SOCIOECONOMIC INEQUALITY AND HEARING HEALTH IN ENGLAND: EXAMINING THE RELATIONSHIP BETWEEN SOCIOECONOMIC INEQUALITY AND THE DEVELOPMENT OF HEARING IMPAIRMENT AND THE IMPACT OF HEARING IMPAIRMENT ON THE LIVES OF OLDER ADULTS IN ENGLAND

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List of abbreviations

APMs	Predictions at the Means
CCGs	Clinical Commissioning Groups
CI	Confidence interval
dB HL	Decibel hearing level
DSM	Diagnostic and Statistical Manual
ELSA	English Longitudinal Study of Ageing
ENT	Ear, Nose, and Throat
GOR	Geographical Office Regions
HHI Model	Model of Hearing Health Inequalities
HL	hearing loss
HSE	Health Survey for England
HTL	Hearing threshold levels
IMD	Index of Multiple Deprivation
IP	Intellectual property
kHz	Kilohertz, equal to 1,000 Hertz (Hz)
LSOA	Lower Layer Super Output Area
NIHR	National Institute for Health Research
NHS	National Health Service
NS-SEC	National Statistics socioeconomic classification
OR	Odds ratio
PAF	Postcode Address File
SD	Standard deviation
SEP	Socioeconomic position
UK	United Kingdom
WHO	World Health Organization

Abstract

Hearing loss (HL) is a significant public health problem estimated to affect over 9 million adults in England. Its negative impact is broader than sensory impairment, as it also affects the mental wellbeing, the interpersonal interactions, and the participation of the individuals in society. There is potential for reducing the prevalence and consequences of HL by understanding the impact of socioeconomic inequality in hearing health, which is currently unclear. This thesis aimed to i) investigate the socioeconomic factors that are related to the development of HL in older adults in England; ii) assess the socioeconomic risks for access to hearing health services and hearing aid use among older adults; iii) examine whether there is a causal link between HL and depression in later life across different socioeconomic groups; and iv) assess whether the hearing aids usage alleviates the depressive symptoms associated with HL in older adults.

The investigation initiated through a critical interpretive synthesis (CIS) review, which led to the formulation of the Conceptual Model for Hearing Health Inequalities (HHI Model). This model depicts the specific mechanisms for hearing health and their evolution over time. Then, using data from the English Longitudinal Study of Ageing, I conducted other four empirical studies: I present the first study that examined the association of objectively measured HL in older adults in England with four different socioeconomic position (SEP) indicators (education, occupation, income and wealth) and several modifiable lifestyle factors. The study showed that HL among older adults is as strongly associated with socioeconomic and lifestyle factors as with core demographic risk factors such as age and gender. Next, I provided time-series analyses of the regional patterns and trends of HL in England, which showed that between 2002 and 2017 there was an estimated increase of 10.2% in the total HL prevalence among the older English population. Even though the samples had similar age profiles, they differed markedly on their HL outcomes, both regionally and chronically. The findings revealed that the increase in HL prevalence is not related to the ageing of the population, as widely believed, but is potentially due to social and lifestyle changes. Next, I explored the concordance of self-reported measures of hearing difficulty with objective data on hearing, measured by a handheld audiometric screening device; this showed that one-third of over-50s may be unaware that have HL and remain undiagnosed. Lastly, across different socioeconomic groups, I examined the longitudinal relationship between HL and depressive symptoms in later life, and whether the use of hearing aids alleviated these symptoms. A graded relationship between HL and depression according to SEP was revealed, with those with HL in the lowest wealth groups experiencing up to double the relative risk of depression compared with those in the highest wealth quintile. Those in the lowest versus the highest wealth quintiles experienced more considerable improvement in their psychosocial wellbeing with the use of hearing aids, and the improvement was slightly greater with the most frequent use of hearing aids.

This thesis resulted in several novel findings that can bring rich insights to the fields of audiology, population health research and health policy. A new conceptualisation of HL is proposed, which argues that HL is not necessarily an inevitable accompaniment to ageing but a preventable lifestyle disease. These findings call for an effective and sustainable HL screening strategy for the early detection of, and intervention for, HL in older adults. A socio-spatial approach is crucial for planning sustainable models of hearing care based on actual needs. The thesis also has novel clinical implications, as it adds to the understanding of the interrelationship between HL and depression, and the impact that hearing aids have. The findings can inform strategies to minimise socioeconomic risks for hearing loss and improve access to hearing health services and hearing aids, in order to mitigate the adverse effects of hearing loss in older adults in England and thus maximise the opportunity for healthy ageing.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright statement

Dedication

To Anastasia.
I could not have done this without you.
Thank you for believing in me,
and for all your support along the way.

Acknowledgement

Words cannot express how grateful I am to my supervisors Dr Maria Panagioti, Professor Evangelos Kontopantelis, and Professor Darren Ashcroft. Without them, this work would be literally impossible. I thank them from the bottom of my heart for the knowledge they conveyed to me, their invaluable support to complete this thesis, and for guiding me to discover what I can accomplish.

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Many others have contributed in large and small ways on my journey, as life is a constant and fluid process of self-improvement. Friends, relatives, colleagues, teachers, professors, coaches, mentors, advisors, supporters I have had throughout my life, who profoundly shaped the way I approach questions and helped me to acquire the skills and knowledge needed to complete this research.

Beloved father, you passed away during my PhD studies, but every day in some small way memories of you come my way. Besides, the topics of this thesis could represent several aspects of your life’s journey with hearing loss; your lived experience has enlightened my eyes of understanding of all these complex issues. Your belief in me has largely contributed to my resilience in difficult times during my PhD studies, and I am sure you would be proud of this work, which is a labour of love.

…many will go back and forth,

and knowledge will increase.

~ Daniel 12:4 ~

Chapter 1

General Introduction

1.1. Thesis format and structure

This thesis conforms to a journal format following the guidelines of the Presentation of Theses Policy issued by the University of Manchester in July 2020. This means that chapters are in a suitable format for submission for publication or have been accepted for publication or have already been published in peer-reviewed journals. Therefore, the work constitutes a publication tending towards a coherent thesis, and the research remains an original contribution to the field of research by the student, regardless of the format of the thesis. In line with the University's Thesis Submission Guide and the University's Intellectual Property (IP) Policy, the student owns the copyright of their thesis unless they have entered into an agreement that transfers copyright/IP (such as an assignment or employment agreement) to another party (including the University of Manchester).

All publications arising from this thesis have been integrated within its structure, and any section that is published or considered for publication is clearly identified. The versions of papers and the access level were informed by the publishers' self-archiving policies and the requirements of the University's Presentation of Theses Policy.

The decision to submit this thesis in journal format was made because the research generated important evidence for older people's hearing health that was previously lacking. The findings had clear potential for directly benefiting patients/service users and the public. Therefore, the approach was to maximise the value of the novel findings generated by the research and to share the outputs timely and openly to the broader research community and the public. Hence, the research findings were made immediately available during the funding period in the form of peer-reviewed publications rather than wait until the end of the PhD to make them publishable. All data that supports the research findings was made available at the point of publication, to support reproducibility and to underpin further research. Data availability statements are provided in each chapter to tell the reader where the data associated with a paper is available. They also include links (where applicable) to the dataset.

The papers arising from this thesis are:

Published:

1. Tsimpida D., Kontopantelis E., Ashcroft D., & Panagioti M. (2019). Socio-economic and lifestyle factors associated with hearing loss in older adults: A cross-sectional study of the English Longitudinal Study of Ageing (ELSA). *BMJ Open, 9*(9), e031030. http://dx.doi.org/10.1136/bmjopen-2019-031030

2. Tsimpida D., Kontopantelis E., Ashcroft D., & Panagioti M. (2020). Comparison of self-reported measures of hearing to an objective audiometric measure: An analysis of the English Longitudinal Study of Ageing (ELSA). *JAMA Network Open, 3*(8), e2015009. http://dx.doi.org/10.1001/jamanetworkopen.2020.15009

3. Tsimpida D., Kontopantelis E., Ashcroft D., & Panagioti M. (2020). Regional patterns and trends of hearing loss in England: Evidence from the English Longitudinal Study of Ageing and implications for health policy. *BMC Geriatrics*, 20(1), 1-14 https://doi.org/10.1186/s12877-020-01945-6

Under review:

4. Tsimpida D., Kontopantelis E., Ashcroft D., & Panagioti M. (2020). Conceptual model of hearing health inequalities (HHI Model): A critical interpretive synthesis. *Trends in Hearing*.

5. Tsimpida D., Kontopantelis E., Ashcroft D., & Panagioti M. (2020). The dynamic relationship between hearing loss, quality of life, socio-economic position,

and depression: Answers from the English Longitudinal Study of Ageing. *Social Psychiatry and Psychiatric Epidemiology.*

As the author of this thesis, I have taken the main role in all aspects of the production of the papers, including planning and execution, data acquisition from the UK Data Service (under a Special License and Secure Access agreement where necessary), statistical analysis and writing the papers. All research findings are derived from original research undertaken after the date I initially registered with the University of Manchester as a PhD student (1 January 2018). Any contribution of the supervisory team to the published papers (Chapters 3, 4, and 5) or the papers that are considered for publication in peer-reviewed journals (Chapters 2 and 6) is made explicitly clear in the relevant chapter.

Furthermore, the contribution of Piers Dawes, PhD, and Neil Pendleton, MD, is acknowledged; they assisted in obtaining funding and were the former supervisors for my PhD studentship [Award Reference: NIHR-INF-0551] but did not fulfil the authorship criteria of the University of Manchester to be included as authors in the papers arising from my thesis.

The funder of this PhD had no role in the design or conduct of the studies; the collection, management, analysis, and interpretation of the data; the preparation, review or approval of the manuscripts; and the decision to submit the manuscripts for publication. All views expressed in the papers are those of the authors and not necessarily those of the NIHR Manchester Biomedical Research Centre, the National Institute for Health Research, or the UK Department of Health.

This PhD thesis is structured around seven chapters. Chapter 1 provides the context of the research, defining the rationale of the investigation of the impact of socio-economic inequality on the consequences of hearing loss in older adults in England. The chapter includes a review of the previous research in the field of investigation. Existing studies examining the role of socio-economic inequality in hearing health are scarce as this is an emerging field. Thus, the chapter summarises the gaps in the research and the strategy employed to address them during the doctoral research.

Chapter 2 approaches the investigation through a critical interpretive synthesis (CIS). As the existing studies in the UK were limited, the aims of the review were two-fold: to provide an interpretive synthesis of the existing international literature in the field of investigation, and to formulate a conceptual model for hearing health inequalities, which depicts the specific mechanisms for hearing health and their evolution over time.

Chapter 3 focuses on modifiable lifestyle factors (such as high body mass index (BMI), physical inactivity, tobacco consumption and alcohol intake above the low-risk-level guidelines) associated with hearing loss (HL) among older adults in England. The study also examines the effects of four different indicators of socio-economic position (SEP) on HL (education, occupation, income, and wealth).

Chapter 4 explores regional patterns and trends of HL during the period 2002–2017 in a representative longitudinal prospective cohort study of the English population aged 50 and over. This is the first study that investigates geographical patterns and trends of HL in a representative cohort of older adults and among adults in general. Thus, a spatial dimension is used to further explore the association of socio-economic and lifestyle determinants of HL among samples of older adults.

Chapter 5 examines the concordance of self-reported measures of hearing difficulty in ELSA with objective hearing data measured by a handheld audiometric screening device. The predictors of the potential discordances among these measures across different population subgroups of a representative sample of people aged 50 and older in England were also examined. The cross-sectional study explores the hearing health pathways of the sample.

The validation of the self-reported measures in ELSA was a necessary step before the examination, in chapter 6, of the longitudinal relationship between HL and depressive symptoms from a socio-economic perspective and the impact of hearing aids in alleviating the depressive symptoms associated with HL in older adults.

Finally, chapter 7 concludes the thesis, drawing together the various outcomes of the work into a coherent synthesis, discussing its strengths and limitations. It also presents the implications for research, health policy and practice along with proposed directions for future work.

1.2. Rationale of the investigation

Hearing loss (HL) is a global public health challenge. Currently, it is estimated that over 466 million people live with disabling HL globally, including one-third of people over 65 years (Chadha et al., 2018; World Health Organization [WHO], 2013). Unless action is taken to address HL, numbers are projected to rise to 630 million by 2030 (Chadha et al., 2018).

The negative impact of HL is wider than sensory impairment. Studies suggest that HL is associated with adverse consequences, including depression and poor quality of life (Lawrence et al., 2020). The adverse consequences of HL pose a substantial risk to the functional ability that enables wellbeing at an older age, which is defined as a 'healthy ageing' (Chadha et al., 2018; Kliegel et al., 2020; Young, 2014). Moreover, the WHO estimates that the annual global cost of unaddressed HL exceeds 750 billion USD (Kasmauski, 2017), which refers to health sector costs, costs of educational support and productivity losses (WHO, 2017).

For many people, HL in adulthood seems to stem from inequalities present throughout their life, and approximately 50% of HL cases could be prevented, according to the WHO (Wilson et al., 2017). Recent studies have highlighted that there is a high potential for reducing the burden of HL provided that potentially modifiable factors linked to socio-economic inequalities in hearing health can be understood and addressed (Emmett & Francis, 2015; Scholes et al., 2018).

HL is a significant public health concern in England. Based on population projections in a study by Davis (1995), it is estimated that HL affects over 9 million people (NHS England, 2016). Health inequalities exist in England with a range of socio-economic indicators and are evident in many health outcomes, including morbidity and mortality (Marmot et al., 2010). The link between socio-economic inequality and vision loss has been examined for over fifteen years, and a range of social, economic and health inequalities faced by older adults with vision impairment has been identified (Gjonça & Nazroo, 2006; Nazroo et al., 2015). In contrast, there is a lack of studies that address the link between hearing loss and older peoples' socio-economic position as well as the impact of inequality on deteriorating and improving hearing in key aspects of their lives (Scholes et al., 2018).

While avoiding the development of risk factors in the first place is a key theme, comprehensive hearing care at all levels is also essential. The evidence shows that a considerable percentage of HL cases that cannot be prevented could be managed satisfactorily with hearing aids (Ferguson et al., 2017), which is vital given the substantial burden of HL (Wilson et al., 2017). Delay in seeking help for hearing difficulties is problematic (National Guideline Centre (UK), 2018), while evidence shows that hearing aids are effective in improving hearing-related quality of life for adults with HL (Ferguson et al., 2017). The above conclusion is reaffirmed by the WHO's visionary programme for the prevention of deafness and HL, for a world in which '*no person experiences hearing loss due to preventable causes and those with unavoidable hearing loss can achieve their full potential through rehabilitation, education and empowerment'* (WHO, 2018).

Interventions to promote hearing aid users need to focus on understanding the reasons for underutilisation (Ismail et al., 2019) and target specific socio-economic groups that are particularly unlikely to access hearing services and use hearing aids (Scholes et al., 2018). To date, HL in England remains largely underdiagnosed and untreated (Benova et al., 2015), and studies investigating correlates of SEP in hearing aid use in the English older population are lacking (Sawyer et al., 2019).

Furthermore, cross-sectional studies consistently suggest that HL is associated with adverse consequences, including depression and poor quality of life, (Lawrence et al., 2020), which poses a substantial risk to the functional ability that enables healthy ageing (Kliegel et al., 2020; Young, 2014). Depression and HL are major public health topics on the world health agenda, being the first and second leading causes of disability, respectively (Naghavi et al., 2017; Olusanya et al., 2014). Both health conditions are responsible for enormous public health costs, morbidity and mortality (Hsu et al., 2016; WHO, 2020), and the association between them is widely reported.

However, a recent meta-analysis showed that certainty in the estimation of the overall effect (Schünemann et al., 2018) remains low, despite the considerable amount of literature that has been published on the topic in the past four decades (Lawrence et al., 2020). Uncertainty still exists in the relationship between HL and depression. Furthermore, several methodological limitations across the 35 studies included in the meta-analysis did not allow a rigorous examination of the impact of using hearing aids on the association between HL and depression (Lawrence et al., 2020); only a few studies adjusted their results for the confounding influence of any covariates, a fact that may have falsely inflated the reported association between HL and depression. Additionally, the numbers of hearing aid owners and hearing aid users, which are not identical, were likely misrepresented as the exact proportions were not reported in the included studies. Thus, it was not possible to effectively examine the moderating impact of hearing aid usage in the relationship between hearing loss and depression (Lawrence et al., 2020).

The increase in life expectancy, resulting in an ageing population and the burden of hearing loss along with the concentration of ill-health among older adults, has highlighted the urgent need to investigate pathways that lead to socio-economic inequalities in later life hearing health (Benova et al., 2015). Understanding the effects of socio-economic inequality on hearing outcomes and hearing health and the impact of poor hearing health on mental health among several socio-economic groups is essential for informing health policy strategies and tackling this major public health issue. Changes in health policy will then help minimise socio-economic risks for hearing impairment, access to hearing health services and hearing aid use and mitigate the adverse effects of hearing impairment in older adults in England.

1.3 Review of previous research

1.3.1 The role of socio-economic factors in the development of hearing loss

This section provides a background to the research on older adults in England. Previous work in HL research concerning the relationship between socio-economic position (SEP) and HL in older adults is limited. The few studies that addressed the impact of SEP on HL used mainly proxy measures to reflect one's total SEP and only had a single domain, usually occupation (Davis, 1989; Davis et al., 2008; Ecob et al., 2008; Lutman, 1991; Lutman & Spencer, 1990). Therefore, occupation was the SEP indicator used to explain the differences among different population groups in hearing acuity; the studies consistently found that the manual occupational group was associated with a higher likelihood of HL (Ecob et al., 2008).

Davis (1989) found a higher prevalence of average hearing impairment in the better ear for those in manual versus those in non-manual occupations (OR 1.7 at ≥25 dB HL and OR 2.2 at ≥45 dB HL, p<001). A similar finding was revealed in another study that examined differences in population groups in extensive pure tone audiometry measures (e.g. 1 kHz and 4 kHz) (Ecob et al., 2008). The excess risk was explained in the studies as being due to occupational noise exposure that is related to manual occupations; noise has long been known as a factor that causes permanent adult-onset HL.

The effect of SEP (manual versus non-manual occupation) was also examined by Lutman and Spencer (1990), who studied the combination of age and occupational noise exposure (estimated retrospectively from a structured interview). They suggested that the combination of these effects accounted for up to 58% of the variance in hearing threshold levels (HTL). The same study found that gender differences in terms of occupational noise exposure resulted in an increase in HTL among males, mainly between 3 and 6 kHz. Differences between genders were found in another study where the reported prevalence of any hearing problem was 54.1% among men and 36.4% among women aged 55–74 years old. Furthermore, participants working in manual occupations reported more Ear Nose and Throat (ENT) symptoms of all types (Davis et al., 2007).

The harmful effect of noise exposure was also highlighted in a study that estimated the associations of age, history of work, music-related noise exposure, socio-economic background and ethnic minority background with hearing problems (Dawes et al., 2014). A large and inclusive sample of 164,770 adults aged 40–69 years from the UK BIOBANK resource was used. HL was based on a speech recognition in noise test with HL identified if speech recognition was poorer than two standard deviations compared to a normative sample of young adults with audiometrically normal hearing. The most deprived were defined as those who had a score lower than the standard deviation (SD) below the average measurement on the Townsend deprivation index. The Townsend deprivation index is a proxy for SEP that consists of four variables based on the geographical area of residence and includes unemployment, non-car ownership, non-home ownership and household overcrowding (Norman, 2010). The study demonstrated that 15% of the most deprived participants were at a 200% higher risk of poor hearing versus the most affluent 15% (OR 2.0, 95% CI 1.8 to 2.2). Age, lower socio-economic and ethnic background increased the odds of HL, which was due to noise exposure.

Overall, only a few researchers have tried to explore the magnitude of how the social class effect is explicable by factors other than noise exposure. Some researchers have tried to investigate the link between parental SEP and hearing health (Ecob et al., 2008; Power et al., 2007). Power et al. (2007) argued about the importance of the social class of origin in terms of the father's occupation in hearing thresholds in adulthood. The study found that SEP in both childhood and adulthood has independent effects on the 4 kHz hearing thresholds in adulthood at age 44–45 years. However, the study did not have a definite answer regarding the possible mechanisms that may explain that association. In a subsequent study, the adjustment for noise exposure and current smoking and drinking behaviours was found to reduce the effect of parental SEP on adulthood's hearing thresholds in all examined frequencies by around one-third on average. Together, these studies highlighted the need for additional risk factors to be examined to help explain the relationship between hearing loss and parental SEP (Ecob et al., 2008).

A relatively recent study analysed population-based data from the Health Survey for England (HSE) 2014 (Scholes et al., 2018). A sample of 3,292 individuals aged 45 years and over was assessed during a nurse visit, which included screening audiometry via the HearCheck™ Screener. The study revealed that multivariable-adjusted odds of HL among men were strongly increased for those in the lowest income tertile (OR 1.77, 95% CI 1.15–2.74) and for those with no qualifications (OR 2.35, 95% CI 1.54–3.59). For women, the associations followed similar patterns; for example, it was higher for those with no qualifications (OR 1.43, 95% CI 0.83–2.48), but these associations were insignificant. Although the HSE is a nationally representative health survey and the study was well designed, the authors suggested that the low nurse-visit response rates (37%) may have affected the representativeness of their sample and their estimates should be considered conservative (Scholes et al., 2018).

1.3.2 Socio-economic inequalities in hearing health care

Health-seeking behaviour is regarded as one of the direct pathways through which SEP may affect health outcomes (Stowasser et al., 2011). A relatively recent study by Benova et al. (2015) aimed to examine SEP gradients in the progression through various self-reported stages of help-seeking behaviour for access to hearing health services. The study examined a representative cohort of the English population aged 50 and above using wave two of ELSA. Self-perceived hearing difficulty was used as a starting point in the help-seeking process and estimated the prevalence of hearing difficulty among the older non-institutionalised population in England.

According to the responses to self-reported questions in ELSA wave two, Benova et al. (2015) distinguished three phases of hearing health-seeking behaviour with two stages in each phase. The first phase was *self-diagnosis and initiation of help-seeking* (stage i: self-reported hearing difficulty; stage ii: told a health professional about hearing difficulties). The second phase was *diagnosis and recommendation* (stage iii: referred to an ear specialist; stage iv: hearing aid recommended). The third phase was *compliance with recommendations and* *adherence* (stage v: obtained a hearing aid; stage vi: used a hearing aid). SEP inequalities in hearing health care were found in the self-diagnosis phase (stage 1) as the higher SEP was found to be strongly associated with lower odds of self-reported hearing difficulty (OR 0.87, 95% CI 0.83–0.91) after adjustment for gender, age, current marital status, retirement status and self-reported ownership of private health insurance.

The authors provided two possible explanations for the higher odds of self-reported hearing difficulty among participants with lower SEP. First, the longer lifetime exposure to noise among individuals in lower occupational categories, which was not controlled for in the model. The authors also considered that faster deterioration in the overall physical health of lower occupational grades, found by Chandola et al. (2007), may also possibly lead to a rapid deterioration in hearing ability.

Benova et al. (2015) found no evidence of SEP inequality in hearing health care in the phases where an individual initiates contact with the health system (stage 2), is referred to an ear specialist (stage 3), receives a recommendation for hearing aid (stage 4), obtains a hearing aid (stage 5) and utilises hearing aids (stage 6). As they did not find an SEP gradient in the access and utilisation of treatment for HL, and as hearing aids are available free of charge through the NHS, the authors concluded that hearing aid users may encounter other direct and indirect expenditures related to the treatment of HL, such as transportation to fitting sessions and battery purchases.

Self-identification of a hearing difficulty is an important stage for the initiation of help-seeking. Lutman (1991) proposed that this is related to manual occupations. The author conducted speech audiometry, which included a speech-in-quiet test with a list of 10 words and speech in noise with a sentence identification in noise (SIiN) test. The study found significant differences between manual and non-manual groups in the sentence identification in noise test (OR 4.1 in monaural and OR 2.5 in binaural identification). Therefore, the author concluded that any study based on self-reported data for the identification of a hearing difficulty needs to be balanced in terms of the confounding variables of age, sex and occupational group.

A recent study by Scholes et al. (2018) investigated whether current hearing aid use is associated with different markers of SEP, analysing population-based data from HSE 2014. The sample consisted of 3,292 participants aged 45 years and over who were asked about their current hearing aid use. The participants that answered negatively were further categorised into those who had tried a hearing aid in the past and those who had never tried one. It was found that the percentage of participants with HL who were current hearing aid users was 30% for men (n=128/425) and 27% for women (n=93/344). Among those who did not use a hearing aid (70% men and 73% women), the majority had never tried one (63% for both men and women). Those who had tried a hearing aid in the past but were not current hearing aid users were 7% men and 10% women.

Regarding the association of hearing aid use with SEP, those with the lowest SEP reported the lowest current hearing aid usage compared to those with the highest SEP. The categories used for the analysis of current hearing aid use were the tertiles of equivalised household income, the tertiles of the Index of Multiple Deprivation (IMD) 2010 (ranging between Q1 and Q5, with Q1 as the least deprived and Q5 as the most deprived) and two categories of educational status (O levels and above and no qualifications). The association between SEP and current hearing aid use was first adjusted for age (Model A). Model B was adjusted further for the severity of HL, exposure to work-related noise and cardiovascular disease risk factors. The associations showed that the multivariable-adjusted odds of hearing aid use for men were almost half for those in the lowest (OR 0.47, 95% CI 0.23–0.97) and middle-income tertiles (OR 0.50, 95% CI 0.25–0.99) compared to those in the highest tertiles. The associations with the other two SEP indices (area deprivation and educational status) were in the same direction, pointing at lower levels of hearing aid use among those in the lower SEP groups, but there was no statistical significance. There were no associations for women due to low numbers in the subcategory.

1.3.3 The link between hearing loss and depression in later life and the impact of hearing aids

Depression and HL are major public health topics on the world health agenda, being the first and second leading causes of disability, respectively (Naghavi et al., 2017; Olusanya et al., 2014), and the association between them is widely reported. However, a recent meta-analysis (Lawrence et al., 2020) showed that certainty in the estimation of the overall effect (Schünemann et al., 2018) on their association remains low, despite over 40 years of research. The findings are also conflicting due to some methodological flaws as only a few of them controlled for SEP factors in their analyses, which may have falsely inflated the association between HL and depression (Lawrence et al., 2020).

Six of the 35 studies included in the meta-analysis examined samples from the United Kingdom (Chou, 2008; Herbst & Humphrey, 1980; Jones et al., 1984; Keidser & Seeto, 2017; Lindesay, 1990; Prince et al., 1998). Of the six studies, only two were from cohort studies (Chou, 2008; Prince et al., 1998) and only the study by Chou (2008) included covariates of SEP in the analyses, such as education, employment and income (Lawrence et al., 2020).

Given the substantial burden of HL on ageing, the evidence that hearing aids reduce disability seems hugely appealing. However, the evidence for the impact of hearing aids on mental health outcomes is limited and inconsistent (Lawrence et al., 2020). The impact of hearing aids in alleviating depressive symptoms associated with HL in older adulthood has not been explored satisfactorily, and a potential SEP gradient in that relationship has not been examined at all, not only in the English older population but also globally (Lawrence et al., 2020).

1.4 Gaps in knowledge in the field of investigation

As Scholes et al. (2018) suggested, there is a huge potential to reduce the prevalence and impacts of HL by understanding and addressing the impact of socio-economic inequality on hearing health. Previous research on the impact of socio-economic inequality on hearing loss focused mainly on the examination of occupation as an SEP indicator. However, various other indicators enable individuals to thrive in society and are not limited to a proxy measure, such as occupation (Galobardes et al., 2006). Hence, the impacts of different SEP indicators on HL (such as education, occupation, income and wealth) are not yet clear. It is crucial to capture most of the variations in socio-economic stratification that may be linked to hearing deterioration in older adults. Furthermore, much uncertainty still exists about whether HL is a driver of low SEP or whether low SEP is a driver of HL, or that both happen successively (Scholes et al., 2018).

No previous study has investigated the effects of SEP indicators on hearing levels in older adulthood in combination with other major explanatory health risk factors associated with SEP, such as smoking, alcohol consumption, BMI and physical activity; nor have their effects been examined in different combinations.

It is also important to explore the spatial dimension in the association of socio-economic and lifestyle determinants of HL among samples of older adults. To date, no research has explored the geographical patterns and trends of HL in a representative cohort of older adults and among adults in general.

Furthermore, there has been little discussion on whether the impact of socio-economic factors is accumulated during the life-course and evolution of hearing problems over time. Power et al. (2007) concluded that manual occupation is an important risk factor for HL and further suggested the importance of the social class of origin (father's occupation) in addition to the current social class (occupation at 42 years). However, the authors did not explain the exact mechanisms behind the argument that adults' HL risk influences are to be found in childhood as well as adulthood. Similarly, Ecob et al. (2008) expressed the view that hearing loss is likely to be determined in childhood, but they did not provide any explanation for the potential mechanisms. Much uncertainty still exists about these concepts; therefore, a conceptual model examining these mechanisms across a lifespan would be beneficial.

The existing evidence shows that the usage of hearing aids is effective in improving the hearing-related quality of life for adults with HL (Ferguson et al., 2017). However, there is a delay in hearing help-seeking (National Guideline Centre (UK), 2018) and the underuse of hearing aids implies a waste of resources of the socially subsidised NHS hearing aids (Ismail et al., 2019). To date, evidence shows that there is SEP inequality in hearing health care at the self-diagnosis stage (Benova et al., 2015) and at the stage of hearing aid usage (Scholes et al., 2018). More research is needed that will focus on the differences in the identification of hearing difficulties and target specific socio-economic groups that are particularly unlikely to access hearing services and use hearing aids. Identifying socio-economic effects in the self-identification of hearing difficulties will be beneficial, as the greater self-identification of hearing difficulties is associated with greater hearing aid use (Ng & Loke, 2015; Sawyer et al., 2019).

Scholes et al. (2018) provided the first examination of socio-economic risks to hearing aid use using objective hearing data. In contrast, Benova et al. (2015) found that self-reported hearing ability and objective measures did not confirm the existence or the severity of HL. Hence, it is not surprising that these two studies found different percentages of those with HL who are currently hearing aid users. This discrepancy in the prevalence of hearing aid usage needs to be further explored. ELSA provides the opportunity to validate the self-reported hearing data with an objective measure to get a clearer picture of the actual underutilisation of hearing aids and its predictors.

Finally, little is known about the potential mechanisms that may explain the relationship between HL and depression, despite over 40 years of research. Several methodological limitations across 35 studies in the meta-analysis by Lawrence et al. (2020) did not allow a rigorous examination of the impact of hearing aid use on the association between HL and depression. Furthermore, the modelling of the impact of hearing aids in a representative longitudinal dataset from a socio-economic perspective and using objective hearing data has not been investigated. The above explorations could offer answers that have the realistic potential to improve the population's hearing health regarding whether hearing aids mitigate some of the adverse impacts of HL and whether the effects of the intervention are different according to SEP.

1.5 Aims and research questions

This thesis aims to examine the relationship between socio-economic inequality and HL and the impact of HL on the lives of older adults in England. Therefore, this body of research has two objectives: to explore the socio-economic causes behind the development of HL and, after its onset, to assess its consequences in people's lives in terms of mental wellbeing, quality of life and economic position.

The research questions that have been formulated are based on previous work in the field.

a) What are the socio-economic factors related to the development of HL in older adults in England? (addressed in chapters 2, 3 and 4)

b) What are the socio-economic risks for access to hearing health services and hearing aid use among older adults in England? (addressed in chapter 5)

c) Is there a causal link between HL and depression in later life across different socio-economic groups in older adults in England? (addressed in chapter 6)

d) Does hearing aid usage alleviate the depressive symptoms associated with HL in older adults in England? (addressed in chapter 6)

1.6 Approach and methodology

1.6.1 Data

A representative cohort of older adults was needed to explore the research questions for the older English population. ELSA is a longitudinal household survey dataset of a representative sample of people aged 50 and over in England (Zaninotto & Steptoe, 2019). It is designed as a large-scale prospective cohort study with repeat measures of core variables over numerous waves to explore trajectories on health, social, wellbeing and economic circumstances (Steptoe et al., 2013).

The original sample from ELSA was drawn from households that had previously responded to the HSE in 1998, 1999 and 2001. The current sample contains data collected from up to eight waves for over 15 years in an ongoing two-year follow-up longitudinal design (Steptoe et al., 2013). ELSA follows the sampling strategy of the HSE, which ensures that every address on the small users' Postcode Address File (PAF) in England has an equal chance of inclusion. Field household contact rates of over 96% were achieved.

The study excludes cases that do not belong to the target population through terminating events, such as deaths, institutional moves and moves out of England since taking part in HSE. As ELSA follows a longitudinal design, the sample is comprised of a sequence of observations on the same individuals across waves and refreshment samples (cohorts 3, 4, 6 and 7) (Zaninotto & Steptoe, 2019).

The great diversity that ELSA offers in health, physical, social and psychological functioning and economic fortunes in the British population allows the examination of the effect of different socio-economic indicators. These indicators include wealth, occupational class categorised using the National Statistics Socio-economic Classification (NS-SEC) and time spent in education (Jivraj et al., 2014). Hence, the large nationally representative multi-purpose sample of around 12,000 respondents aged 50 and over living in England allows the detection of differences among different subgroups according to SEP.

1.6.2 Assessment of hearing

Self-reported measure

Self-rated hearing data was collected from participants across all ELSA waves. According to the study documentation (Zaninotto & Steptoe, 2019), self-reported HL is defined as having declared a fair or poor hearing on a five-point Likert scale (excellent, very good, good, fair or poor), or responded 'Yes' to the question whether they found it difficult to follow a conversation if there is background noise (such as TV, radio or children playing) or not.

The participants that answered positively in the last question answered a separate question about whether they had slight, moderate or great difficulty in following a conversation if there is background noise. That response was used to further classify their hearing difficulty, omitting those that had indicated slight difficulty in following a conversation if there is background noise, to allow for a fair comparison of the categories of moderate, moderately severe or severe objectively measured HL (supplementary Figure 5.1).

Objective measure

Another major strength of ELSA is that it contains objective hearing data (measurement via HearCheck™; Siemens Audiologische Technik GmbH, 2007). The objective hearing health data was available in the seventh wave, where information was collected from 8,529 participants between June 2014 and May 2015. They gave consent to have their hearing acuity measured by a screening audiometry device and declared that they did not have an ear infection or a cochlear implant.

The handheld audiometric screening device, HearCheck™ (Siemens Audiologische Technik GmbH, 2007), was the device used for the objective measurement of hearing acuity. This device is portable and easy-to-use; it tests for audibility of a pure tone beep according to the number of tones that the respondent can hear for each sequence (at 1.0 kHz and 3.0 kHz) for each ear. The functional test sequence begins with a series of three sounds that decrease in volume at 1.0 kHz (55 dB HL, 35 dB HL, 20 dB HL) and afterwards another three sounds with decreasing volume at 3.0 kHz (75 dB HL, 55 dB HL, 35 dB HL).

Prerequisites for the test were that the device had to make proper contact with the ear to be tested; hearing aid(s), glasses, earrings and hairbands had to be removed to prevent them from interfering with the hearing device; the room had to be as quiet as possible. Participants indicated when they heard a sound by raising their finger. The total number of tones that the participants indicated they could hear in the sequence of sounds at 1.0 kHz and 3.0. kHz for each ear was recorded, and the total tones heard in the better-hearing ear was used for the categorisation of those with HL.

Previous studies have assessed the accuracy of Siemens HearCheck™ in detecting hearing loss and compared it with pure-tone air conduction averages designated as gold standard values. Fellizan-Lopez et al. (2011) found that in cases of moderate or severe hearing loss, the HearCheck™ test fulfils all criteria at a high sensitivity rate, high specificity rate and high positive predictive value, and is considered an accurate tool to screen for hearing loss without the need for soundproof audiometry booths.

In all chapters where the objective measure was used, HL was defined as >35 dB HL at 3.0 kHz in the better-hearing ear. Those with HL were further subdivided into two categories depending on the number of tones heard at 3.0 kHz. This is the level where intervention for HL has shown to be beneficial (Davis et al., 2007). For that reason, this categorisation has previously been used in the literature for the characterisation of those assessed by the same audiometric screening device (HearCheck™) (Scholes et al., 2018). Thus, in this study, the potential differences in the association between SEP indicators and HL, according to the severity of HL as measured by HearCheck™, have been explored. The categorisation of those with HL was as follows:

(a) *Moderate HL*: tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (two out of three tones heard at 3.0 kHz).

(b) *Moderately severe or severe HL*: tone heard, or not, at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (zero or one of the three tones heard at 3.0 kHz).

1.6.3 Assessment of depression and quality of life

An eight-item short version of the Centre for Epidemiologic Studies Depression (CES-D) Scale was administered in ELSA to assess clinically significant symptoms of depression (Karim et al., 2015). The respondents had to indicate their feelings sporadically over the week before the interview by confirming or denying a particular feeling (Karim et al., 2015). The questions and scoring criteria of the eight-item short version CES-D are presented in the supplementary material of chapter 6.

The CASP-19 Scale was used in ELSA to measure the quality of life (Wiggins et al., 2008). The measure uses 19 items covering four domains: four items for control (C), five items for autonomy (A), five items for self-realisation (S) and five items for pleasure (P). The questions in all domains and the scoring criteria are listed in the supplementary material in chapter 6.

1.6.4 Assessment of socio-economic position

Education, occupation, income, and wealth were used as the indicators of SEP. Five categories of the highest educational attainment were considered: degree/higher education; A levels (Level 3 of the National Qualifications Framework); O levels CSE (Certificate of Secondary Education); foreign/other; no qualifications.

Tertiles of self-reported occupation were based on the NS-SEC: managerial and professional; intermediate; routine and manual occupations.

The relative financial position of the participants was captured by quintiles of the net household income (first quintile lowest; fifth quintile highest) that is summed across household members.

To avoid the information bias that is related to retirement status, the quintiles of the total non-pension wealth were used as reported at the household level (first quintile lowest; fifth quintile highest), which represents the sum of net financial wealth, net physical wealth and net housing wealth.

The geographic-related information in the ELSA dataset has identifiers, such as the Government Office Region (GOR) and indices that are geographically based, such as the IMD. The geographical variables were provided under a Special License and Secure Access agreement (UK Data Service Project Number: 121175). The nine GORs represent the highest tier of sub-national division in England (North East, North West, Yorkshire and The Humber, East Midlands, West Midlands, East of England, London, South East, South West).

The respondents' geography was determined by their residence postcode on the date of the survey. Different versions of the IMD were provided for the eight waves of ELSA as follows: IMD 2004 (Noble et al., 2004) for waves 1–3, IMD 2007 (Noble et al., 2008) for wave 4, IMD 2010 (McLennan et al., 2011) for waves 5–7 and IMD 2015 (Smith et al., 2015) for wave 8. The IMD was provided in quintiles (the first quintile, least deprived; the fifth quintile, most deprived).

1.6.5 Assessment of other covariates

Age, marital status, retirement status and non-medical determinants of health (BMI, physical activity, tobacco and alcohol consumption) were assessed as covariates in the association between SEP indicators and HL (Tsimpida et al., 2018).

Age was categorised into three groups (50–64, 65–74, 75–89) to allow for a comparison with Benova et al. (2015) who examined the association of socio-economic position with self-reported hearing difficulty in the second wave of ELSA.

Marital status was dichotomised into those who are currently married or not. Those who are currently married included a) married, first and only marriage; b) in a registered civil partnership; c) remarried, in a second or later marriage. Those categorised as not currently married included a) single, never married and never registered in a marriage; b) separated, but still legally married; c) divorced; d) widowed.

Retirement status and social engagement were also considered as covariates in the analyses for the relationship between hearing loss and depression. Retirement status may confound the associations, and the degree of social engagement was proposed to explain the association between HL and depression in older adults (Kiely et al., 2013). Retirement status was dichotomised to those who were retired or not, according to the self-reported employment status. A continuous measure of social engagement was derived from a set of eight binary variables, which are presented in the supplementary material in chapter 6.

BMI measurements were grouped into four categories according to WHO definitions (Bjorntorp et al., 2000): (a) underweight: BMI under 18.5; (b) normal: BMI 18.5 or over but less than 25; (c) overweight: BMI 25 or over but less than 30; (d) obese: BMI 30 or over.

Tobacco consumption of any type of nicotine product was recoded into three categories: current smokers, former smokers and those who never smoked. Both current and former smokers answered the question of 'number of cigarettes smoked per day' to explore whether they were occasional or regular smokers.

Alcohol consumption was recorded using several continuous variables, such as the number of days of alcohol consumption in the last seven days and the number of (a) measures of spirit; (b) glasses of wine; (c) pints of beer that the respondents had consumed during this period. A continuous variable was constructed to represent the sum of the units of alcohol that the participants had consumed in the last seven days according to the Chief Medical Officer's drinking guidelines (Department of Health, 2016), which counts as one unit per measure of spirit and two units per glass of wine or pint of beer. The constructed variable of units of alcohol during the last seven days was further dichotomised into those who consumed more than 14 units of alcohol in the last seven days, or not, in a separate variable.

Levels of physical activity were described by three ordinal variables that examined the frequency that the respondents participated in rigorous, moderate or mild sports or activities, with possible answers (a) more than once a week; (b) once a week; (c) one to three times a month; (d) hardly ever or never.

1.6.6 Approach to statistical modelling

Chapter 3 includes a cross-sectional study of the association of socio-economic and lifestyle factors with HL. Multiple logistic regression models were used to evaluate the odds of HL at various socio-economic strata, controlling for gender, age and non-medical determinants of health (BMI, physical activity, tobacco and alcohol consumption). Additionally, four separate stepwise logistic regression models were fitted to examine the association of HL with non-modifiable (age, gender: step 1), partly modifiable (education, occupation, income, wealth: step 2) and fully modifiable lifestyle risk factors (BMI, physical activity, tobacco and alcohol consumption: step 3).

The variants of pseudo-R-squared statistics were based on the deviance of the models and used to express how much variance in the outcome was explained by the variables in each stepwise multiple logistic regression model. The variance inflation factor (VIF) was used as an indicator of multicollinearity, and the Hosmer-Lemeshow test was used as a post estimation tool, which quantified the goodness-of-fit of the models. For all models, the odds ratios, 95% confidence intervals, unadjusted and adjusted coefficients' beta values, pseudo R^2 and mean VIFs were presented.

As there is no accurate figure for HL, geographical data offered the opportunity to gain a representative picture of the prevalence of HL in older adults in England, which is outlined in chapter 4. The full dataset from the eight waves (74,699 person-years) was used in time-series analyses to strengthen the argument of the correlation between spatial variables and HL over time. Local spatial analysis statistical tools were used to analyse spatial distributions, patterns, processes and relationships of the geographical data. The Spatial Join tool was used to aggregate the number of cases of self-reported HL to the total responses of hearing acuity in each polygon (GOR) to visualise the prevalence rates of HL per GOR in each wave. As a mapping cluster tool, Hot Spot Analysis (Getis-Ord Gi*) was used to identify the locations of statistically significant hot spots and cold spots. *Confidence* levels of *90%,* 95% and 99% were considered in the calculations of *Getis-Ord Gi*.*

Bartlett's test was used for the homogeneity of variances to test that age variances were equal for all samples. Then, one-way ANOVA was applied to compare the means of age among GOR samples in all waves. Adjusted predictions at the means (APMs) and the marginal effects at the means (MEMs) (Williams, 2012) of the HL prevalence in each ELSA wave were computed with age, gender, education, occupation, income, wealth, IMD and alcohol consumption as the factor variables.

The investigation of the validity of self-reported data is presented in chapter 5. The comparison of the self-reported data with the objective hearing measure was essential to explore issues with the underestimation of hearing difficulty that do not allow an individual to progress into the second stage, where an individual, aware of their handicap, initiates contact with the health system. Multiple logistic regression models were fitted to identify predictors of the false-negative report of hearing difficulties in people with objectively identified HL. There were no missing values in the hearing data in the final analytical sample (n=8,529), which was specifically chosen to fulfil the criteria of completed self-assessment of hearing with given consent for assessment by pure-tone-audiometry and without any ear infection or cochlear implant.

Separate analyses were conducted for moderate, moderately severe or severe HL. The performance of self-reported hearing difficulty with second-stage pure tone audiometry screening (sensitivity, specificity, positive and negative predictive values as overall test accuracy) was calculated, and the area under the ROC curve represents the accuracy of all models. The Hosmer–Lemeshow test was used as a post estimation tool, which demonstrates the goodness-of-fit of logistic regression models.

In Chapter 6, dynamic cross-lagged path models (CLPMs) were fitted to estimate the longitudinal association between HL and depression over time. CLPM is a type of structural equation model where two or more variables are measured on two or more occasions, and the focus is on the associations (often causal theories) with each other over time. In the path analysis of the generalised structural equation models (GSEM), the full dataset from the eight waves was used to strengthen the causal argument between HL and depression over time. Minimum Akaike's and Schwarz's Bayesian information criteria (AIC and BIC) values informed the best-fitting recursive path models. Following these criteria, HL was considered as an exogenous predictor that has a uni-directional effect on wealth, which worked as an endogenous outcome variable in the models. Additionally, wealth was examined as a moderating/intermediate dependent variable of depression, which was the outcome variable in the dynamic CLPMs. Wealth was considered the most appropriate SEP indicator due to the age of the sample (aged 50 and above) because wealth status captures SEP in both the later stages of active professional life and the retirement period (Galobardes et al., 2006).

The concept of quality of life (CASP-19) functioned as an endogenous mediator variable that intervenes between HL and wealth, explaining the relationship between HL and SEP (Baron & Kenny, 1986). The concept of quality of life was represented using the confirmatory factor analysis (CFA) approach to generate a latent variable in each wave. A standardised factor score was calculated that weights each item by their salience (loadings and correlation with the other items) rather than their mean or summative scores to allow each item to have its own variance. In the CFA models, alpha reliability estimates were used.

Exponentiated coefficients and summary statistics for each wave are reported. Additionally, mixed-effects regression was used to estimate the interdependence of the repeated measures on the same participants using the intraclass correlation coefficient (ICC) and the variance across the repeated measures. Sobel's test was applied to calculate the significance of mediation in the CLPMs. Finally, the percentage of the total mediated effect (indirect effect/total effect) was calculated to measure the extent of mediation in each CLPM.

For sensitivity analysis, a subgroup analysed the path models to investigate differences in the structural relationships among those who reported using hearing aids most of the time and some of the time, respectively. As a second sensitivity analysis, similar models were fitted to investigate potential differences in parameter estimates of depression in wave 8 of the participants according to a) self-reported measures of hearing difficulties; b) the improved categories of self-reported data (Tsimpida et al., 2020); c) the objective hearing measures via HearCheck™. The compliance rate of hearing aid use (most of the time/some of the time) was entered as a moderator variable in the relationship between HL and depression, and its impact was calculated across different SEP groups.

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Chapter 2

Conceptual Model of Hearing Health Inequalities (HHI Model): A Critical Interpretive Synthesis

2.1. Abstract

Hearing loss is a major health challenge which can have severe physical, social, cognitive, economic and emotional consequences on people's quality of life. Currently, the modifiable factors linked to socioeconomic inequalities in hearing health are poorly understood. Therefore, an online database search (PubMED, Scopus and Psych) was conducted to identify literature which relates hearing loss to health inequalities as a determinant or health outcome. 53 studies were selected to thematically summarise the existing literature, using a critical interpretive synthesis method, where the subjectivity of the researcher is intimately involved in providing new insights with explanatory power. The evidence provided by the literature can be summarised under four key themes: (i) there might be a vicious cycle between hearing loss and socioeconomic inequalities and lifestyle factors; (ii) socioeconomic position (SEP) may interact with less healthy lifestyles, which are harmful to hearing ability; (iii) increasing health literacy could improve the diagnosis and prognosis of hearing loss and prevent the adverse consequences of hearing loss on people's health, and (iv) people with hearing loss might be vulnerable to receiving low quality and less safe healthcare. This study utilises elements from theoretical models of health inequalities to formulate a highly interpretive conceptual model for examining hearing health inequalities. This model depicts the specific mechanisms of hearing health and their evolution over time. There are many modifiable determinants of hearing loss, in several stages across an individual's lifespan; tackling socioeconomic inequalities throughout the life-course could improve the population's health, maximising the opportunity for healthy ageing.

***Keywords**:* Critical interpretive synthesis, Health Inequalities, Healthy Ageing, Health Literacy, Patient Safety

2.2. Introduction

Hearing loss involves the partial or total inability to hear sounds from one or both ears. It can be categorised as mild, moderate, severe, or profound, according to its severity. Approximately 15% of the global adult population suffers from some degree of hearing loss (World Health Organization, 2013). Approximately 432 million adults – almost 7% of the global population – has disabling hearing loss, defined as a pure-tone average (PTA of the audiometric hearing threshold at 500, 1000, 2000, and 4000 Hz (PTA0.5-4.0kHz) greater than 40 dB HL in the better hearing ear (Wilson et al., 2017).

Hearing loss is far beyond a sensory disorder, as it is associated with negative physical, social, cognitive, economic, and emotional consequences. In high-income countries, hearing loss is the third most common chronic health condition among older adults, following high blood pressure and arthritis (Barnett, Koul, & Coppola, 2014). Nevertheless, it should be noted that the magnitude of the effect of age on hearing loss varies considerably among individuals. Nearly one in three people over 70 years old do not develop high-frequency hearing loss, a condition which has traditionally been linked with ageing (Slade, Plack, & Nuttall, 2020). Despite diligent research over the past decades, understanding 'age-related hearing loss' is minimal (Bowl & Dawson, 2019).

What is widely known as 'age-related hearing loss' has similar characteristics to sensorineural hearing loss which can occur at any age. Based on that, as the knowledge on the causes of hearing loss in patients with older age increases, the need for expressions of hearing problems without specific aetiology on older age, through terms like 'presbyacusis', is likely to be diminished (Kiessling et al., 2003). It might be helpful to consider the injurious influences in hearing during individuals' lifespans. The above notion, though, has a long history in hearing research, when the concept of 'socioacusis' first introduced to define 'the hearing loss that develops over time after repeated exposures to loud noise and not to occupational exposure to noise, physiological changes with age, or disease' (Abbate et al., 2005). Rosen and Olin's (1965) studies in the 1960s revealed that the members of the Mabaan tribe in southeast Sudan, living in a dramatically quiet atmosphere, had a significantly superior hearing at 70 years old compared to people with a similar age who lived in noisy industrial areas.

More recently, the term of ‘lifestyle-related hearing loss’ has been added to the literature, where lifestyle refers to ‘social practices and ways of living adopted by individuals that reflect personal, group and socioeconomic identities’ (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2019b). The term incorporated the notion of ‘socioacusis’ by including the hearing loss cases that develop due to exposures to sociospatial and modifiable lifestyle factors (Tsimpida, Kontopantelis, Ashcroft, & Panagioti, 2020b). In practice, many actions could be taken on several levels to make social listening safe, in terms of intensity, duration and frequency of exposure to sounds (World Health Organization, 2015b). The World Health Organisation has suggested that primary prevention could reduce hearing loss prevalence by 50% or more in some world regions (Wilson et al., 2017).

On the other hand, evidence shows that a considerable percentage of hearing loss cases that cannot be prevented can be managed satisfactorily with hearing aids, which is vital given the substantial burden hearing loss causes (Wilson et al., 2017). However, since the cost of rehabilitative services for hearing loss is high, all countries, especially the resource-constrained countries, should focus on primary prevention rather than tertiary prevention (World Health Organisation, 2018). The focus on preventing major causes of deafness and hearing loss reaffirms WHO’s vision of a world in which ‘no person experiences hearing loss due to preventable causes’ (World Health Organisation, 2018). There is great potential for reducing the burden of hearing loss; in order to do, modifiable factors linked to socioeconomic inequalities in hearing health need to be better understood and addressed (Emmett and Francis, 2015; Scholes et al., 2018).

Many researchers have tried to identify the mechanisms which link early-life experiences to health in older age. Various conceptual models on life-course epidemiology have been formulated (Ben-Shlomo & Kuh, 2002). These models aim to facilitate a different understanding of the causal mechanisms. The life-course approach to chronic disease epidemiology examines an individual's life history by investigating how early life events and social determinants of health influence their future decisions and health issues such as diseases. This approach suggests that the diseases which appear in an individual's adult life may originate from their early life experiences (Kuh & Shlomo, 2004).

