60 (1·37–1·86)	37·50%	1·60 (1·37–1·87)	37·50%	1·56 (1·34–1·82)	35·90%
With hearing aids	1·01 (0·92–1·10)	NA	1·02 (0·93–1·12)	NA	1·02 (0·93–1·12)	NA	1·03 (0·94–1·13)	NA
Men with hearing loss								
Without hearing aids	1·47 (1·29–1·67)	31·97%	1·41 (1·23–1·60)	29·08%	1·40 (1·23–1·59)	28·57%	1·35 (1·19–1·54)	25·93%
With hearing aids	1·04 (0·97–1·13)	NA	1·04 (0·96–1·12)	NA	1·04 (0·97–1·13)	NA	1·05 (0·97–1·13)	NA

In model 1 we adjusted for age; model 2 included model 1 additionally adjusted for sex, ethnicity, education, income, and Townsend index of deprivation; model 3 included model 2 additionally adjusted for smoking status, alcohol intake, physical activity, and BMI; and model 4 included model 3 additionally adjusted for hypertension status, diabetes status, cardiovascular disease status, and *APOE* allele status. Sex was only adjusted for total association and not for associations stratified by women and men. AR=attributable risk proportion. HR=hazard ratio. NA=not applicable.

Table 2: **Association of hearing aid use status and all-cause dementia in all participants and by sex**

derived in UK Biobank.[17] Three questions were used: number of people living together in the household (score of 1 for living alone), frequency of visits to or by friends or family (score of 1 for visiting friends or family less than once a month), and engagement in leisure or social activities such as a religious groups or sports clubs (1 score for no participation at least weekly). Participants with a sum score of 2 or 3 were classified as with social isolation, and those with a sum score of 0 or 1 were classified as without social isolation. Information on loneliness was collected via a self-reported question—"Do you often feel lonely?"—with optional responses of "yes" or "no". Depressed mood was measured using a self-reported question: "Over the past 2 weeks, how often have you felt down, depressed, or hopeless?" Responses were categorised as "several days or not at all", "more than half the days", and "nearly every day". Detailed information on covariate collection and definitions is given in the appendix (pp 4–8).

Statistical analysis

Baseline summary statistics are presented as proportions for categorical data and means (SDs) for continuous variables. We used Cox proportional hazards regression models to estimate the hazard ratios (HRs) and 95% CIs between baseline hearing status and hearing aid use status and the risk of dementia (all-cause dementia, Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia). People without hearing loss were used as the reference group. We tested the proportional hazards graphically using a plot of the log cumulative hazard, where the logarithm of time is plotted against the estimated log cumulative hazard. The curves for compared groups (without hearing loss, hearing loss with hearing aid use, and hearing loss without hearing aid use) were approximately parallel; thus, the proportional hazards assumption was deemed reasonable. Hospital inpatient data were censored on Sept 30, 2021 (England), July 31, 2021 (Scotland), and Feb 28, 2018 (Wales). Follow-up for all participants started from the date of recruitment to the date when dementia was diagnosed, date of death, or date of loss to follow-up, whichever occurred first. We first analysed hearing aid use and all-cause dementia, followed by separate analyses with dementia subtypes of Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia. In addition to giving the HR (95% CI) in a full-adjusted model, we also adjusted covariates step by step—ie, in model 1, age was adjusted; in model 2, sex, ethnicity, socioeconomic status variables of education, income, and Townsend index of deprivation were further adjusted on the basis of model 1; in model 3, smoking status, alcohol intake, physical activity, and BMI were further adjusted on the basis of model 2; and in model 4 (full-adjusted model), disease histories of hypertension status, diabetes status, cardiovascular disease status, and *APOE* allele status were further adjusted on the basis of model 3. Additionally, we calculated the attributable risk proportion:

$$\textit{attributable risk proportion} = \frac{\mathrm{HR}-1}{\mathrm{HR}} \times 100\%$$

