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Hearing Loss and Annual Earnings Over a 20-Year Period: The HUNT Cohort Study

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Objectives: The association between hearing loss and income has only been examined in cross-sectional studies. We aim to study annual increase in earnings over 20 years, comparing people with and without hearing loss.

Design: We used data from a population-based hearing study in Norway (The Trøndelag Health Study, 1996–1998), including 14,825 persons (46.2% men, mean age at baseline 30.6 years, age range 20 to 40 years). Hearing loss was defined as the pure-tone average threshold of 0.5 to 4 kHz in the better hearing ear ≥20 dB HL (n = 230). Annual earnings were assessed from 1997 to 2017. Longitudinal analyses were performed with linear mixed models adjusted for age, sex, and education.

Results: People without hearing loss at baseline (before age 40) had a greater annual increase in earnings over a 20-year follow-up period compared with people with hearing loss. For people with normal hearing, annual earnings over 20 years increased by 453 Euro (EUR) (95% confidence interval [CI] = 384 to 522) or 13.2% more per year than for people with hearing loss, adjusted for age and sex. The difference in annual earnings over 20 year was greater among women (462 EUR, 95% CI = 376 to 547) than men (424 EUR, 95% CI = 315 to 533), greater among younger than older adults, and greater among lower than higher educated persons. When including adjustment for education in the model, in addition to age and sex, the difference in annual earnings over 20 years between persons with and without hearing loss was reduced (337 EUR, 95% CI = 269 to 405).

Conclusions: The results from this large population-based study indicates that people with hearing loss experience lower long-term earnings growth compared with people with normal hearing. The findings highlight the need for increased interventions in the workplace for people with hearing loss.

Key words: Hearing loss, Income.

Abbreviations: CI = confidence interval; EUR = Euro; HUNT = The Trøndelag Health Study; SSB = Statistics Norway.

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IDEA

Inclusion, Diversity, Equity, Accessibility Article.

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INTRODUCTION

Hearing loss is one of the most common chronic health problems in the world today (Vos et al. 2016). The World Health Organization reports that throughout the world more than 430 million people experience disabling hearing loss (World Health Organization 2021). Among employed people in Norway, a prevalence of hearing loss of 5.8% has been shown (Jørgensen et al. 2022a, b).

Hearing loss has been associated with lower educational attainment (Idstad & Engdahl 2019), increased risk of work disability (Jørgensen et al. 2022a, b), and earlier retirement (Helviket al. 2012). However, relatively few studies have been performed to evaluate the association between hearing loss and income. A recent systematic review on the association between hearing loss and income (Mossman et al. 2023) states that the available literature consistently supports an association between income and adult-onset hearing loss but is limited entirely to cross-sectional studies, with the directionality remaining unknown. Hence, there is a need for a follow-up study.

This large population study from Norway aims to examine changes in annual earnings over twenty years for people with and without hearing loss, using a follow-up design with longitudinal measures of income. We also aim to assess whether the association between hearing loss and annual earnings depends on sex, age, or education.

MATERIALS AND METHODS

Participants

The Trøndelag Health Study (The HUNT Study) is performed in the Norwegian county of Trøndelag. It is a large ongoing population health study, consisting of four completed study waves conducted between 1984 and 2019 (HUNT1, 2, 3, and 4). The HUNT study includes information from surveys, medical examinations, and biological specimens.

The HUNT2 study wave (1996–1998) included audiometric measurements. This sample, called the HUNT2 Hearing study, was used for analyses in the present study. Altogether 17 of the 24 municipalities in the county provided participants for the HUNT2 Hearing study. A total of 50,560 individuals attended, giving a participation rate of 63% (Engdahl et al. 2020). Hereafter, "HUNT" will be used to refer to the HUNT2 Hearing study.

From the total HUNT population of 50,560 individuals, we excluded persons in the following order: persons not in the age range 20 to 40 years at baseline (N = 35,672), persons with missing audiometric data (N = 51), persons with missing data on education (N = 2), and persons whose income information was missing for every year throughout the follow-up period (1997–2017) (N = 10). We included persons in the age range

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20 to 40 years to avoid bias with regards to retirement during the follow-up period. The final study sample included 14,825 subjects.