The 'theory of causation' (**Figure 2.1**) is another prominent theoretical framework which explains health inequalities. It proposes that social stratification formulates a social gradient in health, having a primary cause of the unequal distribution of power, money and resources (Kröger, Pakpahan, & Hoffmann, 2015). Another significant model is Diderichsen's model of 'the mechanisms of health inequality' (Diderichsen, Evans, & Whitehead, 2001; Diderichsen & Hallqvist, 1998), which explains the several mechanisms which play a role in stratifying health outcomes. Diderichsen's theory describes how the political context contributes to health inequalities (World Health Organisation, 2010).

Recent models on health inequalities focus on the individual's perspective, i.e. on one's education, employment and income (Diderichsen et al., 2012). This perspective emphasises the relationship between one's social position and health, as show-cased by Åberg's model (Åberg Yngwe, 2004) (**Figure 2.2**). However, Åberg's model does not explain the evolution of the early-life socioeconomic circumstances, in terms of the disadvantages of material aspects over time, which is being highlighted as a crucial issue in life-course literature (Cheval et al., 2019).

Purpose of the present study

Today, after decades of research, the burden of adult-onset hearing loss is high, and the aetiology of what is widely known as 'age-related hearing loss' remains unclear (Olusanya, Neumann, & Saunders, 2014). The level of uncertainty regarding potential mechanisms has led to the need to conduct a critical analysis of the existing literature (Dixon-Woods et al., 2006). The goal is to assign explanations of the impact of the early-life socioeconomic circumstances on one's hearing health, and how hearing health inequalities are perpetuated throughout one's life-course.

A conceptual model's importance emerged due to the multifaceted factors that contribute to hearing health disparities (Diez Roux, 2012; Dixon-Woods et al., 2006). A conceptual model can provide a visual representation of the multiple factors that affect a person's hearing in different life stages. Furthermore, a conceptual model offers the framework to generate testable hypotheses and empirically valuable questions to inform future research, interpret results, and design targeted interventions (Diez, 2012).

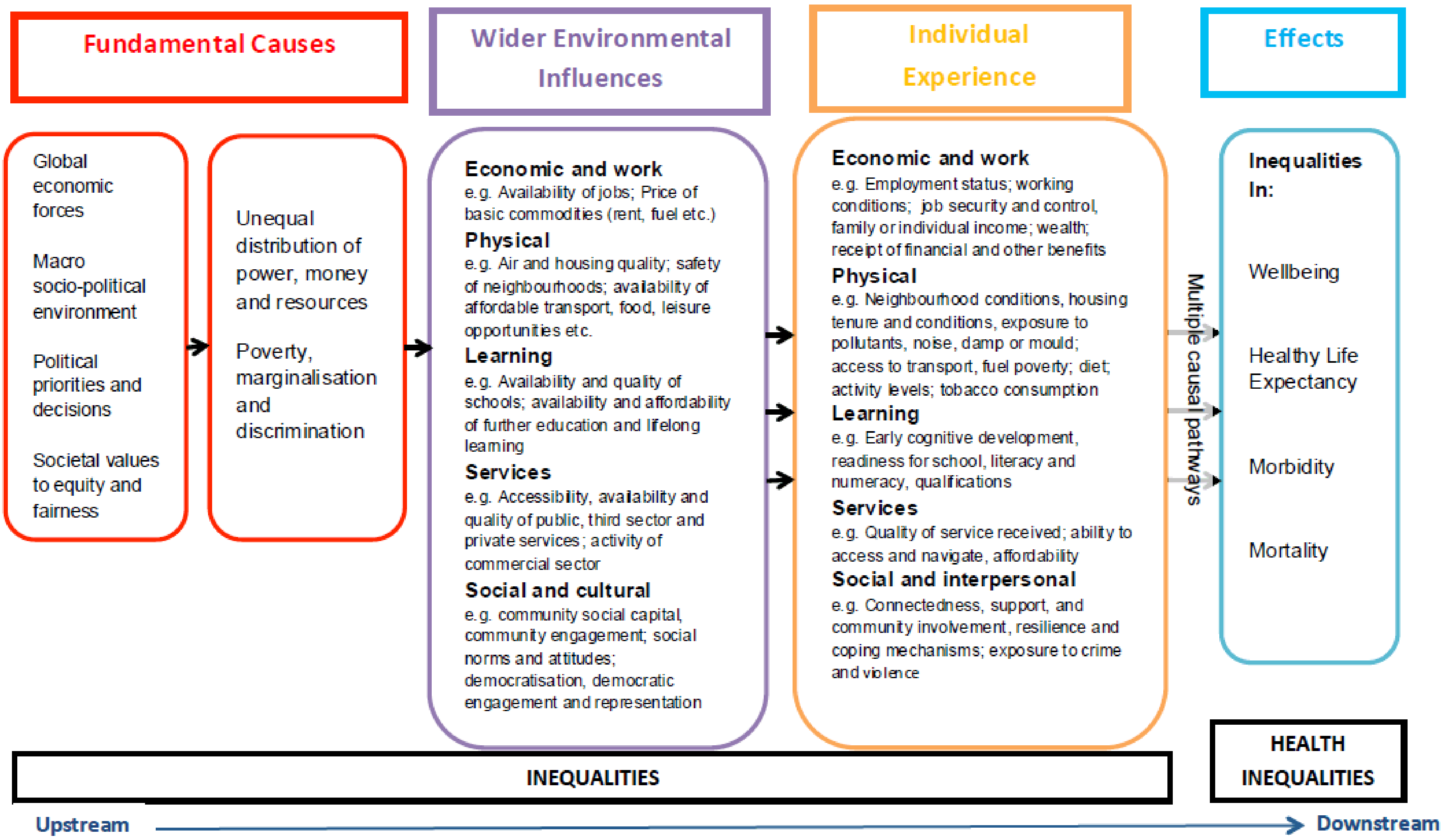

Figure 2.1. Health inequalities: theory of causation (Molony & Duncan, 2016).

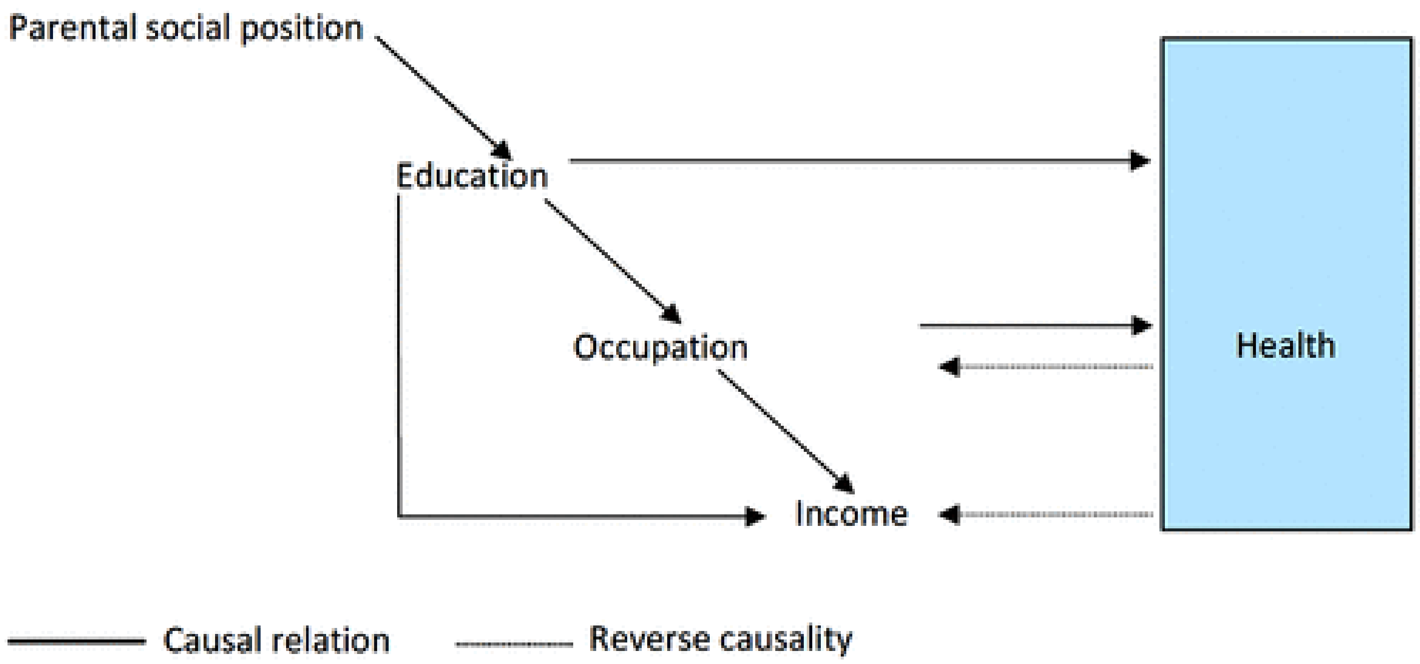

Figure 2. 2. Social position and health and relevant causal mechanisms (Åberg Yngwe, 2004).

The nature of hearing loss also reinforces the need for a separate model for hearing health inequalities; it is a non-communicable disease (World Health Organization, 2015a) with long duration and slow progression during the life-course, and can seriously affect one's lifestyle. The individuals who have hearing loss are more likely to have poorer educational achievements, higher unemployment rates, and lower annual family income than those without hearing loss (Bartley & Blane, 2008). Moreover, there is a considerably higher prevalence of multimorbidity among adults aged 65 and over who suffer from hearing loss, compared to those who do not suffer from hearing loss or with other health conditions, which increases the overall disease burden (McKee, Stransky, & Reichard, 2018; Young, 2014).

Therefore, hearing health inequalities cannot be satisfactorily contextualised within more general models on inequality (Diez, 2012). A new analytical approach, which embraces the notion of structural causation and articulates the mediating mechanisms of the cumulative hearing inequalities and their evolution over time, is needed (Diez, 2012). Given the burden of adult-onset hearing loss, such a conceptual model for identifying hearing health inequalities could improve many indicators of population health status, including the broad measures of individual's physical, mental and social wellbeing.

This review aims to a) provide an interpretive synthesis of the existing literature and give insight into the socioeconomic disparities in hearing health and b) formulate a conceptual model for hearing health inequalities, which depicts the specific mechanisms for hearing health and their evolution over time.

2.3. Methods

This review's scope is broader than testing a specific research question, which could be achieved through a systematic review or scoping review. This paper aims to integrate diverse forms of research evidence. To do so, the methodology of critical interpretive synthesis (CIS) is adopted (Depraetere, Vandeviver, Keygnaert, & Beken, 2020; Flemming, 2010). The CIS is a relatively new review type used for synthesising multi-method research which has its origins in health equity research and is increasingly applied in the social sciences (Depraetere et al., 2020). This review type is distinguished from other review types through its emphasis on theory development and flexibility, involving an iterative approach to searching and selecting evidence (Depraetere et al., 2020).

This method uses theoretical sampling and appraises the quality of evidence based on its relevance to the investigation topic. The quality of research is appraised as the extent to which it informs theory and involves the development of 'synthetic constructs' or 'themes.' These themes are then linked and supported by the relevant evidence, which is placed within its context to build a highly interpretive conceptual model (Dixon-Woods et al., 2006). The authors developed this approach and rejected the concept of a reciprocal translational analysis, i.e. a summary of what has been already used in the literature because the latter is not helpful when dealing with a diverse body of evidence and attempting to develop a theory (Dixon-Woods et al., 2006). The CIS, instead, is 'explicitly oriented towards theory generation,' and adopts a methodology with some steps similar to those of a systematic review in combination with qualitative interpretive approaches, aiming to review and combine existing evidence into a coherent whole, and to provide new insights with explanatory power (Barnett-Page & Thomas, 2009).

This paper relies on CIS reviews' described guidelines to ensure that the reporting is transparent and coherent (Depraetere et al., 2020). The following six activities represent the dynamic process of a CIS:

(1) **Open research question**: The CIS starts with the formulation of an open research question regarding the impact of socioeconomic inequality on hearing loss.

(2) **Literature search**: We searched three databases – PubMED, Scopus and Psych – using the keywords 'hearing AND inequalities,' 'hearing AND disparities' and 'hearing AND determinants' in the Title/Abstract. We identified 779 articles with potentially relevant abstracts. The most recent search was conducted in October 2020.

(3) **Literature selection**: the literature was selected following the inclusion criteria below, not necessarily aiming to identify and include all relevant literature, but rather sources directly relevant to the theoretical framework. We included peer-reviewed studies (empirical studies, systematic reviews and theory-based overviews), which included participants with hearing loss (with no age restrictions) and presented associations between hearing loss and health inequalities either as a determinant factor or as a health outcome. English written articles from any country and setting were eligible for inclusion in this study. A two-stage screening process was applied: first, titles and abstracts were screened against the inclusion criteria; second, a detailed review of the potentially eligible full-texts was completed. Two reviewers were involved in the data screening process (DT; MP). Disagreements were resolved through discussion until a consensus was reached. If the two authors could not reach a consensus, the team of four co-authors would discuss until a consensus was reached.

(4) **Quality appraisal**: We assessed the methodological quality of the included studies, using criteria provided in the guidance on quality assessment components and ratings (Thomas, Ciliska, Dobbins, & Micucci, 2004). The studies were assigned a rating of 1 for each one of the following main criteria met (maximum rating of 4):

(a) *Selection bias*: likely to be representative of the target population and have a response rate or data capture among eligible participants of 70% or greater.

(b) *Design*: cohort analytic, case-control, cohort or an interrupted time series.

(c) *Covariates*: control of a minimum of three critical covariates in the analysis, including sociodemographic characteristics (e.g. age, sex and education).

(d) *Data collection methods*: use of psychoacoustic hearing assessment tools, which are valid and reliable.

The above quality criteria do not examine the theoretical contribution to CIS, thus were not used to exclude studies.

(5) **Data extraction**: A data extraction table was developed, including the following elements of the selected studies: names of authors, publication year, country, key point(s) made by the authors and in which synthetic constructs they were applied. Four recurring concepts/themes were identified from the studies, and the literature was placed within its context, to inform the emerging research themes (Dixon-Woods et al., 2006). **Supplementary Table 2.1** provides the key discussion points for the analysis of the 53 studies, which support the four research themes. **Supplementary Table 2.2** presents the scoring criteria of quality appraisal.

(6) **Formulation of a synthesising argument**: The separate analysis of the sources used in each theme helped to identify the relationships between the four themes. A synthesising argument was then formulated, which also takes into consideration elements of theories on health inequalities. The themes were then synthesised in an inductive approach, and a coherent theoretical conceptual model was formulated, depicting the relationship between the network of the discussed constructs, which aims to contribute to the theoretical development of the synthesis topic (Depraetere et al., 2020).

Definition of key terms

The term 'socioeconomic position (SEP)' is used instead of the term 'socioeconomic status,' to refer specifically to the components of economic and social well-being; this is in line with the suggestion of Krieger et al. (1997). The term SEP is linked to both childhood and adult social class positions. It includes both resource-based (e.g. deprivation) and prestige-related characteristics, which refer to the individual's rank or status in a social hierarchy. We decided to include education, occupation, income and wealth as the selected indicators of socioeconomic position (SEP); according to the list of SEP indicators proposed by Galobardes et al. (2006), these factors encompass aspects of an individual's socioeconomic stratification throughout their life-course.

We use the term 'hearing loss' instead of the term 'hearing impairment,' which looks beyond pathology, addressing issues that interact to affect the individual's ability to maintain as high a level of health and well-being as possible and function within society: according to the Sociopolitical Model of Disability, hearing disability is being approached through the lens of the ‘loss or limitation of opportunities’, rooted in societal barriers (Smart, 2006). We consider this approach more suitable given the aims of this study, which are to examine the social determinants of hearing health. This approach is also consistent with the International Classification of Functioning, Disability and Health (ICF) and Core Sets for Hearing Loss (CSHL), which highlight the importance of a multidimensional model for assessing the functioning and disabilities of people with hearing loss (Alfakir, van Leeuwen, Pronk, Kramer, & Zapala, 2019; Granberg, Swanepoel, Englund, Möller, & Danermark, 2014).

2.4. Results

A total of 779 studies were identified, and following the two-stage screening process, 53 studies were selected for inclusion in the review, which coincides well with the ideal number of around 50 studies which should be included in a CIS (Dixon-Woods et al., 2006). **Figure 2.3** shows the flow diagram of the study identification and selection process.

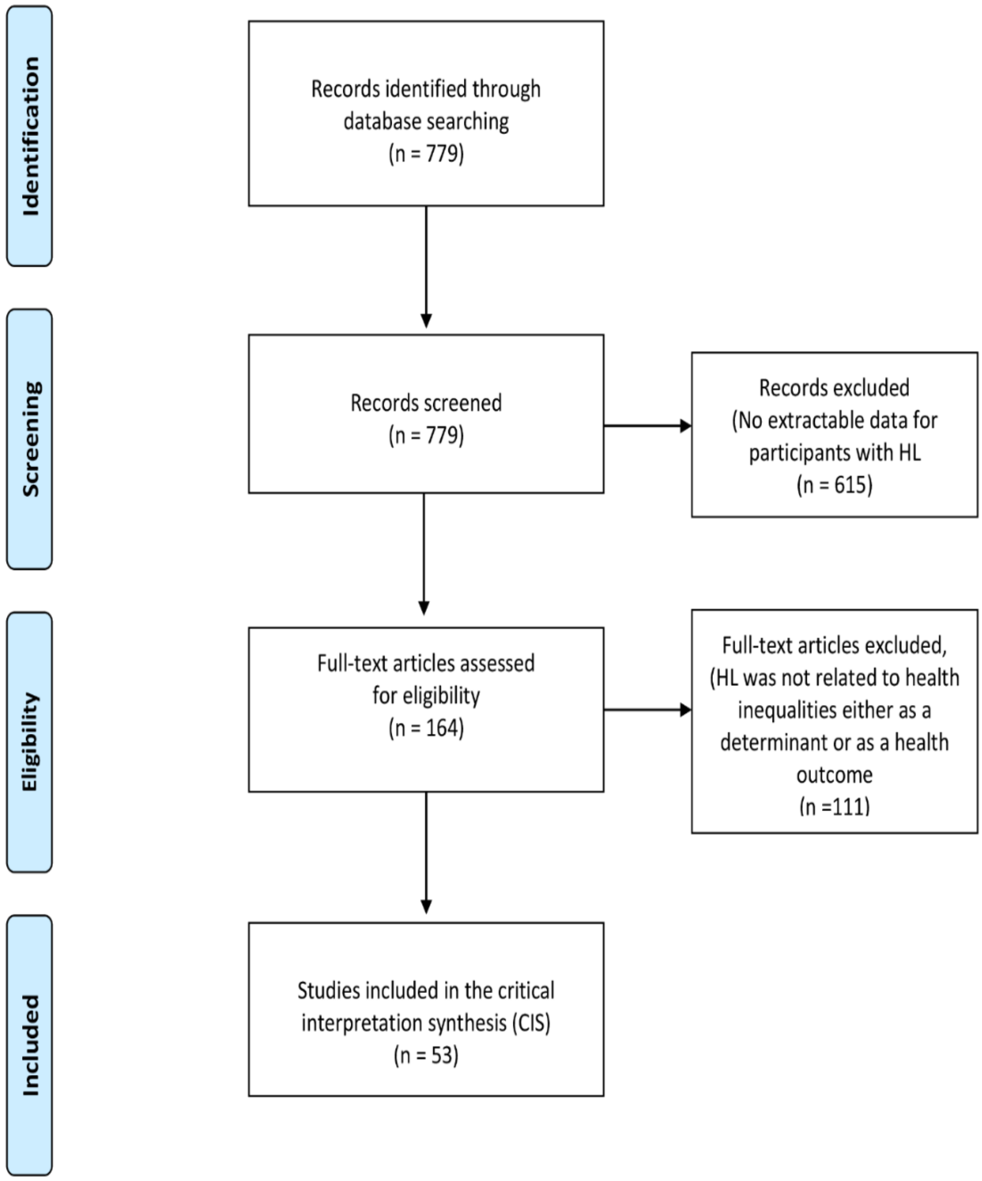

Figure 2. 3. Study identification flow diagram, inclusion and exclusion criteria.

The findings from the CIS are provided below in the form of synthesising arguments, which are based on the following four themes, which are then linked and used for the development of a conceptual model (Depraetere et al., 2020):

Theme 1 (T1): Low socioeconomic position (SEP) and hearing loss form a vicious cycle, as hearing loss may be both a consequence of and a causal contributor to socioeconomic disparity.

Prior research emphasises the health disparities which exist between people with and without disabilities (Dobbertin et al., 2015). The need for attention to disparities within a population with a disability has been underestimated, and there is a lack of research on the disparities related to the type of disability (Horner-Johnson et al., 2013). A number of researchers have reported that low SEP is associated with increased risk of inequalities in the hearing health of mid-aged people (Chou, Beckles, Zhang, & Saaddine, 2015; Kupriianova, Zakharchuk, Zherebtsov, Spivak, & Spivak, 2013; Scholes et al., 2018b).

More specifically, some critical indicators of the socioeconomic stratification (Galobardes et al., 2006), such as education, occupation, income and wealth, have been correlated to hearing loss; for instance, people with less access to education have relatively worse hearing health (Andrade & Lopez-Ortega, 2017; Cruickshanks et al., 1998; Scholes et al., 2018b; Tsimpida et al., 2019b). Furthermore, people who have attained a higher level of educational are less likely to suffer from hearing loss in their adult lives (Chou et al., 2015; Martin et al., 2012; Zhan et al., 2011).

Lower educational attainment is a predictor of social inequality in later life, as it affects employment opportunities and earning potential, limiting people with lower education to less paid jobs. Moreover, a lower level of education is associated with occupations that involve high noise exposure levels, thus increasing an individual's risk of acquiring hearing difficulties (Pierre et al., 2012). High exposure to noise may explain why people with less education suffer more from hearing loss (Martin et al., 2012), as there is a clear relationship between occupational exposure to noise and an increased likelihood of suffering from hearing loss (Cruickshanks et al., 1998; Helvik, Krokstad, & Tambs, 2009; Hétu, Riverin, Lalande, Getty, & St-Cyr, 1988). Notably, in Rosenhall et al.'s (1999) study, the manual workers had a similar level of self-assessed hearing difficulties as non-manual employees ten years older. What is currently unknown is whether the hearing level of industrial workers exposed to hearing health promotion interventions and wear protective equipment differs from workers or the general public who have not undergone such interventions.

Occupation is closely related to income and wealth, which are important determinants of populations' average health and contribute significantly to health inequalities (Wilkinson & Pickett, 2006). Existing literature shows that the financial constraints and inadequate health insurance may affect individuals' willingness to seek help for hearing loss (Chan et al., 2017) and lead to lower hearing aid acquisition and usage (Bainbridge & Ramachandran, 2014). This might explain the higher prevalence of untreated hearing loss among low-income adults, compared to those in the highest income and wealth quintiles (Nieman, Marrone, Szanton, Thorpe, & Lin, 2016; Scholes, Biddulph, Davis, & Mindell, 2018a; Tsimpida et al., 2019b). The consequences of untreated hearing loss vary and depend on the degree, type and configuration of loss. However, hearing loss may significantly affect the ability of individuals to maintain good health and to function within society, as it limits their ability to participate in interpersonal relations, and diminishes their health-related quality of life (Danermark, Granberg, Kramer, Selb, & Möller, 2013; Eisele et al., 2015; Tsimpida, D., Kaitelidou, D., & Galanis, 2018a). This phenomenon can be explained within a broader bio-psycho-social-environmental context, consistent with the WHO's definitions of disability (International Classification of Diseases, 11th Revision (ICD-11), 2018).

Hearing loss is associated with significant adverse outcomes. For example, hearing loss in early life may lead to low educational achievements (Chou et al., 2015; McKee et al., 2018; Pierre et al., 2012; Smith et al., 2016), and may affect an individual's future employment opportunities, and even their ability to continue working or to advance occupationally (Emmett & Francis, 2015; McKee et al., 2018). People who have hearing loss often use a ream of strategies to live and work with it, facing numerous challenges in order to maintain optimal work performance (Shaw et al., 2013). These challenges may affect people's decision to retire early, subsequently affecting their financial position as older adults (Davis et al., 2016; Emmett & Francis, 2015; McKee et al., 2018; Smith et al., 2016). On the other hand, people with good hearing may have better chances to achieve higher-status positions (Chou et al., 2015). Thus, in line with the 'health selection' approach in health inequalities, differences in SEP might result from a lower hearing health status, which suggests that differences in health affect the SEP (Kröger et al., 2015).

Hearing loss, especially when left unaddressed, may limit one's ability to communicate, making things worse for those who have hearing loss and other chronic health conditions commonly comorbid with hearing loss. This may even delay their detection. The delay in detecting health issues could also lead to further socioeconomic disparities in patients with hearing loss, by increasing the disease burden and lowering their health-related quality of life (McKee et al., 2018; Tsimpida et al., 2018a; Young, 2014). Therefore, the already significant burden of having a chronic disease for the more socially and economically disadvantaged could worsen, contributing to enhancing inequalities in morbidity and mortality (Beauchamp et al., 2015). It could be argued that SEP and hearing loss form a vicious cycle, with each causing the other: hearing loss is **both a consequence and a causal contributor to socioeconomic disparity**. Besides, not only can a sensory impairment lead to low economic resources in adulthood (Chou et al., 2015), but also the hearing health inequalities can be accumulated: the more a person functions in a lower SEP during their lifespan, the more their hearing problems will be accumulated.

Theme 2 (T2): Indicators of lower socioeconomic position (SEP) are associated with a less healthy lifestyle, which is harmful to hearing ability.

The associations between indicators of lower SEP and hearing loss may indicate exposure to risk factors which have a damaging effect on hearing (e.g. exposure to loud noise during the employment in noisy occupations) (Lie et al., 2016). However, they may also indicate less healthy lifestyle factors, which are the non-medical determinants of health (Tsimpida et al., 2018a). Evidence shows that several modifiable lifestyle factors – such as smoking (Gopinath et al., 2010), alcohol consumption (Zhan et al., 2011), having a high body mass index (BMI), eating high fat and high-calorie food (Curhan, Eavey, Wang, Stampfer, & Curhan, 2013; Üçler et al., 2016) and insufficient exercise (Curhan et al., 2013; Spankovich & Le Prell, 2013) –

increase the likelihood that a person will have poor hearing health. Hence, adopting a healthy lifestyle, not smoking, maintaining proper nutrition, and exercising regularly, can minimise the lifestyle risk factors for hearing loss in older adults (Davis et al., 2016). Existing studies have investigated the cross-sectional relationship between higher physical activity and hearing sensitivity and suggest that hearing accessibility to fitness programmes may not enable people with sensory losses to participate effectively.

Moreover, the impact of alcohol consumption on hearing thresholds in older age is not yet clear. Studies that have examined this association are generally of poor quality and do not allow for satisfactory analyses and result in controversial findings. For example, the drinking measure used in Ecob et al.'s (2008) study was the number of standard units of alcohol consumed in a typical day at the age of 45 years, coded to 'greater than or equal to seven drinks per day' in contrast to 'all other.' Another study which examines a cohort of the European population was also poorly designed and concluded that moderate alcohol consumption – defined as 'at least one alcoholic drink a week' – was seen to have a protective effect on hearing (Fransen et al., 2008). Also, even though Tsimpida et al.'s 2019b) recent study shows that drinking above the low-risk-level guidelines – i.e. more than 14 units of alcohol in the last seven days – increases the likelihood of hearing loss, the cross-sectional nature of the study does not allow for the generalisation of the findings. By contrast, the longitudinal study of (Gopinath et al., 2010) does not confirm the association between alcohol consumption and prevalent hearing loss. It can thus be suggested that, to date, the impact of alcohol intake on hearing loss is not fully understood. Therefore, future large population-based studies are warranted.

People in lower SEP might face conditions which drive them to adopt health-damaging behaviours and avoid the health-protecting ones (Adler et al., 2007). For instance, it may be the case that the lower a person's income, the less they can afford to buy healthy food, which is almost always more expensive. A lower level of education and income may also lessen one's engagement in healthy daily behaviours such as physical activity (Zhan et al., 2011). Besides, high levels of stress due to lower resources can induce unhealthy behaviours, such as sugar consumption (Spankovich & Le Prell, 2013) and reliance on tobacco and alcohol (Gopinath et al., 2010), as attempts of short-term stress release. Also, evidence shows that those in a lower socioeconomic position, in terms of having a lower level of education and lower income, are more likely to smoke. This phenomenon is not related to the likelihood of smoking initiation, but to the likelihood of quitting, which has been closely related to higher education and higher income levels (Adler & Newman, 2002). The adoption of these behaviours is not due to a lack of will-power or moral fortitude, but to a lack of educational opportunities which shape an individual's earning potential and tend to lead to a lower income (Adler et al., 2007). In general, the lack of material resources, for people who may face pressing problems with income, employment or even personal safety, lowers their possibility to prioritise and contribute their time and energy to adopting healthy behaviours (Adler et al., 2007).

A recent study finds that socioeconomic and lifestyle risk factors, such as body mass index, physical activity, tobacco and alcohol consumption, are associated with hearing loss among older adults as strongly as core demographic risk factors, such as age and gender. The study argues that lifestyle factors (such as high body mass index, physical inactivity, tobacco consumption and alcohol intake above the low-risk-level guidelines) may account for the higher prevalence of hearing loss among males (Tsimpida et al., 2019b). Moreover, socioeconomic and lifestyle factors may interact. Another study shows in fact that smoking behaviour amplifies the damaging effect of occupational noise exposure on hearing (Sung et al., 2013). It can therefore be proposed that lifestyle behaviours act as causal pathways which mediate the relationship between social determinants and hearing health and help to explain the association between them.

Theme 3 (T3): Improving health literacy can mitigate hearing health inequalities and play a significant role in the adoption of beneficial hearing health behaviours, including help-seeking for hearing problems, hearing aid acquisition and usage.

An increasing number of studies attest the fact that people who are less likely to adopt beneficial health behaviours have low health literacy. The concept of health literacy refers to one's ability to make judgments and decisions concerning healthcare, disease prevention and health promotion in their everyday lives (Van den Broucke, 2014). Previous studies show differences in health literacy patterns within population sub-groups, with the most vulnerable demographic groups having lower health literacy (Beauchamp et al., 2015). Therefore, health literacy plays an essential role in explaining the underlying mechanism which drives the relationship between one's low level of education and poor general, physical and mental health (Beauchamp et al., 2015; van der Heide et al., 2013). Consequently, health literacy skills may act as modifiers between people's educational level and their adopted health behaviours (Arcaya, Arcaya, & Subramanian, 2015).

Health literacy is a multidimensional construct that also refers to one's ability to navigate the healthcare system and work out the best care for them and their ability to decide which providers they need to see (Beauchamp et al., 2015). For this reason, an individual with limited financial resources may not feel the urgency to seek medical care for a health need. In contrast, the same individual with ample financial resources may feel able to prioritise their health needs (Barnett et al., 2014). Therefore, having a low SEP may not only be a barrier to accessing hearing health care due to financial costs (Barnett et al., 2014), but it may also reflect disparities in people's access to identification and treatment of hearing problems (Chan et al., 2017; Harrison et al., 2020; Luo, Gao, & Zheng, 2020). The latter is discussed in Benova et al.'s study (Benova, Grundy, & Ploubidis, 2015), which examines four SEP indicators – education, occupation, income, wealth – in the health-seeking process of older adults with hearing loss. They find that there is a strong association between SEP and self-report of hearing difficulty for a referral to secondary health care services. Thus, people with low SEP are less likely to seek help or access hearing health services (Tsimpida, D., Galanis, P. & Kaitelidou, 2019a).

Moreover, after the onset of hearing loss, individuals may face substantial disparities in accessing and using hearing health care (Nieman & Lin, 2017; Tsimpida et al., 2019a). As a result, a person with hearing loss coming from a lower SEP is more likely to experience unmet health care needs due to a combination of factors, including income, education, access to health services and disability. Thus, the disadvantaged social situation of people with functional limitations such as hearing loss is a significant additional barrier to their already limited access to healthcare (Bainbridge & Ramachandran, 2014; Chien & Lin, 2012; Nieman & Lin, 2017; Nieman et al., 2016; Pichetti, Penneau, Lengagne, & Sermet, 2016). It should be noted that the impact of SEP on hearing aid uptake is closely related to the hearing aid dispensing arrangements in each country. For example, financial constraints and lack of or inadequate insurance coverage are significant barriers to hearing healthcare in the United States, where the majority of people are on private health insurance (Chan et al., 2017). In the United States, the average cost of hearing aids exceeds $4700, which can be prohibitive for many potential users (Wilson et al., 2017). The prohibitive cost is reflected in a lower hearing aid uptake among older adults from minority ethnic groups and those in a lower SEP (Nieman & Lin, 2017; Nieman et al., 2016).

However, in addition to costs, other factors, such as a low level of education and disability, also contribute to the lower uptake of hearing aids among lower socioeconomic groups (Reichard et al., 2017). The existence of these factors explains why hearing aid use is also low in countries where most people are covered by public insurance and the cost is therefore not a barrier to hearing aid uptake (Barton et al., 2001). For instance, cost is unlikely to be a significant barrier in the United Kingdom (UK), where the majority of hearing aids are provided in a universal health care setting and are free at the point of delivery. Indeed, although treatment and hearing aid provision is financially supported in the UK through the National Health Service (NHS), people in the lower socioeconomic groups use specialist health services less frequently than those in higher groups (Scholes et al., 2018b). Recent evidence from the UK shows that specific demographic groups are unlikely to obtain hearing aids, proving that people of low SEP face other non-financial barriers. These differences do not only reflect the differences in the health systems and hearing aid provisions among countries, as suggested by Sawyer et al. (2020), but also emphasise individuals' inability to identify their hearing difficulties as a barrier in their help-seeking process, even in countries where the hearing aids are available free of charge (Tsimpida, Kontopantelis, Ashcroft, & Panagioti, 2020a).

An explanation to the above paradox is that the perception of hearing ability acts as a strong predictor of hearing aid acquisition, even when financial factors are mitigated (Bainbridge & Ramachandran, 2014). Ng and Loke (Ng & Loke, 2015) report that individuals' SEP plays a significant role in their readiness to adopt hearing aid; the SEP may influence the self-perceived hearing problems and even the perceived benefit from the hearing aids usage.. Low awareness, denial of hearing loss, self-image implications, discrimination based on age, gender, race or disability and acceptance of hearing loss as a normal part of the ageing process impact individuals' decision to seek hearing care (Nieman et al., 2016a). Therefore, the negative attitude towards deafness and ageing may play a crucial part in perpetuating individuals' neglect of the disorder, its consequences and possibly the onset of the related comorbidity (Fischer et al., 2011). The above non-audiological determinants can be crucial for the process of change which occurs when individuals decide to seek help before further deterioration of their hearing (Feeny et al., 2012).

Theme 4 (T4): Hearing loss risks the quality and safety of individuals' health and poses significant communication barriers in healthcare settings, which may delay the detection and increase the risk and impact of other long-term conditions.

Historically, hearing loss has primarily been conceptualised as impairment within a biomedical model and managed clinically within an isolated care model, with little consideration of comorbidities (Davis et al., 2016). However, hearing loss is commonly comorbid with cardiovascular disease (Bishop, 2012; Genther et al., 2013), dementia (Davies et al., 2017), depression (Armstrong et al., 2016), diabetes (Horikawa et al., 2013), falls (Lin & Ferrucci, 2012) and chronic kidney disease (Nieman & Lin, 2017). Moreover, hearing loss poses significant communication barriers in healthcare settings, and people who suffer from hearing loss are often less satisfied with their access to and the quality of health care provision (Barnett et al., 2014; Tsimpida et al., 2019a). The communication barrier could multiply health disparities in comorbid health conditions, as the sum of multiple health conditions, which is increasingly prevalent with advancing age, has serious consequences (Davis et al., 2016) (von Gablenz, Hoffmann, & Holube, 2017). In a previous study involving older adults of several socio-demographic groups in Australia, people who had four or more chronic conditions reported more difficulties in navigating the healthcare system and having sufficient information for health, which are two of the nine domains of the Health Literacy Questionnaire (Beauchamp et al., 2015). Moreover, multimorbidity – which occurs mainly when an individual has poor mental health – is associated with a two-fold increased risk for patient safety incidents and low quality of patient care (Panagioti et al., 2015).

People with hearing loss also face significant challenges in their communication with health care professionals (Barnett et al., 2014). The communication problems are also challenging for the health providers, as they may not obtain sufficient information for an accurate diagnosis (McKee et al., 2018). This issue can be highly problematic in cases of comorbidity, as it is very likely to lead to misunderstandings about diagnosis and treatment methods, or in cases of inference of patient problems which do not exist, which could lead to unnecessary testing and ineffective treatment (Barnett et al., 2014). In comorbidity, methods are needed to help providers ensure that older patients with hearing loss who are diagnosed with certain conditions do not miss important information and recommendations due to communication barriers (McKee et al., 2018). Therefore, health professionals must tailor the provision of healthcare to the needs of people with hearing loss (Lee & Heo, 2020).

Poor communication between providers and patients can result in a variety of adverse outcomes. It affects patients' awareness of healthy behaviours, appropriate use of health services, understanding the importance of specific management and treatment approaches and the effective transfer of health knowledge (McKee et al., 2018). It may also result in poor adherence to treatment recommendations or have detrimental effects on patients' clinical outcomes (McKee et al., 2018). It can thus be suggested that hearing loss negatively affects the quality and safety of healthcare an individual receives. The above communication barriers in healthcare settings may delay the detection and increase the risk and impact of other long-term conditions, which are commonly comorbid with hearing loss. Therefore, the improvement of the hearing health of the population could also improve the healthcare quality and safety for older people, as well as the broader measures of their physical, mental and social wellbeing. Thus, the growing awareness of novel approaches for fostering hearing loss self-management and the emerging eHealth and mHealth applications aimed at improving hearing-related knowledge of management and treatment is very promising (Ferguson, Maidment, Henshaw, & Heffernan, 2019; Maidment, Coulson, Wharrad, Taylor, & Ferguson, 2020).

The Conceptual Model for Hearing Health Inequalities (HHI Model)

The findings of various studies show that there are many complex factors which interact and contribute to hearing health inequalities. A conceptual model can depict the complex interaction between the socioeconomic indicators and hearing health throughout an individual's lifespan, showing how these indicators impact multiple factors. The proposed model for hearing health inequalities (**Figure 2.4**) draws overtly on Åberg's model presented in **Figure 2.2** (Åberg Yngwe, 2004) and the concept of the dynamic relationship between health and SEP (Adler et al., 2007) to provide a visual representation of the inequalities in hearing health and their evolution over time. Like other models, the HHI model focuses on the individual's perspective, i.e. on one's education, employment, and income (Diderichsen et al., 2012). Wealth was selected as an indicator of SEP in older adulthood (Galobardes et al., 2006). The individual experience in the HHI model is the result of several macro-level factors, which are considered the 'fundamental causes' and the 'wider environmental influences' (**Figure 2.1**) which, through the multiple pathways depicted in the HHI model, lead to hearing health inequalities.

The model builds upon the four (4) previously presented themes (Themes 1-4) which emerged from the critical interpretive synthesis (Dixon-Woods et al., 2006), and incorporates the theoretical frameworks which have been used to explain inequalities in health. The materialist theory on which the Aberg's model is based is also used in the HHI Model, which has been stretched to life stages and supplemented by the following non-materialist approaches: the life-course (regarding processes with accumulative risk throughout one's lifespan); the cultural-behavioural (the adoption of healthy or risk behaviours developed from cultural influences), and the psycho-social approach (in terms of the varying social positions that one may have throughout their life-course). The psycho-social approach suggests that those in a lower SEP will suffer more from health-related issues due to the psycho-social injuries derived from inequality structures, including elevated stress responses by those who work in occupations with high noise exposure and economic strains (Adler & Newman, 2002; Bartley & Blane, 2008; Elstad, 1998; Sundmacher, Scheller-Kreinsen, & Busse, 2011). Given this, the HHI Model provides a multidimensional four-component approach to social stratification, which reflects the interplay among education, occupation, income and wealth, throughout one's lifetime. The particular way the four themes of the critical interpretive synthesis apply to the HHI Model is described in T1, T2, T3 and T4, respectively.

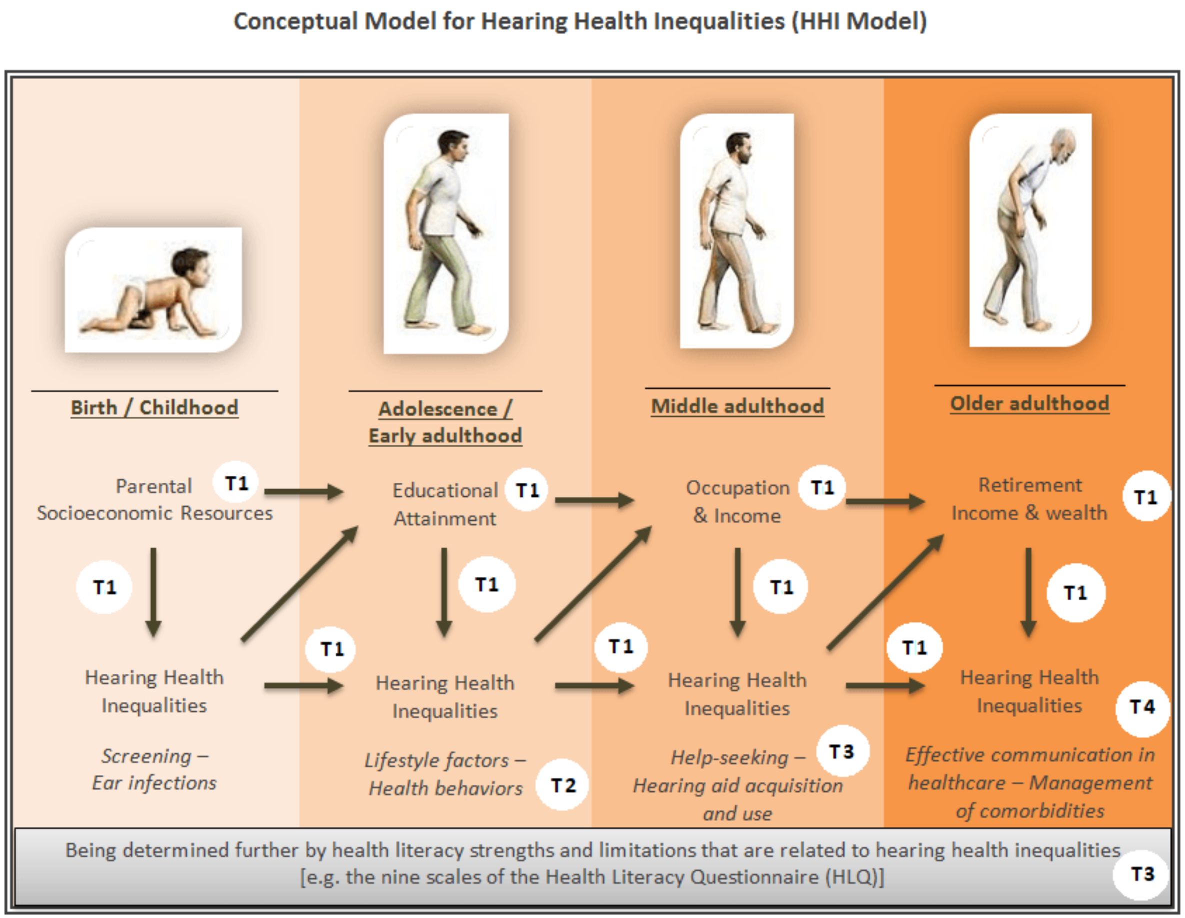

Figure 2.4. *Conceptual Model for Hearing Health Inequalities (HHI Model)* [a]

[a] T1: Low socioeconomic position (SEP) and hearing loss form a vicious cycle, as hearing loss may be both a consequence of and a causal contributor to socioeconomic disparity.

T2: Indicators of lower SEP are associated with a less healthy lifestyle, which is harmful to hearing ability.

T3: Improving health literacy can mitigate hearing health inequalities and play a significant role in the adoption of beneficial hearing health behaviours, including help-seeking for hearing problems, hearing aid acquisition and usage.

T4: Hearing loss risks the quality and safety of individuals' health and poses significant communication barriers in healthcare settings, delaying the detection and increasing the risk and impact of other long-term conditions.

Theme 1 (T1):

The HHI Model proposes that children born to parents from lower SEP tend to experience more health-related issues. The antibiotics used to treat a bacterial infection, especially in sick babies with a genetic predisposition, may affect their hearing health. Thus, many individuals with disabling hearing impairment are disadvantaged children who have been exposed to several risk factors during their prenatal, perinatal or neonatal period of development, or have experienced inequalities in access to screening tests (Mallmann, Tomasi, & Boing, 2020). Parent SEP's role is crucial, as many of these factors are closely linked to socially and economically deprived households and neighbourhoods, for example, the cytomegalovirus (CMV) infection, or nutritional deficiencies (Olusanya et al., 2014).

The exact mechanisms behind the link between parental SEP and hearing health inequality are still unclear. Previous analyses which study this connection (Ecob et al., 2008; Power et al., 2007) suggest the importance of people's social class of origin – in terms of their father's occupation – in their hearing thresholds in adulthood, but do not reach a definite conclusion regarding the possible mechanisms which cause such a link. In Ecob et al.'s (2008) study, the adjustment for noise exposure and smoking and drinking behaviours was found to reduce parental SEP's effect on the likelihood of adulthood hearing loss by around one-third in all examined frequencies. The above notion led the authors to conclude that many other risk factors also need to be examined to explain the relationship between hearing loss and parental SEP.

Theme 2 (T2):

The consequences of hearing loss in childhood may include impairment in language skills and lower educational achievement compared to children with normal hearing (Chorozoglou et al., 2018). Having a lower educational level is a predictor of educational and social inequality in later life, as it limits one's employment opportunities, relegating them to poorly paid jobs in their early adulthood. Manual jobs tend to be those with higher levels of noise exposure that is harmful to hearing ability, along with a possible faster deterioration in one's overall physical health (Chandola, Ferrie, Sacker, & Marmot, 2007). Gender differences in occupational noise exposure may explain why hearing loss is consistently cited as more prevalent among males. Furthermore, a recent study shows that living in noisy neighbourhoods and being in a low SEP further enhances one's likelihood of suffering from hearing loss (Dale et al., 2015).

Theme 3 (T3):

Having a lower educational status is also related to lower health literacy (Van den Broucke, 2014), which helps explain the differences between socioeconomic groups in terms of their health status (Beauchamp et al., 2015; Howard, Sentell, & Gazmararian, 2006). Therefore, health literacy limitations may explain why individuals of a lower SEP tend to adopt an unhealthy lifestyle, with higher levels of smoking and alcohol consumption, a higher body mass index (BMI) and lower levels of physical activity, which all contribute to hearing loss (Howard et al., 2006; Tsimpida et al., 2019b). Occupation and income may also affect one's access to hearing health services and hearing aids (Fischer et al., 2011). Financial barriers (direct/indirect) and one's ability to self-diagnose may influence their motivation to seek help for hearing difficulties.

Theme 4 (T4):

Hearing health inequalities in middle adulthood can then affect older adults' retirement status and income by impacting their ability to continue working or to advance occupationally (Chou et al., 2015). Lastly, hearing loss can add a further burden of disability on the lower socioeconomic groups (Marmot, 2020) by affecting not only their body functions and structures (e.g. deterioration of the ear), but also their ability to participate in society (International Classification of Diseases, 11th Revision (ICD-11), 2018), increasing the barriers to their use of and access to health services. This can severely affect the management of health conditions comorbid with hearing loss (Tsimpida et al., 2018a; Young, 2014). People of lower SEP may, therefore, face a double burden: first, increased levels of health impairments and, second, a lower quality of life after their health impairment occurrence (Raggi et al., 2016).

Also, hearing health inequalities may accumulate: the higher a person's socioeconomic status, the better their hearing health can be throughout their life span. On the other hand, those who are persistently exposed to inadequate socioeconomic resources during their childhood and adulthood face a disproportionately higher chance of suffering from hearing loss. It is now clear how the low SEP and hearing loss form a vicious cycle, as hearing loss can be a consequence and a causal contributor to socioeconomic disparity.

Health literacy has been defined by the World Health Organisation (WHO) as 'the cognitive and social skills that determine individuals' motivation and ability to gain access to, understand and use information in ways that promote and maintain good health' (Nutbeam, 1998). The grey text box about health literacy highlights – from individual's perspective – that health literacy skills act as modifiers, underpinning the relationship between socioeconomic inequalities and hearing health over time (Arcaya et al., 2015). Given this, the conceptual model for hearing health inequalities is not a 'fixed procrustean framework' that enforces uniformity in explaining hearing health inequalities; instead, it recognises the multifactorial inter-individual variance in hearing health inequalities (Diez, 2012). According to the HHI Model to reduce SEP's impact on hearing health, healthy hearing should be promoted as a lifelong process.

2.5. Discussion

This study suggests that: (i) a vicious cycle between hearing loss and socioeconomic inequalities and lifestyle factors exists; (ii) socioeconomic position (SEP) prompts healthy or unhealthy lifestyles which affect people's hearing ability, (iii) people with hearing loss are more at risk of receiving low quality and less safe healthcare; and (iv) increasing health literacy could improve the diagnosis and prognosis of hearing loss and prevent the adverse consequences of hearing loss on people's health. The HHI Model identifies determinants of hearing loss using a life-course approach, which aims to shine new light on the current hearing health research debates. This model can be used as a tool for preventing, identifying, and managing hearing health inequalities and for policy formulation to reduce hearing loss risks.

Limitations

There are significant limitations in terms of the type and quality of existing published literature on the topic. The field of hearing health inequalities is an emerging research field, and most of the evidence cited in the manuscript stems from cross-sectional studies which demonstrate associations. However, although the CIS approach demands attention to study design, it also allows for the inclusion of less methodologically robust papers as long as they are essential in their theoretical contribution (Dixon-Woods et al., 2006). Thus, in line with the CIS principles, this paper views the task of critical synthesis not as aggregation, but as induction and interpretation, aiming to integrate the concepts and provide new insights and unified ways of understanding the amorphous and complex phenomenon of hearing health inequalities, rather than simplifying it.

The line-of-argument emerged from the synthesis of the existing evidence into a conceptual form. During this process, the researchers' subjectivity was intimately involved and reflexively accounted for, which may be controversial (Depraetere et al., 2020). However, the CIS approach explicitly acknowledges the 'authorial voice' in examining a network of synthetic constructs (themes) and the relationships between them and places a great deal of emphasis on the researcher's interpretation (Barnett-Page & Thomas, 2009). Besides, it is common for conceptual models to emphasise some factors than others, which sets the bounds for a complex research topic and specifies which relationships will be espoused as fundamental (Diez, 2012). In his attempt to offer a useful account of the literature, George Box, one of the great statistical minds of the 20th century once stated that 'all models are wrong, but some are useful' (Wasserstein, 2010).

The HHI Model will hopefully guide future research to examine the directionality of associations and conduct longitudinal studies and intervention trials to explore further many of the assertions shared in this manuscript, or potential differences due to residence (Brennan-Jones et al., 2016). It may also be helpful for future epidemiological research to differentiate the hearing loss based on the age of onset and aetiology. The vast majority of the global population (80%) lives in low and middle-income countries LMICs (Wilson et al., 2017), lacking resources for diagnosing and treating hearing loss and experiencing huge hearing health inequalities. It would therefore be useful for robust evidence to be obtained on populations living in LMICs.

Hopefully, the HHI Model will prompt researchers to develop new questions which need to be answered or stimulate them to think in new ways about the existing questions (Diez, 2012). Future research will be then better placed to produce aggregative syntheses using conventional systematic review methods and techniques such as meta-analysis (Dixon-Woods et al., 2006), adding even more elements to the HHI Model.

Implications for health policy

Viewing hearing health care as a health behaviour provides novel insight into the development of effective interventions to increase individuals' help-seeking behaviour, which will allow them to reduce and prevent the adverse effects of hearing loss.

Interventions designed to reduce hearing health inequalities can be implemented across three levels, which, following Geronimus' distinction (Geronimus, 2000), are: a) mitigation; b) preventing; and c) undoing inequalities (see **Figure 2.1**). *Mitigation* refers to actions which aim to reduce the impact of social inequalities on people's hearing health and social outcomes by recognising these barriers. For example, General Practice (GP) appointments would be more effective if the service provider were aware that the patient cannot read well or is not fully conversant with the language to seek help for hearing difficulties. Thus, health service interventions, which aim to increase awareness among health professionals about the high prevalence of hearing loss and the insufficient management of hearing difficulties among different social groups, are needed (Tsimpida et al., 2019b).