We did several sensitivity analyses to test the robustness of our findings. We first only included dementia events that occurred at least 5 or 10 years after baseline. Second, we only included patients who were aged 50 years or older at baseline. Third, we excluded participants who had responded "I am completely deaf" in the hearing difficulty question. Fourth, we did a competing risk analysis considering death as a competing event. We also analysed the association of hearing aid use with age when dementia was diagnosed

	Total effect size	Direct effect		Indirect effect	
		Size	Proportion	Size	Proportion
Loneliness					
Hearing aids→ loneliness→ all cause dementia	0·71	0·65	97·72%	0·06	2·28%
Hearing aids→ loneliness→ Alzheimer's disease	0·56	0·55	98·21%	0·01	1·79%
Hearing aids→ loneliness→ vascular dementia	0·78	0·75	96·15%	0·03	3·85%
Hearing aids→ loneliness→ non-Alzheimer's disease non-vascular dementia	0·71	0·69	97·18%	0·02	2·82%
Social isolation					
Hearing aids→ Social isolation→ cause dementia	0·66	0·65	98·48%	0·01	1·52%
Hearing aids→ social isolation→ Alzheimer's disease	0·55	0·55	99·64%	0·002	0·36%
Hearing aids→ social isolation→ vascular dementia	0·76	0·75	98·68%	0·01	1·32%
Hearing aids→ social isolation→ non-Alzheimer's disease non-vascular dementia	0·70	0·69	98·57%	0·01	1·43%
Depressed mood					
Hearing aids→ depressed mood → All cause dementia	0·70	0·65	92·86%	0·05	7·14%
Hearing aids→ depressed mood → Alzheimer's disease	0·57	0·55	96·49%	0·02	3·51%
Hearing aids→ depressed mood → vascular dementia	0·82	0·75	91·46%	0·07	8·54%
Hearing aids→ depressed mood→ non-Alzheimer's disease non-vascular dementia	0·76	0·69	90·79%	0·07	9·21%

Logistic regression models were used for mediation analysis. p values for total, direct, and indirect effect sizes were all less than 0·05. Arrows indicate pathways.

Table 3: **Mediation analysis of loneliness, social isolation, and depressed mood in the association of hearing aid use and dementia**

(≤75 and >75 years). Further, according to evidence from previous studies,[16,18] we included the following factors as possible mediators: loneliness, social isolation, and depressed mood in the association between hearing aid use and dementia using mediation analysis methods described by Baron and Kenny.[19] Additionally, we examined interaction effects of two socioeconomic status indicators (education and income), behaviours (smoking), morbidity status (cardiovascular disease and diabetes), and *APOE e4* status with hearing aid use on the risk of dementia by adding a product interaction term to the model. We calculated p values by comparing models with and without adding the product interaction. A two-sided p value of 0·05 or less indicated the significance of the interaction effect. We did the analyses following a prospective statistical analysis plan (appendix pp 28–30).

We used SAS (version 9.4) in all statistical analyses. The PHREG procedure was used to fit the Cox proportional hazards regression models. A two-sided p value of 0·05 or less was considered to indicate statistical significance.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

After the exclusion of people who did not answer the question on hearing difficulties (n=25 081 [5·0%]) and those with dementia at baseline visit (n=283 [0·1%]), we included 437 704 people in the analyses (appendix p 3). Participants had a mean age at baseline of 56·0 years (SD 8·0), 235 249 (53·7%) were female, and 202 455 (46·3%) were male. 416 131 (95·1%) participants were White. The mean follow-up duration was 12·1 years (SD 1·7). 325 882 (74·5%) participants had no hearing loss and 111 822 (25·6%) had hearing loss. Among those with hearing loss, 13 092 (11·7%) used hearing aids (table 1). Prevalence of hearing loss increased with age and was more common in men than in women (table 1). People with obesity, cardiovascular disease, loneliness, and depressed mood had a higher prevalence of hearing loss and hearing aid use (table 1).

Compared with participants without hearing loss, people with hearing loss not using hearing aids had an increased risk of all-cause dementia (HR 1·42 [95% CI 1·28–1·57]), whereas no increased risk was found in people with hearing loss who used hearing aids (1·04 [0·98–1·10]; table 2). The attributable risk proportion of hearing loss without hearing aids was 29·08% (table 2). We observed similar findings for associations with subtypes of dementia (appendix pp 9–11). In stratified analyses, findings were similar in both women and men, and the attributable risk proportions for hearing loss without hearing aid use with all-cause dementia (35·90% *vs* 25·93%), Alzheimer's disease (28·06% *vs* 21·88%), vascular dementia (43·82% *vs* 31·03%), and non-Alzheimer's disease non-vascular dementia (43·50% *vs* 25·93%) were higher in women than in men (appendix pp 9–11). Similar associations were found when only dementia events that occurred at least 5 or 10 years after baseline, or only the population who were aged 50 years or older at baseline were included, or those who reported being completely deaf were excluded (appendix pp 12–15). Also, findings were similar when we used competing risk analysis considering death as a competing event

(HR 1·04 [0·98–1·11] in people with hearing loss with hearing aids and 1·42 [1·29–1·57] in people with hearing loss without hearing aids; appendix p 16).

When the roles of mediators were analysed, 1·52% of the total association between hearing aid use and dementia was mediated by improving social isolation, 2·28% by improving loneliness, and 7·14% by improving depressed mood (table 3).

We found statistically significant interactions for education, income level, smoking, cardiovascular disease, dementia, and *APOE e4* allele status. Generally, we found associations with dementia being more prominent in groups at high risk—eg, people with low income, smokers, those with previous disease, and those with two *APOE e4* alleles (appendix pp 18–24). An exception was income, for which we found no increased risk in those with income level 3 in people with hearing loss and without hearing aid use and higher risks in those in the highest income level in this hearing status group (appendix p 20). Across most interaction variables the risk difference remained, with the highest risk in the group with hearing loss and no hearing aid and lower to no risk increase in the group with hearing aid use compared with in individuals with no hearing loss. Notable exceptions were participants in income level 3, who showed no risk difference across hearing loss categories (appendix p 20), and two *APOE e4* alleles that were associated with higher dementia risk and showed little risk differences across hearing loss and hearing aid use (appendix p 24). Most interactions were similar across dementia subtypes. An exception was Alzheimer's disease, for which we found no risk differences across all hearing categories in participants with 12 or more years of education.

Discussion

Our findings indicated that in people with hearing loss, hearing aid use was associated with a risk of having dementia of a similar level to the dementia risk in people without hearing loss, and this was observed in all-cause dementia and cause-specific dementia. Measured indirect effects for each mediator (eg, through reducing loneliness, social isolation, and depressed mood) accounted for less than 8% of the observed all-cause dementia risk, suggesting other mechanisms for the observed protective effect of hearing aid use on dementia.

Evidence has shown that hearing loss is an independent risk factor for poor cognitive function, cognitive decline, and incident all-cause dementia.[5,20] A systematic review and meta-analysis of prospective studies found that hearing loss was associated with a 28% increased odds of all-cause dementia.[5] Similarly, we also found in this study that people with hearing loss without hearing aid use had an over 42% increased risk of dementia.