Second, *preventing* involves acknowledging those who have limited access to hearing health aid and whos working and living conditions put them more at risk of suffering from poor hearing health. Several primary prevention activities – such as improved prenatal, perinatal or neonatal care, universal vaccination programs and antibiotic stewardship practices – can be implemented to reduce the incidence of hearing loss from preconception to adulthood. Additionally, secondary and tertiary prevention activities – such as prompt intervention, fitting of hearing devices (hearing aids, cochlear implants, etc.) and training in sign language and special or inclusive education – are needed and should be actively encouraged (Olusanya et al., 2014).

Finally, *undoing* hearing health inequalities refers to the fact that there could be a differential economic policy that aims to decrease the wealth gap, thereby reducing the hearing health gap. Therefore, governmental policies aimed at reducing socioeconomic and education inequalities are needed to improve the most vulnerable groups' hearing health. Such policies can make essential contributions to preventing further increases in hearing health inequalities (Lorenc et al., 2013). Otherwise, any action that does not focus on the social determinants but only on hearing health improvement may further increase the existing hearing health inequalities of the population's hard-to-reach sub-groups (Lorenc et al., 2013).

Implications for societies

Since the burden of high levels of hearing loss affects the economic growth and development of a country, tackling hearing health inequalities has important implications for individuals and society as a whole. These negative impacts arise from the interaction of hearing loss with the broader social environment and can be significantly mitigated through the early identification and the appropriate management of hearing problems (World Health Organization, 2013). Hearing loss generates costs to society, such as higher welfare payments, health care expenditures and lost tax revenues. Characteristically, it is estimated that unaddressed hearing loss costs the global economy 750 billion annually (Ramsey, Svider, & Folbe, 2018). If this burden of hearing loss persists, it could slow economic growth, with developing countries suffering the most (Ramsey et al., 2018).

Conclusion

The increase in the ageing population and the burden of hearing loss and the concentration of ill-health among older adults have highlighted the urgent need to investigate factors that contribute to socioeconomic inequalities in hearing health. Although previous studies have found correlations between (a) socioeconomic inequalities and hearing loss, (b) hearing loss and comorbidity and (c) hearing impairment and related socioeconomic disparities, this review is the first to examine the mechanisms and explain the relationship between socioeconomic inequalities and hearing health in a life-course perspective, synthesising the existing evidence.

Apart from the physiological and pathological ageing of sense organs, the HHI Model provides a visual representation of several modifiable determinants of hearing loss in distinct life stages, supporting the argument that a substantial proportion of hearing loss in older adulthood is preventable, treatable and even postponable. Understanding that hearing deterioration occurs over a prolonged period of time is an essential step in addressing the burden of hearing loss not within an isolated model of care which focuses on the acquired hearing loss among older adults, but as a lifelong process.

Although reducing hearing health inequalities is a complex ambition, the life-course approach can lead to the development of appropriate interventions and public health strategies that can have significant health policy and practice implications. The management of hearing loss must involve integrated care, which entails considering an individual’s entire health profile and providing ongoing support for each person’s adaptation and self-management. In that way, we will ensure that a more substantial proportion of the population receives high-quality healthcare and maximises the opportunity for healthy ageing.

Conflict of Interest: The authors declare that they have no competing interests.

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Data availability statement The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Authors' contributions DT was responsible for the conceptualisation and the design of the HHI Model, and all authors were responsible for developing the design of the study. DT, EK, DMA and MP critically revised the manuscript. All authors have read and approved the final manuscript.

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2.8. Supplementary Material

Supplementary Table 2.1 Key points derived from the 53 studies that support the four research themes of the translational analysis

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
1	**Andrade & Lopez-Ortega, 2017**	Brazil and Mexico	Association of lower educational attainment with higher odds of hearing loss	√			
2	**Armstrong, et al., 2016**	United States	Comorbidity of hearing loss with depression				√
3	**Bainbridge & Ramachandran, 2014**	United States	Role of income in the lower hearing aid acquisition and usage and disparities among people with hearing loss in access to hearing health services	√		√	
4	**Barnett et al., 2014**	United States	Barriers in access to health services and lower satisfaction among those with hearing loss with the quality of health care provision			√	√

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
5	**Barton et al., 2001**	Denmark Finland Norway Sweden United Kingdom	Factors for the lower hearing aid use			√	
6	**Benova et al., 2015**	United Kingdom	Role of socioeconomic position in the health-seeking process among older adults with hearing loss			√	
7	**Bishop, 2012**	United States	Comorbidity of hearing loss with cardiovascular disease				√
8	**Chan et al., 2017**	United States	Financial barriers to hearing healthcare and factors affecting the help-seeking behaviour	√		√	
9	**Chien & Lin, 2012**	United States	Barriers in access to health services after the onset of hearing loss			√	

No	**Author (s), Year**	**Country**	**Key point made by authors**	**Theme 1**	**Theme 2**	**Theme 3**	**Theme 4**
10	**Chorozoglou et al., 2018**	United Kingdom	Consequences of hearing loss in language skills of children and impact on their educational achievement	√			
11	**Chou et al., 2015**	United States	Correlation between social indicators and the likelihood of developing hearing impairment, the association of hearing loss with significant adverse outcomes	√		√	
12	**Cruickshanks et al., 1998**	United States	The relation between occupational exposure to noise and an increased likelihood of having hearing loss	√			
13	**Curhan et al., 2013**	United States	Role of exercise in the likelihood of hearing loss		√		
14	**Davies et al., 2017**	United Kingdom	Comorbidity of hearing loss with dementia				√

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
15	**Davis et al., 2016**	Review study	Role of nutrition and exercise in the onset of hearing loss, consequences of hearing loss in the decision about early retirement and subsequently the income of older adults, communication barriers in comorbidities	√	√		√
16	**Eisele et al., 2015**	Germany	Role of hearing loss in good health maintenance and social participation	√			√
17	**Emmett & Francis, 2015**	United States	Role of hearing loss in the ability of the individuals to continue working or to advance occupationally	√			
18	**Feeny et al., 2012**	Canada	Disability in hearing is associated with mortality				√
19	**Fischer et al., 2011**	United States	Role of negative attitudes towards deafness and ageing			√	

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
20	**Genther et al., 2013**	United States	Comorbidity of hearing loss with cardiovascular disease				√
21	**Gopinath et al., 2010**	Australia	Smoking and association with hearing loss		√		
22	**Harrison et al., 2020**	Malawi	Barriers in access to health care for people with hearing loss			√	
23	**Helvik et al., 2009**	Norway	Occupational exposure to noise and increased likelihood of hearing loss	√			
24	**Horikawa et al., 2013**	Meta-analysis	Comorbidity of hearing loss with diabetes				√
25	**Kupriianova et al., 2013**	Russia	Social indicators and relation with hearing loss	√			√

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
26	**Lee et al., 2020**	South Korea	Increased health needs among those with hearing loss, using the International Classification of Functioning, Disability and Health				√
27	**Lin & Ferrucci, 2012**	United States	Association of hearing loss with falls in the elderly				√
28	**Luo et al., 2020**	China	Socioeconomic inequalities in hearing loss among working-aged adults			√	
29	**Mallmann et al., 2020**	Brazil	Socioeconomic inequalities in access to neonatal screening tests	√			
30	**Mamo et al., 2016**	United States	Higher prevalence of untreated hearing loss among low-income older adults	√			
31	**Martin et al., 2012**		Association of higher educational attainment with lower odds of hearing	√			

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
		United Kingdom	impairment in adults of working age				
32	**McKee et al., 2018**	United States	Disease burden and low health-related quality of life among older adults with hearing loss	√			√
33	**Ng & Loke, 2015**	Review study	Role of socioeconomic position in an individual's readiness to hearing aid adoption and usage			√	
34	**Nieman & Lin, 2017**	Review study	Disparities in access to health services and comorbidity of hearing loss with chronic kidney disease			√	√
35	**Nieman et al., 2016**	United States	Lower hearing aid uptake among minority older adults and those in a lower SEP			√	
36	**Pichetti et al., 2016**	France	hearing loss is a major barrier in access to care among those in a low socioeconomic position			√	

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
37	**Pierre et al., 2012**	Sweden	Association of low education attainment with occupation involving high levels of noise exposure	√			
38	**Raggi et al., 2016**	Finland Poland Spain	Lower quality of life after a health impairment occurrence among those with low socioeconomic position	√			
39	**Reichard et al., 2017**	United States	Lower uptake of hearing aids among lower socioeconomic groups			√	
40	**Rosenhall et al., 1999**	Sweden	Hearing difficulties among workers of manual occupations	√			
41	**Scholes et al., 2018**	United Kingdom	Association of socioeconomic position with hearing loss and the differences in the use of specialist health services	√		√	
42	**Shaw et al., 2013**	Canada	Challenges among those with hearing loss in work performance and productivity in the workplace	√			

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
43	**Smith et al., 2016**	United Kingdom	Consequences of hearing loss in the income of older adults	√			
44	**Spankovich & Le Prell, 2013**	United States	Impact of physical activity on hearing loss		√		
45	**Sung et al., 2013**	Korea	The damaging effect of occupational noise-exposure in hearing		√		
46	**Tsimpida et al., 2018a**	Greece	Determinants of Health-related Quality of Life (HRQoL) among Deaf and Hard of Hearing Adults	√	√		
47	**Tsimpida et al., 2018b**	Greece	Barriers to the use of health services among adults with hearing loss			√	√
48	**Tsimpida et al., 2019a**	Greece	Inequalities in access to health services faced by the population with hearing loss			√	√

No	Author (s), Year	Country	Key point made by authors	Theme 1	Theme 2	Theme 3	Theme 4
49	**Tsimpida et al., 2019b**	United Kingdom	Socioeconomic and lifestyle factors associated with hearing loss in older adults	√	√		
50	**Üçler et al., 2016**	Turkey	Association with an unhealthy diet with hearing loss		√		
51	**von Gablenz & Holube, 2017**	Germany	The higher prevalence of untreated hearing loss among adults in a low socioeconomic position and possible associations with more severe health problems	√			√
52	**Wilson et al., 2017**	Review study	Role of cost in the lower hearing aid uptake among minority older adults and those in a lower socioeconomic position			√	
53	**Zhan et al., 2011**	United States	Role of lower education with higher odds of hearing loss and association of alcohol consumption with hearing loss	√	√		

Supplementary Table 2. 2 Summary of the quality appraisal of included studies *

No	Author (s), Year	Selection bias [a]	Design [b]	Covariates [c]	Data collection methods [d]	Total quality score
1	**Andrade & Lopez-Ortega, 2017**	**1**	**0**	**1**	**0**	**2**
2	**Armstrong, et al., 2016**	**0**	**1**	**1**	**0**	**2**
3	**Bainbridge & Ramachandran, 2014**	**1**	**0**	**1**	**1**	**3**
4	**Barnett et al., 2014**	**1**	**0**	**1**	**1**	**3**
5	**Barton et al., 2001**	**1**	**1**	**0**	**1**	**3**
6	**Benova et al., 2015**	**1**	**0**	**1**	**0**	**2**
7	**Bishop, 2012**	N/A	N/A	N/A	N/A	N/A
8	**Chan et al., 2017**	**0**	**0**	**0**	**0**	**0**

No	Author (s), Year	Selection bias [a]	Design [b]	Covariates [c]	Data collection methods [d]	Total quality score
9	**Chien & Lin, 2012**	**1**	**1**	**0**	**1**	**3**
10	**Chorozoglou et al., 2018**	**0**	**1**	**1**	**1**	**3**
11	**Chou et al., 2015**	**1**	**1**	**1**	**0**	**3**
12	**Cruickshanks et al., 1998**	**1**	**1**	**1**	**1**	**4**
13	**Curhan et al., 2013**	**1**	**1**	**1**	**0**	**3**
14	**Davies et al., 2017**	**1**	**1**	**1**	**1**	**4**
15	**Davis et al., 2016**	N/A	N/A	N/A	N/A	N/A
16	**Eisele et al., 2015**	**1**	**1**	**1**	**0**	**3**

No	**Author (s), Year**	**Selection bias [a]**	**Design [b]**	**Covariates [c]**	**Data collection methods [d]**	**Total quality score**
17	**Emmett & Francis, 2015**	**1**	**0**	**1**	**1**	**3**
18	**Feeny et al., 2012**	**1**	**1**	**1**	**0**	**3**
19	**Fischer et al., 2011**	**1**	**1**	**1**	**1**	**4**
20	**Genther et al., 2013**	**1**	**1**	**1**	**1**	**4**
21	**Gopinath et al., 2010**	**1**	**1**	**1**	**1**	**4**
22	**Harrison et al., 2020**	**0**	**0**	**0**	**0**	**0**
23	**Helvik et al., 2009**	**1**	**1**	**0**	**1**	**3**
24	**Horikawa et al., 2013**	N/A	N/A	N/A	N/A	N/A

No	Author (s), Year	Selection bias [a]	Design [b]	Covariates [c]	Data collection methods [d]	Total quality score
25	**Kupriianova et al., 2013**	**0**	**0**	**0**	**1**	**1**
26	**Lee et al., 2020**	**0**	**0**	**0**	**0**	**0**
27	**Lin & Ferrucci, 2012**	**1**	**0**	**1**	**1**	**3**
28	**Luo et al., 2020**	**1**	**0**	**1**	**1**	**3**
29	**Mallmann et al., 2020**	**1**	**0**	**1**	**1**	**3**
30	**Mamo et al., 2016**	**1**	**1**	**0**	**1**	**3**
31	**Martin et al., 2012**	**1**	**1**	**1**	**0**	**3**
32	**McKee et al., 2018**	**1**	**1**	**1**	**0**	**3**

No	**Author (s), Year**	**Selection bias [a]**	**Design [b]**	**Covariates [c]**	**Data collection methods [d]**	**Total quality score**
33	**Ng & Loke, 2015**	N/A	N/A	N/A	N/A	N/A
34	**Nieman & Lin, 2017**	N/A	N/A	N/A	N/A	N/A
35	**Nieman et al., 2016**	**1**	**1**	**0**	**1**	**3**
36	**Pichetti et al., 2016**	**1**	**0**	**1**	**0**	**2**
37	**Pierre et al., 2012**	**1**	**0**	**1**	**0**	**2**
38	**Raggi et al., 2016**	**1**	**0**	**0**	**0**	**1**
39	**Reichard et al., 2017**	**1**	**1**	**1**	**0**	**3**
40	**Rosenhall et al., 1999**	**1**	**1**	**0**	**0**	**2**

No	Author (s), Year	Selection bias [a]	Design [b]	Covariates [c]	Data collection methods [d]	Total quality score
41	**Scholes et al., 2018**	**1**	**0**	**1**	**1**	**3**
42	**Shaw et al., 2013**	**0**	**0**	**0**	**0**	**0**
43	**Smith et al., 2016**	**0**	**0**	**0**	**0**	**0**
44	**Spankovich & Le Prell, 2013**	**1**	**0**	**1**	**1**	**3**
45	**Sung et al., 2013**	**0**	**0**	**1**	**1**	**2**
46	**Tsimpida et al., 2018a**	**0**	**0**	**1**	**0**	**1**
47	**Tsimpida et al., 2018b**	**0**	**0**	**1**	**0**	**1**
48	**Tsimpida et al., 2019a**	**0**	**0**	**1**	**0**	**1**

No	Author (s), Year	Selection bias [a]	Design [b]	Covariates [c]	Data collection methods [d]	Total quality score
49	**Tsimpida et al., 2019b**	**1**	**0**	**1**	**1**	**3**
50	**Üçler et al., 2016**	**0**	**1**	**0**	**1**	**2**
51	**von Gablenz & Holube, 2017**	**0**	**0**	**1**	**1**	**2**
52	**Wilson et al., 2017**	N/A	N/A	N/A	N/A	N/A
53	**Zhan et al., 2011**	**1**	**1**	**1**	**1**	**4**

* Each point given indicates the presence of the relevant criterion.
[a] Selection bias: likely to be representative of the target population and have a response rate or data capture among eligible participants of 70% or greater.
[b] Design: cohort analytic, case-control, cohort, or an interrupted time series.
[c] Covariates: control for a minimum of 3 critical covariates in the analysis, including sociodemographic characteristics (e.g. age, sex, education).
[d] Data collection methods: psychoacoustic hearing assessment tools, which are valid and reliable, or data from medical records.

Chapter 3

Socioeconomic and Lifestyle Factors Associated with Hearing Loss in Older Adults: A Cross-sectional Study of the English Longitudinal Study of Ageing (ELSA)

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3.1. Abstract

Objectives: Aims were (a) to examine whether socioeconomic position (SEP) is associated with hearing loss (HL) among older adults in England and (b) whether major modifiable lifestyle factors (high body mass index, physical inactivity, tobacco consumption and alcohol intake above the low risk level guidelines) are associated with HL after controlling for non-modifiable demographic factors and SEP.

Setting: We used data from the wave 7 of the English Longitudinal Study of Ageing (ELSA), which is a longitudinal household survey dataset of a representative sample of people aged 50 and older.

Participants: The final analytical sample was 8,529 participants aged 50-89 that gave consent to have their hearing acuity objectively measured by a screening audiometry device and did not have any ear infection.

Primary and secondary outcome measures: HL defined as >35 dB HL at 3.0 kHz (better-hearing ear). Those with HL were further subdivided into two categories depending on the number of tones heard at 3.0kHz.

Results: HL was identified in 32.1% of men and 22.3% of women aged 50-89. Those in a lower SEP were up to two times more likely to have HL; the adjusted odds of HL were

higher for those with no qualifications versus those with a degree/higher education (men: OR 1.87, 95%CI 1.47 to 2.38, women: OR 1.53, 95%CI 1.21 to 1.95), those in routine/manual occupations versus those in managerial/professional occupations (men: OR 1.92, 95%CI 1.43 to 2.63, women: OR 1.25, 95%CI 1.03 to 1.54), and those in the lowest versus the highest income and wealth quintiles (men: OR 1.62, 95%CI 1.08 to 2.44, women: OR 1.36, 95%CI 0.85 to 2.16, and men: OR 1.72, 95%CI 1.26 to 2.35, women: OR 1.88, 95%CI 1.37 to 2.58, respectively). All regression models showed that socioeconomic and the modifiable lifestyle factors were strongly associated with HL after controlling for age and gender.

Conclusion: Socioeconomic and lifestyle factors are associated with HL among older adults as strongly as core demographic risk factors, such as age and gender. Socioeconomic inequalities and modifiable lifestyle behaviours need to be targeted by health policy strategies, as an important step in designing interventions for individuals that face hearing health inequalities.

3.2. Introduction

Hearing loss (HL) is a major global health challenge and the most prevalent sensory disorder. Approximately 15% of the global adult population has some degree of HL (of at least ≥25 dB HL in the better-hearing ear) (WHO, 2013) and almost 7% has disabling HL (defined as a hearing threshold ≥40 dB HL in the better ear) (Wilson et al., 2017). HL has negative physical, social, cognitive, economic and emotional consequences and is the fourth leading contributor to years lived with disability worldwide (Wilson et al., 2017).

Previous studies have reported that HL increases with age (Stevens et al., 2013), exposure to high occupational and social noise (Lutman & Spencer, 1990) and is more commonly in men (Stevens et al., 2013). There is growing evidence that there are a number of modifiable risk factors for HL (Scholes et al., 2018; Tsimpida, D., Kaitelidou, D., & Galanis, 2018b) and, if eliminated, half cases of HL could be prevented (Wilson et al., 2017). Thus there is a high potential for reducing the burden of HL, if we understand the modifiable factors and the mechanisms that lead to hearing health inequalities, which -following the glossary for health inequalities (Kawachi et al., 2002) - could be defined as the *avoidable differences in people's hearing health across different social and/or population groups*.

Prior research has established health disparities in a wide range of health conditions according to socioeconomic position (SEP) (Michael G Marmot et al., 2010). Furthermore, there is evidence that several modifiable lifestyle factors, such as smoking (Gopinath et al., 2010), alcohol consumption (Zhan et al., 2011b), high body mass index and physical inactivity (Curhan et al., 2013) are associated with hearing health. Of course, causal paths have not been established, and these associations may be confounded by deprivation or aspects of deprivation (e.g. type of occupation). Nevertheless, quantifying such associations is the first step in that direction; hearing health inequalities is an emerging research area and the existing evidence on the relationship of HL with SEP and modifiable lifestyle factors is scarce. There is a major public health need to assess whether HL is associated with SEP and lifestyle factors because this understanding could inform recommendations for HL preventative strategies. These could include wider implementation of interventions to promote 'healthier lifestyles', or governmental policies for socioeconomic equity among older people in the community.

The aims of this study were (a) to examine whether SEP is associated with HL among older adults in England and (b) whether major modifiable lifestyle factors are associated with HL after controlling for non-modifiable demographic factors and SEP in the analyses. This study is the first that examines four different SEP indicators (education, occupation, income, wealth) in HL, encompassing thus aspects of the life-course socioeconomic stratification (Galobardes et al., 2006), to the objectively measured HL in older adults. In addition, this is the first study that explores how major lifestyle factors for general health outcomes in the English population aged 50 years old and above (such as smoking, high BMI, insufficient physical activity, tobacco consumption and alcohol intake above the low risk level guidelines) (Health Profile for England, 2018; Poortinga, 2007) account for the variance in HL.

3.3. Methods

Study population

The present study used data from the English Longitudinal Study of Ageing (ELSA). The ELSA is a longitudinal household survey dataset of a representative sample of people aged 50 and older in England. It is designed as a large-scale prospective cohort study, with repeat measures of core variables over numerous waves, in order to explore trajectories on the health, social, wellbeing and economic circumstances (Steptoe et al., 2012). The current sample contains data from up to eight waves of data collection covering a period of 15 years, with an ongoing two-year follow-up longitudinal design (Clemens et al., 2018).

Objective hearing health data was available only in wave 7, where information was collected from 9,666 participants, between June 2014 and May 2015. For the purposes of this study, the final analytical sample was n=8,529 participants, aged 50-89, that gave consent to have their hearing acuity measured by a screening audiometry device and did not have any ear infection or a cochlear implant.

Hearing test

A handheld audiometric screening device (HearCheck™) (Siemens Audiologische Technik GmbH, 2007) was used for the objective measurement of hearing acuity. This is a portable and easy-to-use hearing screening test by Siemens, that tests for audibility of pure tone beeps, according to the number of tones that the respondent can hear for each sequence (at 1.0 kHz and 3.0 kHz), per each ear. The functional test sequence begins with a series of three sounds, that have decreasing volume at 1.0 kHz (55 dB HL, 35 dB HL, 20 dB HL) and afterwards another three sounds with decreasing volume at 3.0 kHz (75 dB HL, 55 dB HL, 35 dB HL). Prerequisites for the test were the device to make proper contact with the ear that is tested, hearing aid(s), glasses, earrings and hair bands to be removed to prevent from getting in the way of the hearing device and the room to be as quiet as possible. Participants indicated when they hear the sound by raising their finger. The total number of tones that the participants indicated they could hear in the sequence of sounds at 1.0 kHz and 3.0. kHz, per each ear, was recorded and the total tones heard in the better-hearing ear used for the categorization of those with HL.

Previous studies have assessed the accuracy of the Siemens HearCheck™ in detecting hearing loss and compared it with pure tone air conduction averages designated as gold standard values. Fellizan-Lopez *et al.* (2011) found that in cases of moderate or worse hearing loss, the HearCheck™ test fulfils all criteria of high sensitivity rate, high specificity rate and high positive predictive values to be considered an accurate tool to screen for hearing loss, without the need for soundproof audiometry booths (Fellizar-Lopez et al., 2011).

Outcomes

Hearing loss

HL was defined as >35 dB HL at 3.0 kHz, in the better-hearing ear. Those with HL were further subdivided into two categories depending on the number of tones heard at 3.0 kHz. This is the level where intervention for HL has shown to be definitely beneficial (Davis et al., 2007). For that reason this categorisation has previously been used in the literature for the characterisation of those assessed by the same audiometric screening device (HearCheck™) (Scholes et al., 2018). Thus, we further explored potential differences in the association between SEP indicators and HL, according to the severity of HL, as measured by HearCheck™. The categorization of those with HL was as following:

(a) "*Moderate HL*": tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (the first 2 of the three tones at 3.0 kHz heard),

(b) "*Moderately severe or severe HL*": tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (0 or 1 of the three tones at 3.0 kHz heard).

The ordinal variable "hearing acuity" (in the better-hearing ear) was consisted of the above two categories of HL and the category of "normal hearing", which was defined as having heard all the three tones of the hearing screening test at 3.0 kHz.

Indicators of socioeconomic position

Education, occupation, income and wealth were the four selected indicators of SEP and information was collected in the seventh wave of ELSA, between June 2014 and May 2015. We considered five categories of the highest educational attainment: degree/higher education; A level (Level 3 of the National Qualifications Framework); O levels CSE (Certificate of Secondary Education); foreign/other; no qualifications. Tertiles of self-reported occupation were based on the National Statistics socio-economic classification (NS-SEC): managerial and professional; intermediate; routine and manual occupations). The relative financial position of the participants was captured by quintiles of the net household income (first quintile lowest; fifth quintile highest) that is summed across household members. In order to avoid the information bias that is related to the retirement status, we used quintiles of the total non-pension wealth that is reported at the household level (first quintile lowest; fifth quintile highest), which represents the sum of net financial wealth, net physical wealth and net housing wealth.

Covariates

Age, marital status, retirement status and non-medical determinants of health (body mass index, physical activity, tobacco and alcohol consumption) were assessed as covariates in the association between SEP indicators and HL (Tsimpida, D., Kaitelidou, D., & Galanis, 2018b).

Age was categorised into three groups (50-64, 65-74, 75-89), to allow for a comparison with Benova et al., (2015) who examined the association of socioeconomic position with self-reported hearing difficulty in ELSA wave 2.

Marital status was dichotomised into those that are currently married or not. Those who are currently married included the categories a) married, first and only marriage, b) in a registered Civil Partnership, c) remarried, in a second or later marriage. Those that categorised as not currently married included the categories a) single, that is never married and never registered in a marriage, b) separated, but still legally married, c) divorced, d) widowed.

Retirement status was dichotomised into those who were retired or not, according to the self-reported employment status.

Body Mass Index (BMI) measurements were grouped in four categories, according to WHO definitions (Bjorntorp et al., 2000): (a) underweight: BMI under 18.5, (b) normal: BMI 18.5 or over but less than 25, (c) overweight: BMI 25 or over but less than 30, and (d) obese: BMI 30 or over.

Tobacco consumption of any type of nicotine products was recoded into three categories: those that were current smokers, those that were former smokers and those that never smoked. Both current and former smokers answered the question of ‘number of cigarettes smoked per day’, to explore whether they were occasional or regular smokers.

Alcohol consumption was recorded using several continuous variables such as the number of days of alcohol consumption in the last seven days and the number of (a) measures of spirit, (b) glasses of wine and (c) pints of beer that the respondents had consumed during this period. We constructed a continuous variable to represent the sum of units of alcohol that the participants consumed in the last seven days, according to the Chief Medical Officer's Drinking Guidelines (Department of Health, 2016), that counts as 1 unit each measure of spirit and as 2 units each glass of wine of pint of beer. The constructed variable of units of alcohol during the last seven days was further dichotomised into those that consumed more than 14 units of alcohol the last seven days or not, in a separate variable.

Levels of physical activity were described by three ordinal variables that examined the frequency that the respondents do rigorous, moderate or mild sports or activities, with possible answers (a) more than once a week, (b) once a week, (c) one to three times a month and (d) hardly ever, or never.

Statistical analysis

Categorical variables are presented as absolute (n) and relative (%) frequencies, while continuous variables are presented using their mean and standard deviation. The Kolmogorov-Smirnov test and normal plots were used to test the normality of the quantitative variable distributions. All the 8,529 individuals (of the 9,666 initial sample in ELSA wave 7), had usable objective hearing data, measured by a qualified nurse. In total, 257 participants refused to have the assessment (the 2.6% of the full cohort of 9,666 participants). As there was no pattern in the missing data regarding age, sex, education, occupation, income, and wealth and due to low proportion of missingness (<5%), records with missing data were dropped from the analyses.

We fitted multiple logistic regression models to evaluate the odds of HL at various socioeconomic strata, controlling for gender, age and non-medical determinants of health (BMI, physical activity, tobacco and alcohol consumption). Additionally, we fitted four separate stepwise logistic regression models, to examine the association of HL with non-modifiable (age, gender: Step 1), partly modifiable (education, occupation, income, wealth: Step 2, respectively), and fully modifiable lifestyle risk factors (body mass index, physical activity, tobacco, and alcohol consumption: Step 3). Age was entered into the multivariable logistic regression models as a continuous variable, to maximise power. The variants of pseudo-R squared statistics were based on the deviance of the models and used to express how much variance in the outcome is explained by the variables in each stepwise multiple logistic regression model. The variance inflation factor (VIF) was used as an indicator of multicollinearity and the Hosmer-Lemeshow test was used as a post estimation tool, which quantified the goodness-of-fit of the models. For all models, odds ratios, 95% confidence intervals, unadjusted and adjusted coefficients' beta values, pseudo R^2 and mean VIFs are presented. The two-tailed significance level was set ≤0.05. All data were analysed using Stata version 14 (StataCorp, 2015).

3.4. Results

Socio-demographic characteristics

Overall, 26.6% (2,266/8,529) of adults aged 50-89 had HL >35 dB HL at 3.0 kHz. The percentages were 32.1% (1,198/3,728, 95%CI 0.31 to 0.34) for men and 22.3% (1,068/4,801, 95%CI 0.21 to 0.23) for women, respectively. **Table 3.1** shows the distribution of socio-demographic characteristics of the sample (n=8,529, aged 50-89) according to hearing acuity. The proportion of men and women with HL >35 dB HL at 3.0 kHz was 52.8 (1,198) and 47.2 (1,068)), respectively. However, men were 1.5 times more likely to have moderately severe or severe HL compared to women. One in three adults aged 65-75 had hearing loss and the percentage of HL in age band 75-89 was threefold larger than in age band 50-64, as one out of every two adults aged 75-89 had HL >35 dB HL at 3.0kHz.

Lifestyle factors

Lifestyle factors of the participants are presented in **Table 3.2**. Over half of the participants were current or former smokers. In addition, patterns of high levels of alcohol consumption among all participants were revealed, with average consumption of more than 14 units of alcohol in the last seven days for two out of three participants (5,223/8,528, 95%CI 0.60 to 0.61). Nearly one out of every three of those drinking above the low-risk level guidelines (Department of Health, 2016) (1,457/5.223, 95%CI 0.27 to 0.29) had HL >35 dB HL at 3.0 kHz. Three out of four of those with HL >35 dB HL at 3.0 kHz were overweight or obese. Furthermore, those with HL >35 dB HL at 3.0 kHz were twice as likely to hardly ever or never engage in moderate or mild sports activities compared to hearing participants.

Hearing Loss

Table 3.3 and **Figure 3.1** show the results of multiple logistic regression analysis with HL >35 dB HL at 3.0 kHz as the dependent variable and SEP indicators as the independent variables, per each gender. The adjusted odds of HL were higher for those with no qualifications versus those with a degree/higher education (men: OR 1.87, 95% CI 1.47-2.38, women: OR 1.53, 95% CI 1.21-1.95), those in routine/manual occupations versus those in managerial/professional occupations (men: OR 1.92, 95% CI 1.43-2.63, women: OR 1.25, 95% CI 1.03-1.54), and those in the lowest versus the highest income and wealth quintiles (men: OR 1.62, 95% CI 1.08-2.44, women: OR 1.36, 95% CI 0.85-2.16 and men: OR 1.72, 95% CI 1.26-2.35, women: OR 1.88, 95% CI 1.37-2.58, respectively). **Table 3.4** shows the summary of stepwise logistic regression analysis for variables predicting HL >35 dB HL at 3.0 kHz. All regression models were statistically significant. Age and gender only explained about 15% of the variance in the likelihood of HL. The addition of lifestyle factors significantly attenuated the association between the HL and SEP indicators and in total the addition of SEP and lifestyle factors in the regression models explained another 10 to 15% of the variance in the likelihood of HL. The total variance explained in the overall models containing demographic factors, SEP and lifestyle factors ranged between 25 and 27%. This finding suggests that SEP and lifestyle factors have an equal contribution to HL as age and gender.

Table 3.1. Participants socio-demographic characteristics (N=8,529, aged 50-89)

Variable	Hearing acuity % (N) in the better-hearing ear			
	Normal Hearing	HL >35 dB HL at 3.0kHz	Moderate HL*	Moderately severe or severe HL**
Gender				
Male	40.4 (2,530)	52.8 (1,198)	49.5 (741)	59.5 (457)
Female	59.6 (3,733)	47.2 (1,068)	50.5 (757)	40.5 (311)
Age[a]	64.3 (9.29)	69.7 (19.19)	70.0 (15.85)	69.1 (24.41)
Age group				
50-64	51.3 (3,135)	16.2 (349)	19.3 (280)	9.8 (69)
65-74	34.5 5 (2,108)	33.6 (722)	36.9 (535)	26.7 (187)
75-89	14.2 (868)	50.2 (1,081)	43.8 (636)	63.5 (445)
Currently married				
No	31.2 (1,908)	38.4 (826)	37.5 (544)	40.2 (282)
Yes	68.8 (4,202)	61.6 (1,326)	62.5 (907)	59.8 (701)
Retirement status				
Retired	52.4 (3,205)	78.3 (1,685)	76.6 (1,112)	81.3 (573)
Not retired	47.6 (2,905)	21.7 (467)	23.4 (339)	18.3 (128)
Education				
Degree/Higher Education	33.7 (1,996)	26.4 (562)	28.1 (404)	22.9 (158)
A level	10.0 (596)	6.4 (137)	7.0 (100)	5.4 (37)
O level/CSE grade	24.4 (1,448)	22.3 (473)	22.4 (321)	22.0 (152)
Foreign/Other	13.5 (798)	11.9 (252)	11.9 (171)	11.7 (81)
No qualifications	18.4 (1,090)	33.0 (701)	30.6 (439)	38.0 (262)
Occupation based National Statistics Socio-economic Classification (NS-SEC)				
Managerial and professional occupations	23.4 (1,158)	21.5 (423)	21.6 (285)	21.2 (138)
Intermediate occupations (non-manual)	43.4 (2,149)	33.8 (665)	36.2 (477)	28.9 (188)
Routine and manual occupations	33.2 (1,644)	44.7 (1,643)	42.2 (1,318)	49.9 (325)

(Continued)

Table 3.1 (Continued)
Participants socio-demographic characteristics (N=8,529, aged 50-89)

Variable	Hearing acuity % (N) in the better-hearing ear: Normal Hearing	HL >35 dB HL at 3.0kHz	Moderate HL*	Moderately severe or severe HL**
Net Household Income				
First quintile (lowest)	17.0 (872)	21.3 (421)	19.7 (262)	24.8 (159)
Second quintile	18.7 (959)	24.8 (489)	24.7 (329)	24.9 (160)
Third quintile	20.1 (1,034)	23.0 (453)	22.3 (297)	24.3 (156)
Fourth quintile	22.5 (1,154)	18.6 (367)	19.9 (265)	15.9 (102)
Fifth quintile (highest)	21.7 (1,112)	12.3 (243)	13.4 (178)	10.1 (65)
Net Financial Wealth				
First quintile (lowest)	15.5 (794)	14.7 (290)	14.9 (199)	14.2 (91)
Second quintile	17.1 (879)	24.1 (475)	22.1 (294)	28.2 (181)
Third quintile	19.6 (1,006)	23.6 (466)	23.4 (311)	24.1 (155)
Fourth quintile	23.5 (1,204)	20.3 (400)	21.3 (284)	18.1 (116)
Fifth quintile (highest)	24.3 (1,248)	17.3 (342)	18.3 (243)	15.4 (99)

Values are expressed as column % (N) unless otherwise is indicated.
[a]Mean (Standard deviation)
*Moderate hearing loss: tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (the first **2 of the three tones at 3.0 kHz** heard)
Moderately severe or severe hearing loss: tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (0 or 1 of the three tones at 3.0 kHz** heard).

Table 3.2. Participants' lifestyle factors (N=8,529, aged 50-89)

Variable	Normal Hearing	HL >35 dB HL at 3.0kHz	Moderate HL*	Moderately severe or severe HL**
	Hearing acuity % (N) in the better-hearing ear			
Tobacco consumption (any type of nicotine products)				
Current	11.7 (712)	10.0 (215)	9.6 (139)	10.8 (76)
Former	49.0 (2,996)	56.7 (1,219)	55.8 (810)	58.4 (409)
Number of cigarettes smoked per day [a]	12.79 (14)	12.79 (13)	12.69 (13)	11.90 (12)
Never	39.3 (2,403)	33.3 (718)	34.6 (502)	30.8 (216)
Alcohol consumption (in the last 7 days)				
Number of days of alcohol consumption [b]	3 (3)	3 (4)	3 (4)	3 (4)
Number of measures of spirit [a]	2.1 (2)	2.3 (3)	2.2 (3)	2.6 (3)
Number of glasses of wine [a]	4.3 (6)	3.6 (5)	3.9 (6)	3.1 (4)
Number of pints of beer [a]	2.1 (2)	2.3 (3)	2.3 (3)	2.4 (3)
Total units of alcohol in the last 7 days [a]	15.0 (18)	14.2 (19)	14.5 (21)	13.5 (17)
Consumption of more than 14 units	61.6 (3,766)	67.7 (1,457)	67.3 (977)	68.5 (480)
BMI Classification				
Underweight	3.4 (160)	5.0 (92)	4.9 (60)	5.3 (32)
Normal	26.9 (1,255))	20.6 (376)	19.6 (239)	22.7 (137)
Overweight	40.0 (1,869)	42.8 (780)	41.4 (506)	45.4 (274)
Obese	29.7 (1,390)	31.6 (576)	34.1 (416)	26.6 (160))
Physical Activity ***Frequency does rigorous sports or activities***				
More than once a week	23.0 (1,407)	14.3 (307)	16.1 (233)	10.6 (74)
Once a week	10.3 (626)	7.0 (151)	7.9 (115)	5.1 (36)
One to three times a month	10.1 (617)	7.1 (153)	7.6 (111)	6.0 (42)
Hardly ever, or never	56.6 (3,459)	71.6 (1,541)	68.4 (992)	78.3 (549)

(Continued)

Table 3.2. (Continued)
Participants' lifestyle factors (N=8,529, aged 50-89)

Variable	Hearing acuity % (N) in the better-hearing ear			
	Normal Hearing	**HL >35 dB HL at 3.0kHz**	**Moderate HL***	**Moderately severe or severe HL****
Physical Activity (continued)				
Frequency does moderate sports or activities				
More than once a week	68.4 (4,180)	51.3 (1,104)	53.7 (780)	46.2 (324)
Once a week	12.6 (771)	13.6 (292)	14.1 (204)	12.6 (88)
One to three times a month	5.9 (360)	7.8 (169)	7.6 (110)	8.4 (59)
Hardly ever, or never	13.1 (799)	27.3 (587)	24.6 (357)	32.8 (230)
Frequency does mild sports or activities				
More than once a week	83.9	73.7	76.0 (1,103)	68.9 (483)
Once a week	8.2	10.1	9.8 (142)	10.5 (74)
One to three times a month	2.3	3.5	3.3 (48)	4.0 (28)
Hardly ever, or never	5.6	12.7	10.9 (158)	16.6 (116)

Values are expressed as column % (N) unless otherwise is indicated.
[a]Mean (Standard deviation)
[b]Median (Range)
*Moderate hearing loss: tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (the first **2 of the three tones at 3.0 kHz** heard)
Moderately severe or severe hearing loss: tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (0 or 1 of the three tones at 3.0 kHz** heard).

Table 3.3. Multiple logistic regression analysis of N=8,529, aged 50-89 with **HL >35 dB HL at 3.0kHz** in better-hearing ear as dependent variable and **SEP indicators** as independent variables

	Unadjusted OR (95% CI)*		**Adjusted OR (95% CI)****	
	Men	Women	Men	Women
Education				
No qualifications	2.39 (1.96-2.90)	2.67 (2.20-3.24)	1.87 (1.47-2.38)	1.53 (1.21-1.95)
Foreign/Other	1.06 (0.83-1.36)	1.37 (1.07-1.74)	1.46 (1.09-1.94)	0.99 (0.74-1.32)
O level/CSE grade	1.56 (1.29-1.89)	1.00 (0.80-1.25)	1.42 (1.13-1.79)	0.94 (0.73-1.22)
A level	1.01 (0.77-1.32)	0.69 (0.50-0.97)	1.08 (0.78-1.51)	0.82 (0.56-1.21)
Degree/Higher Education (reference)				
Occupation based National Statistics socio-economic classification (NS-SEC)				
Routine and manual occupations	1.69 (1.39-2.08)	1.35 (1.15-1.59)	1.92 (1.43-2.63)	1.25 (1.03-1.54)
Intermediate occupations (non-manual)	1.47 (1.23-1.75)	1.54 (1.19-1.96)	1.61 (1.25-2.08)	1.35 (1.01-1.85)
Managerial and professional occupations (reference)				
Net Household Income				
First quintile (lowest)	1.94 (1.50-2.52)	3.04 (2.31-3.99)	1.62 (1.08-2.44)	1.36 (0.85-2.16)
Second quintile	2.12 (1.67-2.70)	3.00 (2.28-3.93)	1.31 (0.93-1.85)	1.40 (0.89-2.18)
Third quintile	1.98 (1.56-2.51)	2.31 (1.75-3.05)	1.40 (1.01-1.94)	1.08 (0.69-1.67)
Fourth quintile	1.38 (1.08-1.74)	1.65 (1.23-2.20)	1.09 (0.80-1.49)	1.08 (0.70-1.66)
Fifth quintile (highest) (reference)				
Net Financial Wealth				
First quintile (lowest)	1.11 (0.86-1.45)	1.79 (1.38-2.33)	1.72 (1.26-2.35)	1.88 (1.37-2.58)
Second quintile	1.92 (1.52-2.42)	2.39 (1.88-3.04)	1.66 (1.26-2.18)	1.33 (1.00-1.77)
Third quintile	1.63 (1.30-2.04)	1.95 (1.53-2.50)	1.45 (1.12-1.88)	1.41 (1.06-1.88)
Fourth quintile	1.06 (0.85-1.32)	1.48 (1.15-1.91)	0.96 (0.75-1.24)	1.26 (0.94-1.68)
Fifth quintile (highest) (reference)				

*Unadjusted odds ratio (OR) ** Odds Ratio adjusted for age, marital status, retirement status, body mass index, tobacco consumption, alcohol consumption and physical activity.

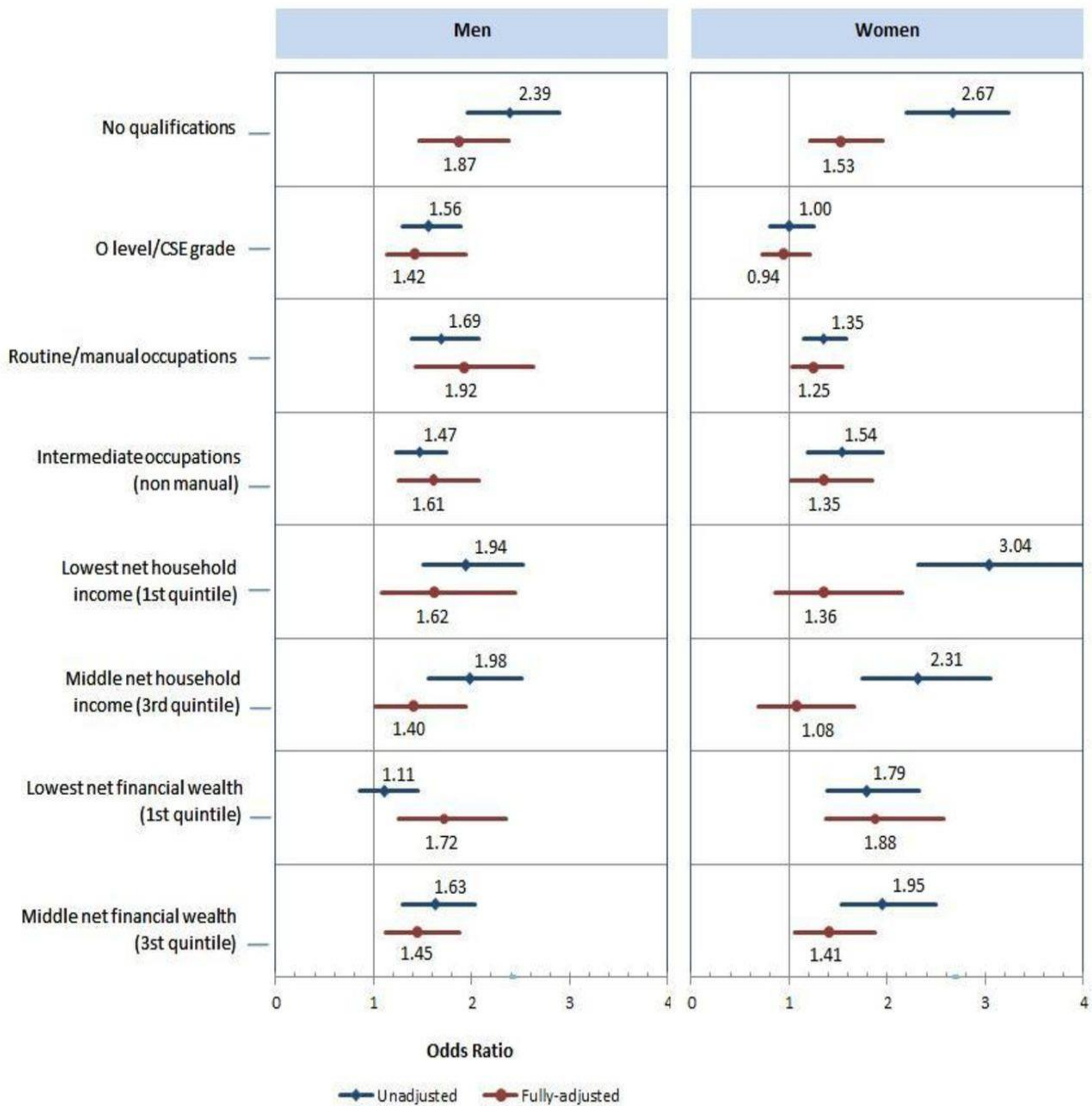

Figure 3.1. Associations between socioeconomic position and hearing loss in middle aged and older adults (N=8,529, aged 50-89).

Indicators of SEP were categories of the highest educational attainment (degree/higher education as a reference), tertiles of self-reported occupation based on the National Statistics Socio-economic Classification (NS-SEC) (managerial and professional as reference), quintiles of the net household income (first quintile lowest; fifth quintile highest) and quintiles of the total non-pension wealth that is reported at the household level (first quintile lowest; fifth quintile highest). Lines represent OR (outcome=hearing loss) and its 95% CI. Model A (rhombus): unadjusted. Model B (circles): adjusted for age, marital status, retirement status, body mass index, tobacco consumption, alcohol consumption and physical activity.

Table 3.4. Summary of stepwise logistic regression coefficients for variables predicting **HL >35 dB HL at 3.0kHz in the better-hearing ear** (N=8,529, aged 50-89), according to different SEP indicators (education, occupation, income, wealth).

		Model A			Model B			Model C			Model D		
	Step/Predictor	**Step 1**	**Step 2a**	**Step 3**	**Step 1**	**Step 2b**	**Step 3**	**Step 1**	**Step 2c**	**Step 3**	**Step 1**	**Step 2d**	**Step 3**
1	**Non-modifiable**		(Education)			(Occupation)			(Income)			(Wealth)	
	Gender (female)	-.62***	-.59***	-.72***	-.62***	-.64***	-.68***	-.62***	-.69***	-.70***	-.62***	-.69***	-.62***
	Age	.12***	.11***	.10***	.12***	.13***	.11***	.12***	.11***	.11***	.12***	.11***	.12***
2	**Partly modifiable**												
2a	Education		-.15***	-.11***		-	-		-	-		-	-
2b	Occupation (manual)			-		.26***	.20***		-	-		-	-
2c	Net Household Income			-		-	-		-.14***	-.09***		-	-
2d	Net Financial Wealth			-		-	-		-	-		-.17***	-.11***
3	**Modifiable**												
	Smoking (current/former)			.10*			.09			.10*			.09**
	Alcohol consumption (> 14 units per week)			.24***			.19***			.17***			.18**
	Body mass index (<25)			-.05*			-.06			-.03			-.04
	Physical Activity (*rigorous* sports or activities, once or more/week)			-.14***			-.16***			-.12***			-.13***
	Physical Activity (*moderate* sports or activities, once or more/week)			-.24***			-.24***			-.24***			-.24***
	Physical Activity (*mild* sports or activities, once or more/week)			-.17***			-.15***			-.15***			-.14***
	Pseudo R^2	.15	.18	.28	.15	.19	.26	.17	.18	.29	.17	.18	.27
	Δ Pseudo R^2	-	.03	.10	-	.04	.07	-	.01	.11	-	.01	.09
	Mean VIF	-	-	1.16	-	-	1.20	-	-	1.24	-	-	1.15

$^*p < .05$. $^{**}p < .01$ $^{***}p < .001$

The differences in hearing loss prevalence between males and females were observed across all age bands investigated. However, we noticed that the rate of deterioration of hearing acuity as age increases was similar between each age band and nearly to 60% in both genders (**Figure 3.2**). The difference in prevalence begins at the age band “50-64”, where men were twice as likely to have HL.

3.5. Discussion

Summary of main findings

In this study we examined whether SEP and modifiable lifestyle factors are associated with HL among older adults in England. We found that variation in education, occupation, income, and wealth, which are important determinants of health inequality, are associated with HL. SEP was strongly associated with the likelihood of HL in older adults, with the higher levels of education, income and wealth being less likely to be associated with HL, and the manual occupations increased the likelihood of HL. We also found that socioeconomic and several modifiable lifestyle factors (such as high body mass index, physical inactivity, tobacco consumption and alcohol intake above the low risk level guidelines) (Department of Health, 2016) are associated with the likelihood of HL as strongly as well-established demographic factors such as age and gender HL. These findings suggest that a large proportion of HL burden is potentially preventable and support the proposition of Scholes et al., (2018), that there is serious potential to reduce the prevalence and impacts of HL by understanding the impact of socioeconomic inequality in hearing health. Thus, the incidence and severity of HL in England could be significantly reduced by governmental policies to mitigate socioeconomic disparities and public health interventions to promote healthier lifestyles in middle-aged and older adults in England. The occurrence of objective hearing data eliminated the different types of bias that occur in self-reporting hearing difficulties (Andrade & Lopez-Ortega, 2017), strengthening the accuracy of findings.

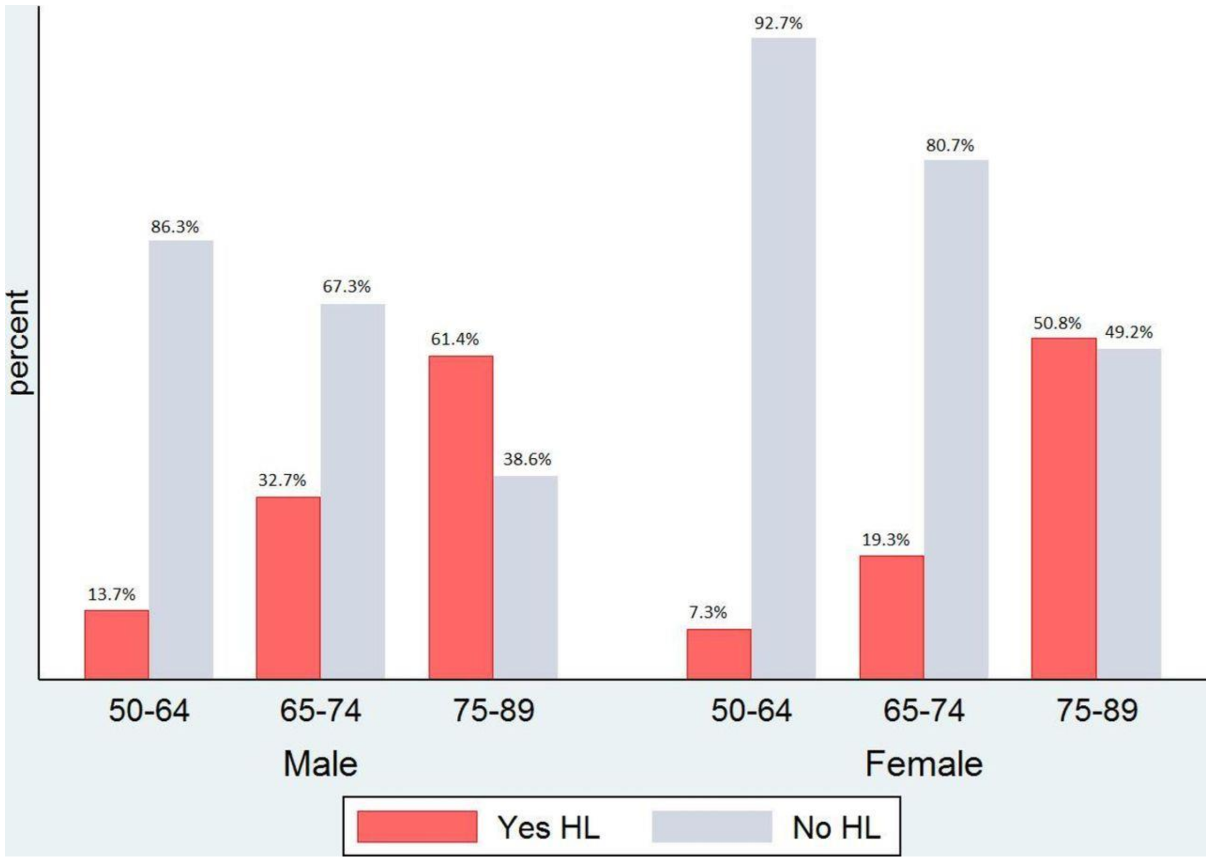

Figure 3.2. Hearing loss by age group and gender* (N=8,529 participants, aged 50-89, from the seventh wave of the English Longitudinal Study of Ageing (ELSA). Hearing loss was defined as >35 dB HL at 3.0 kHz, in the better hearing ear
*Prevalence estimates for males (N=3,728) and females (N=4,801).

Strengths and limitations

The main strength of our study was that is the first to examine the association of four separate SEP indicators with HL among older adults in England, instead of a proxy measure to reflect one's total SEP, capturing therefore most of the variation in socioeconomic stratification (Galobardes et al., 2006) and also the role of modifiable lifestyle risk factors in these associations. Another strength is that the analyses were based on a representative cohort of 8,529 participants contained in ELSA, which is a rich resource of information on the dynamics of health, social, wellbeing and economic circumstances in the English population aged 50 and older (Clemens et al., 2018).

However, there are also important limitations. First, no causal or temporal relationships can be established between lifestyle factors and HL in this cross-sectional study. Unhealthy lifestyle behaviours could lead to HL in older people but is also possible that older people adopt less healthy lifestyles after HL. Second, all the analysed factors explained less than one third of the variance for the prevalence of HL suggesting that there are additional major factors associated with HL in older adults which have not been included in our analyses. Longitudinal analyses using a broader range of physical health, mental health and social care variables are highly recommended to obtain a comprehensive understanding of modifiable factors that contribute to HL among older adults in England. Third, the ELSA dataset did not include information concerning the occupational and social noise exposure, which has a damaging effect in hearing (M E Lutman & Spencer, 1990). We, therefore, were not able to examine the association of noise exposure with smoking in the relationship of SEP with HL, as in a previous study which found that the smoking habit in workers exposed to occupational noise greatly influenced HL (Sung et al., 2013). However, we examined the association of manual occupations with HL and its attenuation by modifiable determinants including smoking habit, which is of a higher prevalence among those that work in routine and manual occupations in England (Health Profile for England, 2018). Finally, we did not run weighted analyses, which may have reduced the generalizability of our findings, as the ELSA sample members at Wave 7 could be healthier on average than the population, potentially resulting in an underestimation of relationships.

Research and policy implications

A number of previous studies have reported that the odds of HL in older adults were significantly increased for those with lower educational attainment (Martin et al., 2012; Pierre et al., 2012; Scholes et al., 2018; Zhan et al., 2011b), and those in manual versus non-manual occupations (Rosenhall et al., 1999) (A Davis, 1989). Besides, income is a correlate of HL, with the prevalence of untreated HL being higher among low-income older adults in the United States (Mamo et al., 2016). In our study, those in the lowest quintile of net household income had disproportionally higher percentages of moderate HL compared to moderately severe or severe HL, but this pattern was not found in the quintiles of wealth, as expected. This may indicate a possible delay in diagnosis of hearing problems among those in lower SEP due to financial barriers in access to health services (Tsimpida, D., Kaitelidou, D., & Galanis, 2018a), which needs further exploration, as HL is highly undiagnosed and untreated among older adults in England (Benova et al., 2015).

International studies have also shown that tobacco consumption, high body mass and high fat and high calorie food consumption can have an adverse impact on hearing (Bishop, 2012; Curhan et al., 2013; Hoffman et al., 2017; Üçler et al., 2016). On the other hand, a higher level of physical activity is related with a lower risk of HL (Bishop, 2012). In our study, two out of three participants were drinking more than the low risk level of the 14 units of alcohol a week (Department of Health, 2016). We considered therefore that alcohol consumption above the low risk level guidelines may play an important role in the association between SEP and HL among the English population and thus we included this variable in the regression models, which has not been previously examined in the literature for the English population. Our findings showed that drinking above the low risk level guidelines increased the likelihood of HL. This finding is in line with Chief Medical Officer's Drinking Guidelines (Department of Health, 2016), which suggest that *it is safest not to drink regularly more than 14 units per week, to keep health risks from drinking alcohol to a low level*.

The associations between indicators of lower socioeconomic position and hearing loss may be markers of less healthy lifestyle (Tsimpida, D., Kaitelidou, D., & Galanis, 2018b), which may explain the link between HL and socioeconomic and lifestyle factors investigated. Cruickshanks et al., (2015) did not find significant associations between hearing impairment and body mass index, smoking, and alcohol in multivariable analyses using a younger population-based sample (aged 18 to 74 years) of Hispanics/Latinos. Hence, it is likely that hearing loss in older population (e.g. 50 years and above) is associated with different risk factors or combinations of socioeconomic and lifestyle risk factors across the life-course.

The higher prevalence of HL among men aged 50 and above compared to women has also been reported in other studies (Scholes et al., 2018; Stevens et al., 2013). However, we observed that the rate of deterioration of hearing acuity as age increases was similar between each age band and nearly to 60% in both genders. The difference in prevalence begins at the age band "50-64", where men were twice as likely to have HL. Thus, the differences in modifiable lifestyle factors that were revealed in the stepwise regression models may finally explain why the male sex is often cited as consistent risk factor for hearing loss (Karen J Cruickshanks et al., 2015; Hoffman et al., 2017; Lin et al., 2011) leading to the exploration of modifiable determinants that are common in both genders (Tsimpida, D., Kaitelidou, D., & Galanis, 2018b) and paving the way for interventions to improve the population's hearing health.

In terms of policy, generating evidence concerning the critical variables associated with HL is an important step in designing targeted services and interventions for individuals that face hearing health inequalities, and especially for those in the lowest

SEP groups, where the burden of HL falls highest. This is of major importance for the population in England, as sensor diseases are the first leading cause of morbidity among adults 70 years and older and the second leading cause among adults 50-69 years (Health Profile for England, 2018). Our findings support the view that HL is a non-communicable disease (World Health Organization, 2015) which can be prevented or ameliorated by governmental policies to mitigate socioeconomic disparities and public health interventions to promote healthier lifestyles in middle-aged and older adults in England.

Conclusion

The main finding of our study is that HL is strongly associated with socioeconomic factors and modifiable lifestyle behaviours. Our findings are supportive of a new conceptualisation of HL which argues that HL is not necessarily an inevitable accompaniment of ageing, but also a potential preventable lifestyle disease, paving the way for the term *lifestyle-related hearing loss*, where *lifestyle* refers to *social practices and ways of living adopted by individuals that reflect personal, group, and socio-economic identities* (Gochman, 2013) instead of the non-inclusive term "*age-related hearing loss*". Future research in hearing health inequalities should investigate the role of the prolonged exposure to these modifiable lifestyle behaviours in the development of HL and the role of other comorbid chronic diseases in the elderly.

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Chapter 4

Regional Patterns and Trends of Hearing Loss in England: Evidence from the English Longitudinal Study of Ageing (ELSA) and Implications for Health Policy

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4.1. Abstract

Background: Hearing loss (HL) is a significant public health concern globally and is estimated to affect over nine million people in England. The aim of this research was to explore the regional patterns and trends of HL in a representative longitudinal prospective cohort study of the English population aged 50 and over.

Methods: We used the full dataset (74,699 person-years) of self-reported hearing data from all eight Waves of the English Longitudinal Study of Ageing (ELSA) (2002–2017). We examined the geographical identifiers of the participants at the Government Office Region (GOR) level and the geographically based Index of Multiple Deprivation (IMD). The primary outcome measure was self-reported HL; it consisted of a merged category of people who rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor) or responded positively when asked whether they find it difficult to follow a conversation if there is background noise (e.g. noise from a TV, a radio or children playing).

Results: A marked elevation in HL prevalence (10.2%) independent of the age of the participants was observed in England in 2002–2017. The mean HL prevalence increased from 38.50 (95%CI 37.37–39.14) in Wave 1 to 48.66 (95%CI 47.11–49.54) in Wave 8. We identified three critical patterns of findings concerning regional trends: the highest HL prevalence among samples with equal means of age was observed in GORs with the highest prevalence of participants in the most deprived (IMD) quintile, in routine or manual occupations and misusing alcohol. The adjusted HL predictions at the means (APMs) showed marked regional variability and hearing health inequalities between Northern and Southern England that were previously unknown.

Conclusions: A sociospatial approach is crucial for planning sustainable models of hearing care based on actual needs and reducing hearing health inequalities. The Clinical Commissioning Groups (CCGs) currently responsible for the NHS audiology services in England should not consider HL an inevitable accompaniment of older age; instead, they should incorporate socio-economic factors and modifiable lifestyle behaviours for HL within their spatial patterning in England.

Keywords: Hearing loss; ELSA, inequalities; social epidemiology; health geography

4.2. Introduction

Hearing loss (HL) is a significant public health concern that costs the UK economy £25 billion a year in productivity and unemployment (Hill, Holton, & Regan, 2015), an amount that equates to one-fifth of the total annual health spending in England in 2018/19 (Service & Schemes, 2019). HL affects over nine million people in England, and it is estimated that, by 2035, the number of people with HL will rise to around 13 million. The above estimates, along with the local hearing needs in England, are calculated by population projections based on the study of Davis (Davis, 1995), who collected and analysed audiological data in the 1980s. This study remains the primary source of local estimates of HL prevalence (Akeroyd, Foreman, & Holman, 2014); recently, these estimates have also been visualised in the form of a hearing map, offering a rough guide to the prevalence of HL among adults across the UK (National Community Hearing Association, 2016).

Despite its importance to the history of hearing care in the UK, Davis's study had some significant limitations. First, the English samples were solely derived from the cities of Nottingham and Southampton, which are very unlikely to be representative of the whole population of England (Davis, 1995). The role of place in health is well-established (Cabrera-Barona, Blaschke, & Gaona, 2018; Curtis & Jones, 1998), and research has shown that it affects health outcomes [6]. Second, scientific thinking in HL research was formed in previous decades around the concepts of older age and the male sex being the main leading causes of HL in adults, with little or no consideration for modifiable risk factors for hearing acuity. However, recent findings have suggested that socio-economic factors and modifiable lifestyle behaviours are associated with the likelihood of HL as firmly as well-established demographic factors such as age and sex (Tsimpida et al., 2019). Thus, the study of Davis did not consider in its estimations the effects of place and socio-economic factors such as high occupational noise exposure from manual occupations (Lie et al., 2016) and differences in regions with strong and weak manufacturing industries (NHS England, 2016).

The Clinical Commissioning Groups (CCGs) are currently responsible for the NHS audiology services in England, including the provision of hearing aids (NICE, 2018). However, the lack of robust hearing data makes it difficult to plan efficient, effective and sustainable models of hearing care based on patient needs (NHS England, 2016). Exploratory spatial data analysis of hearing data from a representative population sample in England would reveal regional patterns and trends of HL, shedding light on potential socio-economic inequalities in hearing health. This updated analysis of HL prevalence could inform the health policy strategies of the NHS England and Department of Health, particularly in respect of the new governmental programme, 'Action Plan on Hearing Loss' (Hill et al., 2015).

The aim of this study was, therefore, to explore regional patterns and trends of HL in a representative longitudinal prospective cohort study of the English population aged 50 and over.

4.3. Methods

The study utilised data from the English Longitudinal Study of Ageing (ELSA). The ELSA is a longitudinal prospective cohort study that collects multidisciplinary data from a nationally representative sample of community-dwelling middle-aged and older (aged 50 and above) adults in England (Steptoe, Breeze, Banks, & Nazroo, 2013). The study started in 2002 and is collecting responses every two years on participants' health, social, wellbeing and economic circumstances.

The current sample contains data from eight Waves, covering the period 2002–2017 (Zaninotto & Steptoe, 2019). As the ELSA follows a longitudinal design, the sample is comprised of a sequence of observations on the same individuals across Waves and the refreshment samples (Cohorts 3, 4, 6 and 7). (Zaninotto & Steptoe, 2019) Proxy interviews were carried out in case an ELSA panel member refused to further participate (Banks, Nazroo, & Steptoe, 2018). In our analyses, we used the full dataset (74,699 person-years) of self-reported hearing data from all eight Waves of the ELSA.

The ELSA follows the sampling strategy of the Health Survey for England (HSE), which ensures that every address on the small users' Postcode Address File (PAF) in England has an equal chance of inclusion. Field household contact rates of over 96% were achieved. The study excluded cases not belonging to the target population through 'terminating events', such as deaths, institutional moves and moves out of England since taking part in the HSE (Marmot, Banks, Blundell, Lessof, & Nazroo, 2003).

Outcomes

Hearing acuity

Self-rated hearing data was collected from participants across all Waves. According to the study's documentation, self-reported HL was defined as declarations of fair or poor hearing on a five-point Likert scale (excellent, very good, good, fair or poor) or 'Yes' responses to the question concerning whether or not the participants find it difficult to follow a conversation if there is background noise (e.g. noise from a TV, a radio or children playing) (Zaninotto & Steptoe, 2019) (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti, 2020).

Geographical variables

The geographically related information of the ELSA dataset was in the form of identifiers such as the Government Office Region (GOR) (Office for National Statistics, n.d.), and indices that are used as measure of poverty of different geographical areas, such as the Index of Multiple Deprivation (IMD). The geographical variables were provided to the first author under a Special License and Secure Access agreement (UK Data Service Project Number: 121175).

Each respondent's geography is determined by their residence postcode at the time of the survey interview date. Different versions of the IMD were provided for the eight Waves of the ELSA: IMD 2004 (Noble et al., 2004) for Waves 1–3, IMD 2007 (Noble, Wilkinson, & Barnes, 2008) for Wave 4, IMD 2010 (McLennan et al., 2011) for Waves 5–7 and IMD 2015 (Smith et al., 2015) for Wave 8. The IMD was provided in quintiles (the first quintile being the least deprived, the fifth being the most deprived).

The nine GORs represent the highest tier of sub-national division in England (North East, North West, Yorkshire and the Humber, East Midlands, West Midlands, East of England, London, South East, South West).

Covariates

For covariates, we examined non-modifiable factors (age, sex), partly modifiable indicators of socio-economic position (SEP) (education, occupation, income, wealth) and alcohol consumption as a fully modifiable lifestyle risk factor for HL. Age was assessed both as a discrete (as only certain values could be taken) and categorical variable in three groups (50–64, 65–74, 75–89). We used this categorisation to allow for a comparison with Benova et al. (Benova, Grundy, & Ploubidis, 2015), who examined the association of SEP with self-reported hearing difficulties in Wave 2 of the ELSA.

We considered five categories regarding highest educational attainment: no qualifications, foreign or other, O level Certificate of Secondary Education, A level (Level 3 Qualification of the National Qualifications Framework) and a degree or higher education.

Tertiles of self-reported occupation were based on the National Statistics Socio-economic Classification (NS-SEC): routine and manual occupations; intermediate; managerial and professional. The relative financial position of the participants was captured by quintiles of net household income (the first quintile being the lowest, the fifth being the highest). Wealth was examined in quintiles of the net total non-pension wealth reported at the household unit level (the first quintile being the highest, the fifth being the lowest).

Alcohol consumption was selected as the only lifestyle factor that was consistently recorded in all Waves. We constructed a continuous variable to represent the sum of units of alcohol that each participant consumed during the last seven days. This variable was dichotomised into those that consumed more than 14 units of alcohol in the last seven days and those that did not, using the Chief Medical Officer's Drinking Guidelines (Department of Health, 2016).

Data analysis

Categorical variables are presented as absolute (n) and relative (%) frequencies, while continuous variables are presented through their mean and standard deviation. We used the full dataset from the eight Waves (74,699 person-years) to strengthen the argument that there is a correlation between spatial variables and HL over time. A small number of cases (one in Wave 0 and eight in Wave 2) in the geographical identifiers had missing values because the address was located within Wales (which uses its own deprivation index). Due to the low proportion of missingness in the variables, records with missing data were excluded from analyses (3.2% of all records in listwise deletion). We used Bartlett's test for homogeneity of variances to test that age variances were equal for all samples. Following this, we applied one-way analysis of variance (ANOVA) to compare the means of age among GOR samples in all Waves. We also computed adjusted predictions at the means (APMs) and the marginal effects at the means (MEMs) (Williams, 2012) for the HL prevalence in each Wave of the ELSA, with age, sex, education, occupation, income, wealth, IMD and alcohol consumption as the factor variables.

We used local spatial analysis statistical tools for analysing spatial distributions, patterns, processes and relationships in the geographical data. We used the Spatial Join tool to aggregate the number of cases of self-reported HL to total responses of hearing acuity in each polygon (GOR) in order to visualise the prevalence rates of HL per GOR. We used the Natural Breaks (Jenks) classification to optimise the arrangement of the sets of HL values into 'natural' classes, a method also known as the goodness of variance fit (GVF). Furthermore, we used the Hot Spot Analysis (Getis-Ord Gi*) as a mapping cluster tool to identify the locations of statistically significant Hot Spots and Cold Spots. The Getis-Ord Gi* is an inferential statistic for the conceptualisation of spatial relationships, used when one is looking for unexpected spatial spikes of high values. In essence, this tool works by looking at each feature within the context of neighbouring features and assessing whether high or low values cluster spatially. Due to the small scale of the analysis, we chose this local spatial statistic tool so that the value of each feature could be included in its own analysis, along with the neighbouring features.

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (1)$$

Here, x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features and:

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\overline{X})^2} \quad (3)$$

The G_i^* statistic is a z-score, so no further calculations are required.

The spatial relationship was defined according to the 'Contiguity Edges Corners', a method that was selected in order to allow all neighbouring polygon features that share a boundary or node to influence the target polygon feature's computations. Confidence levels of 90%, 95% and 99% were considered in the calculations of Getis-Ord Gi*. Data were analysed using Stata version 14 (StataCorp, 2015) and ESRI ArcGIS Desktop 10.7.1 (ESRI, 2011).

4.4. Results

The results of one-way ANOVA indicated that the null hypothesis was not rejected in Waves 2, 6, 7 and 8 (as p>0.05), which means that there is sufficient evidence to conclude that the means of age among GORs' samples were equal (Kim, 2017). In addition, the means of age across Waves were significantly equal for all samples (p=0.996). Using Bartlett's test, we found that the variances of the means of age among GORs were equal in Waves 3, 5, 6, 7 and 8 and across all Waves. A table presenting the one-way ANOVA test results – including sums of squares, mean squares, degrees of freedom and the F-values and p-values of means of age across the nine GORs in eight Waves of the ELSA – is provided in the Supplement.

Table 4.1 shows the participants' non-modifiable demographic factors and HL prevalence in England in eight Waves of the ELSA. We observed considerable variation in the prevalence rate of HL among GORs (normalised per GOR population), which reached 12.3%. In Wave 5, the prevalence of HL was 39.55 in the South East (95%CI 37.12–42.04) versus 51.85 in the North East (95%CI 47.66–56.02).

Table 4.2 shows participants' socio-economic and lifestyle factors and HL prevalence in England in eight Waves of the ELSA. In Waves 2–8, the highest prevalence of HL was reported in the GORs that had the highest prevalence of participants belonging to the most deprived quintiles (fifth) according to the IMD. Compared to other GORs, the North East had the highest HL prevalence consistently in all Waves, along with the highest percentage of participants in the most deprived IMD quintile. The rates reached the highest in Wave 7 (2015–2017), with 50.12% of the participants self-reporting HL (95%CI 45.26–54.98) and 39.12% for those residing in an area in the most deprived IMD quintile (95%CI 36.62–41.67).

Moreover, the highest prevalence of HL was reported in the GORs with the highest prevalence of participants belonging in the group of routine or manual occupations. In

Waves 1–5, participants from the North East had both the highest rates of routine or manual occupations and the highest prevalence rates of HL among all GORs.

Finally, we observed an increasing trend over time in total alcohol misuse (alcohol consumption above the low-risk level guidelines) in all Waves; the prevalence of alcohol misuse increased in 2002–2017, going from an average of 10.17% in Wave 1 to 33.98% in Wave 8. The South West had one of the highest prevalence rates of alcohol misuse, in parallel with one of the highest prevalence rates of self-reported HL. It is worth mentioning that their sample was of a higher SEP in all Waves (with respect to education, occupation, income, wealth and IMD).

Figure 4.1 illustrates the prevalence of HL in each GOR across the eight Waves of the ELSA. There was an increasing trend over time in the HL prevalence for all five classes. In samples of significantly equal means of age between GORs, the mean HL prevalence increased from 38.50 (95%CI 37.37–39.14) in Wave 1 to 48.66 (95%CI 47.11–49.54) in Wave 8.

Figure 4.2 depicts the Hot Spot and Cold Spot analyses in England, based on the Getis-Ord Gi* statistic; the analyses identified statistically significant spatial clusters of high values (Hot Spots) and low values (Cold Spots) in all Waves of the ELSA. We observed some statistically significant spatial clusters of HL prevalence covering specific GORs in England as all Hot and Cold Spots were found in the northern and southern parts of England, respectively. In essence, we observed spatial clustering of high (Hot) or low (Cold) values that were more pronounced than one would expect in a random distribution of these same values. In Waves 1–6, the z-score value in the North East GOR was positive, which means that the spatial distribution of high values in this part of England was more spatially clustered than would be expected if the underlying spatial processes were truly random. On the other hand, during the same period the z-score value in the South East GOR was negative, which means that the spatial distribution of low values in the dataset was more spatially clustered than would be expected if the underlying spatial processes were truly random.

Figure 4.3 shows the predicted probabilities of HL prevalence in each region and Wave of the ELSA, holding all other variables in the model at their means. The results tell us that if we had two otherwise-average individuals in each Wave, the probability of them having HL would vary significantly among regions. For example, in Wave 1, one's probability of having HL in Yorkshire and the Humber would be 10.2% higher than it would be for an otherwise-comparable participant in London (Yorkshire and the Humber APM= .437, London APM = .335, MEM = .437 – .335 = .102) (please also see the Supplement). The predicted probability of having HL demonstrated an increasing trend over time in all regions. The maximum increase of predicted HL probability among older adults of significantly equal age in the 15-year period was in the South West, which had a 45% increase (Wave 1:37.3 [34.4–40.2], Wave 8: 54.1 [48.9–59.2]).

Table 4.1. Participants' non-modifiable demographic factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)[c]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)
	WAVE 1 (2002-2003)							**WAVE 2 (2004-2005)**						
North East	325 (42.54)	323 (41.79)	450 (58.21)	366 (49.80)	245 (33.33)	124 (16.87)	64.33 (10.53)	254 (43.34)	251 (42.33)	342 (57.67)	272 (47.06)	189 (32.70)	117 (20.24)	65.79 (9.97)
North West	603 (38.78)	692 (43.88)	885 (56.12)	799 (53.30)	410 (27.35)	290 (19.35)	64.24 (10.95)	432 (36.86)	517 (43.34)	676 (56.66)	551 (48.25)	337 (29.51)	254 (22.24)	66.21 (10.91)
Yorkshire and The Humber	549 (43.06)	573 (44.28)	721 (55.72)	646 (52.73)	351 (28.65)	228 (18.61)	63.84 (10.91)	401 (40.46)	438 (43.63)	566 (56.37)	474 (48.77)	294 (30.25)	204 (20.99)	65.57 (10.39)
East Midlands	449 (39.18)	528 (45.21)	640 (54.79)	605 (55.50)	297 (27.25)	188 (17.25)	63.30 (11.06)	335 (35.52)	425 (44.41)	532 (55.59)	481 (52.17)	247 (26.79)	194 (21.04)	64.99 (10.42)
West Midlands	452 (36.78)	550 (43.69)	709 (56.31)	599 (49.92)	358 (29.83)	243 (20.25)	64.77 (10.99)	375 (38.82)	422 (43.28)	553 (56.72)	445 (47.34)	290 (30.85)	205 (21.81)	66.06 (10.64)
East of England	507 (37.50)	596 (43.95)	760 (56.05)	663 (51.88)	368 (28.79)	247 (19.33)	64.19 (11.16)	400 (37.00)	491 (44.84)	604 (55.16)	507 (48.33)	317 (30.22)	225 (21.45)	65.81 (10.85)
London	385 (34.16)	484 (42.31)	660 (57.69)	574 (53.75)	268 (25.09)	226 (21.16)	64.46 (11.54)	292 (35.39)	347 (41.61)	487 (58.39)	406 (50.94)	222 (27.85)	169 (21.20)	66.05 (11.22)
South East	681 (36.13)	823 (43.04)	1089 (56.96)	951 (52.57)	484 (26.76)	374 (20.67)	64.27 (10.97)	513 (35.19)	628 (42.58)	847 (57.42)	688 (48.38)	391 (27.50)	343 (24.12)	66.14 (10.79)
South West	510 (38.37)	602 (44.83)	741 (55.17)	605 (47.79)	363 (28.67)	298 (23.54)	65.12 (11.38)	420 (39.77)	468 (43.90)	598 (56.10)	462 (44.90)	307 (29.83)	260 (25.27)	66.64 (10.61)
	WAVE 3 (2006-2007)							**WAVE 4 (2008-2009)**						
North East	284 (47.81)	259 (42.81)	346 (57.19)	289 (49.49)	160 (27.40)	135 (23.12)	65.51 (10.67)	284 (47.81)	274 (41.96)	379 (58.04)	306 (48.19)	185 (29.13)	144 (22.68)	66.53 (10.50)
North West	458 (40.39)	508 (43.76)	653 (56.24)	593 (54.45)	276 (25.34)	220 (20.20)	64.53 (11.41)	458 (40.39)	586 (44.46)	732 (55.54)	682 (53.41)	352 (27.56)	243 (19.03)	65.15 (10.57)
Yorkshire and The Humber	452 (42.68)	475 (43.70)	612 (56.30)	546 (53.37)	275 (26.88)	202 (19.75)	64.16 (11.16)	452 (42.68)	492 (42.89)	655 (57.11)	573 (52.04)	322 (29.25)	206 (18.71)	64.95 (10.41)
East Midlands	368 (37.98)	440 (44.44)	550 (55.56)	537 (57.19)	227 (24.17)	175 (18.64)	63.43 (10.95)	368 (37.98)	496 (44.36)	622 (55.64)	597 (55.28)	294 (27.22)	189 (17.50)	64.88 (10.34)
West Midlands	392 (39.68)	435 (43.28)	570 (56.72)	503 (52.89)	243 (25.55)	205 (21.56)	65.13 (11.64)	392 (39.68)	511 (44.40)	640 (55.60)	565 (50.81)	314 (28.24)	233 (20.95)	66.00 (10.71)
East of England	461 (40.33)	524 (44.86)	644 (55.14)	585 (52.89)	297 (26.85)	224 (20.25)	64.42 (11.48)	461 (40.33)	596 (45.05)	727 (54.95)	667 (52.73)	391 (30.91)	207 (16.36)	64.96 (10.44)

Table 4.1. Participants' non-modifiable demographic factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)[c]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)
London	348 (40.65)	356 (40.78)	517 (59.22)	451 (55.41)	199 (24.45)	164 (20.15)	64.77 (12.06)	348 (40.65)	404 (43.44)	526 (56.56)	487 (54.90)	242 (27.28)	158 (17.81)	65.44 (11.09)
South East	534 (35.77)	654 (42.63)	880 (57.37)	767 (52.86)	371 (25.57)	313 (21.57)	64.84 (11.42)	534 (35.77)	781 (43.51)	1014 (56.49)	902 (52.17)	496 (28.69)	331 (19.14)	65.28 (10.35)
South West	453 (43.06)	476 (44.61)	591 (55.39)	495 (48.82)	266 (26.23)	253 (24.95)	65.81 (11.51)	453 (43.06)	530 (44.06)	673 (55.94)	561 (48.32)	351 (30.23)	249 (21.45)	66.14 (10.54)
	WAVE 5 (2010-2011)							**WAVE 6 (2012-2013)**						
North East	295 (51.85)	255 (43.29)	334 (56.71)	241 (41.70)	177 (30.62)	160 (27.68)	66.78 (12.69)	249 (50.00)	226 (43.38)	295 (56.62)	185 (36.42)	167 (32.87)	156 (30.71)	66.97 (14.74)
North West	481 (42.68)	531 (44.81)	654 (55.19)	575 (49.74)	338 (29.24)	243 (21.02)	65.03 (12.99)	471 (46.96)	481 (45.00)	588 (55.00)	442 (42.14)	359 (34.22)	248 (23.64)	66.61 (12.61)
Yorkshire and The Humber	457 (45.11)	442 (42.34)	602 (57.66)	484 (47.78)	315 (31.10)	214 (21.13)	65.29 (12.26)	453 (48.81)	407 (42.05)	561 (57.95)	401 (42.57)	305 (32.38)	236 (25.05)	66.58 (12.54)
East Midlands	399 (39.66)	467 (44.18)	590 (55.82)	522 (50.68)	297 (28.83)	211 (20.49)	64.85 (12.34)	391 (41.68)	430 (43.61)	556 (56.39)	406 (42.34)	333 (34.72)	220 (22.94)	65.86 (13.36)
West Midlands	413 (40.73)	484 (45.23)	586 (54.77)	461 (44.93)	333 (32.46)	232 (22.61)	64.45 (15.38)	399 (42.95)	436 (44.58)	542 (55.42)	354 (37.78)	323 (34.47)	260 (27.75)	65.58 (16.05)
East of England	503 (42.20)	556 (44.80)	685 (55.20)	556 (46.37)	384 (32.03)	259 (21.60)	65.28 (13.34)	514 (46.77)	504 (44.02)	641 (55.98)	438 (39.75)	393 (35.66)	271 (24.59)	65.74 (14.78)
London	333 (40.71)	349 (40.77)	507 (59.23)	404 (49.75)	238 (29.31)	170 (20.94)	63.54 (15.57)	302 (41.26)	322 (41.82)	448 (58.18)	314 (42.43)	255 (34.46)	171 (23.11)	65.08 (15.46)
South East	615 (39.55)	697 (42.97)	925 (57.03)	739 (46.89)	490 (31.09)	347 (22.02)	65.46 (13.06)	639 (44.53)	648 (43.23)	851 (56.77)	569 (38.89)	523 (35.75)	371 (25.36)	66.45 (13.40)
South West	469 (42.95)	504 (44.02)	641 (55.98)	489 (44.01)	354 (31.86)	268 (24.12)	66.14 (13.12)	489 (48.71)	476 (44.99)	582 (55.01)	378 (37.06)	361 (35.39)	281 (27.55)	66.28 (15.16)
	WAVE 7 (2014-2015)							**WAVE 8 (2016-2017)**						
North East	212 (50.12)	195 (43.43)	254 (56.57)	132 (30.28)	158 (51.92)	146 (33.49)	68.10 (15.45)	202 (53.72)	172 (43.22)	226 (56.78)	82 (20.97)	161 (41.18)	148 (37.85)	70.39 (13.04)
North West	378 (43.15)	402 (43.41)	524 (56.59)	308 (34.07)	365 (61.21)	231 (25.55)	67.15 (13.72)	370 (48.49)	349 (43.68)	450 (56.32)	205 (26.42)	357 (46.01)	214 (27.58)	68.02 (14.45)
Yorkshire and The Humber	360 (46.51)	339 (42.06)	467 (57.94)	262 (33.04)	318 (59.85)	213 (26.86)	68.19 (11.71)	339 (48.36)	302 (41.20)	431 (58.80)	188 (26.18)	310 (43.18)	220 (30.64)	69.04 (12.69)

Table 4.1. Participants' non-modifiable demographic factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)[c]	Hearing loss[b]	Men	Women	Age 50-64	Age 65-74	Age 75-89	Mean age (SD)
East Midlands	351 (42.39)	374 (43.19)	492 (56.81)	296 (35.03)	327 (59.52)	222 (26.27)	67.51 (13.18)	351 (47.56)	331 (43.04)	438 (56.96)	204 (27.20)	330 (44.00)	216 (28.80)	68.64 (13.53)
West Midlands	359 (44.65)	390 (45.56)	466 (54.44)	274 (33.21)	299 (54.23)	252 (30.55)	66.78 (16.46)	340 (48.02)	346 (45.89)	408 (54.11)	203 (28.04)	294 (40.61)	227 (31.35)	67.52 (16.94)
East of England	417 (42.55)	448 (43.62)	579 (56.38)	324 (32.69)	383 (57.39)	284 (28.66)	67.24 (14.55)	423 (47.37)	402 (43.37)	525 (56.63)	218 (24.17)	385 (42.68)	299 (33.15)	68.81 (14.20)
London	258 (40.12)	284 (42.07)	391 (57.93)	239 (36.66)	241 (58.30)	172 (26.38)	66.50 (15.04)	249 (46.03)	239 (42.00)	330 (58.00)	158 (28.42)	223 (40.11)	175 (31.47)	68.83 (13.78)
South East	537 (42.96)	551 (41.90)	764 (58.10)	388 (30.29)	512 (57.32)	381 (29.74)	67.85 (13.94)	508 (46.35)	479 (41.87)	665 (58.13)	253 (22.71)	499 (44.79)	362 (32.50)	69.17 (14.36)
South West	413 (46.67)	411 (43.82)	527 (56.18)	279 (30.79)	348 (55.48)	279 (30.79)	67.59 (15.39)	399 (52.02)	344 (43.05)	455 (56.95)	175 (22.58)	349 (45.03)	251 (32.39)	68.79 (15.24)

Values are expressed as column N (%) unless otherwise is indicated.

[a] GOR: Government Office Regions

[b] Self-reported hearing loss: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).

[c] Mean (SD): mean age in years (Standard deviation)

Table 4.2. Participants' socioeconomic and lifestyle factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Lowest education[c]	Manual Occupation[d]	Lowest Income[e]	Lowest wealth[f]	Most deprived[g]	Alcohol misuse[h]	Hearing loss	Lowest education	Manual Occupation	Lowest Income	Lowest wealth	Most deprived	Alcohol misuse
	WAVE 1 (2002-2003)							**WAVE 2 (2004-2005)**						
North East	325 (42.54)	362 (46.89)	404 (53.02)	169 (23.06)	169 (23.87)	261 (33.76)	74 (9.9	254 (43.34)	249 (42.35)	320 (54.89)	125 (22.52)	148 (26.31)	191 (32.21)	96 (29.91)
North West	603 (38.78)	699 (44.38)	744 (48.00)	296 (20.05)	296 (20.60)	441 (27.96)	179 (11.	432 (36.86)	486 (40.77)	550 (46.61)	233 (20.77)	231 (19.52)	298 (24.98)	233 (34.88)
Yorkshire and The Humber	549 (43.06)	596 (46.09)	662 (52.21)	280 (23.12)	280 (23.31)	323 (24.96)	131 (10.	401 (40.46)	431 (43.01)	501 (50.86)	226 (24.04)	183 (22.13)	236 (23.51)	175 (30.92)
East Midlands	449 (39.18)	493 (42.25)	552 (47.83)	205 (19.21)	205 (19.18)	158 (13.53)	122 (10.	335 (35.52)	396 (41.42)	447 (47.25)	161 (18.34)	175 (19.70)	115 (12.02)	182 (33.46)
West Midlands	452 (36.78)	633 (50.28)	604 (48.99)	261 (22.19)	261 (22.48)	201 (15.97)	130 (10.	375 (38.82)	456 (47.06)	458 (48.06)	181 (19.93)	189 (18.83)	145 (14.87)	168 (31.88)
East of England	507 (37.50)	540 (39.82)	539 (40.50)	204 (16.16)	204 (16.20)	57 (4.20)	101 (7.7	400 (37.00)	398 (36.58)	427 (39.61)	143 (14.19)	137 (17.36)	48 (4.38)	224 (34.46)
London	385 (34.16)	488 (42.69)	445 (40.83)	255 (24.36)	255 (23.94)	237 (20.72)	109 (10.	292 (35.39)	328 (39.38)	326 (40.70)	162 (21.15)	189 (16.97)	163 (19.54)	133 (33.84)
South East	681 (36.13)	651 (34.05)	703 (37.45)	261 (14.61)	261 (14.76)	66 (3.45)	215 (11.	513 (35.19)	449 (30.61)	513 (35.33)	224 (16.40)	198 (19.18)	46 (3.12)	370 (40.31)
South West	510 (38.37)	483 (35.99)	556 (42.54)	227 (18.17)	227 (17.57)	64 (4.77)	100 (7.8	420 (39.77)	352 (33.08)	426 (40.69)	186 (18.49)	154 (16.20)	40 (3.75)	213 (34.80)
	WAVE 3 (2006-2007)							**WAVE 4 (2008-2009)**						
North East	284 (47.81)	218 (36.33)	323 (54.56)	117 (21.35)	146 (26.64)	204 (33.72)	84 (26.33)	296 (47.21)	225 (34.72)	334 (53.27)	114 (19.29)	143 (24.20)	196 (30.02)	117 (35.03)
North West	458 (40.39)	341 (29.45)	505 (43.95)	209 (20.29)	236 (22.91)	299 (25.75)	198 (31.94)	511 (40.36)	379 (29.04)	520 (41.63)	217 (18.63)	243 (20.86)	288 (21.85)	262 (39.70)
Yorkshire and The Humber	452 (42.68)	372 (34.35)	518 (48.82)	225 (23.20)	186 (19.18)	238 (21.90)	183 (30.86)	491 (44.60)	351 (30.76)	519 (47.18)	224 (21.66)	207 (20.02)	223 (19.44)	207 (34.56)
East Midlands	368 (37.98)	321 (32.59)	434 (44.60)	193 (22.29)	175 (20.21)	116 (11.72)	163 (31.05)	434 (40.49)	357 (32.19)	475 (44.35)	218 (22.13)	172 (17.46)	109 (9.74)	199 (32.52)
West Midlands	392 (39.68)	363 (36.23)	451 (46.02)	168 (18.79)	182 (20.36)	141 (14.03)	170 (31.89)	461 (41.31)	405 (35.31)	502 (45.43)	204 (19.84)	199 (19.36)	188 (16.33)	219 (36.44)
East of England	461 (40.33)	329 (28.41)	447 (39.01)	173 (17.06)	144 (14.20)	49 (4.20)	200 (30.86)	530 (41.15)	374 (28.55)	464 (36.65)	197 (17.00)	166 (14.32)	62 (4.69)	241 (32.66)

Table 4.2. Participants' socioeconomic and lifestyle factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Lowest education[c]	Manual Occupation[d]	Lowest Income[e]	Lowest wealth[f]	Most deprived[g]	Alcohol misuse[h]	Hearing loss	Lowest education	Manual Occupation	Lowest Income	Lowest wealth	Most deprived	Alcohol misuse
London	348 (40.65)	267 (30.76)	319 (37.71)	157 (20.55)	175 (22.91)	152 (17.41)	152 (36.54)	348 (38.71)	266 (28.94)	315 (36.04)	171 (20.90)	201 24.57)	184 (19.78)	159 (35.49)
South East	534 (35.77)	348 (22.77)	512 (33.84)	209 (15.61)	202 (15.09)	50 (3.26)	364 (40.00)	669 (38.45)	399 (22.37)	595 (34.33)	227 (14.39)	199 (12.62)	81 (4.51)	396 (37.71)
South West	453 (43.06)	267 (25.24)	401 (38.26)	163 (17.23)	129 (13.64)	33 (3.09)	217 (36.35)	501 (43.00)	283 (23.86)	406 (35.09)	180 (16.73)	148 (13.75)	44 (3.66)	257 (37.63)
	WAVE 5 (2010-2011)							**WAVE 6 (2012-2013)**						
North East	295 (51.85)	196 (33.73)	287 (49.91)	99 (18.50)	146 (27.29)	155 (26.27)	116 (38.16)	249 (50.00)	172 (33.46)	239 (46.59)	90 (19.11)	95 (20.17)	142 (27.26)	104 (37.96)
North West	481 (42.68)	317 (27.26)	455 (39.16)	187 (17.76)	229 (21.75)	236 (19.92)	249 (36.89)	471 (46.96)	288 (27.32)	397 (37.59)	171 (18.08)	162 (17.12)	215 (20.11)	212 (38.69)
Yorkshire and The Humber	457 (45.11)	330 (31.88)	491 (48.18)	195 (20.81)	193 (20.60)	197 (18.87)	195 (34.64)	453 (48.81)	288 (30.16)	440 (46.17)	204 (23.53)	149 (17.19)	175 (18.08)	165 (34.74)
East Midlands	399 (39.66)	331 (31.95)	457 (44.59)	226 (24.25)	172 (18.45)	99 (9.37)	163 (30.47)	391 (41.68)	296 (30.58)	410 (42.05)	199 (22.85)	128 (14.70)	101 (10.24)	163 (33.33)
West Midlands	413 (40.73)	357 (33.81)	450 (42.98)	214 (22.62)	186 (19.66)	162 (15.14)	216 (38.43)	399 (42.95)	322 (33.23)	404 (41.87)	188 (21.58)	149 (17.11)	150 (15.34)	166 (33.07)
East of England	503 (42.20)	357 (29.24)	456 (37.72)	186 (16.80)	147 (13.28)	61 (4.92)	236 (33.86)	514 (46.77)	303 (26.81)	401 (35.55)	169 (16.41)	125 (12.14)	57 (4.98)	212 (33.76)
London	333 (40.71)	230 (27.19)	290 (35.32)	153 (20.35)	199 (26.46)	156 (18.22)	162 (40.30)	302 (41.26)	200 (26.42)	253 (33.91)	145 (21.17)	148 (21.61)	136 (17.66)	126 (34.81)
South East	615 (39.55)	336 (21.07)	543 (34.24)	220 (15.51)	185 (13.05)	76 (4.69)	367 (38.23)	639 (44.53)	297 (20.14)	473 (31.89)	188 (14.37)	127 (9.71)	70 (4.67)	337 (37.40)
South West	469 (42.95)	249 (22.11)	380 (34.08)	188 (18.29)	162 (15.76)	40 (3.49)	220 (33.79)	489 (48.71)	225 (21.66)	377 (36.04)	166 (17.44)	113 (11.87)	40 (3.78)	200 (34.90)
	WAVE 7 (2014-2015)							**WAVE 8 (2016-2017)**						
North East	212 (50.12)	141 (31.76)	204 (46.05)	77 (19.40)	75 (18.89)	575 (39.12)	78 (32.64)	202 (53.72)	114 (29.16)	196 (50.26)	91 (24.73)	42 (11.41)	97 (24.37)	69 (33.82)
North West	378 (43.15)	233 (25.46)	324 (35.41)	157 (19.12)	114 (13.89)	860 (32.72)	190 (39.09)	370 (48.49)	190 (24.11)	289 (36.72)	138 (19.49)	141 (19.92)	151 (18.90)	172 (41.15)
Yorkshire and The Humber	360 (46.51)	234 (29.32)	361 (45.35)	156 (21.64)	120 (16.64)	715 (30.59)	126 (30.88)	339 (48.36)	209 (29.11)	354 (49.65)	151 (23.20)	95 (14.59)	140 (19.10)	108 (30.34)

Table 4.2. Participants' socioeconomic and lifestyle factors and hearing loss prevalence in England in 8 Waves of English Longitudinal Study of Ageing (ELSA)

GOR[a]	Hearing loss[b]	Lowest education[c]	Manual Occupation[d]	Lowest Income[e]	Lowest wealth[f]	Most deprived[g]	Alcohol misuse[h]	Hearing loss	Lowest education	Manual Occupation	Lowest Income	Lowest wealth	Most deprived	Alcohol misuse
East Midlands	351 (42.39)	242 (28.40)	350 (40.89)	168 (21.73)	119 (15.39)	440 (19.29)	154 (34.00)	351 (47.56)	205 (27.22)	306 (40.53)	155 (22.33)	126 (18.16)	78 (10.14)	118 (31.13)
West Midlands	359 (44.65)	262 (30.82)	350 (41.22)	173 (22.97)	102 (13.55)	670 (27.66)	142 (33.81)	340 (48.02)	209 (28.21)	309 (41.59)	147 (22.24)	106 (16.04)	112 (14.85)	130 (33.94)
East of England	417 (42.55)	257 (25.42)	343 (33.93)	134 (14.66)	84 (9.19)	250 (10.92)	180 (33.27)	423 (47.37)	216 (23.89)	321 (35.51)	127 (15.19)	201 (24.04)	52 (5.61)	174 (34.05)
London	258 (40.12)	170 (25.41)	215 (32.98)	112 (19.15)	118 (20.17)	575 (27.43)	103 (34.56)	249 (46.03)	134 (24.06)	183 (33.33)	98 (19.41)	113 (22.38)	79 (13.88)	86 (33.20)
South East	537 (42.96)	242 (18.63)	411 (31.62)	177 (15.43)	112 (9.76)	275 (10.00)	259 (34.35)	508 (46.35)	198 (17.66)	356 (31.62)	181 (17.73)	299 (29.29)	46 (4.02)	221 (34.05)
South West	413 (46.67)	178 (19.22)	326 (35.09)	138 (16.51)	84 (10.05)	160 (6.88)	165 (33.60)	399 (52.02)	141 (18.08)	254 (32.52)	139 (19.39)	201 (28.03)	43 (5.38)	146 (34.11)

[a] GOR: Government Office Regions
[b] Self-reported hearing loss: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).
[C] No qualifications
d Manual occupations
e Income categories in quantiles
f Wealth categories in quantiles
g IMD: Index of Multiple Deprivation (in quintiles)
h Alcohol intake above the low-risk level guidelines (>14 units/week)

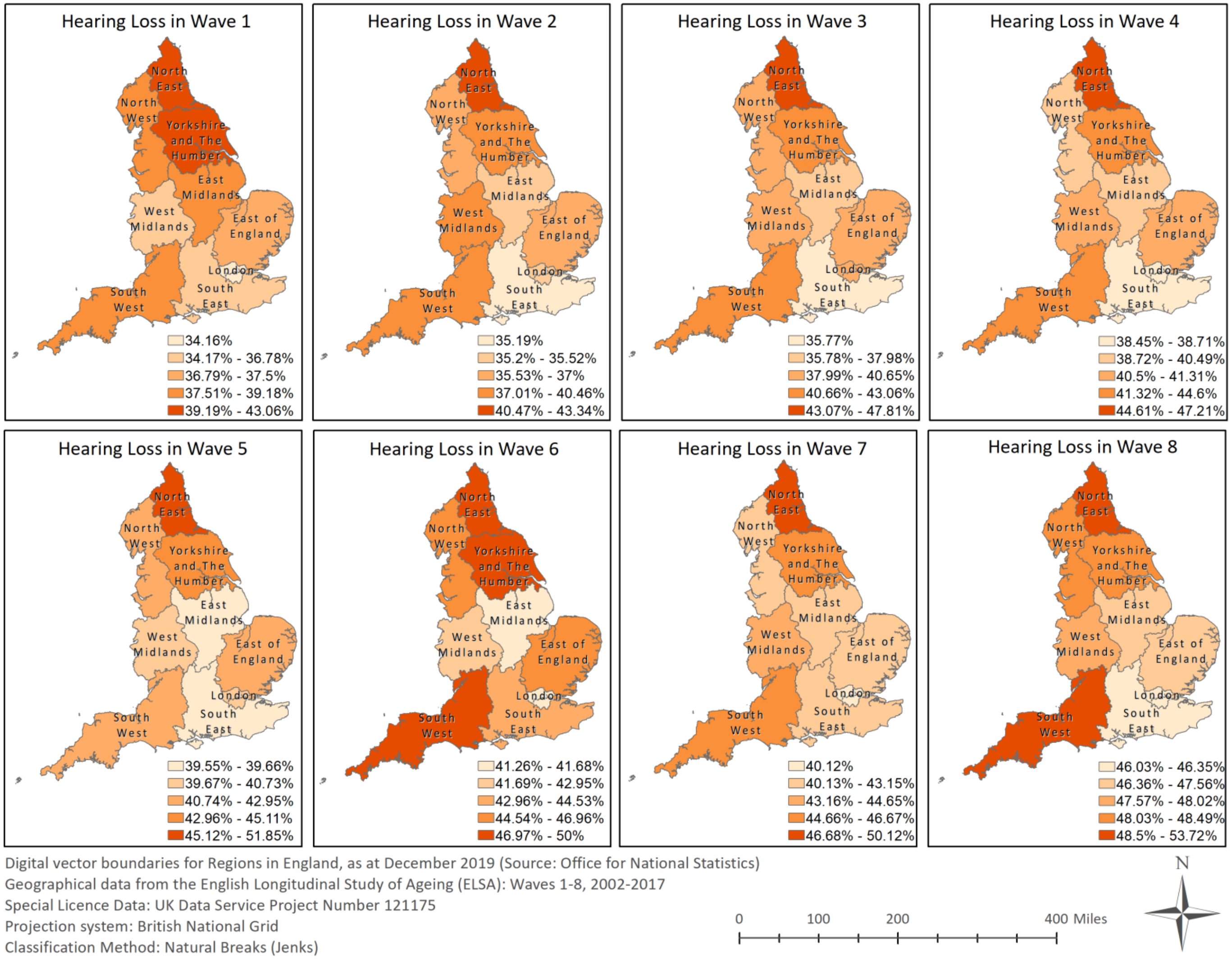

Figure 4.1. Map of England by Government Office Regions, showing prevalence rates of self-reported hearing loss in eight Waves of the English Longitudinal Study of Ageing (ELSA). This work by Dialechti Tsimpida is licensed under a Creative Commons Attribution 4.0 International License.