Possible mechanisms underlying the relationship of hearing loss with dementia include the reallocation of cognitive resources to auditory perceptual processing,[21] cognitive deterioration due to long-term deprivation of auditory input,[22] a common neurodegenerative process in the ageing brain that drives both cognitive decline and hearing loss,[23] and social isolation caused by both hearing and cognitive loss.[24] Also, hearing loss manifested as central auditory dysfunction is generally viewed as an early marker of dementia.[23] The underlying mechanisms linking hearing aid use and a reduced dementia risk remain unclear. Direct and indirect pathways might exist. Hearing aids might delay cognitive decline by preventing auditory deprivation.[25] First, individuals with hearing loss might require increased cognitive resources for auditory perceptual processing as they perform effortful listening—ie, have high cognitive load.[13] Hearing aids might reduce the cognitive load from listening, redirecting cognitive resources back to cognitive tasks. Second, sensory deprivation caused by hearing loss might lead to structural alterations, including reduced volumes in the primary auditory cortex, whole brain, and right temporal lobe. These physical changes subsequently lead to cognitive decline.[14] Hearing aid use might relieve or eliminate sensory deprivation and hence improve cognitive ability. Additionally, indirect effects of hearing aids on cognitive decline are also possible. People with hearing loss, especially older people, are more likely to experience loneliness, social isolation, and depression than their peers without hearing loss.[26] Studies have found that these psychosocial problems are linked to increased risk of cognitive decline.[26–28] Thus, these problems might be on the causal pathway between hearing loss and dementia. However, whether hearing aid use reduces the risk of dementia via reduction of the adverse effects of hearing loss on loneliness, social isolation, and depression is unclear.[29] We found that less than 11% of the association between hearing aid use and decreased all-cause dementia risk was mediated through improving psychosocial problems, which indicates that the direct effect or other unmeasured mechanisms of hearing aid use on the risk of dementia dominated.

Previous studies mainly focus on the association of hearing aid use with cognitive function of specific domains (eg, episodic memory),[18] and found that hearing aids might have a mitigating effect on trajectories of cognitive decline in later life.[25] A few studies have examined the association between hearing aid use and dementia with discordant findings[10–12,30] and usually with small sample sizes of people using hearing aids. In a prospective study of participants older than 65 years, Amieva and colleagues[12] found that compared with people without hearing loss, people with hearing impairment had an HR for dementia risk of 0·86 (95% CI 0·59–1·26) with hearing aids and 1·21 (1·05–1·40) without hearing aids. However, only 26 participants used hearing aids.[12] Also, in 387 participants with hearing loss, Deal and colleagues[11] found that the HR between hearing aid use and dementia

was 0·84 (0·51–1·39). The wide CI might be due to the small sample size.[11] Bucholc and colleagues[30] found that hearing aid use was independently associated with a decreased risk of conversion from mild cognitive impairment to dementia. However, the analytical sample for this study was limited to patients with mild cognitive impairment with hearing loss. Mahmoudi and colleagues[10] also found that hearing aid use was associated with delayed diagnosis of Alzheimer's disease. Nevertheless, this study only included patients with Alzheimer's disease within 3 years of hearing loss diagnosis, and the association of hearing aid use on long-term dementia outcome was not clear. By contrast, we included people without hearing loss as the reference group, and analysed those with hearing loss by hearing aid use status in a large sample of participants without dementia at baseline.

We found some interactions for education, income level, smoking, cardiovascular disease, diabetes, and *APOE e4* allele status. Because of the large sample size of the study and clustering of risk factors in categories, these associations might not reflect meaningful differences. In two cases interactions resulted in risk associations that were not in line with the overall findings. This was the case for education and Alzheimer's disease, for which we found no increased risk in those with hearing loss without hearing aid use, and for participants with two *APOE e4* alleles that had an increased risk of all-cause dementia, in both those with hearing loss without hearing aids and with hearing aids.

One important strength of our study is the large sample size and the long duration of follow-up. Also, dementia status was ascertained from primary care, hospital admissions, and mortality data records, avoiding bias from self-reported data. Dementia outcomes have been validated previously. A study in England[31] reported that for hospital dementia diagnoses the sensitivity was 78·0% and the specificity was 92·0% when compared with dementia diagnosis at secondary mental health care as gold standard.