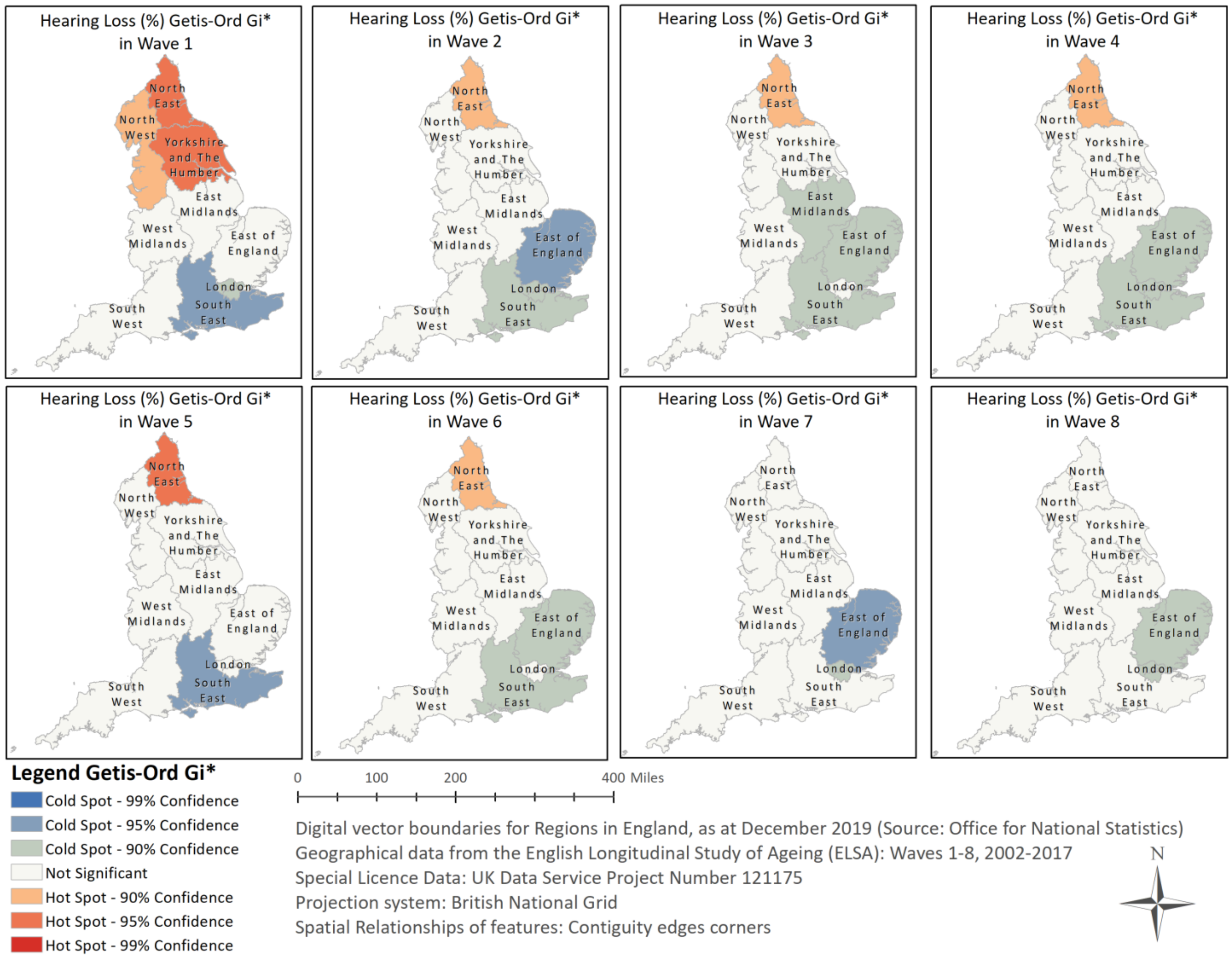

Figure 4.2. Map of England by Government Office Regions showing the spatial clusters of hearing loss prevalence according to Hot Spot and Cold Spot analyses [a] using the Getis-Ord Gi* statistic in eight Waves of the English Longitudinal Study of Ageing (ELSA).

[a] The Hot Spots and Cold Spots indicate unexpected spatial spikes of high or low values, respectively, showing that the distribution of these values in the dataset is more spatially clustered than would be expected if underlying spatial processes were truly random.

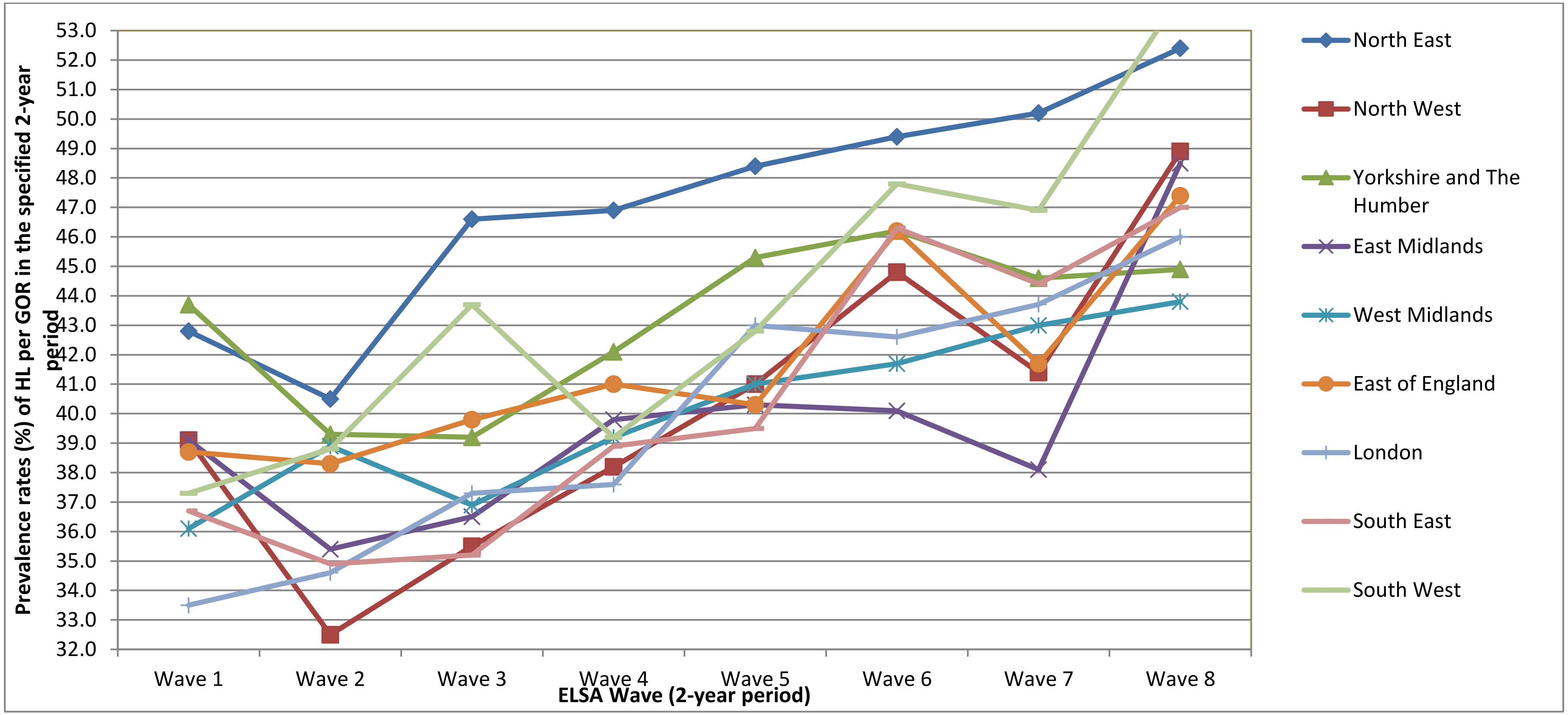

Figure 4.3. Predicted probabilities and 95% Confidence Intervals of hearing loss (HL) prevalence at Regions of England in eight Waves of the English Longitudinal Study of Ageing (ELSA) [a, b]

[a] The x-axis refers to ELSA Wave (Wave 1: 2002-3, Wave 2: 2004-5, Wave 3: 2006-7, Wave 4: 2008-9, Wave 5: 2010-11, Wave 6: 2012-13, Wave 7: 2014-15, Wave 8: 2016-17), and the y-axis refers to prevalence rates of HL per GOR in the specified 2-year period.

[b]The factor variables (age, sex, education, occupation, income, wealth, IMD and alcohol consumption) were hold at their means for each ELSA Wave.

4.5. Discussion

Summary of main findings

In this study, we examined the regional patterns and trends of HL prevalence in England in the ELSA over 15 years (2002–2017). We found that among samples with equal means of age, there was a 15-year increasing trend in HL prevalence in all five classes. The mean HL prevalence increased from 38.50 (95%CI 37.37–39.14) in Wave 1 to 48.66 (95%CI 47.11–49.54) in Wave 8. We identified three critical patterns of findings concerning regional trends: the highest HL prevalence among samples with equal means of age was observed in GORs with the highest prevalence of participants (a) in the most deprived (IMD) quintile (fifth), (b) in routine or manual occupations and (c) that misused alcohol, irrespective of SEP. The APMs for HL showed marked regional variability and evidence of a North–South divide.

Comparison with previous literature

Previous research has utilised geographical indices representing social and material disadvantages for identifying health inequalities (Cabrera-Barona et al., 2018). Our study provided evidence for the existence of sociospatial inequalities in HL, adding to our previous work that challenged the existing conceptualisation of HL as an inevitable accompaniment of growing old (Tsimpida et al., 2019). Globally, there is a dramatic increase in HL cases, going from 42 million people in 1985 to about 360 million in 2011 and over 466 million in 2019 (Olusanya, Neumann, & Saunders, 2014). Our study presented a similar increase pattern but also showed that the increase in HL prevalence is not related to the ageing of the population, as widely believed (Akeroyd, Browning, Davis, & Haggard, 2019; International Organization for Standardization, 2017), but could potentially be due to social and lifestyle changes in the population (Marmot, 2020). Supporting our assumption, a previous study found a decline in HL prevalence among US adults aged 20–69 from the 2011–2012 cycle of the US National Health and Nutrition Examination Survey when compared to participants from the previous decade (Hoffman, Dobie, Losonczy, Themann, &

Flamme, 2017). The explanation given by the authors for the declining prevalence was a reduction in exposure to occupational noise and the beneficial lifestyle changes of the participants, though that population study is not comparable to the ELSA cohort.

In our study, a North-South divide was revealed in hearing health inequalities that was previously unknown. The North-South gap is not surprising, as there is a significant history of socio-economic and health disparities between Northern and Southern England (Buchan, Kontopantelis, Sperrin, Chandola, & Doran, 2017; Doran, Drever, & Whitehead, 2004). The higher rates of unemployment and no qualifications in the North than in the South are in line with previous research in England (Lloyd, 2016). We also found that alcohol misuse was high in areas with a high prevalence of HL, such as the South West, which over time developed one of the highest prevalence rates of alcohol misuse despite its higher socio-economic status compared to other GORs. This finding supports a previous study on the ELSA that found that alcohol intake above the low-risk-level guidelines (Department of Health, 2016) was significantly associated with HL among older adults in England, along with socio-economic factors (Tsimpida et al., 2019). However, the findings from this study indicate that the relationship between SEP and drinking habits is rather complicated; the last statistical release on adult drinking habits in Great Britain showed that those in managerial and professional occupations drink alcohol in higher proportions compared to those in routine and manual occupations. In addition, similarly to our study, it was found that the South East GOR, when compared to other GORs in England, had a higher proportion of adults drinking alcohol the week before the interview (National Statistics, 2018).

Strengths and limitations

This is the first study to investigate the geographical patterns and trends of HL in a representative cohort of older adults and among adults in general. The findings provide evidence that HL has increased over time, but the increasing trend in HL prevalence is not *age-related*, as widely believed. We found wide variation in HL prevalence in representative samples from different regions in England that had similar age profiles, and the increase rate of HL ranged from 3.2% to 45%. Thus, the strengths of this study are that HL is highlighted as an increasingly important public health problem in England and a spatial dimension is added to the evidence for the association of socio-economic and lifestyle determinants of HL among samples of older adults.

However, there are also important limitations. First, the unit of our analyses (in GORs) had a low geographic resolution, which introduces uncertainty in the observed relations and may fail to reveal geographic details that we could notice with smaller geographic units. Moreover, it was not possible to perform geographically weighted regression analyses; a minimum of 30 input features is required (instead of nine GORs) to explore the relationships between the areas' socio-economic characteristics and HL prevalence. Furthermore, the ELSA's size is regarded as too small to conduct geographic analysis on a larger scale, as numerous participants would be required in each unit.

Future research should build on this analysis using small area statistics (such as Lower Layer Super Output Areas) and investigate more localised patterns and determinants of place-to-place HL differences in England (Lloyd, 2016). Such research would help to quantify potential 'area effects' on hearing health outcomes, allowing for generalisable results of spatial associations with HL rates. Moreover, the research could help to separate the role of proxies of areas (such as area deprivation) to individual-level determinants of HL (such as lifestyle behavioural choices), as individual choices are rooted in the broader social and economic structural contexts (Marmot, 2020).

We were aware that the self-reported measures of HL in the ELSA might underestimate the real HL outcomes; for this reason, we conducted additional work to examine the validity of self-reported data through comparisons with the findings of objective HL measures available only in Wave 7 of the ELSA. We found that the self-reported measures correctly classified seven in every ten people with objectively assessed HL (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti, 2020).

However, for the scope of our analyses, we assumed the available hearing measure as a suitable indicator of HL.

Another limitation is that the ELSA concentrates on individuals living in private households, so individuals living in institutions (e.g. residential and nursing homes) are not included in the samples (Marmot et al., 2003). Furthermore, ELSA does not capture the type of HL; future analyses examining types of HL would add important value.

Finally, the domains of IMD are not provided with the ELSA geography file, thereby not allowing further exploration. There was a small number of respondents moving to a different area between Waves, which resulted in an associated change in the IMD quintile (Banks et al., 2018). However, a similar number of respondents experienced an increase or a decline in their IMD quintile, and the total numbers of movers did not exceed 1% for any Wave (Banks et al., 2018); thus, we concluded that this would be unlikely to affect the validity of our findings.

Research and policy implications

According to the Global Burden of Disease Study, HL is the third leading cause of years lived with disability in England (Vos et al., 2017), and accurate prevalence estimates are needed to inform the strategic planning of hearing health policy and health services. To date, the prevalence of HL estimates in the UK is still based on the Medical Research Council National Hearing Study (Davis, 1995). In addition, the NHS England has recently published the NHS Hearing Loss data tool (NHS England, 2019), which provides estimates of the number of people with HL between 2015 and 2035 in order to help organisations plan services on local authority (LA) and CCG levels. However, according to our study, the above tool is inappropriate for estimating the number of people with HL; this study showed that in a representative cohort, there were important differences across different regions in England, which contradicts the Hearing in Adults study that did not find differences across the only four British cities that it was based on (Cardiff, Glasgow, Nottingham and Southampton) (Davis, 1995).

HL has affected a markedly larger proportion of the UK population in 2002–2017. The high levels of spatial clustering for hearing-related outcomes have significant implications for the planning of health services, including the availability of access to hearing aids. The high-risk regions in England must be expansively recognised based on their spatiotemporal HL profiles (Kontopantelis et al., 2018). This kind of spatial evidence could provide commissioners with robust data based on actual needs, rather than inaccurate estimates of HL prevalence. Such prior knowledge could potentially have altered the North Staffordshire CCG's decision in 2015 to end the routine free provision of hearing aids for people with mild or moderate HL in their area of duty (The Audiology Community, 2014), where according to our analyses, the burden of HL is greatest. This study revealed, therefore, the potential risks from the paucity of robust epidemiological hearing data, which are needed now as much as ever to increase understanding of the impact of social, financial and personal health advantages on HL across the life course (Hill et al., 2015).

The findings from the time-series analyses in this manuscript might encourage HL preventive strategies, including interventions to promote 'healthier lifestyles' and targeted interventions in areas where there are high levels of deprivation clustering. Future research should also explore spatiotemporal diffusion patterns in the ELSA's international sister studies to acquire a global perspective of socio-spatial inequalities in hearing health.

CONCLUSIONS

We have identified elevated social and geographical patterning of trends in HL; different levels of exposure to socio-economic and lifestyle factors lead to geographical hearing health variation among English populations of significantly equal age. The socio-economic, lifestyle and regional patterns and trends in HL support the argument that the increase of HL is not '*age-related*', as widely believed, and HL, therefore, might be a highly preventable lifestyle-related condition.

These findings also point to the need for a stronger health policy response. According to the inextricable link of health and geography, the regional variation in hearing health outcomes should be examined for health policy decisions according to spatial needs. The audiological services may need to be redesigned to take socio-economic and lifestyle risk factors for HL into account in order to prevent the further exacerbation of inequalities in regions with spatial hearing health inequality.

Declarations

Ethics approval and consent to participate Ethical approval for all the ELSA waves was granted from the National Research and Ethics Committee (MREC/01/2/91), and written informed consent was obtained from all participants. Details of the ELSA study design, sample and data collection are available at the ELSA's project website [https://www.elsa-project.ac.uk/].

Consent to publish Not applicable

Availability of data and materials The English Longitudinal Study of Ageing dataset is publicly available via the UK Data Service (http://www.ukdataservice.ac.uk). The geographical variables were provided to the first author under a Special License and Secure Access agreement (UK Data Service Project Number: 121175), and so are not publicly available. Statistical code is available from the corresponding author upon reasonable request at dialechti.tsimpida@manchester.ac.uk.

Competing interests The authors declare that they have no competing interests

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Authors' contributions DT was responsible for the conceptualisation, and all authors were responsible for developing the design of the study. DT was responsible for conducting the analyses and mapping, interpreting the results, and drafting the manuscript. DT, EK, DMA and MP critically revised the manuscript. All authors have read and approved the final manuscript.

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4.6. References

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4.7. Supplement

Supplementary Table 4.1. One-Way ANOVA results of means of age at Regions of England in eight Waves of the English Longitudinal Study of Ageing (ELSA)

	Source	Degrees of Freedom DF	Sum of Squares SS	Mean Square MS	F-Stat	P-Value	Bartlett's test for equal variances	Prob>chi2
Wave 1 (2002/3)	Between Groups	8	2681.90354	335.237942	2.74	0.0052	11.4703	0.17
	Within Groups	11,818	1448107.05	122.54439				
Wave 2 (2004/5)	Between Groups	8	1733.55958	216.694947	**1.90**	**0.0557**	14.2375	0.07
	Within Groups	9,184	1048209.21	114.146707				
Wave 3 (2006/7)	Between Groups	8	3982.75449	497.844312	3.83	0.0002	16.0442	0.04
	Within Groups	9,481	1231740.12	129.916688				
Wave 4 (2008/9)	Between Groups	8	2812.61074	351.576342	3.17	0.0014	8.1569	0.41
	Within Groups	10,630	1178966.28	110.90934				
Wave 5 (2010/11)	Between Groups	8	5725.07332	715.634165	3.97	0.0001	124.8517	<0.001
	Within Groups	9,801	1766317.22	180.218062				
Wave 6 (2012/13)	Between Groups	8	2399.91545	299.989431	**1.49**	**0.1547**	130.4451	<0.001
	Within Groups	8986	1807938.53	201.217421				
Wave 7 (2014/15)	Between Groups	8	1984.25469	248.031836	**1.20**	**0.2933**	129.6364	<0.001
	Within Groups	7,850	1619949.92	206.389339				
Wave 8 (2016/17)	Between Groups	8	2916.22388	364.527985	**1.76**	**0.0795**	86.7473	<0.001
	Within Groups	6,884	1424110.07	206.902524				
Across all Waves	Between Groups	7	138.508	19.787	**0.12**	**0.996**	621.81893	<0.001
	Within Groups	64	10,148.390	158.569				

Supplementary Table 4.2. Predicted probabilities and 95% Confidence Intervals of hearing loss prevalence at Regions of England in eight Waves of the English Longitudinal Study of Ageing (ELSA)*

	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5	Wave 6	Wave 7	Wave 8	increase Wave 1-8
North East	42.8 (38.9-46.7)	40.5 (34.6-46.4)	46.8 (40.8-52.8)	46.9 (41.0-52.8)	48.5 (42.2-54.7)	49.6 (43.1-56.1)	50.1 (43.1-57.1)	52.5 (45.1-59.9)	22.7%
North West	39.1 (36.4-41.8)	32.5 (28.7-36.4)	35.6 (31.4-39.8)	38.2 (34.0-42.3)	41.1 (37.0-45.2)	44.8 (40.2-49.4)	41.2 (36.5-46.0)	49.1 (43.8-54.4)	25.6%
Yorkshire and The	43.7(40.7-46.7)	39.3 (35.0-43.7)	39.3 (34.9-43.6)	42.1 (37.8-46.5)	45.3 (40.8-49.9)	46.3 (41.3-51.2)	44.5 (39.2-49.8)	45.1 (39.4-50.8)	3.2%
East Midlands	39.1 (36.0-42.3)	35.2 (30.9-39.5)	36.3 (31.8-40.8)	39.8 (35.5-44.0)	40.2 (35.6-44.8)	40.0 (35.3-44.8)	38.1 (33.3-43.0)	48.6 (43.1-54.1)	24.3%
West Midlands	36.1 (33.1-39.1)	38.7 (34.2-43.2)	36.8 (32.3-41.3)	39.0 (34.7-43.4)	41.0 (36.5-45.5)	41.6 (36.8-46.3)	43.0 (37.7-48.2)	43.8 (38.3-49.3)	21.3%
East of England	38.7 (35.8-41.6)	38.3 (34.2-42.4)	39.8 (35.6-44.1)	41.1 (37.1-45.0)	40.3 (36.2-44.3)	46.1 (41.7-50.4)	41.7 (37.1-46.2)	47.4 (42.6-52.2)	22.5%
London	33.5 (30.4-36.7)	34.6 (29.4-39.7)	37.1 (31.9-42.2)	37.7 (32.6-42.7)	43.0 (37.6-48.4)	42.8 (37.1-48.5)	43.8 (37.4-50.1)	45.7 (38.9-52.6)	36.4%
South East	36.7 (34.2-39.1)	35.1 (31.6-38.5)	35.3 (31.8-38.8)	38.9 (35.5-42.3)	39.5 (36.1-43.0)	46.5 (42.7-50.2)	44.4 (40.4-48.5)	46.9 (42.6-51.3)	27.8%
South West	37.3 (34.4-40.2)	38.7 (34.5-42.9)	43.6 (39.2-48.0)	39.1 (35.0-43.1)	42.5 (38.3-46.7)	47.5 (43.0-52.0)	47.1 (42.3-51.9)	54.1 (48.9-59.2)	45.0%

* Holding factor variables (age, gender, education, occupation, income, wealth, IMD and alcohol consumption) at their means for each ELSA Wave.

Chapter 5

Comparison of Self-reported Measures of Hearing to an Objective Audiometric Measure in Adults in the English Longitudinal Study of Ageing (ELSA)

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5.1. Abstract

Importance: An effective and sustainable hearing loss (HL) screening strategy for the early detection of and intervention for HL in older adults is needed.

Objectives: To examine the concordance of self-reported measures of hearing difficulty with objective hearing data and the factors associated with the potential discordances among these measures across different population subgroups of a representative sample of people 50 years and older in England.

Design, Setting, and Participants: This study was a cross-sectional analysis of wave 7 of the English Longitudinal Study of Ageing (ELSA), a large, population-based, prospective cohort study that provides a unique resource for exploring issues associated with aging in England in the 21st century. The full analytic cohort was composed of 9666 individuals participating in the ELSA wave 7, which collected information from June 1, 2014, to May 31, 2015. This study further analyzed a sample of 8529 adults 50 to 89 years of age who had an assessment of their hearing by self-reported measures, and consented to assessment by a qualified nurse via a hearing screening device, and did not have an ear infection or a cochlear implant. Bivariate analyses were performed from July 1 to December 30, 2018, and multivariate analysis from January 1 to June 30, 2019. Multiple logistic regression models examined factors associated with misclassification of hearing difficulties across several categories among those with objectively identified HL.

Exposures: The study examined whether age, marital status, retirement status, indicators of socioeconomic position, and lifestyle factors (such as body mass index, physical activity, and tobacco and alcohol consumption) were associated with the concordance between self-reported hearing problems and manual audiometry among older adults.

Main Outcomes and Measures: Self-reported hearing measures, including hearing in background noise, compared with objective audiometric assessments.

Results: A total of 9666 study participants (5368 female [55.5%]; mean [SD] age, 67.4 [14.4] years) provided responses regarding their hearing difficulties, hearing in noise, quality of care in hearing, and hearing aid recommendation in ELSA wave 7. Within the cohort, 684 individuals (30.2%) with objectively measured HL greater than 35 dB HL at 3.0 kHz went undetected by the self-report measure, whereas the new constructed categories for moderate and moderately severe or severe HL resulted in 9.3%increased sensitivity. Factors associated with misreporting hearing difficulties (while they had objectively measured HL >35 dB HL at 3.0 kHz, in the better-hearing ear) were as follows: female sex (odds ratio [OR], 1.97; 95%CI, 1.18-3.28), no educational qualifications (OR, 1.37; 95%CI, 1.26-2.55), routine or manual occupation (OR, 1.43; 95%CI, 1.28-2.61), tobacco consumption (OR, 1.14; 95%CI, 1.08-1.90), alcohol intake above the low-risk-level guidelines (OR, 1.13; 95%CI, 1.11-2.34), and lack of moderate physical activity (OR, 1.25; 95%CI, 1.03-1.42). Age was largely associated with misreporting of moderately severe to severe HL; the odds were 5.75 (95%CI, 1.17-8.13) higher for those 65 to 74 years of age and 7.08 (95%CI, 1.41-9.30) higher for those 75 to 89 years of age to not report their hearing difficulties compared with those 50 to 64 years of age. In addition, socioeconomic indicators, such as educational level (OR, 1.95; 95%CI, 1.63-6.01) and occupation (OR, 2.07; 95%CI, 1.78-5.40), along with lifestyle factors, such as smoking (OR, 1.46; 95% CI, 1.25-2.48) and alcohol intake above the low-risk-level guidelines (OR, 1.86; 95%CI, 1.67-5.12), were factors associated with misreporting moderately severe or severe HL.

Conclusions and Relevance: The use of a screening measure for audiometric testing and a self-report measure is essential for accurately identifying older people with HL.

The results of this study should be considered by HL researchers who analyze self-reported hearing data as a surrogate measurement of audiometric hearing to identify bias in their observed analytic research results.

Keywords: hearing loss, screening audiometry, HearCheck Screener, primary care, hearing health inequalities

5.2. Introduction

Hearing Loss (HL) is an important public health concern (The Lancet, 2016), with an estimated 432 million adults worldwide and one third of people older than 65 years affected by disabling HL (World Health Organization, 2019). As a non-communicable disease, HL is far beyond a sensory disorder and can have profound effects on people's quality of life (Davis et al., 2016; Tsimpida, D., Kaitelidou, D., & Galanis et al., 2018; Wilson et al., 2017; World Health Organization, 2015), which reinforces the importance of early detection and intervention for the maintenance of physical and emotional well-being among older adults, where the burden of disease is the highest (Brennan-Jones et al., 2016; Davis et al., 2016).

The World Health Organization has highlighted the pressing need for measures to promote public health action by facilitating early identification of hearing difficulties that supports prioritization of service provision at the community level and integration within primary care systems (World Health Organisation, 2018). Large-scale hearing screening programs and tools to detect HL in major healthcare sectors, such as primary care, do not exist globally, including high-income countries (The Lancet, 2016). This lack of screening programs (Benova et al., 2015) excludes the early detection and treatment of patients with gradually progressive HL (Wilson et al., 2017), and the annual cost of unaddressed HL exceeds $750 billion globally (World Health Organisation, 2018). Moreover, in the absence of HL screening programs that could identify those who are unaware that they have HL (i.e., unacknowledged HL) (Mukari & Wan Hashim, 2018), hearing help-seeking depends on self-recognition of hearing difficulties (Benova et al., 2015) as a crucial step for the initiation of contact with a health care professional in primary health care settings (Barnett et al., 2017), and consequently the referral to ear specialists and hearing aid provision (World Health Organisation, 2018).

Self-reported measures are frequently used to gather hearing health data in population-based epidemiological studies. Evidence indicates a discordance between self-reported and objective measures of hearing because adults self-report HL according to their beliefs, which are influenced by a range of contextual factors (Keidser et al., 2015; Pronk et al., 2018). However, the validity and the factors associated with the concordance between self-reported HL and manual audiometry remain mostly unknown (Brennan-Jones et al., 2016). The hearing measures in the English Longitudinal Study of Ageing (ELSA) are comparable to 7 other global ageing surveys with harmonized physical and anthropometric measurements (Eunjee Kwon, 2018). Thus, the validation of hearing measures is essential for hearing data quality evaluation and can help explain some of the inconsistencies in findings regarding the association of HL with functional outcomes in older adults (Choi et al., 2016; National Academies of Sciences and Medicine, 2016).

The aims of this study were to examine the concordance of self-reported measures of hearing difficulty in ELSA, with objective hearing data measured by a handheld audiometric screening device, and the factors associated with the potential discordances among these measures across different population subgroups of a representative sample of people aged 50 and older in England.

5.3. Methods

Study population

We used data from ELSA, which is a large, population-based, prospective cohort study that provides a unique resource for exploring issues associated with aging in England in the 21st century (Steptoe et al., 2013). The full analytic cohort was composed of 9,666 individuals participating in the wave 7 of ELSA, which collected information from June 1, 2014, to May 31, 2015. For the purpose of this cross-sectional analysis, we further analyzed a sample of 8,529 adults 50 to 89 years of age who had an assessment of their hearing by self-reported measures, consented for assessment by a qualified nurse via a hearing screening device (Siemens Audiologische Technik GmbH, 2007), and did not have an ear infection or a cochlear implant. All participants gave written informed consent at the recruitment wave to participate in ELSA and at each subsequent wave. All data were anonymized. Ethical approval was granted by the National Research and Ethics Committee (Natcen Social Research, n.d.). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Outcomes

Self-reported hearing difficulty

According to ELSA documentation, (Natcen Social Research, n.d.) hearing difficulty is defined as having declared fair or poor hearing on a 5-point Likert scale (with 1 indicating excellent; 2, very good; 3, good; 4, fair; and 5, poor), or finding it difficult to follow a conversation if there is background noise (such as television, radio, or children playing). The participants who positively answered the last question then answered in a separate question whether they had slight, moderate or great difficulty in following a conversation if there is background noise. We used that response for a further classification of their hearing difficulty into categories, eliminating those who had indicated slight difficulty following a conversation if there is background noise to allow for a fair comparison with the categories of moderate and moderately severe or severe objectively measured HL (**Figure 5.1 in the Supplement**).

Objectively measured HL

The objective measurement of hearing acuity was performed by the HearCheck™ Screener, a handheld audiometric screening device (Siemens Audiologische Technik GmbH, 2007). The HearCheck™ Screener automatically generates 6 tones in total: a fixed series of 3 midfrequency sounds at decreasing volume at 1 kHz (at 55 dB HL, 34 dB HL, 20 dB HL) and afterwards another 3 pure high-frequency sounds at decreasing intensities at 3 kHz (at 75 dB HL, 55 dB HL, and 35 dB HL), testing for audibility for each sequence and per each ear. Participants indicated when they hear the sound by raising their finger.

The HearCheck™ Screener is an accurate tool in detecting HL when compared to pure-tone air conduction averages, which are designated as gold standard values. In cases of moderate or worse HL, the HearCheck™ Screener fulfils all the criteria of high sensitivity, high specificity and high positive predictive values (Fellizar-Lopez et al., 2011).

Hearing level was defined as greater than 35dB HL at 3.0 kHz in the better-hearing ear because this is the level at which intervention for HL is definite beneficial (Scholes et al., 2018). Those with HL were further subdivided according to a categorization that has been previously used in the literature for the characterization of those assessed by the same audiometric screening device (Scholes et al., 2018) as follows:

(1) moderate HL (tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL) or

(2) moderately severe or severe HL (tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL).

Covariates

We selected as indicators of socioeconomic position (SEP), the highest educational attainment [no qualifications; foreign/other; O levels CSE (Certificate of Secondary Education); A level (Level 3 Qualification of the National Qualifications Framework); and degree or higher education], tertiles of the self-reported occupation according to the National Statistics socio-economic classification (NS-SEC) (routine and manual occupations, intermediate, or managerial and professional) and quintiles of the net household income and the total non-pension wealth (first quintile indicating the lowest and fifth quintile indicating the highest).

We considered as covariates age, sex, and lifestyle factors (such as body mass index, physical activity, and tobacco and alcohol consumption) because these are key risk factors for HL among older adults (Tsimpida et al., 2019). We dichotomised marital status into currently married (married, first and only marriage; in a registered civil partnership; or remarried, in a second or later marriage) or not (single, ie, never married and never registered in a marriage; separated but still legally married; divorced; or widowed). Retirement status was also dichotomised to being currently retired or not.

Statistical analysis

Bivariate analyses were performed from July 1 to December 30, 2018 and multivariate analysis from January 1 to June 30, 2019. Descriptive statistical measures were reported on hearing difficulties, hearing in noise, quality of care in hearing and hearing aid recommendation in ELSA Wave 7 (n=9,666). Participants' self-reported and objectively measured HL (moderate and moderately severe or severe) was reported as absolute number (relative frequency).

We fitted multiple logistic regression models to identify factors associated with the false-negative report of hearing difficulties in people with objectively identified HL. Age was categorised into 3 groups (50-64, 65-74, and 75-89) to allow for a comparison with the study of Benova et al., (2015), which examined the self-reported hearing difficulty in ELSA wave 2. There were no missing values in the hearing data of the final analytical sample (n=8,529), which was specifically chosen for the study to fulfill the criteria of completed assessment of hearing by self-reported measures, with given consent for assessment by pure-tone-audiometry and without any ear infection or cochlear implant. Separate analyses were conducted for moderate and moderately severe or severe HL. Because some data were missing at random on many variables, we excluded records with missing data from our analyses, concluding that this would be unlikely to affect the validity of our findings (Little & Rubin, 2019; Mittag, 2013).

For all models, odds ratios (ORs) and 95% CIs are presented. The performance of self-reported hearing difficulty with second stage pure tone audiometry screening (sensitivity, specificity, positive and negative predictive values as overall test accuracy) was calculated, and the area under the receiver operating characteristics curve represents the accuracy of all models. We used the Hosmer–Lemeshow test as a postestimation tool, which demonstrates the goodness-of-fit of logistic regression models. A 2-tailed $P \leq .05$ was considered to be statistically significant. All data were analyzed using Stata, version 14 (StataCorp, 2015).

5.4. Results

Self-Reported Hearing Acuity

A total of 9,666 study participants (5,368 female [55.5%]; mean [SD] age, 67.4 [14.4] years provided responses regarding their hearing difficulties, hearing in noise, quality of care in hearing, and hearing aid recommendation in ELSA Wave 7 (**Figure 5.1**) (Zaninotto & Steptoe, 2019). Within the cohort, 3,801 (39.3%) reported that they had hearing difficulties. Of those 3,801 individuals with self-reported hearing difficulty, 1,949 (51.3%) did not tell a physician or nurse about their hearing problems, thereby missing the opportunity to be referred for further assessment.

Examining the characteristics of the 2 separate categories (not mutually exclusive events) that the self-reported hearing difficulty was composed of, we found that not informing a health care professional was more common among those who reported difficulty in following conversations in the presence of background noise (1,752 of 3,424 [51.2%]), compared to those who had fair to poor self-reported hearing (691 of 2,086 [33.1%]). Importantly, 1,894 of the 3,425 participants (55.3%) who had responded that they found it difficult to follow a conversation if there is background noise (such as television, radio or children playing) and did not have hearing aids had reported that have good, very good, or excellent hearing, which indicates that more than half of them had unacknowledged HL, with 718 of 1,894 (37.9%) of them having moderate or great difficulty (**Table 5.1**).

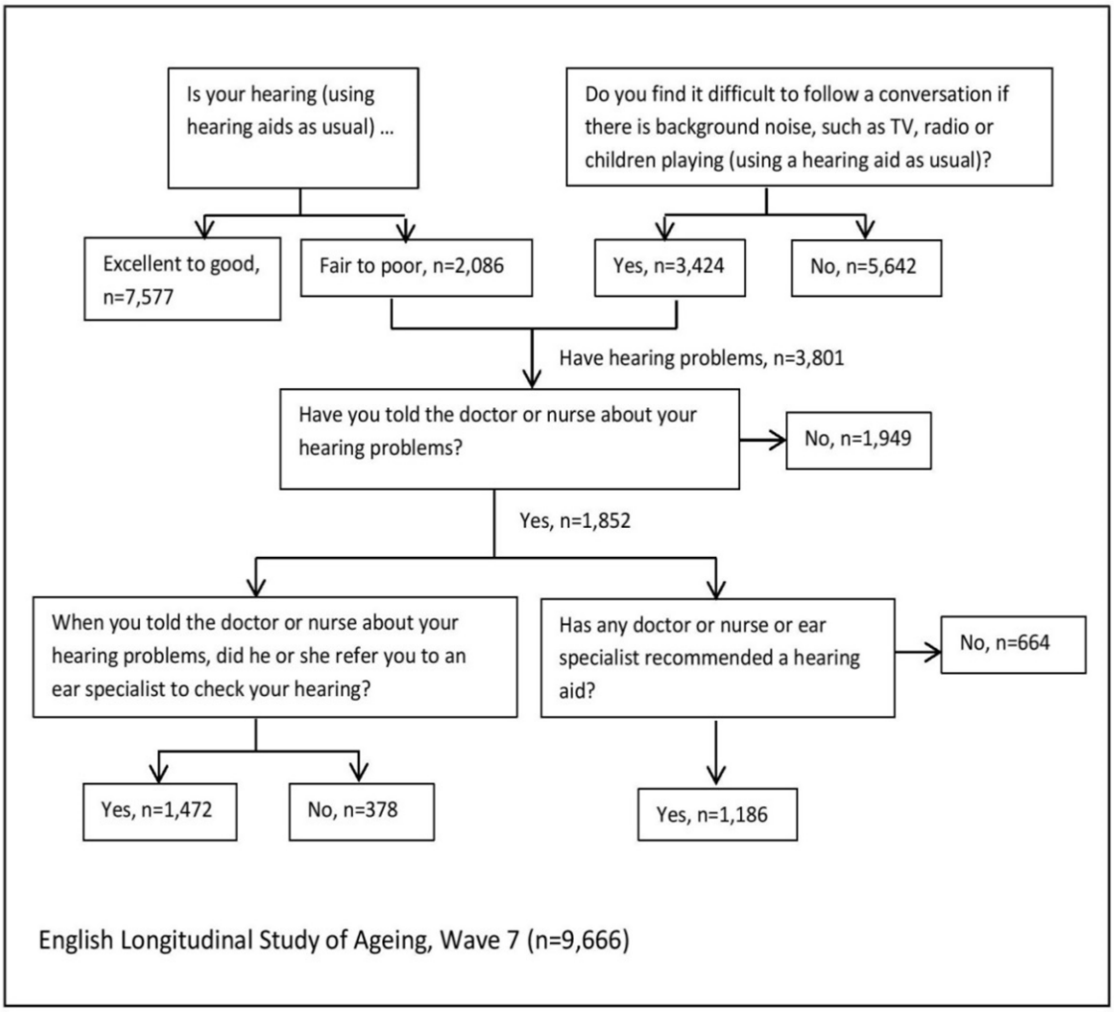

Figure 5.1. The questions on hearing difficulties, hearing in noise, quality of care in hearing and hearing aid recommendation in ELSA Wave 7.

Eliminating from the categories of self-reported hearing difficulties those that had indicated slight difficulty following a conversation if there is background noise (such as television, radio or children playing), we had 2,249 complete cases with hearing difficulty instead of the initial 3,505. This sample size improved the classification accuracy substantially for those with self-reported hearing difficulty, resulting in 9.3% increased sensitivity (79.12%), which refers to the ability of the self-reported measure to correctly identify those with HL (true-positive results) (**Table 5.2**). Under that new categorisation, 20.9% of those with HL as measured by the handheld audiometric screening device went undetected by the self-reported measure, instead of 30.2% (false-negative results: 298/1,427).

Objectively Measured HL

Table 5.3 gives the distribution of sociodemographic characteristics of participant's self-reported and objectively measured HL. **Table 5.4** gives the summary of multiple logistic regression for variables associated with false-negative report of hearing difficulties on the sample with (1) objectively identified HL greater than 35dB HL at 3.0kHz (n=2,266), (2) moderate HL at 3.0kHz (n=1,498), and (3) moderately severe or severe HL at 3.0kHz (n=768) in the better-hearing ear of 8,529 participants 50 to 89 years of age in ELSA Wave 7.

The multiple logistic regression models showed that demographic, socioeconomic, and lifestyle factors were associated with the inaccuracy in the self-identification of the objectively identified HL. Significant factors associated with total misreporting were: female sex (OR, 1.97, 95%CI, 1.18-3.28), no educational qualifications (OR, 1.37, 95%CI, 1.26-2.55), routine or manual occupation (OR, 1.43, 95%CI, 1.28-2.61), tobacco consumption (OR, 1.14, 95%CI, 1.08-1.90), alcohol intake above the low risk level guidelines (OR, 1.13, 95%CI, 1.11-2.34), and lack of moderate physical activity (OR, 1.25, 95%CI, 1.03-1.42).

Age was largely associated with misreporting of moderately severe to severe HL; the odds were 5.75 (95%CI, 1.17-8.13) higher for those 65 to 74 years of age and 7.08 (95%CI, 1.41-9.30) for those 75 to 89 years of age to not report their hearing difficulties compared to those 50 to 64 years of age. In addition, socioeconomic indicators, such as education (OR, 1.95, 95%CI, 1.63-6.01) and occupation (OR, 2.07, 95%CI, 1.78-5.40), along with lifestyle factors, such as smoking (OR, 1.46, 95%CI, 1.25-2.48) and alcohol intake above the low-risk level guidelines (OR, 1.86, 95%CI, 1.67-5.12) were factors for misreporting moderately severe or severe HL.

Table 5.1. Participant's characteristics on questions on hearing difficulties and hearing in noise in ELSA Wave 7 (n=9,666)

Finds it difficult to follow a conversation if there is background noise					
	Yes (n=3,425)			No (n=5,642)	Total
Self-reported hearing	Slight difficulty	Moderate difficulty	Great difficulty		
Don't know [a]	-	-	-	-	0 (3)
Excellent	86 (5.3)	21 (1.6)	9 (1.9)	1,448 (25.7)	17.4 (1,678)
Very good	331 (20.5)	119 (8.9)	7 (1.5)	2,095 (37.1)	27.7 (2,674)
Good	759 (47.1)	478 (35.8)	84 (17.5)	1,721 (30.5)	33.4 (3,225)
Fair	389 (24.1)	558 (41.8)	185 (38.6)	339 (6.0)	16.3 (1,573)
Poor	47 (2.9)	158 (11.8)	194 (40.5)	39 (0.7)	5.3 (513)
Total	1,612 (100)	1,334 (100)	479 (100)	5,642 (100)	9,666 (100)

Values are expressed as column N (%) unless otherwise is indicated.
[a] Three participants in total answered they do not know whether they find it difficult to follow a conversation or not if there is background noise (indicated by dashed lines)

Table 5.2. Statistical outcomes of complete cases with self-reported and objective hearing data in ELSA Wave 7 (n=8,529)

Outcome	Self-reported hearing difficulty (n=3,505) [a]	New categorisation of self-reported hearing difficulty (n=2,036) [b]
Objectively measured hearing loss, No	2,266	1,427
Total overlap, No	1,582	1,129
Sensitivity, % (95% CI)	69.8 (95% CI 67.9 to 71.7)	79.1 (95% CI 76.9 to 81.2)
Specificity, % (95% CI)	69.3 (95% CI 68.1 to 70.4)	47.8 (95% CI 45.4 to 50.1)
Positive Predictive Value, % (95% CI)	45.1 (95% CI 43.5 TO 46.8)	55.5 (95% CI 53.3 to 57.6(
Negative Predictive Value, % (95% CI)	86.4 (95% CI 85.4 to 87.3)	73.5 (95% CI 70.8 to 76.1)
Positive Likelihood Ratio (95% CI)	2.3 (95% CI 2.2 to 2.4)	1.5 (95% CI 1.4 to 1.6)
Negative Likelihood Ratio (95% CI)	0.4 (95% CI 0.4 to 0.5)	0.4 (95% CI 0.4 to 0.5)
ROC Area (95% CI)	0.69 (95% CI 0.68 to 0.71)	0.64 (95% CI 0.62 to 0.65)

[a] Current categories of self-reported measures: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).

[b] New categorisation of self-reported measures: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded that they have moderate or great difficulty to follow a conversation if there is background noise (such as TV, radio or children playing).

Table 5.3. Participant's self-reported and objectively measured HL in the better-hearing ear (N=8,529, aged 50-89)

	Self-reported measurement			Objective measurement		
Variable	**Self-reported hearing difficulty (n=2,249)**	Moderate self-reported hearing difficulty (n=1,565)	Moderately severe or severe self-reported hearing difficulty (n=684)	**HL >35dB HL at 3.0kHz (n=2,266)**	Moderate HL [a] (n=1,498)	Moderately severe or severe HL [b] (n=768)
Sex						
Male	1,243 (55.3)	832 (53.2)	411 (60.1)	1,198 (52.9)	741 (49.5)	457 (59.5)
Female	1,006 (44.7)	733 (46.8)	273 (39.9)	1,068 (47.1)	757 (50.5)	311 (40.5)
Missing	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Age group						
50-64	624 (28.9)	456 (30.2)	168 (26.0)	349 (16.2)	280 (19.3)	69 (9.8)
65-74	739 (34.2)	545 (36.0)	194 (30.0)	722 (33.6)	535 (36.9)	187 (26.7)
75-89	796 (36.9)	511 (33.8)	285 (44.0)	1,081 (50.2)	636 (43.8)	445 (63.5)
Missing	90 (4.0)	53 (3.3)	37 (5.4)	114 (5.0)	47 (3.1)	67 (8.7)
Currently married						
No	814 (36.2)	562 (35.9)	252 (36.8)	826 (38.4)	544 (37.5)	282 (40.2)
Yes	1,435 (63.8)	(1,003 (64.1)	432 (63.2)	1,326 (61.6)	907 (62.5)	419 (59.8)
Missing	0 (0)	0 (0)	0 (0)	114 (5.0)	47 (3.1)	67 (8.7)
Retirement status						
Retired	1,563 (69.5)	1,076 (68.8)	487 (71.2)	1,685 (78.3)	1,112 (76.6)	573 (81.7)
Not retired	686 (30.5)	489 (31.2)	197 (28.8)	467 (21.7)	339 (23.4)	128 (18.3)
Missing	0 (0)	0 (0)	0 (0)	114 (5.0)	47 (3.1)	67 (8.7)
Education						
Degree/Higher Education	646 (29.5)	471 (31.0)	175 (26.2)	562 (26.5)	404 (28.2)	158 (22.9)
A level	180 (8.2)	127 (8.3)	53 (7.9)	137 (6.5)	100 (6.9)	37 (5.4)
O level/CSE grade	476 (21.7)	350 (23.0)	126 (18.9)	473 (22.3)	321 (22.4)	152 (22.0)
Foreign/Other	256 (11.7)	182 (12.0)	74 (11.1)	252 (11.9)	171 (11.9)	81 (11.7)
No qualifications	632 (28.9)	392 (25.8)	240 (35.9)	701 (33.0)	439 (30.6)	262 (38.0)
Missing	59 (2.6)	43 (2.7)	16 (2,3)	141 (6.2)	63 (4.2)	78 (10.1)

(Continued)

Table 5.3. (Continued)

Participant's self-reported and objectively measured HL in the better-hearing ear (N=8,529, aged 50-89)

	Self-reported measurement			Objective measurement		
Variable	**Self-reported hearing difficulty (n=2,249)**	Moderate self-reported hearing difficulty (n=1,565)	Moderately severe or severe self-reported hearing difficulty (n=684)	**HL >35dB HL at 3.0kHz (n=2,266)**	Moderate HL [a] (n=1,498)	Moderately severe or severe HL [b] (n=768)
Occupation based National Statistics Socio-economic Classification (NS-SEC)	484 (24.8)	353 (26.0)	131 (22.0)	423 (21.5)	285 (21.6)	138 (21.2)
Managerial and professional occupations	684 (35.0)	495 (36.5)	189 (31.7)	665 (33.8)	477 (36.2)	188 (28.9)
Intermediate occupations (non-manual)	784 (40.2)	508 (37.5)	276 (46.3)	881 (44.7)	556 (42.2)	325 (49.9)
Routine and manual occupations	297 (13.2)	209 (13.3)	88 (12.8)	297 (13.1)	180 (12.0)	117 (15.2)
Missing						
Net Household Income						
Fifth quintile (highest)	284 (14.3)	217 (15.7)	67 (11.2)	243 (12.3)	178 (13.4)	65 (10.1)
Fourth quintile	391 (19.7)	291 (21.0)	100 (16.7)	367 (18.6)	265 (19.9)	102 (15.9)
Third quintile	461 (23.2)	297 (21.4)	164 (27.3)	453 (23.0)	297 (22.3)	156 (24.3)
Second quintile	460 (23.2)	312 (22.5)	148 (24.7)	489 (24.8)	329 (24.7)	160 (24.9)
First quintile (lowest)	389 (19.6)	268 (19.4)	121 (20.2)	421 (21.3)	262 (19.7)	159 (24.8)
Missing	264 (11.7)	180 (11.5)	84 (12.2)	293 (12.9)	167 (11.1)	126 (16.4)
Net Financial Wealth						
Fifth quintile (highest)	386 (19.5)	280 (20.2)	106 (17.7)	342 (17.3)	243 (18.3)	99 (15.4)
Fourth quintile	391 (19.7)	283 (20.4)	108 (18.0)	400 (20.3)	284 (21.3)	116 (18.1)
Third quintile	457 (23.0)	331 (24.0)	126 (21.0)	466 (23.6)	311 (23.4)	155 (24.1)
Second quintile	443 (22.3)	301 (21.7)	142 (23.7)	475 (24.1)	294 (22.1)	181 (28.2)
First quintile (lowest)	308 (15.5)	190 (13.7)	118 (19.6)	290 (14.7)	199 (14.9)	91 (14.2)
Missing	264 (11.7)	180 (11.5)	84 (12.2)	293 (12.9)	167 (11.1)	126 (16.4)

Values are expressed as column N (%) unless otherwise is indicated.

[a] Moderate HL: tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (the first **2 of the three tones at 3.0 kHz** heard)

[b] Moderately severe or severe HL: tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (**0 or 1 of the three tones at 3.0 kHz** heard).

Table 5.4. Summary of multiple logistic regression for variables associated with false-negative report of hearing difficulties by sample [a]

Variable	Model 1 [b]	Model 2 [c]	Model 3 [d]
Sex (female)	1.97 (1.18-3.28)	0.94 (0.55-1.60)	1.23 (1.18-3.16)
Age (65-74)	0.59 (0.28-1.26)	0.86(0.40-1.84)	5.75 (1.17-8.13)
Age (75-89)	0.55 (0.25-1.21)	0.85 (0.37-1.94)	7.08 (1.41-9.30)
Retirement status (not retired)	0.92 (0.46-1.78)	1.13 (1.08-2.15)	1.07 (0.39-2.93)
Education (no qualifications)	1.37 (1.26-2.55)	1.07 (1.05-2.45)	1.95 (1.63-6.01)
Occupation (routine/manual)	1.43 (1.28-2.61)	1.66 (1.09-1.98)	2.07 (1.78-5.40)
Income (lowest)	0.94 (0.77-1.15)	1.69 (1.19-3.19)	0.97 (0.73-1.27)
Smoking habit (current/former)	1.14 (1.08-1.90)	2.32 (1.80-3.75)	1.46 (1.25-2.48)
Excessive alcohol consumption (>14 units/week)	1.13 (1.11-2.34)	0.99 (0.97-1.02)	1.86 (1.67-5.12)
Physical Activity (moderate sports or activities hardly ever, or never)	1.25 (1.03-1.42)	1.10 (0.82-1.47)	1.02 (0.73-1.41)
Hosmer-Lemeshow chi2	9.43	3.82	11.39
Prob > chi2	0.31	0.87	0.18

Abbreviation: HL, hearing loss.

[a] Data are presented as odds ratio (95% CI) unless otherwise indicated.
[b] Model 1: did not report hearing difficulties while they had objectively measured HL by HearCheck (>35 dB HL at 3.0 kHz in the better-hearing ear) (n = 2,266).
[c] Model 2: did not report moderate hearing difficulties while they had objectively measured moderate HL (n = 1498); objective moderate HL: tones heard at 75 dB HL and 55 dB HL but not at 35 dB HL (the first 2 of the 3 tones at 3.0 kHz heard).
[d] Model 3: did not report moderately severe or severe hearing difficulties while they had objectively measured moderately severe or severe HL (n = 768); objective moderately severe or severe HL: tone heard or not at 75 dB HL and tones not heard at 55 dB HL and 35 dB HL (0 or 1 of the 3 tones at 3.0 kHz heard).

5.5. Discussion

In this study, we examined the validity of self-reported measures compared with HL as measured by the HearCheck™ Screener. We found that in a population-based sample of 8,529 adults 50 to 89 years of age, nearly one-third of those had objectively identified HL that went undetected by the self-report measures. These findings suggest that the use of a screening measure for audiometric testing along with a self-report measure in epidemiological studies and clinical practice is essential for accurately identifying older people with HL. Moreover, we found that female sex, older age, socioeconomic inequalities, and unhealthy lifestyle (tobacco use, alcohol intake above the low-risk level guidelines, and lower levels of physical activity), which are recognised as key risk factors for HL among older adults (Tsimpida et al., 2019), were largely associated with the inaccuracy of self-identification of hearing difficulties in those with objectively identified HL.

Comparison with previous literature

Our findings are consistent with previous studies that have examined on a smaller scale the performance of self-reported hearing difficulties in combination with pure tone audiometry among elderly individuals (Brennan-Jones et al., 2016; Choi et al., 2016; Curti et al., 2019; Diao et al., 2014; Ferrite et al., 2011; Kamil et al., 2015; Kiely et al., 2012; Louw et al., 2018; Mukari & Wan Hashim, 2018). However, to our knowledge, our study is the first vigorous examination of the validity of self-reported measures of hearing, including difficulties in background noise, with objective audiometric assessments in such a large and nationally representative cohort.

In general, all studies except for the studies of Diao et al., (2014) and Ferrite et al., (2011) argued that self-reported hearing should not be considered representative in associations with functional outcomes. The study of Diao et al., (2014) concluded that the Hearing Handicap Inventory for the Elderly-Screening Version (HHIE-S) could be considered a reliable and valid screening tool. Professional organisations have suggested the use of HHIE-S in combination with pure-tone screening because HHIE-S is focused mainly on the assessment of the social and emotional aspects of HL on the individual (handicap) and not the self-reported hearing ability (Diao et al., 2014). The study of Ferrite et al., (2011) focused on a small sample (n=188) of a younger adult population (30-65 years of age), drawn from a population-based cohort study, which may reveal that different factors may affect the sensitivity and specificity of self-reported hearing measures in an older population.

The role of age and sex in the inaccuracy of the self-reported measures has also been highlighted by Kamil et al., (2015), who found that the agreement rates between subjective and objective hearing measures were lower among the older age group (>60 years of age) and among women. This finding may reflect that people tend to undervalue the importance of hearing and consider its loss as an inevitable accompaniment of getting older (Tsimpida et al., 2019), and therefore adapt to HL over time (National Academies of Sciences and Medicine, 2016), underestimating the magnitude of their HL (Kiely et al., 2012).

Regarding the role of SEP, our findings are consistent with previous studies that found that agreement rates between subjective and objective hearing measures were relatively lower among those of a lower education attainment (Kamil et al., 2015) and occupational groups subject to noise-induced HL (Kirk et al., 2012). The role of income in the false-negative report of hearing difficulties may reflect financial barriers to using of and access to hearing healthcare (Tsimpida, D., Galanis, P. & Kaitelidou, 2019) and the downgrade of HL as a health priority (Diao et al., 2014).

Implications for Research, Policy and Practice

These findings have important public health implications and call for a revised assessment approach for HL in older adults; clinical research often relies on self-report measure of HL, but our findings indicate that this could not be regarded as well-suited and accurate measure to identifying individuals with HL without the additional use of a screening measure for audiometric testing (Louw et al., 2018). The underestimation of hearing difficulties poses a significant barrier to HL intervention and the self-report measures should not be considered reliable measures of hearing acuity to influence the judgement for referral to secondary care.

The help-seeking behaviour for hearing difficulties starts with individuals' self-diagnosis and initiation of contact with a health provider in primary health care settings (Pronk et al., 2018). In addition, unacknowledged HL constitutes a significant nonfinancial barrier. The existence of objective hearing measures is crucial, particularly for those belonging to high-risk groups that are most likely to remain unrecognised, such as people who face socioeconomic inequalities and adopt an unhealthy lifestyle, because these factors may affect the initiation of help-seeking, and consequently the referral to ear specialists.

Our findings address important conflicts in the literature, shedding light on the inconsistencies across studies regarding the relationship of HL with functional outcomes (Choi et al., 2016), and may reflect attitudinal differences across different cultures and geographical variation in the acknowledgement of hearing difficulties.

Strengths and limitations

The main strength of our study is that it provides the largest and most accurate evaluation of the discordance between objective and self-reported measures of HL today. Our study is also the first, to our knowledge, to address the association of lifestyle factors with the agreement rate, which had not been previously examined in the literature (Choi et al., 2016).

However, the study also has significant limitations. First, the cross-sectional analyses did not allow for causal or temporal relationships among the factors associated with the inaccuracy of self-reported measures. In addition, questionnaires that contain few questions to assess hearing deficits may have validity (Gibson et al., 2014). A relatively small proportion of participants who responded having “good”, “very good” or “excellent” hearing were also using a hearing aid, which may have confounded their response. Finally, the comparison of self-reported measure to the results from HearCheck™ Screener may contain information bias because the screening tool identified only those with HL greater than 35dB HL at 3.0 kHz in the better-hearing ear, whereas the self-reported questions did not specify that criterion.

Conclusion

Our study found that self-report measurement of HL had limited concordance with objective measures of HL. In light of these findings, the importance of an effective and sustainable HL screening strategy for the early detection and intervention for HL in older adults is reinforced. The lack of screening programmes excludes the early detection and treatment of patients with gradually progressive HL, especially those with unacknowledged HL. These results should be considered by HL researchers who analyse self-reported hearing data as a surrogate measurement of audiometric hearing to identify bias in their observed analytic research results. Future research should examine the role of other environmental and personal factors in the agreement rate between self-reported and objective measures of hearing, for which little is known (Choi et al., 2016) and investigate socio-spatial hearing health inequalities.

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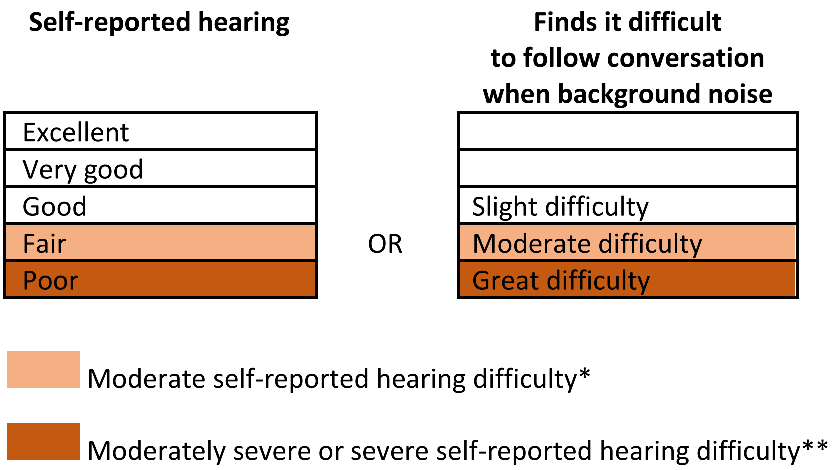
5.7. Supplement



Supplementary Figure 5.1. Definitions of categories of self-reported hearing difficulty

* Moderate self-reported hearing difficulty: if hearing was fair OR had moderate difficulty following a conversation in background noise.
** Moderately severe or severe self-reported hearing difficulty: if hearing was poor OR had great difficulty following a conversation in background noise.

Chapter 6

The Dynamic Relationship between Hearing Loss, Quality of Life, Socioeconomic Position and Depression and the Impact of Hearing Aids: Answers from the English Longitudinal Study of Ageing (ELSA)

6.1. Abstract

Background: The adverse impact of HL extends beyond auditory impairment and may affect the psychosocial wellbeing of the individuals. To date, the psychosocial mechanisms for the relationship between hearing loss (HL) and depression, and whether hearing aids reduce the prevalence of depressive symptoms remain unclear.

Methods: We examined the longitudinal relationship between HL and depressive symptoms (CES-D) applying dynamic cross-lagged mediation path models. We used the full dataset (74,908 person-years), from all eight Waves of the English Longitudinal Study of Ageing (ELSA). The quality of life (CASP-19 Scale) and the wealth of the participants were examined as the mediator and moderator of this relationship, respectively. Subgroup analyses investigated differences among those with hearing aids within different models of subjectively and objectively identified HL. All models were adjusted for age, gender, retirement status and social engagement.

Results: Socioeconomic position influenced the strength of the relationship between HL and depression, which was stronger in the lowest versus the highest wealth quintiles. Even the less frequent use of hearing aids was beneficial for depression. Those in the lowest wealth quintiles experienced a lower risk for depression after the use of hearing aids compared to those in the highest wealth quintiles.

Conclusions: HL poses a substantial risk to psychosocial wellbeing in older adults and especially those who experience socioeconomic inequalities. The early detection of

HL and provision of hearing aids may not only promote better hearing health but will also enhance the psychosocial wellbeing of older adults, particularly those in a lower socioeconomic position.

Keywords: hearing loss, psychosocial wellbeing, depression, hearing aids, ageing, social epidemiology

6.2. Introduction

Hearing loss (HL) is the third most common health condition affecting older adults after heart disease and arthritis (Brewster et al., 2018). According to global estimates, over 1.3 billion people live with some degree of HL (Wilson et al., 2017) and one-third of people above 65 years old are affected by disabling HL (World Health Organisation, 2018). The adverse impact of HL extends beyond auditory impairment and may affect the psychosocial wellbeing of the individuals. (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2020b) However, firm evidence about the psychosocial mechanisms implicated in the relationship between HL and depression are lacking, especially so in a longitudinal context. A recent systematic review and meta-analysis (Lawrence et al., 2019) found that HL was associated with 1.47 higher odds of depression in older adults (95%CI 1.31-1.65). However, the evidence had large inconsistency and the studies included had substantial heterogeneity (I^2=83.26%).

Two important factors which might be implicated in the relationship between HL and depression are the socioeconomic position (SEP) of the individuals and the use of hearing aids. There is increasing evidence that SEP is associated with HL among older adults. Recent findings indicate that key determinants of SEP such as the lower levels of education, income and wealth were associated with a higher likelihood of HL and the strength of these associations were as strong as those of well-established demographic factors such as age and gender. (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2019) Moreover, hearing aids have been advocated as an effective and scalable intervention for HL. (World Health Organisation, 2018) However, whether hearing aids reduce the prevalence of depressive symptoms is currently unclear. (Shukla et al., 2019) Preliminary evidence indicates that the use of hearing aids may reduce depression in older people with HL, (Nkyekyer et al., 2019), but large prospective studies are needed to confirm it.

Given the rising prevalence of HL, (World Health Organisation, 2018) it is crucial to fill the above knowledge gaps, as depression and HL are both responsible for large public health costs, morbidity and mortality. (Hsu et al., 2016) This study, aims to a) assess the causal psychosocial pathways (SEP, quality of life) between HL and depression in later life using a structural equation modelling (SEM) approach, and (b) to investigate whether the use of hearing aids prospectively reduces the risk of depression among older adults with HL.

6.3. Methods

Study Population

The analyses used the full dataset from the English Longitudinal Study of Ageing (ELSA). The ELSA is a longitudinal prospective cohort study that collects multidisciplinary data from a representative sample of adults aged 50 years old and above in England. (Steptoe et al., 2012) The study has an ongoing two-year follow-up longitudinal design with repeated measures of core variables over numerous Waves. Thus, it allows for an exploration of change in levels of hearing acuity, and trajectories on the social, wellbeing and economic impacts of such a change.

ELSA follows the sampling strategy of the Health Survey for England (HSE), which ensures that every address on the small users' Postcode Address File (PAF) in England has an equal chance of inclusion. Field household contact rates of over 96% were achieved. The study excluded cases not belonging to the target population through "terminating events", such as deaths, institutional moves and moves out of England since taking part in HSE. (Marmot et al., 2003)

As ELSA follows a longitudinal design, the sample is comprised of a sequence of observation on the same individuals across Waves and the refreshment samples (Cohorts 3, 4, 6 and 7). (Zaninotto & Steptoe, 2019) In our analyses, we used the full dataset of participants aged 50-89 years, from all eight Waves of ELSA, spanning the period 2002/3 to 2016/7 (74,908 person-years). We present a summary of the exact number of interviews by each Wave, and the fieldwork period as supplementary material (page 1, item 1). (Natcen Social Research, 2018)

We further analysed a sample of 8,529 adults aged 50-89 years from Wave 7 that had an assessment in their hearing by both self-reported measures and consented for assessment by a qualified nurse via a hearing screening device (Siemens Audiologische Technik GmbH, 2007), plus did not have an ear infection or a cochlear implant.

All participants gave written informed consent at the recruitment wave to participate in ELSA and at each subsequent Wave. Ethical approval was granted by the National Research and Ethics Committee. (Natcen Social Research, 2018) The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Outcome Measures

Depression

An 8-item short version of the Center for Epidemiologic Studies Depression (CES-D) Scale was administered in ELSA to assess clinically significant symptoms of depression. (Karim et al., 2015) The respondents had to indicate their feelings much of the time over the week before the interview, by confirming or not the particular feeling, respectively. (Karim et al., 2015) The questions and the scoring criteria of the 8-item short version CES-D are presented in the supplementary material (page 1, items 2 and 3).

Exposure measures

Hearing loss

ELSA uses a self-reported measure of hearing in each Wave. (NatCen Social Research, n.d.) The category of self-reported HL consists of a merged category of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor) or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).

Objective measurement of hearing acuity via HearCheck™ Screener was available only in ELSA Wave 7. Hearing acuity was classified by the hearing performance in HearCheck™ Screener and defined as >35dB HL at 3.0 kHz in the better-hearing ear, a level where intervention has been shown as definite beneficial. (Scholes et al., 2018)

We carried out additional work in a separate study (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2020a) to examine the validity of self-reported data, and we found that the self-reported measure of hearing classified correctly seven in every ten people with objectively assessed HL via HearCheck™ Screener. In that work, we also proposed an improved categorisation of self-reported hearing difficulties. However, since additional variables of self-reported data were not available in Waves other than Wave 7 to allow for the use of these improved categories of self-reported data, we assumed for the scope of our analyses the available self-reported measure as a suitable indicator of HL.

Mediator

Quality of life

The CASP-19 Scale is the measure of the quality of life used in ELSA. (Wiggins et al., 2008) The measure uses 19 items, covering four domains: four items for control (C), five items for autonomy (A), five items for self-realisation (S) and five items for pleasure (P). The questions of all domains and the scoring criteria are listed as supplementary material (page 1, item 4).

Moderators

Socioeconomic position

Educational level was used as an exogenous variable, whose value is independent of the states of other variables in the models. It was modelled in five categories of educational level as presented in the ELSA datasets: degree/higher education; A level (Level 3 of the National Qualifications Framework); O levels CSE (Certificate of Secondary Education); foreign/other; no qualifications.

We considered wealth as the most appropriate SEP indicator due to the age of the sample (aged 50 years old and above) because the wealth status captures the SEP in both the later stages of active professional life and retirement period. (Galobardes et al., 2006) Wealth was examined as a moderating/intermediate dependent variable of depression. The variable is provided in ELSA dataset in quintiles of the net total non-pension wealth, as reported at the household unit level (first quintile highest; fifth quintile lowest). (NatCen Social Research, n.d.) The full definition of the net total non-pension wealth and the cut-off points for the wealth groups are presented in the supplementary material (page 2, items 6 and 7).

Hearing aid use

As regards to the questions covering treatment for HL, the participants in Wave 7 were asked whether they ever wear hearing aids with potential answers (a) “Yes, most of the time”, (b) “Yes, some of the time”, and (c) “No”.

Covariates

We controlled for age, which influences the associations between HL and depression. (Cosh et al., 2019) Age was entered in all SEMs as a continuous variable, to maximise power. We also considered gender, retirement status, and social engagement as covariates in the analyses. The retirement status may confound the associations, and the degree of social engagement has been proposed to explain the association between HL and depression in older adults. (Kiely et al., 2013) Retirement status was dichotomised to those who were retired or not, according to the self-reported employment status. A continuous measure of social engagement was derived from a set of eight binary variables, which are presented in the supplementary material (page 2, item 8).

Data analysis

We fitted dynamic cross-lagged path models (CLPMs) to estimate the association between HL and depression over time. CLPM is a type of structural equation model used where two or more variables are measured at two or more occasions, and the focus is on the associations (often causal theories) with each other over time. In the path analysis part of the generalised structural equation models (GSEM), we used the full dataset from the 8 Waves (74,908 person-years), to strengthen the causal argument between HL and depression over time. Minimum Akaike's and Schwarz's Bayesian information criteria (AIC and BIC) values informed on the best-fitting recursive path models. Following these criteria, we considered HL as an exogenous predictor that has a uni-directional effect on wealth, which worked as an endogenous outcome variable in the models. Additionally, we examined wealth as moderating/intermediate dependent variable of depression, which was the outcome variable in the dynamic CLPMs.

The concept of quality of life functioned as an endogenous mediator variable that intervenes between HL and wealth, explaining the relation between HL and SEP. (Baron & Kenny, 1986) We represented the concept of quality of life using the confirmatory factor analysis (CFA) approach to generate a latent variable in each Wave. We calculated a standardised factor score that weights each item by their salience (loadings and correlation with the other items), rather than their mean or summative scores to allow each item to have its own variance. In the CFA models, we used the alpha reliability estimates to estimate reliability.

Exponentiated coefficients and summary statistics for each Wave are reported. Also, mixed-effects regression was used to estimate the interdependence of the repeated measures on the same participants using the intraclass correlation coefficient (ICC) and the variance across the repeated measures. We applied Sobel's test to calculate the significance of mediation in the CLPMs. Finally, we calculated the percentage of the total effect that is mediated (indirect effect/ total effect) as the measure of the extent of mediation in each CLPM.

Regarding missing data, we used a full information approach that utilised available information in the presence of missing values on one or more variables, without the use of listwise deletion, applying the *method (mlmv)* command in Stata. That method provides a maximum likelihood estimate using all observed values, assuming joint normality and that the missing values were missing at random. As we conducted analyses combining data from multiple Waves, we applied the longitudinal weighting using *svy* commands, in order to account for any bias arising from Wave non-response and attrition. The two-tailed significance level was set at ≤0.05. All data were analysed using Stata version 14. (StataCorp, 2015)

As a sensitivity analysis, we conducted subgroup analyses of the path models to investigate differences in the structural relationships among those who reported use of hearing aids most of the time and some of the time, respectively. As a second sensitivity analysis, we fitted similar models to investigate potential differences in parameter estimates of depression in Wave 8 of the participants, according to the a) self-reported measures of hearing difficulties, b) the improved categories of self-reported data, (Tsimpida et al., 2020a) and c) the objective hearing measures via HearCheck^{TM}. The compliance rate of hearing aids use (most of the time/some of the time) was entered as a moderator variable in the relationship between HL and depression, across different SEP groups.

6.4. Results

The alpha reliability estimates for the CFA models ranged from 0.83 to 0.86, which is over the 0.70 minimum standard value, (Tavakol & Dennick, 2011) showing excellent reliability of the scales for the actual score of quality of life. Results for PCFA and the factor scoring coefficients of the latent variables of quality of life for each

Wave, are included as **Table 6.1** and **Figures 6.1-6.8** of supplementary material, respectively.

Figure 6.1 shows the probability (%) of elevated depressive symptoms in 8 Waves of ELSA. The relative risk for depressive symptoms was higher for those who had reported HL than for those who had not reported HL (ranging from 1.40 in Wave 1 to 1.58 in Wave 8).

Figure 6.2 shows the CLPMs for HL and depression in the 8 Waves of ELSA. The ICC was 0.51 showing a high degree of statistical dependence of the observations across the repeated measures in ELSA. The variance within people (across the repeated measures) was 0.12, representing small differences from Wave to Wave.

Figure 6.3 depicts the dynamic CLPM model we constructed, and the standardised path coefficients of the effects of quality of life and wealth in the association between HL (Wave 1) with depression (Wave 2). The direct effect of HL on depression was weak. However, the relationship between HL and depression was temporally explained by the quality of life as a mediator. HL affected the different wealth groups disproportionally, mediated by the quality of life; those in the lowest wealth stratum experienced up to a double the effect of HL compared to those with the highest wealth. Next, the SEP moderated the effect of HL on depression: the effect of HL was stronger for those in the lowest wealth group (total effect: 0.72, interpreted as a correlation coefficient) compared to those in the highest, who were experiencing a more modest association between HL in Wave 1 and depression in Wave 2 (total effect: 0.48).

Sobel's tests in all CLPMs indicated that there was variation in the role of quality of life across different SEP, for those with HL; in all Waves, those in the lowest wealth quintiles experienced over double the effect of quality of life compared to those in the highest wealth quintiles. Wealth moderated the association between HL and depression; in all Waves, those in the lowest wealth quintiles were experiencing strong/very strong association between HL and elevated depressive symptoms two years later (e.g. standardised β coefficient 0.72 to 0.98). In contrast, the association for those in the highest wealth quintiles was low to moderate (e.g. standardised β coefficient 0.48 to 0.58). **Table 6.1** shows the standardised mediation effects for each endogenous effect in the CLPMs of **Figure 6.2**. All CLPMs are presented as Figures **6.9-6.15** of supplementary material.

Table 6.2 shows the results of the subgroup analyses of the CLPMs. The self-reported measure of hearing in ELSA underestimated the effect that HL has on SEP, showing a weak coefficient for all wealth groups. The improved self-reported definition of hearing data in Wave 7 (Tsimpida et al., 2020a) revealed a stronger association between HL and SEP, of similar strength to the association observed when using the objective measures of hearing in ELSA Wave 7.

Regarding the magnitude of strength of the association of HL with depression, all measures showed a graded relationship; those in the lowest wealth quintile were experiencing a strong/very strong association between HL and elevated depressive symptoms, but the association in those in the highest wealth quintiles was moderate: (standardised β coefficient 0.89 versus 0.52 for self-reported, 0.98 versus 0.51 for improved self-reported and 0.86 versus 0.51 for the objective measure of HL, respectively).

We also found that the use of hearing aids moderated the effect of HL on depressive symptoms disproportionally, according to wealth; the moderation effect of hearing aids on depressive symptoms was higher for those in the lowest versus those in the highest wealth quintiles; the standardised β coefficient in those with self-reported HL in ELSA Wave 7 became 0.56 from 0.89 for the lowest wealth quintile (improvement of effect: b=0.33) while remained stable in the highest wealth quintile. The improved self-reported measures of HL showed a slightly higher beneficial effect of hearing aids in the lowest wealth groups (improvement of effect: b=0.40).

The results of the sensitivity analyses according to the different hearing measures and the compliance rate of hearing aids use (most of the time/ some of the time) are included as **Figure 6.16** and Figures **6.17-6.19** of supplementary material, respectively.

6.5. Discussion

This study examined the psychosocial mechanisms that can help to explain the prospective relationship between HL and depression in older adults, which was previously unknown. (Lawrence et al., 2019) HL affected the different wealth groups disproportionally, mediated by the quality of life of individuals. SEP moderated the effect of HL on depression, determining the magnitude of their association, which was higher in the lowest wealth quintiles. We, therefore, suggest a graded relationship between HL and depression according to SEP, with those in lowest SEP having a higher risk for depression compared to those in the highest SEP.

We also found that aural rehabilitation, in the form of hearing aids potentially alleviated the depressive symptoms associated with HL. Those in the lowest versus the highest wealth quintiles experienced more considerable improvement in their psychosocial wellbeing after the use of hearing aids, and the improvement was slightly greater with the most frequent use of hearing aids. The graded benefit from hearing aids was shown irrespective of the HL measure used.

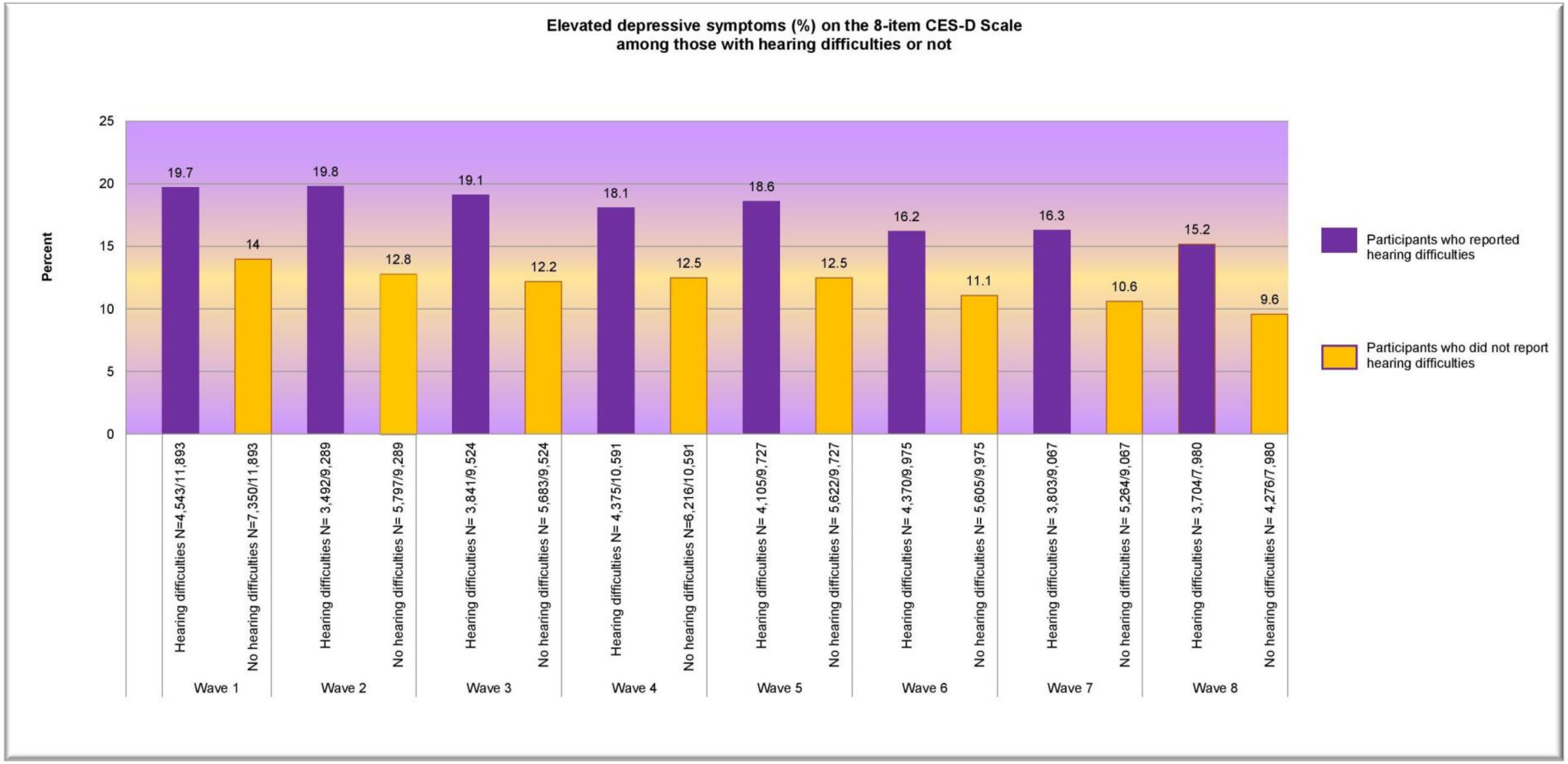


Figure 6.1. Clustered stacked bars for the probability (%) of elevated depressive symptoms [a] (on the 8-item CES-D Scale) among those with self-reported HL [b] or not in the 8 Waves of the English Longitudinal Study of Ageing (ELSA)

[a] Elevated depressive symptoms: the cut point of the eight-item dichotomous response scale (greater than or equal to four symptoms on the Scale) (8CES-D$\geqslant$4).

[b] Self-reported HL (hearing difficulties): the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).

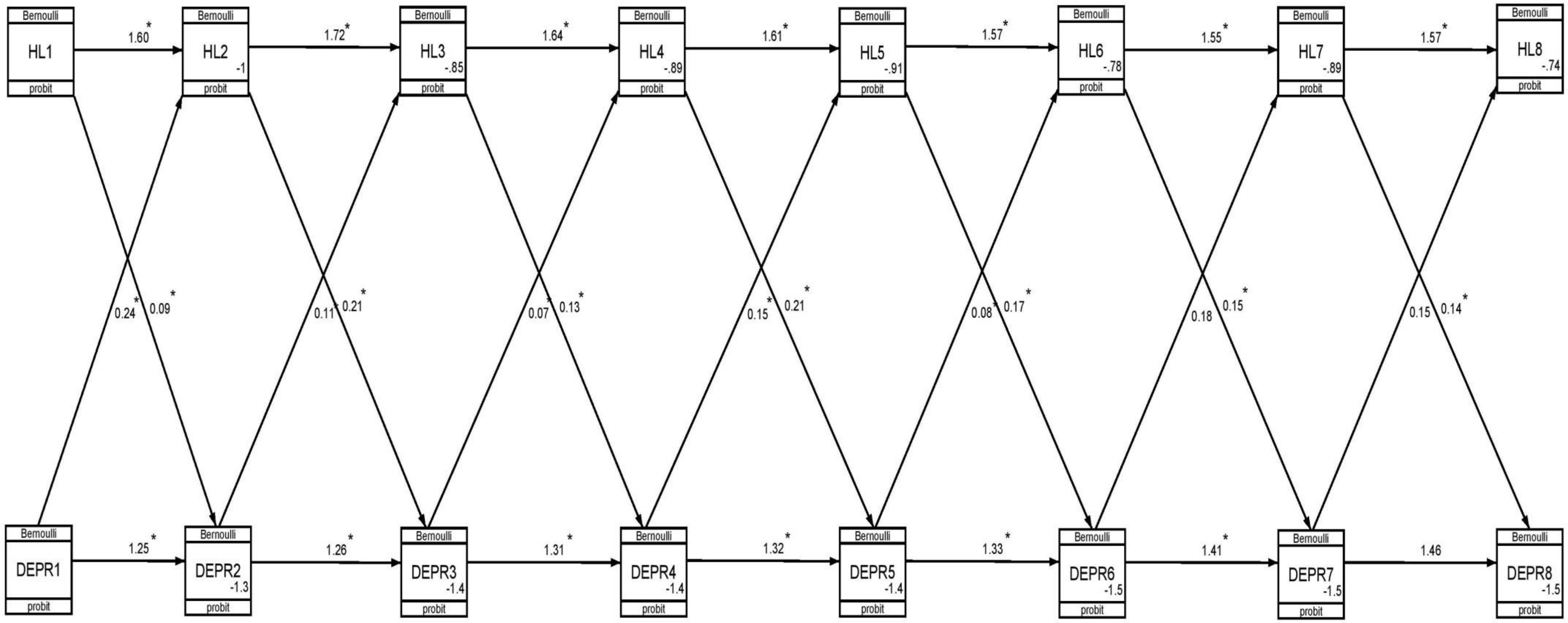


Figure 6.2. Cross-lagged path diagram model for hearing loss (HL) and depression (DEPR) in the 8 Waves of English Longitudinal Study of Ageing (ELSA)*

*p<0.05

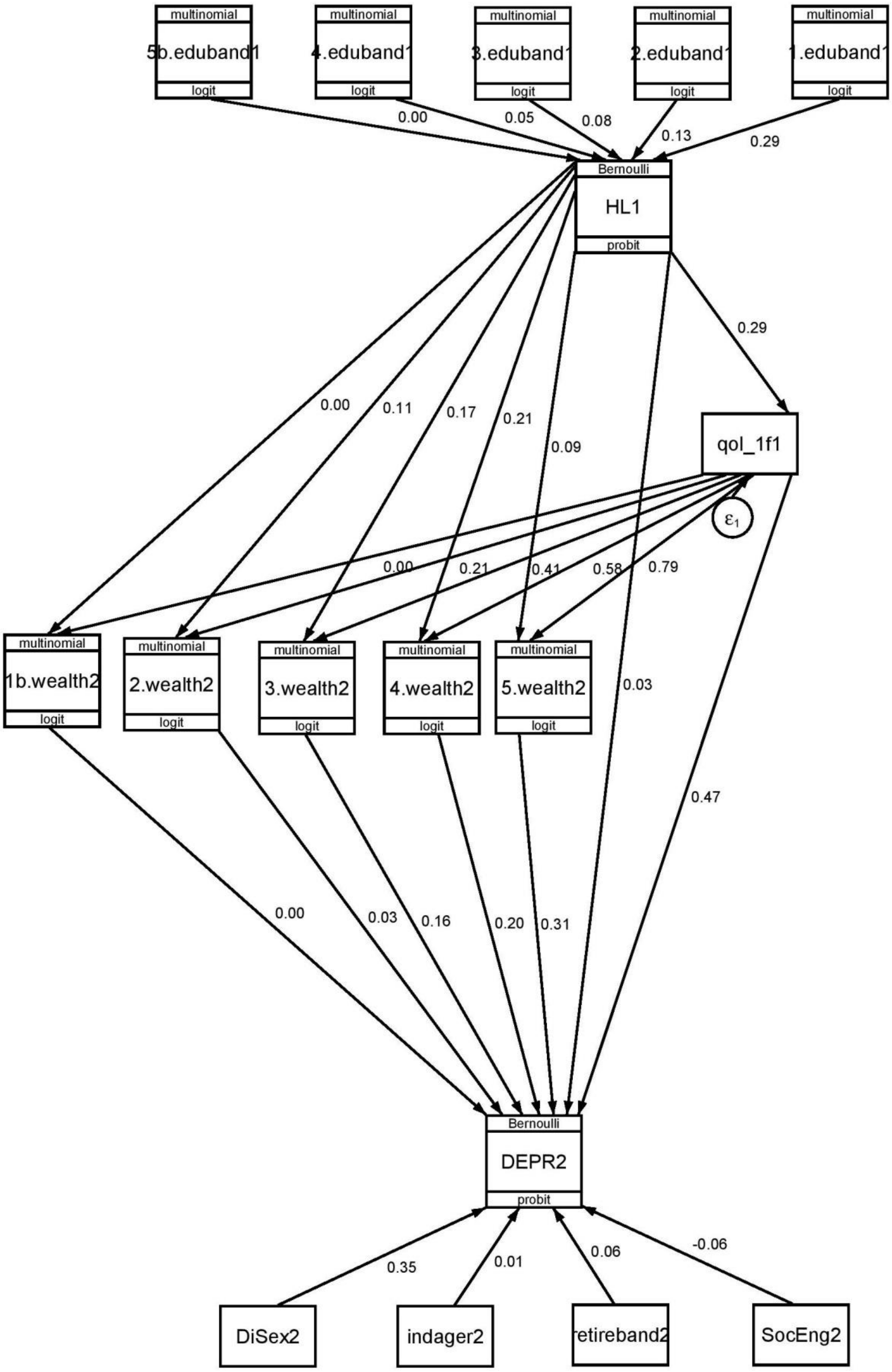


Figure 6.3. Standardised beta weights of the structural equation model representing the dynamic relationship between hearing loss in Wave 1, quality of life in Wave 1,

socioeconomic position in Wave 2 and depression in Wave 2 of the English Longitudinal Study of Ageing (ELSA)*

* exogenous variable eduband: representing the educational level in five categories (5: degree/higher education; 4: A level; 3: O levels CSE; 2: foreign/other; 1: no qualifications).
HL: self-reported hearing loss in Wave 1; examined as an exogenous predictor that has a uni-directional effect on wealth
qol_1f1: CASP-19 confirmatory factor analyses factor score in Wave 1; functioned as an endogenous mediator variable that intervenes between HL and wealth, explaining the relation between HL and SEP
wealth2: socioeconomic position according to wealth in Wave 2; functioned both as an endogenous outcome variable and a moderating/intermediate dependent variable of depression (1 represents highest quintile; 5 represents lowest quintile).
DEPR2: exogenous outcome variable; represents participants with CES-D Score ⩾4 in Wave 2.
Control factors: **DiSex**: sex of study participants, **indager2**: age of the participants in Wave 2, **retireband2**: retirement status of the participants in Wave 2, **SocEng2**: social engagement in Wave 2

Table 6.1. Standardised effects of the generalised structural equation modelling (GSEM) mediation analyses of 74,908 person-years in the 8 Waves of English Longitudinal Study of Ageing (ELSA) (full details in the footnote)

Outcome	Direct effect[1]	Indirect effect	Total effect	Sobel Test[2]	% of effect mediated [3]
Cross-lagged model[4] path No1					
QoL[5] at Wave 1					
HL[6]1->QoL1[7]	0.29				
SEP [8] at Wave 2 as mediated by the quality of life					
HL1->1wealth2[9]	(Reference)				
HL1->2wealth2	0.11	0.06	0.17	4.94	35.29
HL1->3wealth2	0.17	0.12	0.29	8.40	41.38
HL1->4wealth2	0.21	0.17	0.38	10.25	44.74
HL1->5wealth2	0.09	0.23	0.32	11.69	71.88
DEPR[10] at Wave 2 due to HL, according to wealth (quintiles)					
HL1->DEPR2	0.03				
QoL1(HL1)->DEPR2 for 1wealth2		(Reference)			
QoL1(HL1)->DEPR2 for 2wealth2	0.47 (direct effect)	0.01	0.48	0.42	2.08
QoL1(HL1)->DEPR2 for 3wealth2		0.07	0.54	2.58	12.96
QoL1(HL1)->DEPR2 for 4wealth2		0.12	0.59	2.80	20.34
QoL1(HL1)->DEPR2 for 5wealth2		0.25	0.72	4.32	34.72
Cross-lagged model path No2					
QoL at Wave 3					
HL3->QoL3	0.29				
SEP at Wave 4 as mediated by the quality of life					
HL3->1wealth4	(Reference)				
HL3->2wealth4	-0.07	0.05	-0.02	4.08	-250.00
HL3->3wealth4	0.12	0.10	0.22	7.49	45.45
HL3->4wealth4	0.07	0.14	0.21	8.12	66.67
HL3->5wealth4	-0.09	0.24	0.15	10.86	160.00
DEPR at Wave 4 due to HL, according to wealth (quintiles)					
HL3->DEPR4	0.13				
QoL3(HL3)->DEPR4 for 1wealth4		(Reference)			
QoL3(HL3)->DEPR4 for 2wealth4	0.54 (direct effect)	0.03	0.57	1.72	5.26
QoL3(HL3)->DEPR4 for 3wealth4		0.05	0.59	1.58	8.47
QoL3(HL3)->DEPR4 for 4wealth4		0.14	0.68	3.40	20.59
QoL3(HL3)->DEPR4 for 5wealth4		0.28	0.82	4.11	34.15
Cross-lagged model path No3					
QoL at Wave 5					
HL5->QoL5	0.29				
SEP at Wave 6 as mediated by the quality of life					
HL5->1wealth6	(Reference)				
HL5->2wealth6	-0.06	0.07	0.01	4.73	700.00
HL5->3wealth6	-0.02	0.14	0.12	9.36	116.67
HL5->4wealth6	0.11	0.20	0.31	11.10	64.52
HL5->5wealth6	-0.10	0.26	0.25	11.34	104.00
DEPR at Wave 6 due to HL, according to wealth (quintiles)					
HL5->DEPR6	0.12				
QoL5(HL5)->DEPR6 for 1wealth6		(Reference)			
QoL5(HL5)->DEPR6 for 2wealth6	0.53 (direct effect)	0.01	0.54	-0.62	1.85
QoL5(HL5)->DEPR6 for 3wealth6		0.07	0.60	1.85	11.67
QoL5(HL5)->DEPR6 for 4wealth6		0.21	0.74	3.66	28.38
QoL5(HL5)->DEPR6 for 5wealth6		0.35	0.88	4.70	39.77

(Continued)

Table 6.1. Standardised effects of the generalised structural equation modelling (GSEM) mediation analyses of 74,908 person-years in the 8 Waves of English Longitudinal Study of Ageing (ELSA) (full details in the footnote)

Outcome	Direct effect[1]	Indirect effect	Total effect	Sobel Test[2]	% of effect mediated [3]
Cross-lagged model path No4					
QoL at Wave 7					
HL7->QoL7	0.26				
SEP at Wave 8 as mediated by the quality of life					
HL7->1wealth8	(Reference)				
HL7->2wealth8	0.00	0.05	0.05	3.63	100.00
HL7->3wealth8	-0.09	0.12	0.03	6.31	400.00
HL7->4wealth8	0.07	0.16	0.23	7.14	69.57
HL7->5wealth8	-0.12	0.22	0.10	7.70	220.00
DEPR at Wave 8 due to HL, according to wealth (quintiles)					
HL7->DEPR8	0.15				
QoL7(HL8)->DEPR8 for 1wealth8		(Reference)			
QoL7(HL8)->DEPR8 for 2wealth8	0.51 (direct effect)	0.01	0.52	0.65	1.92
QoL7(HL8)->DEPR8 for 3wealth8		0.14	0.65	3.23	21.54
QoL7(HL8)->DEPR8 for 4wealth8		0.18	0.69	3.02	26.09
QoL7(HL8)->DEPR8 for 5wealth8		0.38	0.89	4.24	42.70
Cross-lagged model path No5					
QoL at Wave 2					
HL2->QoL2	0.26				
SEP at Wave 3 as mediated by the quality of life					
HL2->1wealth3	(Reference)				
HL2->2wealth3	0.02	0.08	0.10	5.36	80.00
HL2->3wealth3	0.12	0.13	0.25	7.69	52.00
HL2->4wealth3	0.17	0.18	0.35	9.45	51.43
HL2->5wealth3	0.01	0.24	0.25	10.81	96.00
DEPR at Wave 3 due to HL, according to wealth (quintiles)					
HL2->DEPR3	0.17				
QoL2(HL2)->DEPR3 for 1wealth3		(Reference)			
QoL2(HL2)->DEPR3 for 2wealth3	0.50 (direct effect)	0.07	0.57	2.77	12.28
QoL2(HL2)->DEPR3 for 3wealth3		0.16	0.66	4.09	24.24
QoL2(HL2)->DEPR3 for 4wealth3		0.29	0.79	5.31	36.71
QoL2(HL2)->DEPR3 for 5wealth3		0.48	0.98	5.84	48.98
Cross-lagged model path No6					
QoL at Wave 4					
HL4->QoL4	0.25				
SEP at Wave 5 as mediated by the quality of life					
HL4->1wealth5	(Reference)				
HL4->2wealth5	-0.03	0.07	0.04	5.77	175.00
HL4->3wealth5	0.06	0.09	0.15	7.56	60.00
HL4->4wealth5	0.04	0.16	0.20	9.85	80.00
HL4->5wealth5	-0.03	0.20	0.17	10.64	117.65
DEPR at Wave 5 due to HL, according to wealth (quintiles)					
HL4->DEPR5	0.19				
QoL4(HL4)->DEPR5 for 1wealth5		(Reference)			
QoL4(HL4)->DEPR5 for 2wealth5	0.50 (direct effect)	0.00	0.50	0	0
QoL4(HL4)->DEPR5 for 3wealth5		0.02	0.52	0.85	3.85
QoL4(HL4)->DEPR5 for 4wealth5		0.17	0.67	3.62	25.37
QoL4(HL4)->DEPR5 for 5wealth5		0.32	0.82	5.50	39.02

Table 6.1. Standardised effects of the generalised structural equation modelling (GSEM) mediation analyses of 74,908 person-years in the 8 Waves of English Longitudinal Study of Ageing (ELSA) (full details in the footnote)

Outcome	Direct effect[1]	Indirect effect	Total effect	Sobel Test[2]	% of effect mediated [3]
					(Continued)
Cross-lagged model path No7					
QoL at Wave 6					
HL6->QoL6	0.22				
SEP at Wave 7 as mediated by the quality of life					
HL6->1wealth7	(Reference)				
HL6->2wealth7	-0.04	0.04	0	3.76	0
HL6->3wealth7	-0.07	0.09	-0.02	6.68	-450.00
HL6->4wealth7	-0.06	0.14	0.08	8.23	175.00
HL6->5wealth7	-0.23	0.18	-0.05	9.20	-360.00
DEPR at Wave 7 due to HL, according to wealth (quintiles)					
HL6->DEPR7	0.20				
QoL6(HL6)->DEPR3 for 1wealth7		(Reference)			
QoL6(HL6)->DEPR3 for 2wealth7	0.56 (direct effect)	0.02	0.58	0.97	3.45
QoL6(HL6)->DEPR3 for 3wealth7		0.05	0.61	1.32	8.20
QoL6(HL6)->DEPR3 for 4wealth7		0.23	0.79	3.90	29.11
QoL6(HL6)->DEPR3 for 5wealth7		0.36	0.92	4.60	39.13

[1] Coefficient (b): Weak = 0.00 to 0.29, Low = 0.30 to 0.49, Moderate = 0.50 to 0.69, Strong = 0.70 to 0.89, Very Strong = 0.90 to 1.00 (Pett, 2015)
[2] Sobel test larger than 1.96 in absolute value is significant at the .05 level
[3] The percentage of the total effect that is mediated (indirect effect/ total effect)
[4] All models were adjusted for age, gender, retirement status and social engagement
[5] QoL: Quality of life (CASP-19 confirmatory factor analyses factor score)
[6] HL: Hearing loss
[7] Numbers *after* each variable indicate the Wave in ELSA
[8] SEP: categories of wealth (1st quintile highest; 5th quintile lowest)
[9] Wealth: represents the value of the primary house minus the outstanding primary house mortgage, the value of savings and shares minus depts, and the value of other properties and businesses, also known as the sum of net financial, physical and housing wealth
[10] DEPR: CES-D Score ⩾4

Table 6.2. Standardised effects of the generalised structural equation modelling (GSEM) mediation analyses according to different hearing loss measures in Waves 7 and 8 of the English Longitudinal Study of Ageing (ELSA) and the effect of intervention with hearing aids (full details in the footnote)

Outcome	Direct effect[11]	Indirect effect	Total effect	Sobel Test[12]	% of effect mediated [13]	Direct effect	Indirect effect	Total effect	Sobel Test	% of effect mediated	Direct effect	Indirect effect	Total effect	Sobel Test	% of effect mediated
	Self-reported HL*					**Self-reported HL (improved measures**)**					**Objective HL (via HearCheck Screener)*****				
QoL at Wave 7															
HL7->QoL7	0.26					0.25					0.20				
SEP at Wave 8 as mediated by the quality of life															
HL7->1wealth8	(Reference)					(Reference)					(Reference)				
HL7->2wealth8	0.00	0.05	0.05	3.63	100.00	0.19	0.01	0.20	0.50	5.00	0.35	0.04	0.39	3.30	10.26
HL7->3wealth8	-0.09	0.12	0.03	6.31	400.00	0.24	0.09	0.33	3.51	27.27	0.43	0.09	0.52	5.27	17.31
HL7->4wealth8	0.07	0.16	0.23	7.14	69.57	0.56	0.13	0.69	4.55	18.84	0.67	0.12	0.79	5.85	15.19
HL7->5wealth8	-0.12	0.22	0.10	7.70	220.00	0.44	0.21	0.65	5.17	32.31	0.37	0.16	0.53	5.99	30.19
SEP at Wave 8 as mediated by the quality of life (hearing aids some of the time 17.15%, n=566)						**(hearing aids use some of the time 23.17%, n=457)**					**(hearing aids use some of the time 22.90%, n=481)**				
HL7->1wealth8	(Reference)														
HL7->2wealth8	0.02	0.09	0.11	1.90	81.82	0.19	0.05	0.24	0.94	20.83%	0.37	0.04	0.41	1.04	9.76
HL7->3wealth8	0.06	0.08	0.14	1.45	57.14	0.31	0.04	0.35	0.77	11.43%	0.56	0.02	0.58	0.45	3.45
HL7->4wealth8	0.20	0.11	0.31	2.30	35.48	0.64	0.07	0.71	1.30	9.86%	0.85	0.04	0.89	1.04	4.49
HL7->5wealth8	0.10	0.04	0.14	-0.70	28.57	0.59	0.08	0.67	-1.16	11.94%	0.61	0.08	0.69	-1.52	11.59
SEP at Wave 8 as mediated by the quality of life (hearing aids use most of the time 10%, n=330)						**(hearing aids use most of the time 13.69%, n=270)**					**(hearing aids use most of the time 13.19%, n=277)**				
HL7->1wealth8	(Reference)														
HL7->2wealth8	0.04	0.02	0.06	0.47	33.33	0.21	0.00	0.21	0.00	0.00	0.46	0.06	0.52	-1.60	11.54
HL7->3wealth8	0.06	0.05	0.11	1.38	45.45	0.30	0.04	0.34	0.87	11.76	0.62	0.05	0.67	-1.16	7.46
HL7->4wealth8	0.17	0.12	0.29	3.07	41.38	0.63	0.08	0.71	1.70	11.27	0.90	0.02	0.92	-0.62	2.17
HL7->5wealth8	0.08	0.03	0.11	0.59	27.27	0.58	0.03	0.61	-0.62	4.92	0.64	0.06	0.70	-1.44	8.57
DEPR at Wave 8 due to HL, according to wealth (quintiles)															
HL7->DEPR8	0.15					0.01					0.16				
QoL7(HL8)->DEPR8 for 1wealth8		(Reference)					(Reference)					(Reference)			
QoL7(HL8)->DEPR8 for 2wealth8	0.51 (direct effect)	0.01	0.52	0.65	1.92	0.50 (direct effect)	0.01	0.51	0.44	1.96	0.50 (direct effect)	0.01	0.51	0.50	1.96
QoL7(HL8)->DEPR8 for 3wealth8		0.14	0.65	3.23	21.54		0.14	0.64	2.37	21.88		0.11	0.61	2.49	18.03
QoL7(HL8)->DEPR8 for 4wealth8		0.18	0.69	3.02	26.09		0.23	0.73	2.84	31.51		0.14	0.64	2.26	21.88
QoL7(HL8)->DEPR8 for 5wealth8		0.38	0.89	4.24	42.70		0.48	0.98	3.37	48.98		0.36	0.86	4.19	41.86

(Continued)

Table 6.2. Standardised effects of the generalised structural equation modelling (GSEM) mediation analyses according to different hearing loss measures in Waves 7 and 8 of the English Longitudinal Study of Ageing (ELSA) and the effect of intervention with hearing aids (full details in the footnote)

Outcome	Direct effect[11]	Indirect effect	Total effect	Sobel Test[12]	% of effect mediated [13]	Direct effect	Indirect effect	Total effect	Sobel Test	% of effect mediated	Direct effect	Indirect effect	Total effect	Sobel Test	% of effect mediated
DEPR at Wave 8 due to HL, according to wealth in quintiles (hearing aids some of the time 17.15%, n=566)						**(hearing aids use some of the time 23.17%, n=457)**					**(hearing aids use some of the time 22.90%, n=481)**				
	Self-reported HL*					**Self-reported HL (improved measures**)**					**Objective HL (via HearCheck Screener)*****				
QoL7(HL8)->DEPR8 for 1wealth8		(Reference)					(Reference)					(Reference)			
QoL7(HL8)->DEPR8 for 2wealth8	0.51 (direct effect)	0.03	0.54	0.74	5.56	0.50 (direct effect)	0.03	0.53	0.65	5.66	0.50 (direct effect)	0.01	0.51	0.45	1.96
QoL7(HL8)->DEPR8 for 3wealth8		0.09	0.60	1.35	15.00		0.07	0.57	0.75	12.28		0.02	0.52	0.44	3.85
QoL7(HL8)->DEPR8 for 4wealth8		0.12	0.63	1.40	19.05		0.12	0.62	1.23	19.35		0.05	0.55	0.96	9.09
QoL7(HL8)->DEPR8 for 5wealth8		0.08	0.59	-0.70	13.56		0.19	0.69	-0.77	27.54		0.17	0.67	-0.82	25.37
DEPR at Wave 8 due to HL, according to wealth in quintiles (hearing aids use most of the time 10%, n=330)						**(hearing aids use most of the time 13.69%, n=270)**					**(hearing aids use most of the time 13.19%, n=277)**				
QoL7(HL8)->DEPR8 for 1wealth8		(Reference)					(Reference)					(Reference)			
QoL7(HL8)->DEPR8 for 2wealth8	0.51 (direct effect)	0.01	0.52	0.42	1.92	0.50 (direct effect)	0.00	0.50	0.00	0.00%	0.50 (direct effect)	0.01	0.51	-0.48	1.96
QoL7(HL8)->DEPR8 for 3wealth8		0.07	0.58	1.06	12.07		0.06	0.56	0.84	10.71%		0.05	0.55	-1.07	9.09
QoL7(HL8)->DEPR8 for 4wealth8		0.13	0.65	2.26	20.00		0.13	0.63	1.54	20.63%		0.02	0.52	-0.60	3.85
QoL7(HL8)->DEPR8 for 5wealth8		0.05	0.56	0.58	8.93		0.08	0.58	-0.61	13.79%		0.12	0.62	-1.32	1..35

[11] Coefficient (b): Weak = 0.00 to 0.29, Low = 0.30 to 0.49, Moderate = 0.50 to 0.69, Strong = 0.70 to 0.89, Very Strong = 0.90 to 1.00 (Pett, 2015)

[12] Sobel test larger than 1.96 in absolute value is significant at the .05 level

[13] The percentage of the total effect that is mediated (indirect effect/ total effect)

*Current categories of self-reported data: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded positively in the question whether they find it difficult to follow a conversation if there is background noise (such as TV, radio or children playing).

**Improved categorisation of self-reported data: the sum of those that rated their hearing as fair or poor on a five-point Likert scale (excellent, very good, good, fair or poor), or responded that they have moderate or great difficulty in following a conversation if there is background noise (such as TV, radio or children playing).