Our study has several limitations. First, we used self-reported hearing loss, hearing aid use, and some covariates (eg, smoking status, depressed mood, and disease histories), which can lead to misreporting. Nonetheless, studies have shown that self-reported hearing loss is highly correlated with audiometric measures in middle-aged and older adults.[32,33] Second, hearing aid use was collected in all participants after 2009, but only in those who reported having hearing difficulties before 2009. There might be misclassifications on hearing aid use because those who reported no hearing problems before 2009 might have done so because they used hearing aids. Thus, the effectiveness of hearing aid use on dementia might be underestimated. Additionally, the hearing aid question was not asked to participants who reported deafness and the question on deafness lacked specificity. Thus, results might not be generalisable to this subgroup of people with hearing difficulties. Some covariates might also have misclassification bias; for instance, the lowest income level might not represent a lifelong poverty status but might be a reflection of age because older people might have stopped earning and be receiving a pension. Third, the association between hearing loss and dementia might be due to reverse causation through neurodegeneration or other shared mechanisms. However, the consistent findings after sensitivity analyses with 5-year and 10-year lag implied that the reverse causation was less likely. Fourth, no information on the timing of when hearing aid use was initiated and length of hearing aid use was not collected. Thus, quantitative relationships between length of hearing aid use and risk of dementia could not be analysed, and estimates might be biased by short-term users. Fifth, we used hearing aid use status at baseline. Those with hearing loss without hearing aids at baseline might have used hearing aids at subsequent follow-up, which might also underestimate the effectiveness of hearing aid use on the reduction of dementia risk. Sixth, although the positive predictive value for all-cause dementia and Alzheimer's disease in UK Biobank data was relatively good, the positive predictive value for vascular dementia was shown to be low (33·3%) compared with clinical expert adjudication of the medical record even with additional inclusion of primary care data.[34] Given that people with non-Alzheimer's disease non-vascular dementia (most were unspecified dementia) accounted for about 45% of total dementia cases, misclassification bias might be present for dementia subtypes. Seventh, the observational study design is inherently limited by lack of randomisation of covariates. Although a series of covariates were adjusted, there might be unmeasured confounding. For example, people who used hearing aids might also have better access to other health-related resources, and the cognitive level in hearing aid users and non-users might have been imbalanced at baseline. Last, most UK Biobank participants are White, which might limit the generalisability of the findings.

In conclusion, compared with people with normal hearing, those with hearing loss had a 42% higher risk of dementia, and the use of hearing aids was associated with a risk of dementia similar to that of people without hearing loss. The associations were observed in both all-cause dementia and cause-specific dementia subtypes (Alzheimer's disease, vascular dementia, and non-Alzheimer's disease non-vascular dementia). Well-designed clinical trials are needed to assess the effect of hearing aid use in dementia risk and to qualify the role of types of hearing aids and length of hearing aid use for the prevention of dementia in different types of hearing impairment.

Despite beneficial effects, most people with hearing loss do not use hearing aids.[35] Hearing loss might begin

early in one's 40s, and the prodromal phase of dementia also lasts for 20–25 years. Our findings highlight the urgent need to take measures to address hearing loss across the life course to improve cognitive decline. Public health strategies are necessary to raise awareness of hearing loss and the potential harm of untreated hearing impairment, increase accessibility to hearing aids by reducing cost, encouraging screening, and delivering potential interventions such as fitting hearing aids.

Contributors

DZ and CZ conceived the study and contributed to interpretation of the results. FJ and DZ did statistical analyses and drafted the first manuscript. SRM, NS, AO, SSV, HK, TB, CZ, and DZ contributed to critical revision of the manuscript. DZ attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. FJ and DZ have accessed and verified the underlying data. All authors had access to the data and accept responsibility for the decision to submit for publication.

Declaration of interests

AO has received consulting fees from Medical Network Systems (MNES) and payment from Kyowa Kirin, outside the submitted work. All other authors declare no competing interests.

Data sharing

UK Biobank data are available online at https://www.ukbiobank.ac.uk. Syntax for the generation of derived variables and for the analysis that we used for this study will be submitted to UK Biobank for record.

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