***Objective HL: >35dB HL at 3.0 kHz, in the better-hearing ear.

QoL: CASP-19 confirmatory factor analyses factor score in Wave 7; functioned as an endogenous mediator variable that intervenes between HL and wealth, explaining the relation between HL and SEP

Wealth8: socioeconomic position according to wealth in Wave 8; functioned both as an endogenous outcome variable and a moderating/intermediate dependent variable of depression (1 represents the highest quintile; 5 represents the lowest quintile).

DEPR8: exogenous outcome variable; represents participants with CES-D Score ⩾4 in Wave 2.

Strengths and limitations

An important strength of the paper was the use of dynamic GSEMs as opposed to static "baseline-predicts-outcome" methodologies, which have limitations when investigating variables that change over time with increasing age, such as HL and depression in later life. GSEMs combine the power and flexibility of both SEM and generalised linear models, offering the opportunity to evaluate causal relationships within a unified modelling framework and to calculate both direct and indirect effects of multiple interacting factors simultaneously, reaching a high predictive ability of the effects. (Gunzler et al., 2013; Lombardi et al., 2017) Also, the confirmatory factor analysis (CFA) that generated a latent variable for quality of life in each Wave led to a strong predictive power in the theoretically causal associations between variables.

Another strength was the grouping of wealth in ELSA into quintiles, which reduced the measurement error and allowed the comparison of the health measures across the equally sized groups within the given population. (Fink et al., 2017)

However, the findings must be interpreted in light of several limitations. In our analyses, omitted variable bias may occur, as we never know whether all relevant predictors have been included in our models, and one of those left out may determine the value of an endogenous variable. (Petersen & van der Laan, 2014)

Another limitation was that the CES–D scale does not measure the duration of symptoms; therefore, *DSM* criteria for major or minor depression cannot be applied to these data. Besides, predicting the presence of clinically elevated depressive symptoms over time, as we did in our study, refers less directly to symptom severity. (Cosh et al., 2019)

We were aware that the self-reported data in ELSA underestimated objectively measured hearing problems. (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2020a) The error introduced by the self-reported measures is likely to reduce external validity, as responses may be biased by cultural or population characteristics.

Comparison with previous literature

The systematic review and meta-analysis by Lawrence et al., (Lawrence et al., 2019) synthesised evidence examining the association between HL and depression. Studies reporting an association are conflicting, which may be explained by the unrecognised effect of SEP modification we have now identified, that distorted the effect of HL on depression. Previous studies did not focus on the modifiable factors linked to socioeconomic inequalities in hearing health, and research on this topic is limited. (Tsimpida, D., Kontopantelis, E., Ashcroft, D., Panagioti, 2020b) Only five of the 24 cross-sectional and seven of the 11 cohort studies in the meta-analysis by Lawrence et al. (Lawrence et al., 2019) adjusted for the confounding influence of SEP covariates, which resulted in significant variance in the crude association between HL and depression across studies. It is worth mentioning that the two studies (Mick & Pichora-Fuller, 2016),(K.-L. Chou, 2008) that adjusted for a variety of SEP measures in their analyses were the ones that did not find an association of HL with depression in older adults. Thus, our study adds to the existing body of literature by focusing on the role of SEP, which we suggest may explain the causal, the temporal and graded relationship between HL and depression.

Similarly, the socioeconomic pattern we identify for the first time to the benefit from hearing aids on psychosocial wellbeing among those with HL may also explain why no effect of hearing aids use was found in the recent meta-analysis by Lawrence et al. (Lawrence et al., 2019); no previous study examined the role of hearing aids under a socioeconomic perspective, so as to identify their effect heterogeneity according to SEP and to firmly conclude, therefore, about the effectiveness of hearing aids in the psychosocial wellbeing.

Implications for research, policy, and practice

Our findings revealed the importance of health policy strategies to tackle the complex health and care needs of people with HL. HL is a highly underdiagnosed and untreated chronic health condition and the leading cause of morbidity among older adults in England. (Benova et al., 2015; Health Profile for England, 2018) Untreated HL leads not only to negative consequences for individuals but also for the society, as it widens the socioeconomic inequalities and the concomitant mental health inequalities due to HL. Besides, untreated HL may also impact negatively on healthy ageing, as recent evidence from longitudinal studies of ageing suggested that wealth is the most influential socioeconomic predictor of healthy ageing among English participants. (Lu et al., 2019)

This study also has novel clinical implications, as it adds to the understanding of the interrelationship between HL and depression. HL is on the rise, (World Health Organisation, 2018) and the early detection of HL by primary care professionals in routine assessments could help prevent or delay the onset of depression, particularly in lower wealth groups. Taking SEP into account is considered an essential element for depression prevention strategies in the general population, (Freeman et al., 2016) and our findings confirm that SEP is equally important for preventing depression in older people with HL.

Future research should examine common underlying factors among participants with similar SEP, that could lead to preventive psychological interventions, along with online and web-based interventions (Cosh et al., 2019) for older adults with comorbid HL and depression. Large scale RCTs are needed to guide clinical practice and to investigate whether treatment for HL could be a monotherapy treatment for depression or as augmentation with antidepressant medications. (Brewster et al., 2018)

Conclusion

HL may place older adults at risk of developing significant depressive symptoms, with the lowest SEP groups experiencing up to double the relative risk for depression. The use of hearing aids reduces the risk of depression, suggesting that interventions with hearing aids could alleviate the psychological burden of HL. Increasing the HL treatment rate could be one effective strategy for risk reduction of depression, given the high prevalence of HL in older age, and its low treatment levels. However, early intervention requires early identification of HL that could mitigate the negative impact of HL on psychosocial wellbeing. Our findings highlight the potential of the inclusion of screening for HL in the routine geriatric assessment guidelines as a way to enhance the psychosocial health of older adults.

Declarations

Authors' contributions DT, EK, DMA and MP developed the idea and designed the study. DT was responsible for conducting the analyses, interpreting the results, and drafting the manuscript. DT, EK, DMA and MP critically revised the manuscript. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval and consent to participate Not required. The study used data from the English Longitudinal Study of Ageing (ELSA).

Consent for publication Not applicable

Availability of data and materials The English Longitudinal Study of Ageing dataset is publicly available via the UK Data Service (http://www.ukdataservice.ac.uk). Statistical code is available from the corresponding author at dialechti.tsimpida@manchester.ac.uk

Competing interests The authors declare that they have no competing interests.

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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. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

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6.7. Supplement

1. Number of Interviews by Waves in the English Longitudinal Study of Ageing (ELSA)

	Fieldwork Period	Total archived interviews	Core Member interviews	Partner interviews
Wave 1	March 2002 – March 2003	12,099	11,391	708
Wave 2	June 2004 – July 2005	9,432	8,780	652
Wave 3	May 2006 – August 2007	9,771	8,810	961
Wave 4	May 2008 – July 2009	11,050	9,886	1,164
Wave 5	June 2010 – July 2011	10,274	9,090	1,184
Wave 6	May 2012 – June 2013	10,601	9,169	1,432
Wave 7	June 2014 – May 2015	9,666	8,249	1,417
Wave 8	May 2016 – June 2017	8,445	7,223	1,222

2. Questions of the 8-item short version of the Center for Epidemiologic Studies Depression (CES-D) Scale:

a) “Did you feel depressed”?
b) “Did you feel everything you did was an effort”?
c) “Was your sleep restless”?
d) “Were you happy”?
e) “Did you feel lonely”?
f) “Did you enjoy life”?
g) “Did you feel sad”?
h) “Were you unable to get going”?

3. Scoring criteria of the 8-item short version of the Center for Epidemiologic Studies Depression (CES-D) Scale: The lowest possible score was 0 (no symptoms of depression), and the highest possible score was 8 (the highest number of symptoms of depression. We utilised the cut point of the eight-item dichotomous response scale (greater than or equal to four symptoms on the Scale) to denote elevated depressive symptoms. This level has shown good predictive accuracy to define clinically significant depressive symptoms that indicate risk for adverse outcomes.

4. The CASP-19 Scale questions of all domains:

Control:

1) How often feels age prevents them from doing things they like
2) How often feels what happens to them is out of their control
3) How often feels free to plan for the future
4) How often feels left out of things

Autonomy:
5) How often can do the things they want to do
6) How often family responsibilities prevent them from doing things
7) How often feels they can please themselves what they do
8) How often feels their health stops them doing what they want to do
9) How often shortage of money stops them doing things

Self-realisation:
10) How often feels full of energy these days
11) How often chooses to do things they have never done before
12) How often feels satisfied with the way their life has turned out
13) How often feels that life is full of opportunities
14) How often feels the future looks good to them

Pleasure:
15) How often look forward to each day
16) How often feels that their life has meaning
17) How often enjoys the things they do
18) How often enjoys being in the company of others
19) How often looks back on their life with a sense of happiness

5. Scoring criteria of the CASP-19 Scale:
The summation of 19 items (with response options within a 4-point Likert scale ranging from 0, "never" to 3, "often") yields a range from 0 to 57 for the total score of quality of life for each respondent. Higher scores indicate higher total levels of satisfaction of quality of life and in each Scale of control, autonomy, self-realisation and pleasure, respectively.

6. Definition of net total non-pension wealth
The value of the primary house minus the outstanding primary house mortgage, the value of savings and shares minus depts, and the value of other properties and businesses, also known as *the sum of net financial, physical and housing wealth*.

7. The cut-off points for the wealth group definition were:
Wave 1 (2002-3): Lowest -less than £22k, 2nd-between £22k-£132k, 3rd-between £132k-£229k, 4th-between £229k-£403k, Highest –More than £403k,
Wave 4 (2008-09): Lowest -less than £60k, 2nd-between £60k-£201k, 3rd-between £201k-£303k, 4th-between £303k-£496k, Highest –More than £496k,
Wave 8 (2016-17): Lowest -less than £71k, 2nd-between £71k-£210k, 3rd-between £210k-£354k, 4th-between £354k-£575k, Highest –More than £575k.

8. Definition of social engagement
A continuous measure of social engagement included in the analysis, derived from a set of eight binary variables, asking whether the respondent is a member of various civic and social organisations, including a political party, neighbourhood watch group, church or religious group, charitable association, educational or evening class, social club, sports club, or exercise class, or any other organisation. The summation of 8 items yields a range from 0 to 8 for the total score of social engagement.

Supplementary Table 6.1. Results of the principal component factor analysis (PCFA) for the 19-items of CASP-19 in 8 Waves of ELSA

	Eigenvalue for each factor and Cumulative proportion of variance															
Factor	**Wave 1**	**Cum.***	**Wave 2**	**Cum.***	**Wave 3**	**Cum.***	**Wave 4**	**Cum.***	**Wave 5**	**Cum.***	**Wave 6**	**Cum.***	**Wave 7**	**Cum.***	**Wave 8**	**Cum.***
Factor 1	5.55	0.29	5.77	0.30	5.79	0.30	5.92	0.31	6.01	0.32	6.05	0.32	6.08	0.32	6.06	0.31
Factor 2	1.95	0.39	2.01	0.40	1.98	0.40	1.97	0.41	2.00	0.43	2.03	0.43	2.06	0.43	2.05	0.43
Factor 3	1.25	0.46	1.26	0.48	1.18	0.47	1.15	0.48	1.16	0.49	1.14	0.49	1.20	0.49	1.16	0.49
Factor 4	1.15	0.52	1.18	0.54	1.10	0.53	1.11	0.53	1.07	0.54	1.09	0.54	1.09	0.55	1.09	0.55
Factor 5	0.96	0.57	0.95	0.59	0.89	0.58	0.91	0.58	0.92	0.59	0.93	0.59	0.93	0.60	0.95	0.60
Factor 6	0.89	0.62	0.89	0.64	0.97	0.62	0.88	0.63	0.89	0.64	0.89	0.64	0.85	0.64	0.87	0.64
Factor 7	0.80	0.66	0.77	0.68	0.83	0.67	0.80	0.67	0.79	0.68	0.80	0.68	0.80	0.69	0.78	0.68
Factor 8	0.75	0.70	0.74	0.71	0.76	0.71	0.75	0.71	0.74	0.72	0.72	0.72	0.74	0.72	0.75	0.72
Factor 9	0.70	0.74	0.67	0.75	0.70	0.74	0.69	0.74	0.69	0.76	0.66	0.75	0.66	0.76	0.74	0.76
Factor 10	0.67	0.77	0.65	0.78	0.68	0.78	0.65	0.78	0.66	0.79	0.63	0.79	0.64	0.79	0.62	0.79
Factor 11	0.62	0.81	0.61	0.81	0.63	0.81	0.63	0.81	0.61	0.82	0.59	0.82	0.60	0.82	0.59	0.82
Factor 12	0.59	0.84	0.58	0.85	0.58	0.84	0.59	0.84	0.56	0.85	0.56	0.85	0.54	0.85	0.55	0.85
Factor 13	0.55	0.87	0.52	0.87	0.54	0.87	0.52	0.87	0.50	0.88	0.51	0.88	0.52	0.88	0.50	0.88
Factor 14	0.51	0.89	0.50	0.90	0.50	0.89	0.49	0.90	0.47	0.90	0.49	0.90	0.47	0.90	0.48	0.90
Factor 15	0.47	0.91	0.44	0.92	0.46	0.92	0.45	0.92	0.43	0.93	0.44	0.93	0.42	0.93	0.44	0.92
Factor 16	0.44	0.94	0.43	0.95	0.42	0.94	0.43	0.95	0.40	0.95	0.42	0.95	0.40	0.95	0.42	0.95
Factor 17	0.41	0.96	0.36	0.97	0.38	0.96	0.37	0.97	0.36	0.97	0.36	0.97	0.34	0.97	0.36	0.97
Factor 18	0.40	0.98	0.35	0.98	0.37	0.98	0.34	0.98	0.34	0.98	0.34	0.98	0.33	0.98	0.35	0.98
Factor 19	0.31	1.00	0.30	1.00	0.30	1.00	0.29	1.00	0.29	1.00	0.29	1.00	0.30	1.00	0.30	1.00
Number of obs.	9,723		7,193		7,561		8,595		8,299		7,237		6,263		5,580	
Retained factors	4		4		4		4		4		4		4		4	
Alpha reliability	0.83		0.85		0.85		0.85		0.86		0.85		0.86		0.85	

*Cumulative proportion of variance of the 19-items in each Wave

Figure 6.1.

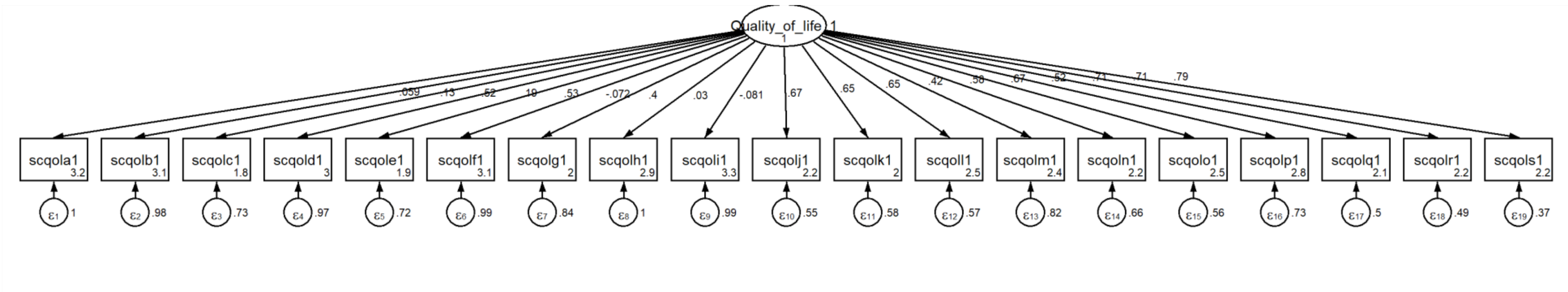


Figure 6.2.

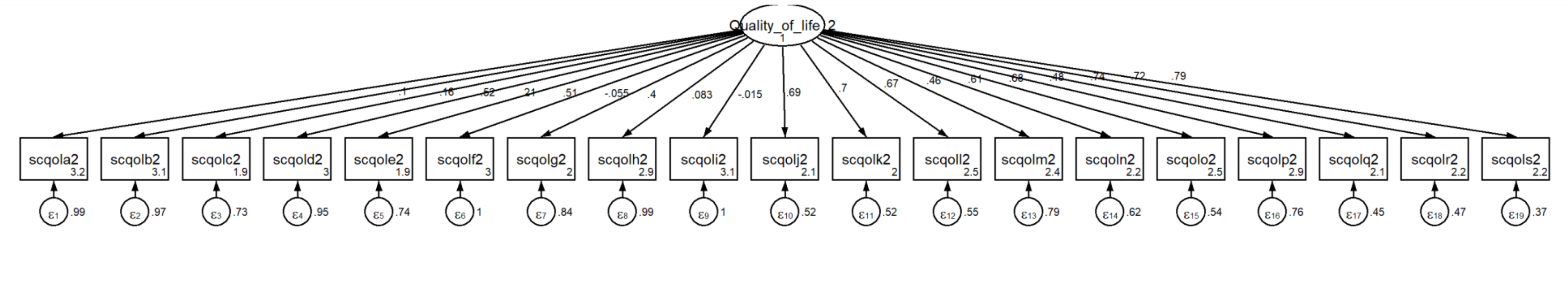


Figure 6.3.

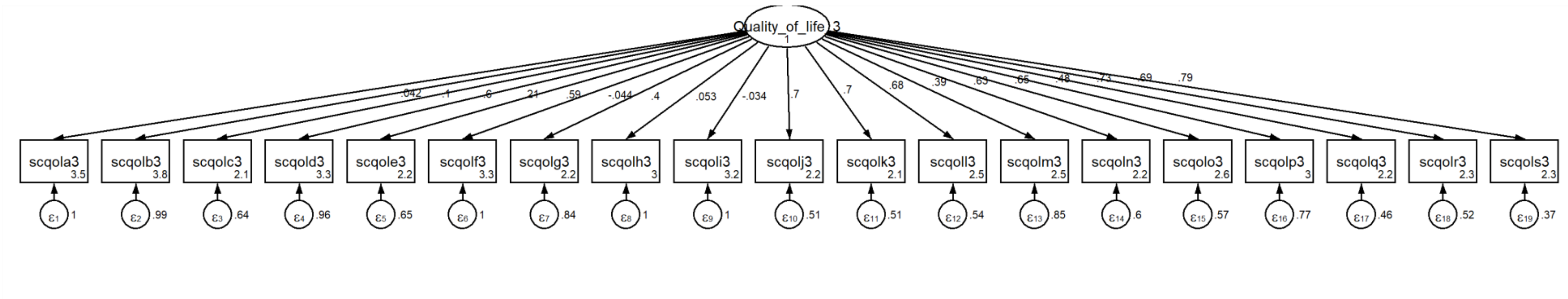
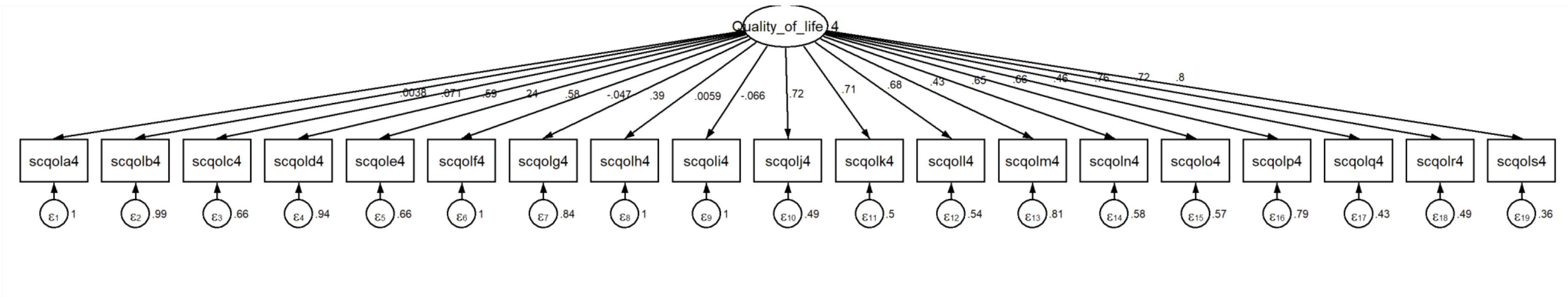


Figure 6.4.



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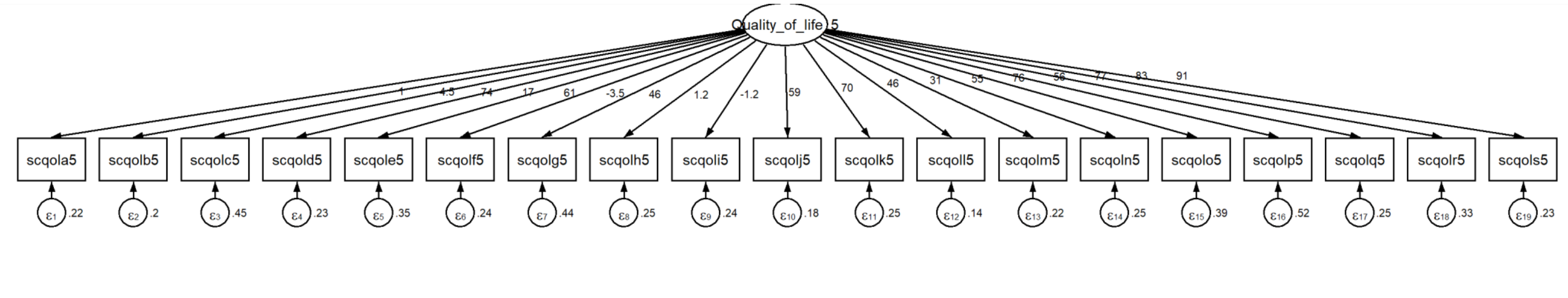


Figure 6.6.

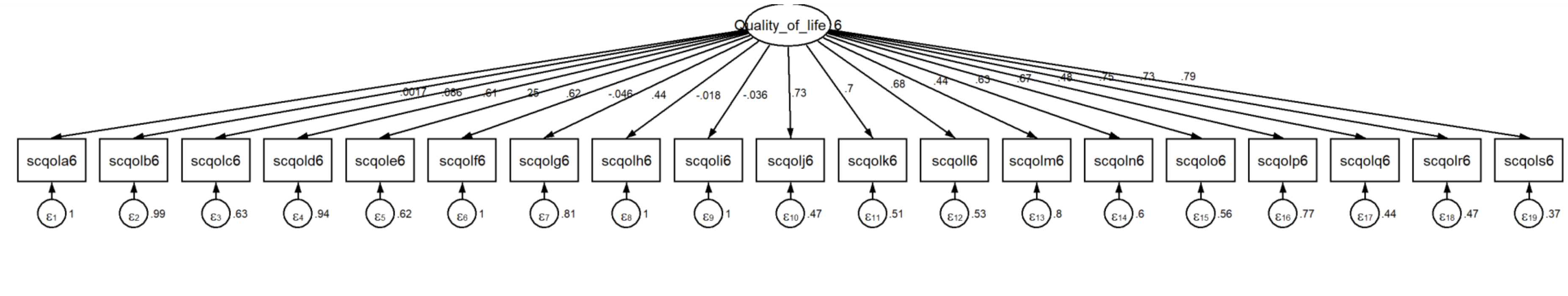


Figure 6.7.

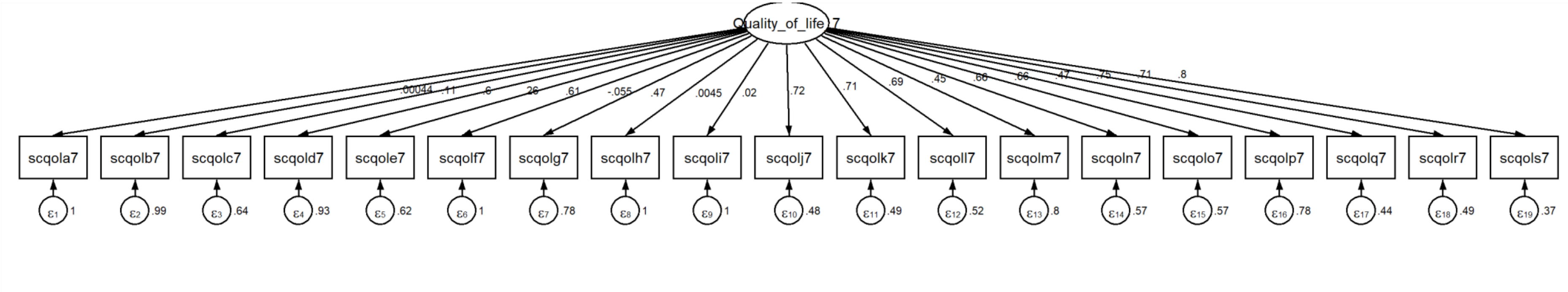
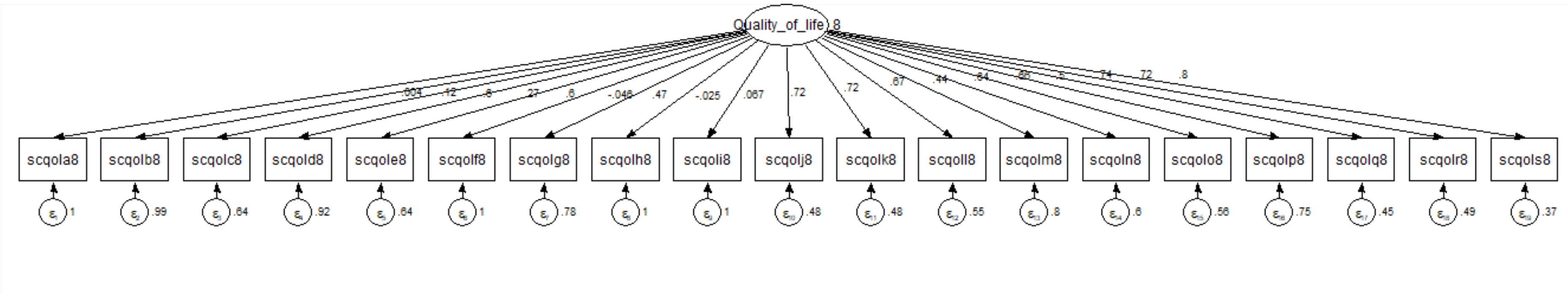


Figure 6.8.



Supplementary Figure 6.1-8. Factor scoring coefficients of Quality-of-Life latent variables (standardized beta weights of the confirmatory factor analysis for the 19-items of CASP-19) in the 8 waves of English Longitudinal Study of Ageing (ELSA)

Figure 6.9.

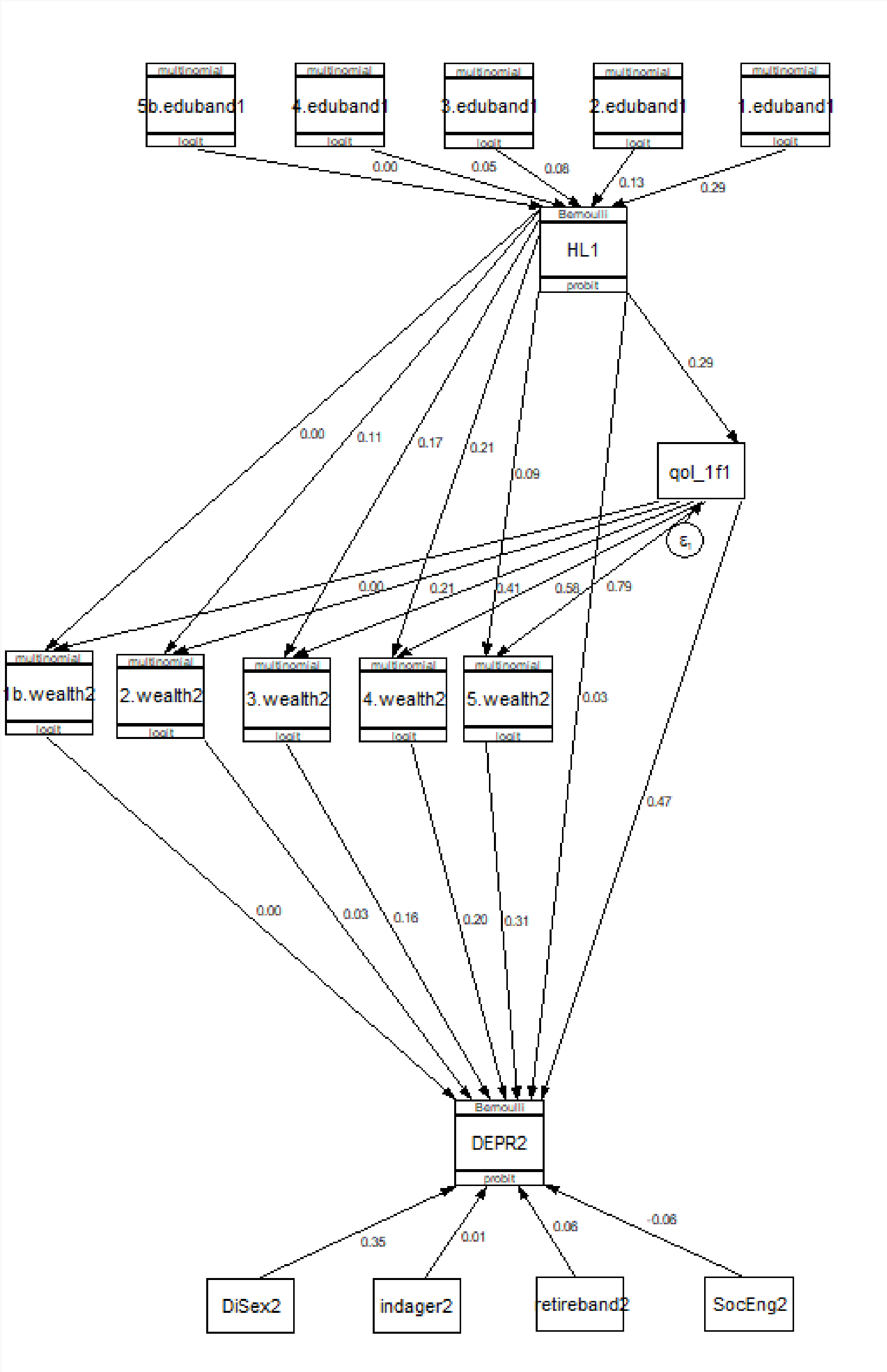
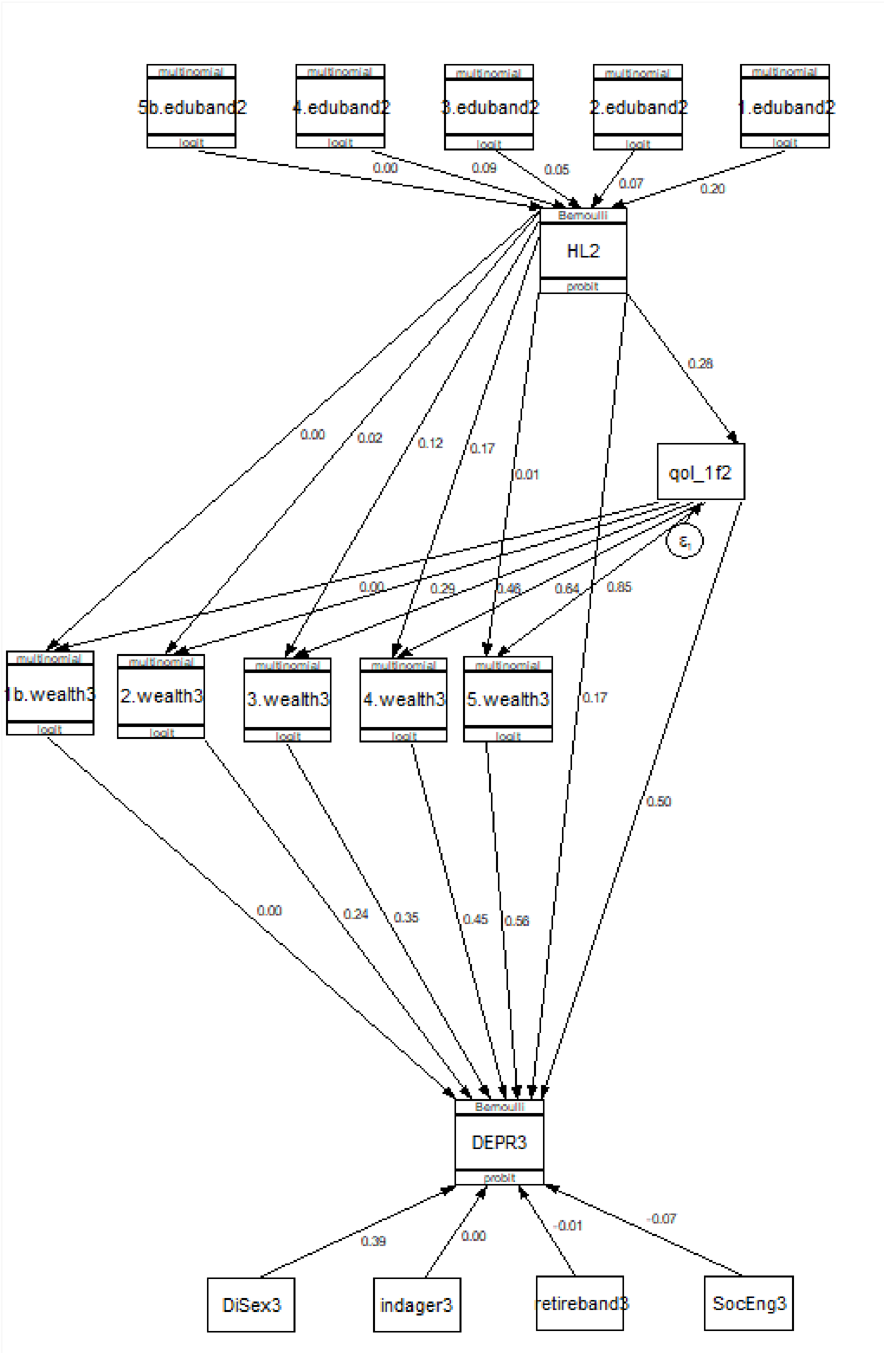

5b.eduband1
4.eduband1
3.eduband1
2.eduband1
1.eduband1
0.00
0.05
0.08
0.13
0.29
HL1
0.29
qol_1f1
0.00
0.11
0.17
0.21
0.09
0.00
0.21
0.41
0.58
0.79
1b.wealth2
2.wealth2
3.wealth2
4.wealth2
5.wealth2
0.03
0.47
0.00
0.03
0.16
0.20
0.31
DEPR2
0.35
0.01
0.06
-0.06
DiSex2
indager2
retireband2
SocEng2

Figure 6.10.



5b.eduband2
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2.eduband2
1.eduband2
HL2
qol_1f2
1b.wealth3
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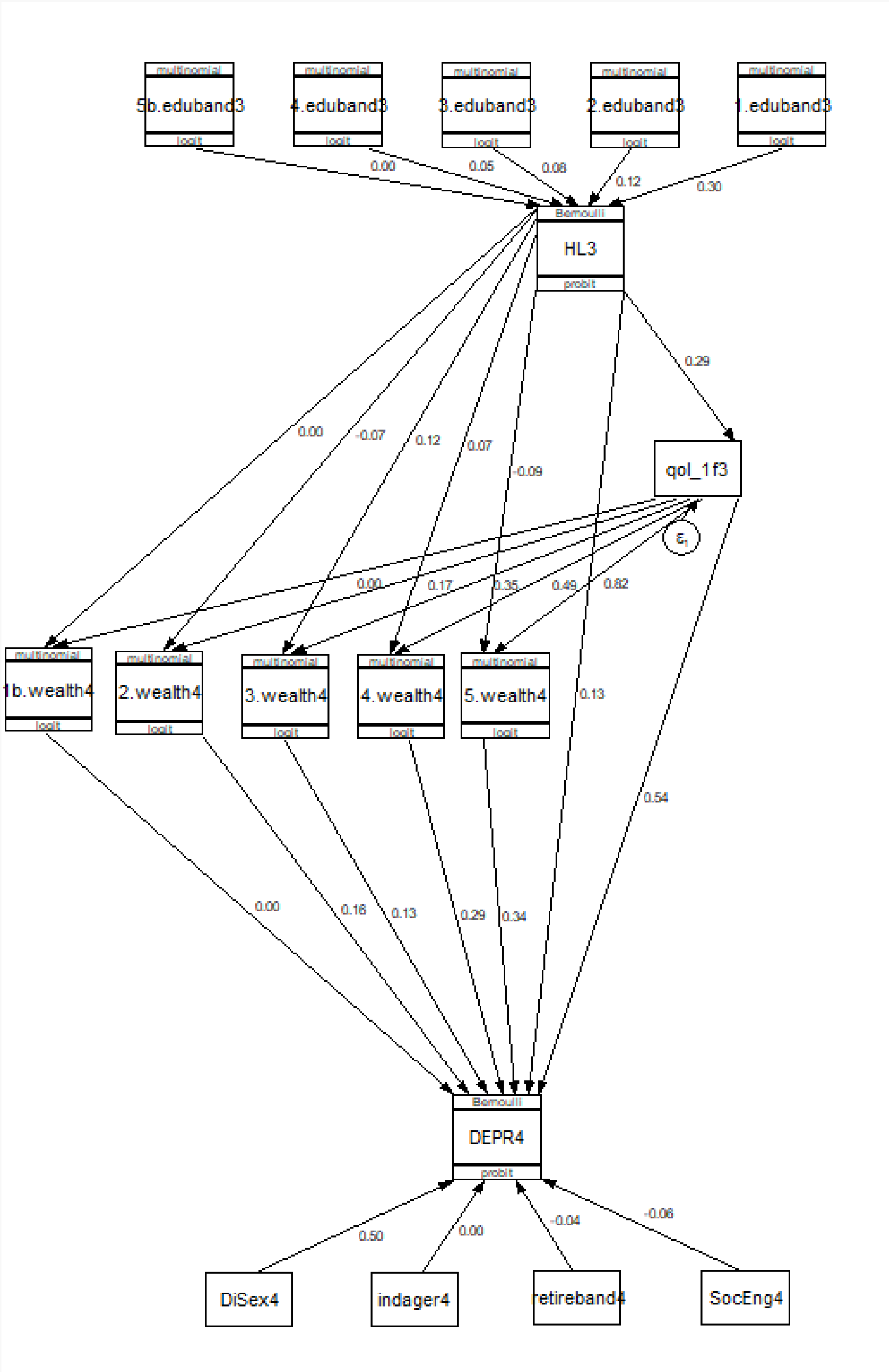
3.wealth3
4.wealth3
5.wealth3
DEPR3
DiSex3
indager3
retireband3
SocEng3

Figure 6.11.



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1.eduband3
HL3
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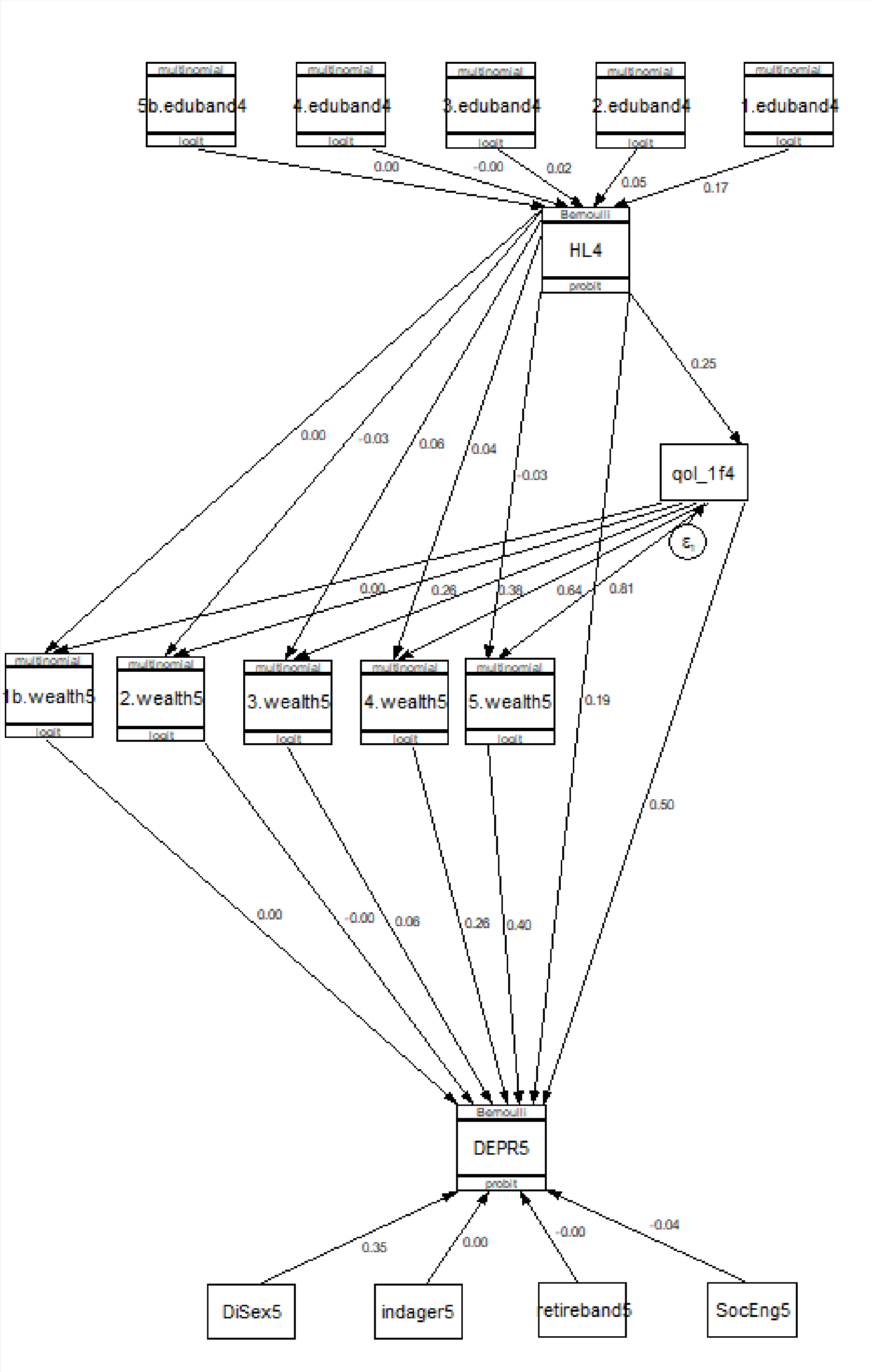
Figure 6.12.



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4.wealth5
5.wealth5
DEPR5
DiSex5
indager5
retireband5
SocEng5
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-0.00
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0.05
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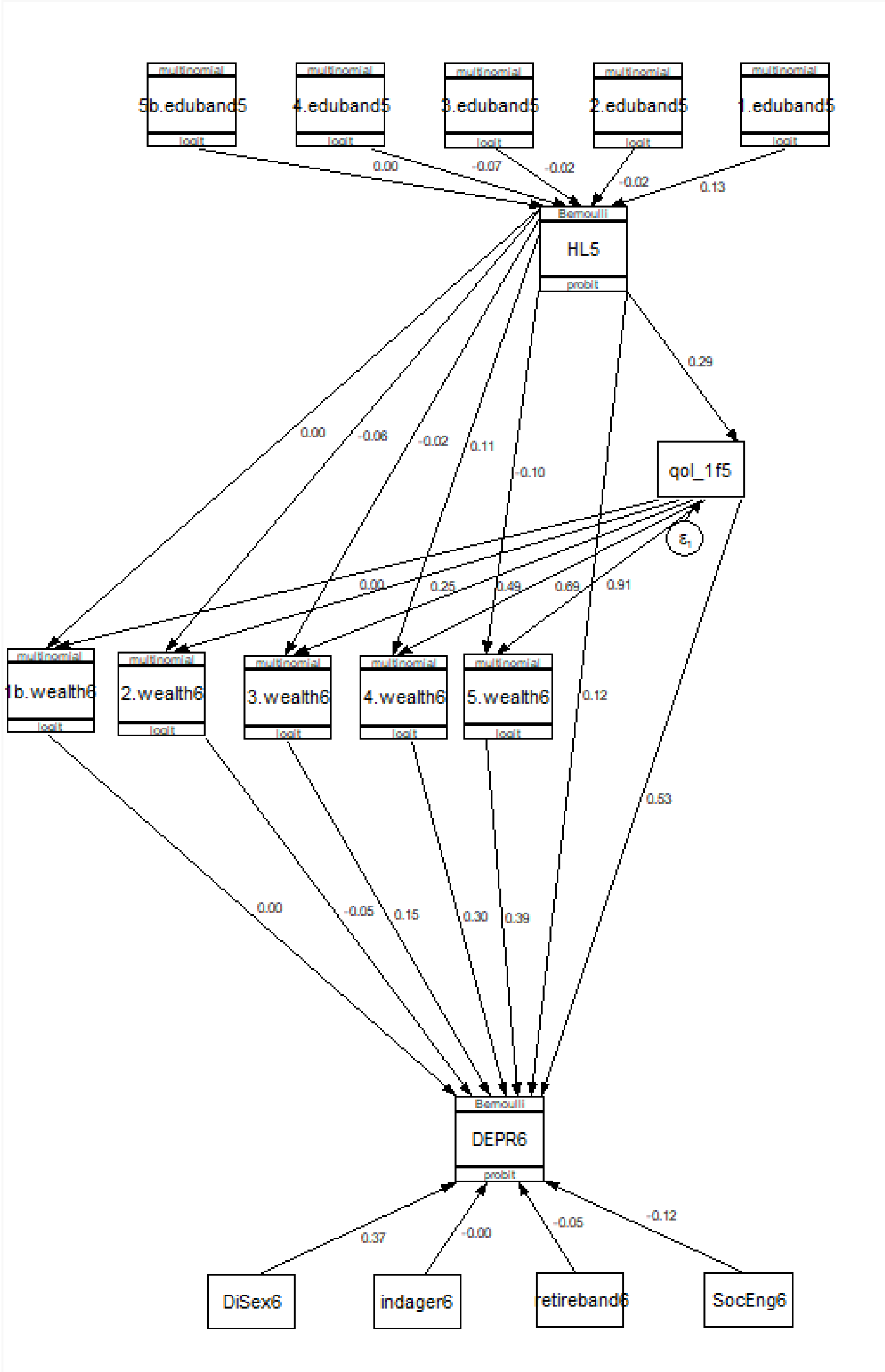
Figure 6.13.



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1.eduband5
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Figure 6.14.

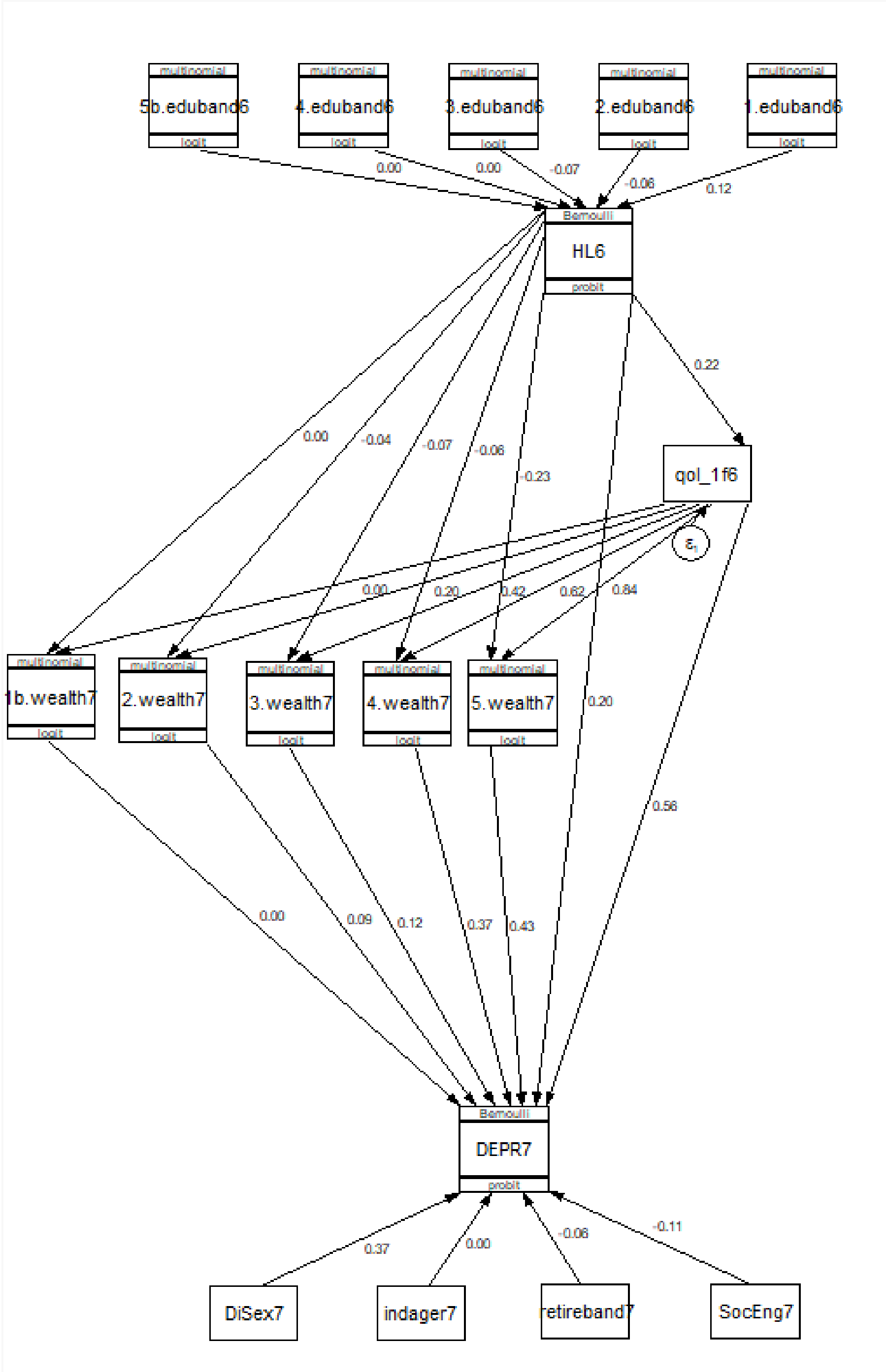
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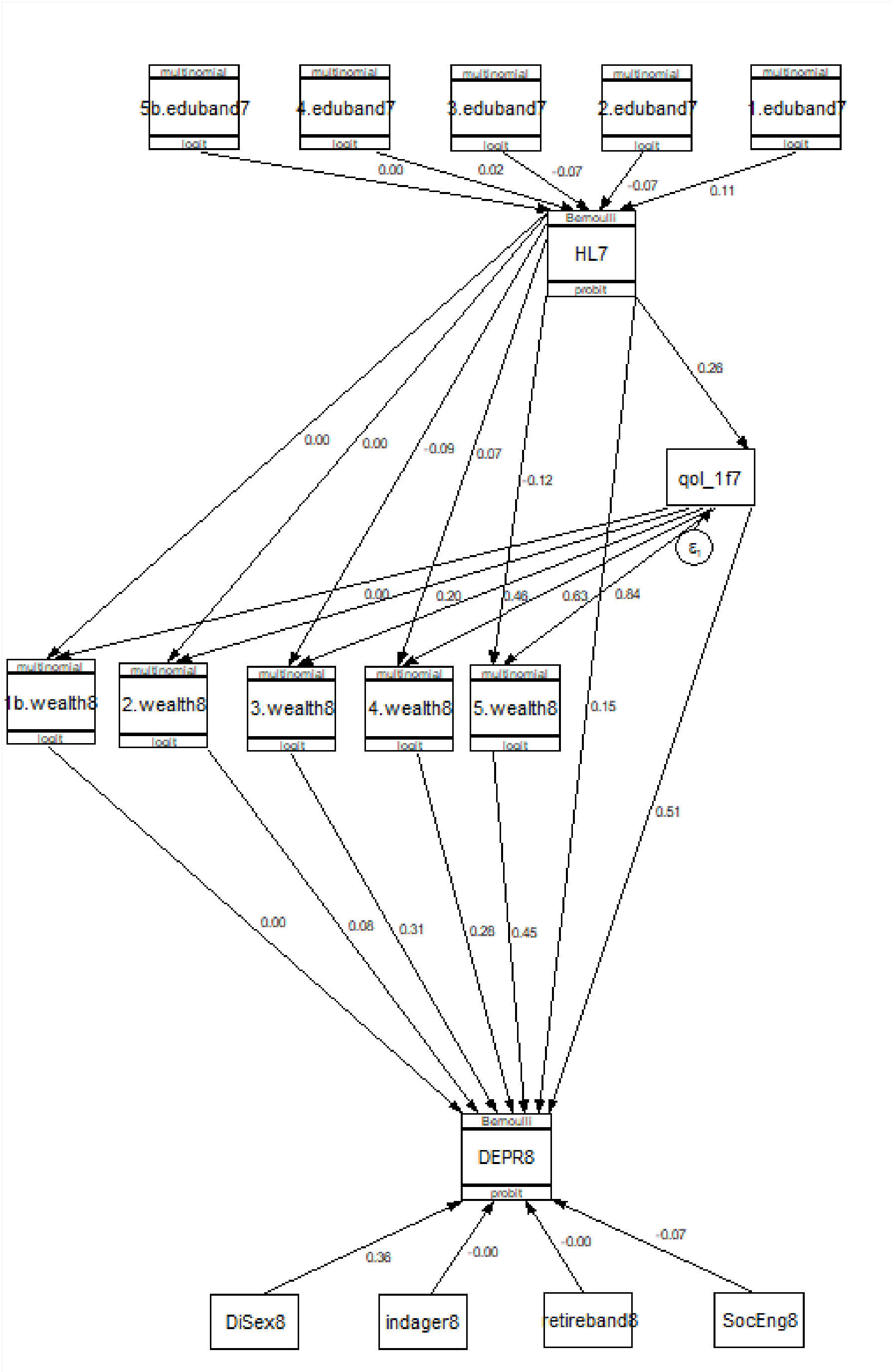
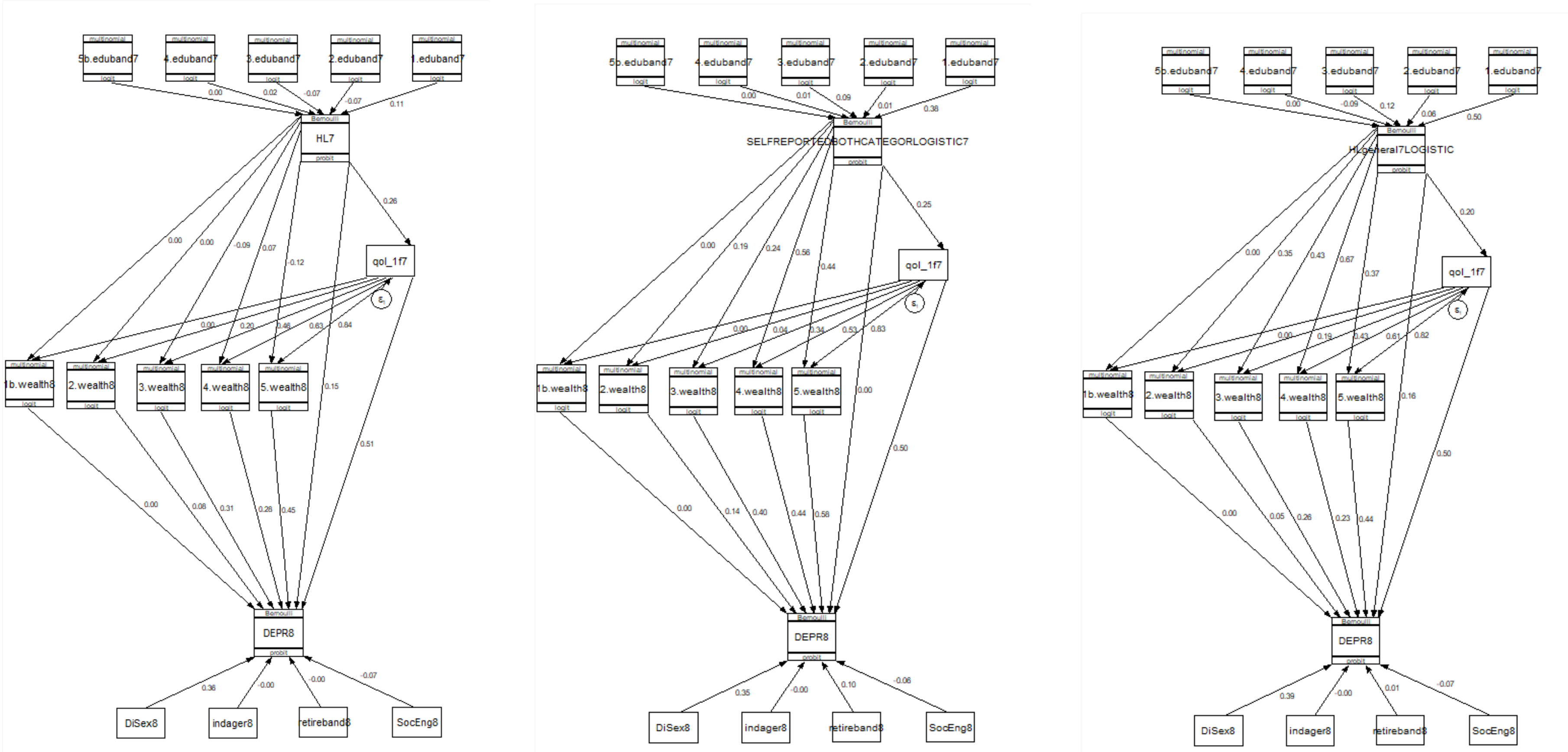
Figure 6.15.



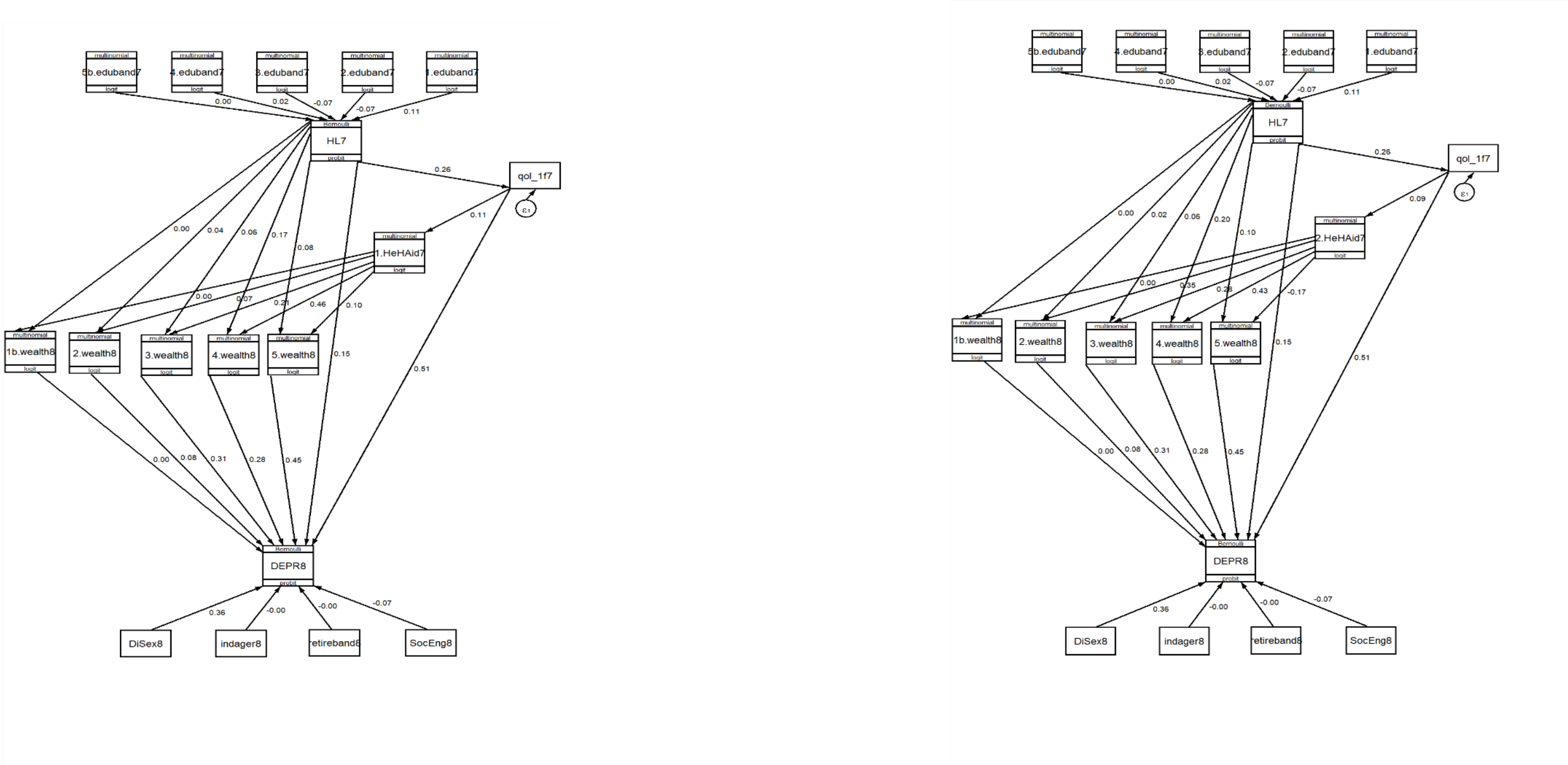
Supplementary Figure 6.9-15. Factor scoring coefficients (Standardized beta weights) of the generalised structural equation model representing the dynamic relationship between hearing loss, quality of life, socioeconomic position and depression in 8 Waves of English Longitudinal Study of Ageing (ELSA)

Figure 6.16.



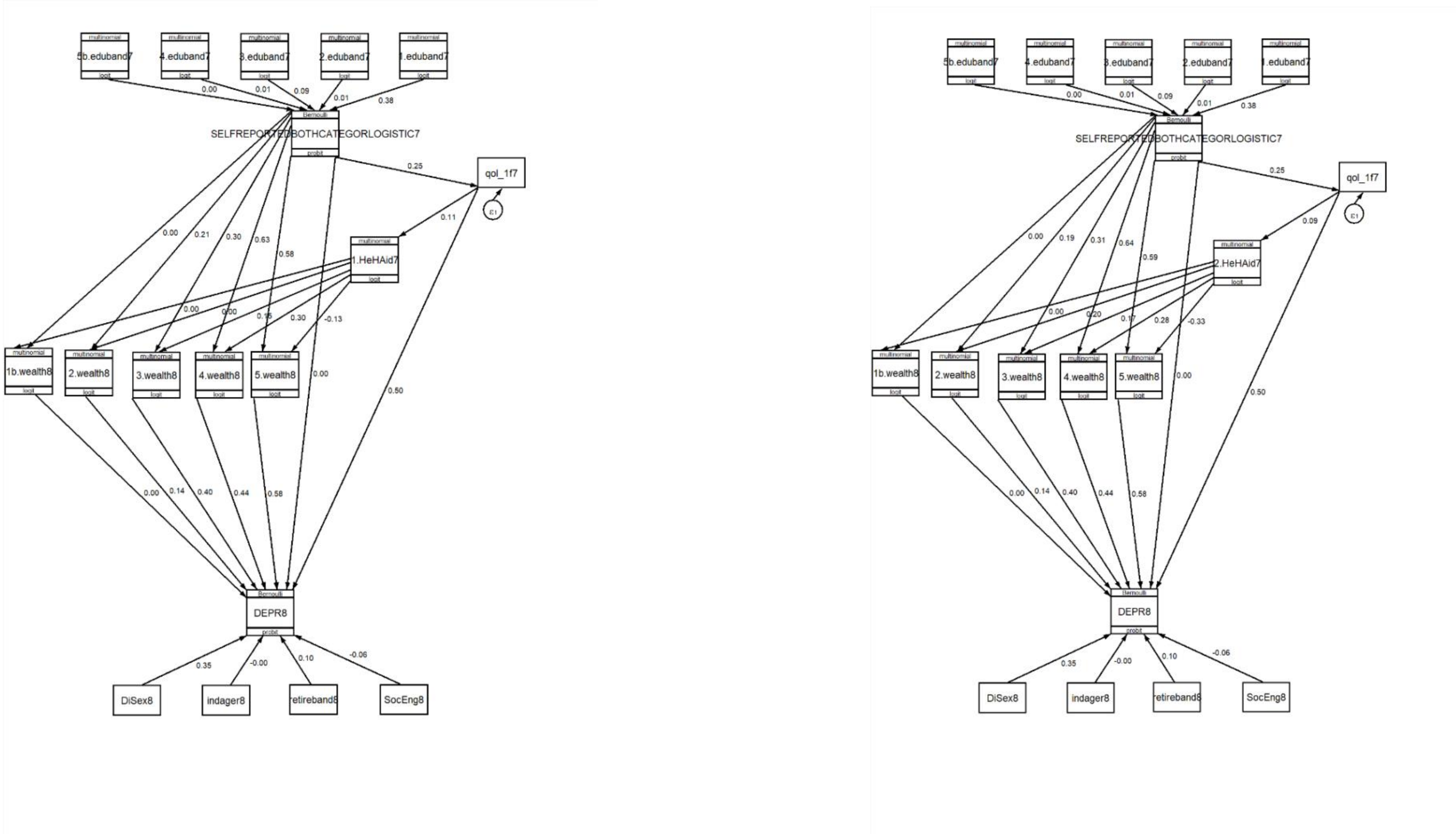
Supplementary Figure 6.16. Factor scoring coefficients (Standardized beta weights) of the structural equation model representing the dynamic relationship between hearing loss, quality of life, socioeconomic position and depression according to different HL measures in 7th Wave of English Longitudinal Study of Ageing (ELSA)

Figure 6.17.



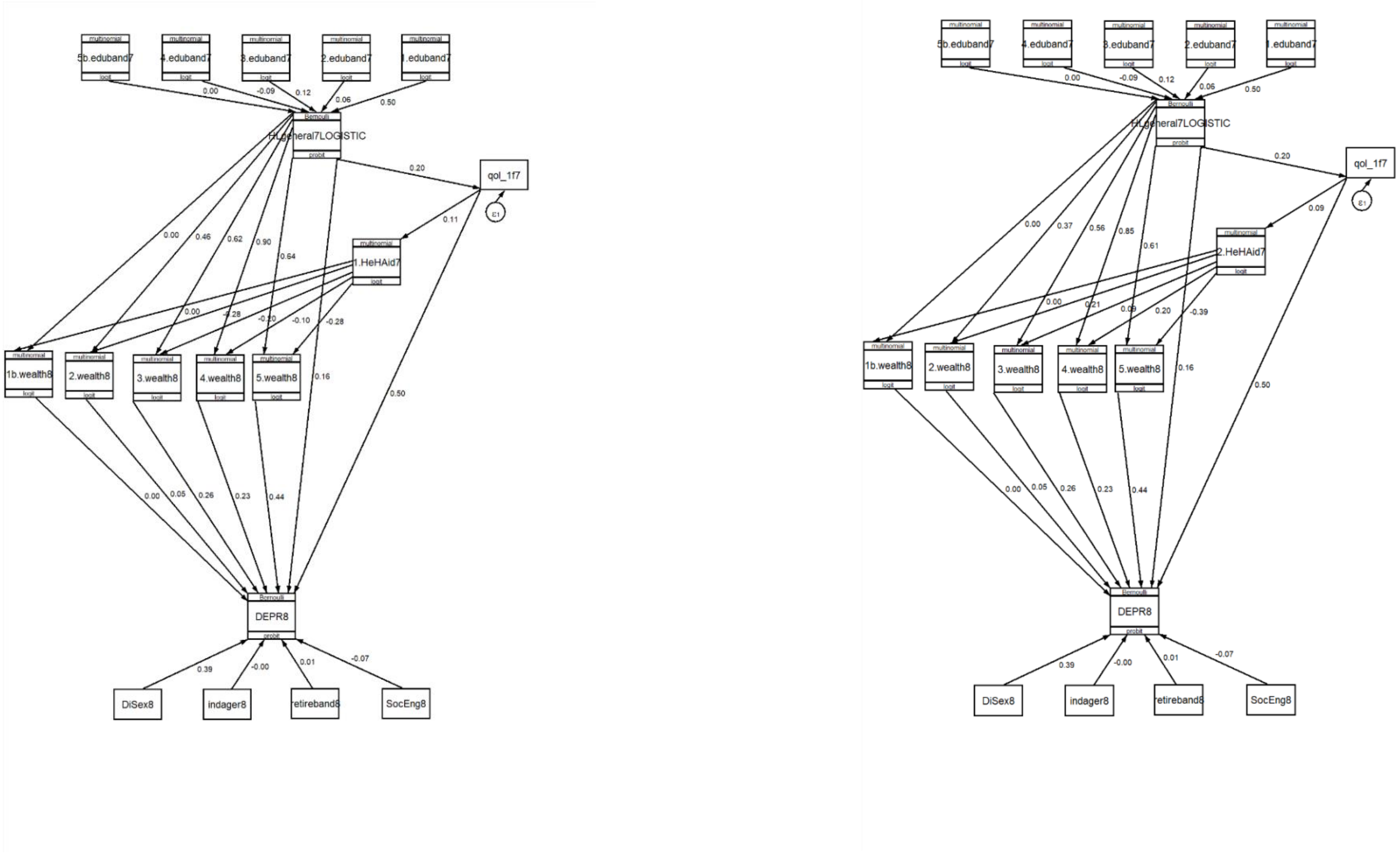
Supplementary Figure 6.17. Factor scoring coefficients (Standardized beta weights) of the structural equation model representing the dynamic relationship between self-reported hearing loss, quality of life, socioeconomic position and depression, moderated by hearing aid use (a. most of the time, b. some of the time) in the 7th Wave of English Longitudinal Study of Ageing (ELSA)

Figure 6.18.



Supplementary Figure 6.18. Factor scoring coefficients (Standardized beta weights) of the structural equation model representing the dynamic relationship between improved self-reported hearing loss, quality of life, socioeconomic position and depression, moderated by hearing aid use (a. most of the time, b. some of the time) in the 7th Wave of English Longitudinal Study of Ageing (ELSA)

Figure 6.19.



Supplementary Figure 6.19. Factor scoring coefficients (Standardized beta weights) of the structural equation model representing the dynamic relationship between objectively measured hearing loss, quality of life, socioeconomic position and depression, moderated by hearing aid use (a. most of the time, b. some of the time) in the 7th Wave of English Longitudinal Study of Ageing (ELSA).

Chapter 7

General Discussion of the Thesis

7.1. Overall summary

This thesis aimed to contribute to the growing area of research in hearing health inequalities by addressing the consequences of socioeconomic inequality regarding hearing loss (HL) in older adults in England. This chapter concludes the thesis by providing a general discussion. It aims to draw together the key findings from the five studies into a coherent synthesis and discuss its overall strengths and limitations. In addition, the implications for research, health policy and practice are presented, along with proposed directions for future work.

The thesis aimed to:

a) **Examine the socioeconomic factors that are related to the development of HL in older adults in England**.

This aim was addressed initially by an interpretive synthesis of the existing international literature in the field of investigation that gave insight into the socioeconomic disparities in hearing health (**Chapter 2**). As the existing studies in the UK were limited, the review had two aims: to provide an interpretive synthesis of the existing international literature in the field of investigation, and to formulate a conceptual model for the emerging research field of hearing health inequalities in order to depict the specific mechanisms for hearing health and their evolution over time (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., & Panagioti M., 2020b).

The review was followed by the cross-sectional examination of the relationship several socioeconomic indicators and major modifiable lifestyle factors have with objectively measured HL in older adults in England (**Chapter 3**). The study was the first in the field of audiology that examined four different socioeconomic position (SEP) indicators of HL (education, occupation, income and wealth) instead of using a proxy measure to reflect the total SEP; therefore, it captured most of the variation in socioeconomic stratification regarding objectively measured HL in older adults. Furthermore, it was the first study to focus on modifiable lifestyle factors (such as high body mass index, physical inactivity, tobacco consumption and alcohol intake above the low-risk-level guidelines) associated with HL among older adults in England. The study introduced to the literature the term '*lifestyle-related HL'*, where lifestyle refers to social practices and ways of living adopted by individuals that reflect personal, group and socioeconomic identities (Gochman, 2013), in contrast to the non-inclusive term '*age-related HL*'.

A spatial dimension was subsequently added to the evidence for the association of socioeconomic and lifestyle determinants of HL among samples in **Chapter 4**. The regional patterns and trends of HL in England in 2002–2017 were examined through a representative longitudinal prospective cohort study of the English population aged 50 and over. The study was the first that investigated geographical patterns and trends of HL in older adults and among adults in general. In addition, the study revealed a North–South divide in hearing health inequalities in England, which was previously unknown (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti M., 2020c).

b) **Explore the socioeconomic risks for access to hearing health services and hearing aid use among older adults in England**.

This aim was addressed in **Chapter 5**, which explored the hearing pathways of 9,666 participants from the seventh wave of the English Longitudinal Study of Ageing (ELSA). The study provided the largest and most accurate evaluation of the discordance between objective and self-reported measures of hearing, including difficulties in background noise, to date. In addition, the study examined the predictors of the potential discordances among these measures across different population subgroups of a large and nationally representative sample of people aged 50 and older in England. It was the first study to address the role of lifestyle factors that may affect the agreement rate between self-reported and objective hearing measures, which had not been previously examined in the literature (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., & Panagioti M., 2020a).

c) **Address the relationship between HL and depression in later life across different socioeconomic groups in older adults in England.**

This aim was addressed in **Chapter 6**, which examined the longitudinal relationship between HL and depressive symptoms in older adults. The study assessed the causal psychosocial pathways (SEP and quality of life) between HL and depression in later life using a novel structural equation modelling (SEM) approach (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti M., 2020d). The study examined the psychosocial mechanisms that can help to explain the relationship between HL and depression in older adults, which was previously unknown despite over 40 years of research in this field. HL affected the different wealth groups disproportionally, mediated by the quality of life of individuals. SEP moderated the effect of HL on depression, determining the magnitude of their association, which was higher in the lowest wealth quintiles. The study, therefore, suggested a graded relationship between HL and depression according to SEP, with those in the lowest SEP having a higher risk for depression compared to those in the highest SEP.

d) **Examine whether hearing aid usage alleviates the depressive symptoms associated with HL in older adults in England**.

This aim was addressed in **Chapter 6**, which investigated whether the use of hearing aids was associated with a reduced risk of depression among older adults with HL. The study was novel in that it was the first to examine the above research question under a socioeconomic perspective (Tsimpida et *al.*, 2020d). The findings showed that aural rehabilitation in the form of hearing aids was associated with a lower risk of depressive symptoms related to HL. Those in the lowest wealth quintiles experienced more considerable improvement in their psychosocial wellbeing after the use of hearing aids than those in the highest, and the improvement was slightly greater the more frequently the hearing aids were used. The graded benefit from hearing aids, according to SEP, was shown irrespective of the kind of the HL measure used (self-reported or objective).

7.2. Critical evaluation of the findings

This thesis resulted in several novel findings that offer crucial evidence for research, policy and practice in the fields of audiology and population health. First of all, the findings from Chapters 3 and 4 supported a new conceptualisation of HL, which argues that HL is not necessarily an inevitable accompaniment of ageing, but rather, a potentially preventable lifestyle disease (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti M., 2019). The decline in hearing as age progresses has established an association of HL with age; however, an association does not equal causation (Altman & Krzywinski, 2015). The findings from the study presented in Chapter 3 contributed to the identification of potentially modifiable factors for HL, showing that several socioeconomic and lifestyle factors were equally strongly associated with the likelihood of HL in older adults as age was. Although the study examined cross-sectional associations, this novel conceptualisation has been gaining popularity among prominent researchers in the field of audiology and HL research, who commented in their recent work that '*it may be pertinent to distinguish between age per se as a cause of hearing loss and all cumulative causes of hearing loss over the lifespan that affect hearing acuity in older age*' (Slade, Plack, & Nuttall, 2020).

The study in Chapter 4 was the first to provide evidence for the existence of sociospatial inequalities in HL, adding to our previous work that challenged the existing conceptualisation of HL as an inevitable accompaniment of growing old (Tsimpida, D., Kontopantelis, E., Ashcroft, D.M., Panagioti, 2019). The study revealed that between 2002 and 2017, there was a 15-year increasing trend in HL of 10.2% in the total HL prevalence in those that participated in the ELSA, which is a representative sample of the English population aged 50 and over (Tsimpida et *al.*, 2020c). This was an unanticipated finding that challenges the current thinking in HL research; a wide variation in HL prevalence was found between representative samples from different regions in England that had significantly similar age profiles, with the increase rate of HL ranging from 3.2% to 45% (Tsimpida et *al.*, 2020c). These findings in the time-series analyses were unexpected and provided surprising evidence that the increasing trend in HL prevalence was not age-related, as widely believed. In addition, there were three critical patterns in the findings concerning regional trends. The highest HL prevalence among samples with an equal mean age was observed in GORs with the highest prevalence of participants (a) in the most deprived (IMD) quintile (fifth), (b) in routine or manual occupations and (c) with the highest prevalence of alcohol misuse, irrespective of their SEP.

The findings further support the ideas of Scholes et al. (2018), who also took into account risk factors for cardiovascular disease (smoking, body mass index, physical inactivity, diabetes, hypertension and dyslipidaemia). However, Scholes et al. (2018) did not examine the role of some important lifestyle risk factors for HL, such as alcohol consumption, which has been linked to risk of HL (Zhan et al., 2011). Before our study, only Ecob et al. (2008) had attempted to explore whether alcohol intake is involved in the relationship between SEP and HL in the English older population; however, that study had important methodological flaws and did not provide sufficient answers. For example, the drinking measure used was the number of standard units of alcohol consumed in a typical day at the age of 45, coded to '*greater than or equal to seven drinks per day*' in contrast to '*all other*'. This kind of coding did not allow for a potential explanatory variable, such as alcohol consumption, to be examined satisfactorily in the analyses, and the effect of social class was attributed to noise exposure itself (Ecob et al., 2008).

Another study that examined a cohort of the European population had also been poorly designed and concluded that moderate alcohol consumption (coded as 'at least one alcoholic drink a week') was seen to have a protective effect for hearing (Fransen et al., 2008). One alcoholic drink was defined as one glass of wine, spirit or beer, while the effect of heavy drinking was not investigated. It can thus be suggested that the impact of alcohol intake on HL had previously not been explored satisfactorily in the literature, and this thesis provided rich insights in that topic.

The implications of the dynamic relationship between hearing health and socioeconomic resources have been demonstrated in Chapter 5; one of the issues that emerged from the findings is that several demographic, socioeconomic and lifestyle factors were associated with inaccuracy in the self-identification of objectively identified HL. This is the initial stage of help-seeking for hearing problems, in which one must initiate contact with the health system. These findings are significant as they show that those belonging in the most-at-risk groups for HL, as presented in Chapter 3 (Tsimpida *et al.*, 2019), were those at highest risk of not recognising their hearing had deteriorated; thus, they were less likely to seek help (Tsimpida *et al.*, 2020a). Further work is required to establish the above relationships as causal, though, as both studies were cross-sectional Tsimpida *et al.*, 2020a). Still, these findings suggest that the use of a screening measure for audiometric testing along with a self-report measure in epidemiological studies and clinical practice is essential for accurately identifying older people with HL, as nearly one-third of those with objectively identified HL >35 dB in 3.0 kHz by HearCheck™ Screener had not self-reported any hearing difficulty. The findings might mean millions of people in England are not seeing ear specialists or given hearing aids when their hearing has considerably deteriorated.

The above findings are critical for population health; the early identification of HL in primary care settings is crucial, as evidence consistently suggests that HL is associated with adverse mental health consequences (Cosh, Helmer, Delcourt, Robins, & Tully, 2019). There is abundant room for further progress in determining the relationship between HL and depression in older adults. The study in Chapter 6 offered novel psychosocial mechanisms that help to explain the prospective relationship between HL and depression in older adults, as there has been a lack of such mechanisms despite over 40 years of research in the field (Lawrence et al., 2020). Specifically, these mechanisms can help explain how HL affects different socioeconomic groups disproportionally; those with HL in the lowest wealth groups experience up to twice the relative risk of depression compared with those in the highest wealth quintile. Thus, the study adds to the existing body of literature by focusing on the role of SEP, which I suggest may explain the causal, temporal and graded relationship between HL and depression. These findings, therefore, support the conceptual premise of the HHI Model regarding the vicious cycle of SEP and HL (Tsimpida *et al.*, 2020a).

Another novel finding with major applied value is that the use of hearing aids was associated with reduced risk of depression among those with HL, and the lower the SEP was, the greater the risk reduction. The socioeconomic pattern I was first to identify regarding the benefit of hearing aids for psychosocial wellbeing among those with HL may also explain why no effect for hearing aid usage was found in the recent meta-analysis by Lawrence et al. (2020). No previous study had examined the role of hearing aids under a socioeconomic perspective, adjusting for control factors accordingly, so as to identify their effect heterogeneity according to SEP and firmly conclude, therefore, about the effectiveness of hearing aids regarding psychosocial wellbeing.

Providing evidence concerning the critical variables associated with HL is an important step in designing targeted services and interventions for individuals that face hearing health inequalities, ensuring the wellbeing of older populations. Sensory diseases are quite prevalent in the English older population – they are the first leading cause of morbidity among adults aged 70 and older, and the second leading cause among adults aged 50–69 years (Health Profile for England, 2018). The studies in Chapters 3 and 5 provided cross-sectional evidence of the relationships depicted in the HHI Model; of course, more research is needed to verify the causality of the relationships. Causal inference can instead be detected in the multiple time-series analyses in Chapter 4, as I examined repeated measurements of the same variables across several waves in the ELSA. In addition, the study in Chapter 6 examined the longitudinal relationships that can explain how hearing health inequalities in adulthood may affect wealth status in older adulthood, as depicted in the fourth panel of the HHI Model.

The recent evidence from longitudinal studies of ageing suggests that wealth is the most influential socioeconomic predictor of healthy ageing among English participants (Lu, Pikhart, & Sacker, 2019). Hence, as HL might impact on the wealth of the population, this thesis has shown that HL that is unacknowledged and untreated may negatively impact on the wellbeing of the population and, thus, healthy ageing (Kliegel, Iwarsson, Wahrendorf, Minicuci, & Aartsen, 2020). Furthermore, the findings from Chapter 6 show that untreated HL may have negative consequences not only for the individuals but also for society as a whole, as it can widen socioeconomic and concomitant mental health inequalities. This novel insight has not previously been described in the literature. Tackling hearing health inequalities before older adulthood could therefore act as a protective factor for the healthy ageing of the English population; moreover, it could also be beneficial to their wealth, benefitting the whole of English society. It can thus be proposed that the findings in all four empirical chapters in this thesis verify that the novel HHI Model, presented in Chapter 2, can work well as a helpful tool towards valuable research and policy action with the aim of helping in the prevention, identification and management of hearing health inequalities (Tsimpida *et al.*, 2020c).

7.3. Strengths and limitations of current research

The major strength of this research was that it provided new insights and unified ways of understanding the amorphous and complex phenomenon of inequalities in hearing health. The HHI Model has gone some way towards enhancing our understanding of the emerging research area of hearing health inequalities. The process of integrating various sources and synthesising the existing evidence into a conceptual form is particularly valuable to the study of health disparities (Diez, 2012). It is hoped it will have a profound impact on the identification of new questions that need to be answered and stimulate new ways of thinking about the old questions (Diez, 2012). Through its theoretical nature, the HHI Model will hopefully guide future research in the examination of the directionality of associations and conduct of longitudinal studies and intervention trials, to further explore many of the assertions shared in Chapter 2.

The ELSA is a rich source of information on the dynamics of the health, social, wellbeing and economic circumstances of the English population aged 50 and older.

It offered the opportunity to explore some of the associations presented in the HHI Model. Although Scholes et al. (2018) had also examined a cohort coming from the HSE, the low nurse-visit response rates in their study (37%) may have significantly affected the representativeness of their sample. For that reason, the researchers suggested their estimates should be considered as conservative, as an unknown number of people with deafness were not included in the study due to having communication difficulties with the interviewer.

Chapter 3 extended our knowledge by presenting the first examination of four separate SEP indicators with HL, along with the impact of major lifestyle risk factors. This was the first time that four separate associations were run to examine these relationships while avoiding potential multicollinearity within a latent variable of SEP. This analysis extended the simple manual/non-manual divide as a social descriptor of the participants' position that has been commonly used in the literature, mainly in the National Study of Hearing (Akeroyd, Browning, Davis, & Haggard, 2019). The occurrence of objective hearing data strengthened the accuracy of the findings, as they eliminated the different types of bias that occur in self-reporting hearing difficulties (Andrade & Lopez-Ortega, 2017).

This research will serve as a basis for future studies, as it was the first to challenge the term 'age-related HL'. The study offered some insights that were soon verified by the first study that investigated the geographical patterns and trends of HL in a representative cohort of older adults and adults in general, as presented in Chapter 4. A strength of the time-series analysis was that it was the first to provide the surprising evidence that although the prevalence of HL has increased over time, the trend is not age-related as widely believed. The study revealed wide variations in HL prevalence in representative samples from different regions in England with similar age profiles, with the increase rate of HL in 2002–2017 ranging between 3.2% and 45%.

An important strength of the study presented in Chapter 5 was that it examined data from a large and representative cohort of older adults and provided the largest and most accurate evaluation of the discordance between objective and self-reported measures of HL to date. Furthermore, it was the first study to address the role of lifestyle factors in affecting the agreement rate, which had not been previously examined in the literature (Choi et al., 2016). The findings also address some important conflicts in the literature, shedding light on the inconsistencies across studies regarding the relationship between HL and functional outcomes (Choi et al., 2016). Furthermore, they may reflect the attitudinal differences across different cultures and geographical variation in the acknowledgement of hearing difficulties.

Finally, the significance of the study presented in Chapter 6 was that it examined the relationship between HL and depression in older age. A major strength in the examination of the relationship between SEP and depression was the use of dynamic GSEMs as opposed to static 'baseline-predicts-outcome' methodologies, which have limitations when investigating variables that change over time with increasing age, such as HL and depression in later life. GSEMs combine the power and flexibility of both SEM and generalised linear models, offering the opportunity to evaluate causal relationships within a unified modelling framework and calculate both direct and indirect effects of multiple interacting factors simultaneously, reaching a high predictive ability (Gunzler, Chen, Wu, & Zhang, 2013; Lombardi, Santini, Marchetti, & Focardi, 2017). In addition, the confirmatory factor analysis (CFA) that generated a latent variable for quality of life in each wave led to strong predictive power in the theoretically causal associations between variables, depicting the impacts of HL on SEP.

However, the findings in this thesis must be interpreted in light of several limitations. As with the construction of the HHI Model, the reflexive interpretation is grounded in the findings of the current literature on the potential drivers and relationship between SEP and hearing health, which may have excluded several other currently unknown explanatory factors. The lines-of-argument synthesis in CIS builds on a general interpretation of the separate studies included in the synthesis, which are conceptual in-process and output (Dixon-Woods et al., 2006). During this process, the subjectivity of the researchers is intimately involved and reflexively accounted for, which may be controversial (Depraetere, Vandeviver, Keygnaert, & Beken, 2020). However, the CIS approach explicitly acknowledges the 'authorial voice' in the examination of a network of synthetic constructs (themes) and the relationships between them; furthermore, it places a great deal of emphasis on their interpretation by the researchers (Barnett-Page & Thomas, 2009). In addition, it is a common phenomenon for conceptual models to highlight one set of factors over another, which sets the bounds around a complex research topic and specifies which relationships will be espoused as fundamental in an attempt to offer a useful account of the literature (Diez, 2012).

The findings of the studies in Chapter 3 and 5 are limited due to the use of a cross-sectional design, which did not allow for causal or temporal relationships to be proposed. The unhealthy lifestyle behaviours could lead to HL in older people; however, it is also possible that older people adopt less healthy lifestyles after their HL has considerably deteriorated (Tsimpida *et al.*, 2019). The current investigation was limited as the only lifestyle factor that was consistently measured in all waves of the ELSA was alcohol consumption. Thus, the generalisability of these associations is subject to certain limitations. Unfortunately, the examination of these associations was beyond the scope of the study in Chapter 6; therefore, the impact of alcohol consumption on HL was not examined longitudinally but only added as a controlling factor in the models.

Another important limitation was that the ELSA dataset did not include information concerning occupational and social noise exposure, which has a damaging effect on hearing (Lutman & Spencer, 1990). Consequently, it was not possible to examine the association of noise exposure with smoking in the relationship between SEP and HL. A previous study found that smoking habit in workers exposed to occupational noise greatly influenced HL (Sung et al., 2013). In this study, however, we were able to examine the association between manual occupations and HL, as well as its attenuation by modifiable determinants such as smoking habit, which has higher prevalence among those with routine and manual occupations in England (Health Profile for England, 2018).

Furthermore, due to the low geographic resolution of the variables that were available in the ELSA dataset, it was not possible to perform geographically weighted regression analyses in Chapter 4. A minimum of 30 input features was required (e.g. Lower Layer Super Output Areas [LSOAs] instead of nine GORs) to allow for the exploration of the relationships between the area's socioeconomic characteristics and HL prevalence.

Another limitation is that the ELSA study concentrates on individuals living in private households; thus, individuals living in institutions such as residential and nursing homes are not included in the samples (Marmot, Banks, Blundell, Lessof, & Nazroo, 2003).

Unfortunately, the ELSA dataset did not include information regarding the onset and type of HL or about Deaf signing participants. This is an important limitation, as Deaf British Sign Language users face significant barriers in their access to health services. Furthermore, they have reduced physical and mental health compared to the general population (Shields, Rogers, Young, Dedotsi, & Davies, 2020).

The comparison between the self-reported measure and the results from the HearCheck™ Screener (Chapter 5) may contain information bias, as the screening tool identified only those with HL >35dB HL at 3.0 kHz in the better-hearing ear, while the self-reported questions did not specify that criterion. In addition, the screening results should be cautiously interpreted, as they simply provide an indication of the likelihood of a patient benefitting from hearing aids and should not be used as an audiometric assessment.

Lastly, the CES–D scale used in Chapter 6 does not measure the duration of depressive symptoms; therefore, the DSM criteria for major or minor depression could not be applied to the data. Regardless, predicting the presence of clinically elevated depressive symptoms over time, as I did in that study, refers less directly to symptom severity (Cosh et al., 2019).

7.4. Implications for health policy and practice

The findings from this thesis indicate that health policy strategies are needed to tackle the complex health and care needs of people with HL. In England, HL is a highly underdiagnosed and untreated chronic health condition and the leading cause of morbidity among older adults (Benova, Grundy, & Ploubidis, 2015; Health Profile for England, 2018). Generating evidence concerning the critical variables associated with HL is an important step in designing targeted services and interventions for individuals that face hearing health inequalities, particularly for those in the lowest SEP groups, where the burden of HL is greatest.

The findings suggest that the severity of HL in England could be reduced by governmental policies to mitigate socioeconomic disparities and public health interventions in middle-aged and older adults in England (Tsimpida *et al.*, 2019). The findings encourage HL preventive strategies, including interventions to promote healthier lifestyles and targeted interventions in areas where there are high levels of deprivation clustering (Tsimpida *et al.*,2020c).

The NICE guideline on HL recommended HL prevalence in people who under-present for HL as an important area for research, highlighting significant health benefits for those whose HL is identified at an early stage (NICE, 2018). The findings in Chapter 5 resulted in an important discovery: the self-identification of hearing difficulties may be a major non-financial barrier that can affect hearing aid uptake and use. Self-report measures should not be considered reliable measures of hearing acuity or influence judgements concerning referrals to secondary care. The existence of objective hearing measures is crucial, particularly for those belonging in high-risk groups that are most likely to remain unrecognised, such as people who face socioeconomic inequalities and adopt an unhealthy lifestyle, as these factors may affect the initiation of help-seeking and, consequently, referral to ear specialists (Tsimpida *et al.*, 2020a). This discovery can explain why those in lower SEP less frequently use specialist health services despite financial support for the treatment and hearing aids being provided through the NHS in the UK. The above conclusion could have important implications for the hearing healthcare in the UK and globally, initiating health policy strategies for specific population groups aimed at early detection of hearing problems and the consequently increased hearing aid uptake and use (Tsimpida *et al.*, 2020a).

In August 2020, the UK National Screening Committee (NSC) initiated a national consultation on screening for HL in adults (NICE, 2020). It became apparent from the draft review that there is a lack of evidence in relation to the benefits of screening for HL, and there is insufficient evidence regarding a) the accuracy of screening tests in people who have not sought help for HL and b) whether clinical detection and management of HL are currently well-implemented in the UK. As was written in the draft review, of the studies included in the draft regarding the first question,

> *most had a risk of bias, mainly about patient selection and none were carried out in the UK. A larger volume of evidence from high-quality studies to establish the accuracy of screening tests in people who have not sought help for hearing loss are needed* (p. 28 of the draft).

Regarding the second question,

> *no studies were identified that explored the proportion of people seeking help for hearing-related problems and the subsequent proportions that were referred, diagnosed and treated or remained undiagnosed. No studies were identified about people's experiences of the hearing loss clinical pathway. No studies were identified that addressed the proportion of people with hearing loss which may remain undiagnosed* (p. 39 of the draft).

The draft review assessed the literature up to 20 January 2020; our study, which was published in JAMA Network Open on 27 August 2020 (Tsimpida *et al.*, 2020a), could therefore not have been included. However, the NSC asked for feedback during a consultation period (lasting until 26 October 2020) in which experts could provide feedback regarding whether significant studies had been missed. I took part in this consultation, sending my comments to inform the Screening Evidence team about our recently published study that provided some evidence regarding the above questions. Of course, a sufficient volume of evidence is needed to address such important questions for population health. However, our study has the realistic potential to inform hearing health policy in the UK, provide some helpful answers regarding the unmet needs of the population and offer insights for future investigation.

According to the Global Burden of Disease Study, HL is the third leading cause of years lived with disability in England (Vos et al., 2017), and accurate prevalence estimates are needed to inform the strategic planning of hearing health policy and health services. To date, the prevalence of HL estimates in the UK is still based on the Medical Research Council National Hearing Study (Davis, 1995). In addition, NHS England has recently published the NHS Hearing Loss data tool (NHS England, 2019), which provides estimates of the number of people with HL between 2015 and 2035 to help organisations plan services on local authority (LA) and Clinical Commissioning Group (CCG) levels. However, the above tool is inappropriate for estimating the number of people with HL; the study in Chapter 4 showed that in a representative cohort, there were important differences across different regions in England, which contradicts the *Hearing in Adults* study that did not find differences across the only four British cities that it was based on (Cardiff, Glasgow, Nottingham and Southampton) (Davis, 1995).

The high-risk regions in England must be expansively recognised based on their spatial–temporal HL profiles (Kontopantelis et al., 2018). This kind of spatial evidence could provide commissioners with robust data based on actual needs, rather than inaccurate estimates of HL prevalence (NICE, 2018). Such prior knowledge could potentially have altered the North Staffordshire CCG's decision in 2015 to end the routine free provision of hearing aids for people with mild or moderate HL in their area of duty (NHS England, 2016; The Audiology Community, 2014), where, according to my analyses, the burden of HL is greatest. This thesis revealed, therefore, the potential risks from the paucity of robust epidemiological hearing data, which are needed now as much as ever to increase understanding of the impact of social, financial and personal health advantages on HL across the life course (Hill, Holton, & Regan, 2015; Tsimpida *et al.*, 2020b).

Finally, this thesis also has novel clinical implications, as it adds significantly to the understanding of the interrelationship between HL and depression. HL is on the rise (World Health Organisation, 2018), and the early detection of HL by primary care professionals in routine assessments could help prevent or delay the onset of depression, particularly in the lower wealth groups. Taking SEP into account is considered an essential element for depression prevention strategies in the general population (Freeman et al., 2016), and the findings from this thesis confirm that SEP is equally important for preventing depression in older people with HL.

7.5. Directions for future work

This research has thrown up many questions in need of further investigation. More research is needed to determine the relationships between socioeconomic factors and modifiable lifestyle behaviours, as well as the factors that potentially moderate these relationships. Future research in hearing health inequalities should also investigate the role of prolonged exposure to these modifiable lifestyle behaviours in the development of HL (Tsimpida *et al.*, 2019). It is also recommended that further research be undertaken in the longitudinal examination of a range of physical health, mental health and social care variables to help in developing a comprehensive understanding of the factors that are related to HL among older adults in England and globally.

A review of the ISO standard – which suggests that hearing is related to male sex, with hearing sensitivity declining more than twice as fast in men than in women – may be needed. The current ISO standard provides information on the statistical distribution of HL with regard to age and sex without consideration for socioeconomic stratification or any risk factors for detrimental effects on hearing that increase with age, caused by factors such as noise (International Organization for Standardization, 2017). To date, the prevalence of hearing impairment is still believed to be higher among adult men than women (Benova et al., 2015; Stevens et al., 2013). However, the findings in Chapter 3 showed that the decline in hearing acuity is similar in both sexes (Tsimpida *et al.*, 2019). The differences in modifiable lifestyle factors that were revealed in the stepwise regression models may finally explain why the male sex is often cited as a consistent risk factor for HL (Cruickshanks et al., 2015; Hoffman, Dobie, Losonczy, Themann, & Flamme, 2017; Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). Taking into consideration and exploring the modifiable determinants that are common in both males and females (such as body mass index, physical inactivity, tobacco use and alcohol misuse) will pave the way for interventions to improve the population's hearing health.

Another possible area of future research would be to investigate more localised patterns and determinants of place-to-place HL differences in England, using small area statistics (Lloyd, 2016). This would help to quantify potential 'area effects' on hearing health outcomes, allowing for generalisable results of spatial associations of HL rate. Moreover, investigating sociospatial hearing health inequalities could help to separate the role of proxies of areas (such as area deprivation) to individual-level determinants of HL (such as lifestyle behavioural choices), as the individual choices are rooted in the broader social and economic structural contexts (Marmot, 2020). Future research should also explore spatial–temporal diffusion patterns in the ELSA's international sister studies (Eunjee & Peifeng, 2018) so that a global understanding of sociospatial inequalities in hearing health can be developed.

Depression and HL are major public health topics on the world health agenda, being the first and second leading causes of disability, respectively (Naghavi et al., 2017; Olusanya, Neumann, & Saunders, 2014). The association between them is widely reported. The evidence from Chapter 6 offered novel psychosocial mechanisms to explain the prospective relationship between HL and depression in older adults. The same study suggested that the use of hearing aids in older people in England reduces the prevalence of depressive symptoms associated with HL (Tsimpida *et al.*, 2020c). The Cochrane review of Ferguson et al. (2017) concluded that although hearing aids have a large beneficial effect on hearing-related quality of life, the quality of evidence for the adverse effects is very low. Thus, future research might explore whether these promising findings from the ELSA are reproducible through further analyses in cohort international sister studies in order to increase the overall quality of the evidence (Schünemann, Brożek, Guyatt, & Oxman, 2018).

The Deaf signing population faces a range of unmet health and social care needs (Shields et al., 2020; Young, 2014) that cannot be examined using the ELSA, as that cohort study did not include any information regarding the culturally Deaf population. A domain for future work could be the exploration of health outcomes of this population using de-identified patient data through the Clinical Practice Research Datalink (CPRD). The CPRD, which encompasses over 11.3 million patients from 674 practices in the UK (Herrett et al., 2015), has the realistic potential to offer important information regarding the health state of the Deaf signing population through data included in the General Practice (GP) primary care datasets.

Future research should examine common underlying factors among participants of similar SEP; this could lead to preventive psychological interventions, along with online and web-based interventions (Cosh et al., 2019), for older adults with comorbid HL and depression. Large scale RCTs are also needed to guide clinical practice and investigate effective treatments for HL and depression (for example, whether treatment for HL with hearing aids could be combined with psychosocial or medication treatment for depression) (Brewster et al., 2018). As acquired HL in adults is a non-communicable disease with low duration and slow progression (World Health Organization, 2015), having the characteristics of a chronic physical condition, it is worth examining whether collaborative care could be useful in people with HL and comorbid depression (Panagioti et al., 2016). The view of HL being a trigger for depression is worth examining and could offer answers for the population's mental health, as the opposite approach – screening for depression – has received much criticism and does not appear to be an effective strategy (Gilbody, Sheldon, & Wessely, 2006). Of course, randomised data will be needed first to support such an approach; however, it might be a fruitful area for future research initiatives.

The populations around the world are rapidly ageing (Beard & Bloom, 2015); it is crucial to push the limits of current knowledge around HL and mental health problems, as both are responsible for enormous public health costs, morbidity and mortality (Hsu et al., 2016; World Health Organization, 2020). A natural progression of this work is to acquire a global perspective across several countries through the ELSA's international sister studies (Eunjee & Peifeng, 2018) in order to provide a global and rigorous overview of the issue. Building the evidence base to that level could guide health policies globally to support increasing access to affordable and effective treatments, having important societal, clinical and policy implications.

7.6. Conclusions

Globally, there is a dramatic increase in HL cases; the numbers increased from 42 million people in 1985 to about 360 million in 2011 and over 466 million in 2019 (Olusanya et al., 2014). Tackling hearing health inequalities will have important implications not only for individuals but also for the whole of society, as the burden of HL affects economic growth and economic development. HL generates costs for society, such as higher welfare payments, healthcare expenditures and lost tax revenue. Characteristically, it is estimated that unaddressed HL costs the global economy 750 billion dollars annually (Ramsey, Svider, & Folbe, 2018). If this burden persists, it could potentially slow economic growth, with developing countries experiencing the most significant impact (Ramsey et al., 2018).

Tackling health inequalities is a national priority for the UK and an important part of the NHS Long Term Plan (NHS Long Term Plan, 2019). Interventions designed to reduce hearing health inequalities could be implemented across three levels, following the distinctions of Geronimus (Geronimus, 2000): a) ***mitigation***, b) ***preventing*** and c) ***undoing*** **inequalities**. First, ***mitigation*** refers to actions aimed to reduce the impact that social inequalities have on people's hearing health and social outcomes by recognising these barriers. For example, GP appointments will be more effective if the service provider is aware that the patient cannot read well or is not fully conversant with the language to seek help for hearing difficulties. The need for GP training in recognition of communication difficulties for those with hearing issues for which referral to audiological assessment is needed has been recently highlighted in the NICE quality standard for HL in adults (NICE, 2019). Thus, health service interventions that increase awareness among health professionals about the high prevalence of HL and the poor management of hearing difficulties among different populations or social groups are needed (Tsimpida *et al.*,2019).

Second, ***preventing*** refers to acknowledging that those who have limited access to hearing health-enhancing living and working conditions (e.g. those with low-quality housing, unhealthy dietary habits, unsafe working and living environments) are most at risk for poor hearing health. Several activities in primary prevention can be implemented to reduce the incidence of HL from preconception to adulthood, such as improved prenatal, perinatal or neonatal care, universal vaccination programmes and antibiotic stewardship practices. Additionally, secondary and tertiary prevention activities are needed and should be actively encouraged, such as prompt intervention, the fitting of hearing devices (hearing aids, cochlear implants, etc.), training in sign language and special or inclusive education (Olusanya et al., 2014). Thus, services and facilities are needed to prevent the negative health impact of the adverse social and economic circumstances that many people face. On that level, public health interventions should aim to improve awareness about HL and its preventability by early screening, engaging in healthy lifestyles and encouraging discussions with health providers. Furthermore, the design of self-management interventions for people with moderate or severe HL (particularly those with comorbid conditions) could help to prevent low-quality healthcare and patient safety incidents.

Lastly, ***undoing*** hearing health inequalities refers to the fact that there could be differential economic policies aimed at decreasing the wealth gap, thus also decreasing the hearing health gap. On this level, governmental policies to reduce socioeconomic and education inequalities are needed to improve hearing health in the most vulnerable groups. Such policies can make essential contributions to preventing further increases in hearing health inequalities (Lorenc, Petticrew, Welch, & Tugwell, 2013). Otherwise, any action not focused on the social determinants but only on hearing health improvement may further increase the existing hearing health inequalities of the seldom-heard sub-groups of the population (Lorenc et al., 2013).

Although reducing hearing health inequalities is a complex ambition, the life course approach in tacking hearing health inequalities can lead to the development of appropriate interventions and public health strategies, having significant implications for health policy and practice. Accepting the promotion and management of healthy hearing as a lifelong process is an essential step in addressing the burden of HL in targeted interventions during the life course, and not within an isolated biomedical model of care that focuses on the acquired HL among older adults as something that needs fixing. The consideration of the individual's entire health profile and the ongoing support of each person's adaptation and self-management will both ensure that a more substantial proportion of the population receives high quality, safe healthcare and maximise the opportunity for healthy ageing (Beard et al., 2016).

7.7. References

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