Measurements

Exposure Variable: Hearing loss • The hearing study comprised pure-tone audiometry, otoscopy, and a questionnaire. Pure-tone air-conduction hearing threshold levels were determined in accordance with ISO 8253-1 (International Organization for Standardization 2010), with eight fixed test frequencies 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz, using an automatic procedure. Manual audiometry was offered to persons not able to follow the automatic procedure. Bone conduction thresholds were not measured, nor was masking used. Previous detailed description of the audiometry procedure is available (Engdahl et al. 2020). We created a dichotomous variable using the Global Burden of Disease definition of hearing loss and the average of the hearing thresholds recorded at frequencies 0.5, 1, 2, and 4 kHz in the best hearing ear, with any hearing loss (≥20 dB) considered exposed and normal hearing serving as the reference category. We also created a categorical variable with normal hearing (≥20 dB) as the reference group, mild hearing loss (20 to 34 dB), or disabling hearing loss (≥35 dB) as exposed.

Outcome Variable: Annual Earnings • Based on the personal identification number given to all Norwegian residents, data from the HUNT study were linked on an individual level with data from Statistics Norway (SSB), covering yearly information on income (or earnings) from 1993 to 2017. The SSB income variable includes the yearly sum of wages and private business income in Norwegian kroner. Sick leave wages and parental leave wages are also included in the variable. Some individuals had one or several years of zero registered income. Reasons for this include nonemployment, disability, being a stay-at-home parent, or in full-time education. The annual earnings were adjusted according to consumer price index inflated to the 2017 value and converted from Norwegian kroner to Euro (EUR) based on the exchange rate in 2017.

Covariates • We adjusted for age, sex, and education. We used data on education from SSB. Minimum age at inclusion was 20 years, which meant that not all the included participants had completed their education at baseline. We therefore used the highest obtained educational level at end of follow-up in 2017. Educational level was categorized in four groups: primary education, secondary education, university <4 years, university ≥4 years.

Statistical Analyses

We used STATA version 17.0 (“Stata Statistical Software: Release 17” 2021). Statistical significance was determined using 95% confidence intervals (CIs). We used linear mixed model analyses to assess the difference in earnings for people with hearing loss compared with normal hearing at baseline (before age 40). The change in the difference in annual earnings between the two groups was estimated with an interaction term between hearing loss and time: Hearing Loss × Time (years). We included three analysis models: a crude model (model A), one model where we adjusted for age and sex, and their interactions with time (Sex × Time, and Age × Time) (model B), and one where we adjusted for age, sex and education, and their interactions with time (Sex × Time, Age × Time, and Education × Time) (model C).

We included an initial analysis with observations from 1993 to 2017 treating time as a categorical variable and estimating interaction coefficients for each year with 2017 as reference. The years from 1993 to 1996 were included for indication of prior trends.

To present more parsimonious models (a simpler measurement model with a smaller number of parameters needed to explain the results), we restricted the models to 1997–2017 with time treated as linear in the interaction term. The more parsimonious model with a linear interaction term with time fitted the data well, both crude and when adjusting for covariates as evidenced by the visual inspection of the predicted values (Fig. 1). When we attempted to improve the model by adding a second-order polynomial (quadratic term) to the interaction with time, the fit did not improve (Likelihood-ratio test, p-value = 0.513), suggesting that a simpler linear interaction was sufficient. However, the overall annual trend in the data was nonlinear. To capture this nonlinearity in the time effect, we added a second-order polynomial term for time as a main effect. This significantly improved the model fit (Likelihood-ratio test against simpler model, p-value <0.0001). Therefore, while the interaction between time and other variables was best modeled linearly, the overall effect of time on the outcome was better captured with a nonlinear (quadratic) term.

Ethics

The Regional Committee for Medical and Health Research Ethics approved the study (23178 HUNT hearing). General Data Protection Regulation requirements were met, and a Data Protection Impact Assessment was conducted. Only participants who had given written informed consent were included in this study. All methods were conducted in accordance with the principles of the Declaration of Helsinki.

RESULTS

Descriptive Results

Characteristics of the Sample • The final sample included 14,825 persons (46.2 % men, mean age at baseline 30.6 years). Of the total sample, 230 participants had hearing loss at baseline (before age 40). Compared with the normal hearing group, the group with hearing loss was somewhat older (32.3 vs 30.6 years), had a higher proportion of males (54.8 % vs 46.0%), and somewhat lower annual income at baseline (23 342 EUR vs 25 555 EUR). People with normal hearing at baseline had a higher income at baseline, compared with people with hearing loss (Tables 1 and 2).

Results From the Mixed Model Analyses

Trends in Earnings • Figure 1A shows annual mean wage for people with and without hearing loss at baseline, measured before the age of 40, as well as yearly wage differences between the two study groups. Wages grew linearly initially with a gradual leveling off in both groups. People with normal hearing had a steeper curve of annual mean earnings over the 20-year follow-up period compared with people with hearing loss. The wage difference between the two groups increased linearly over

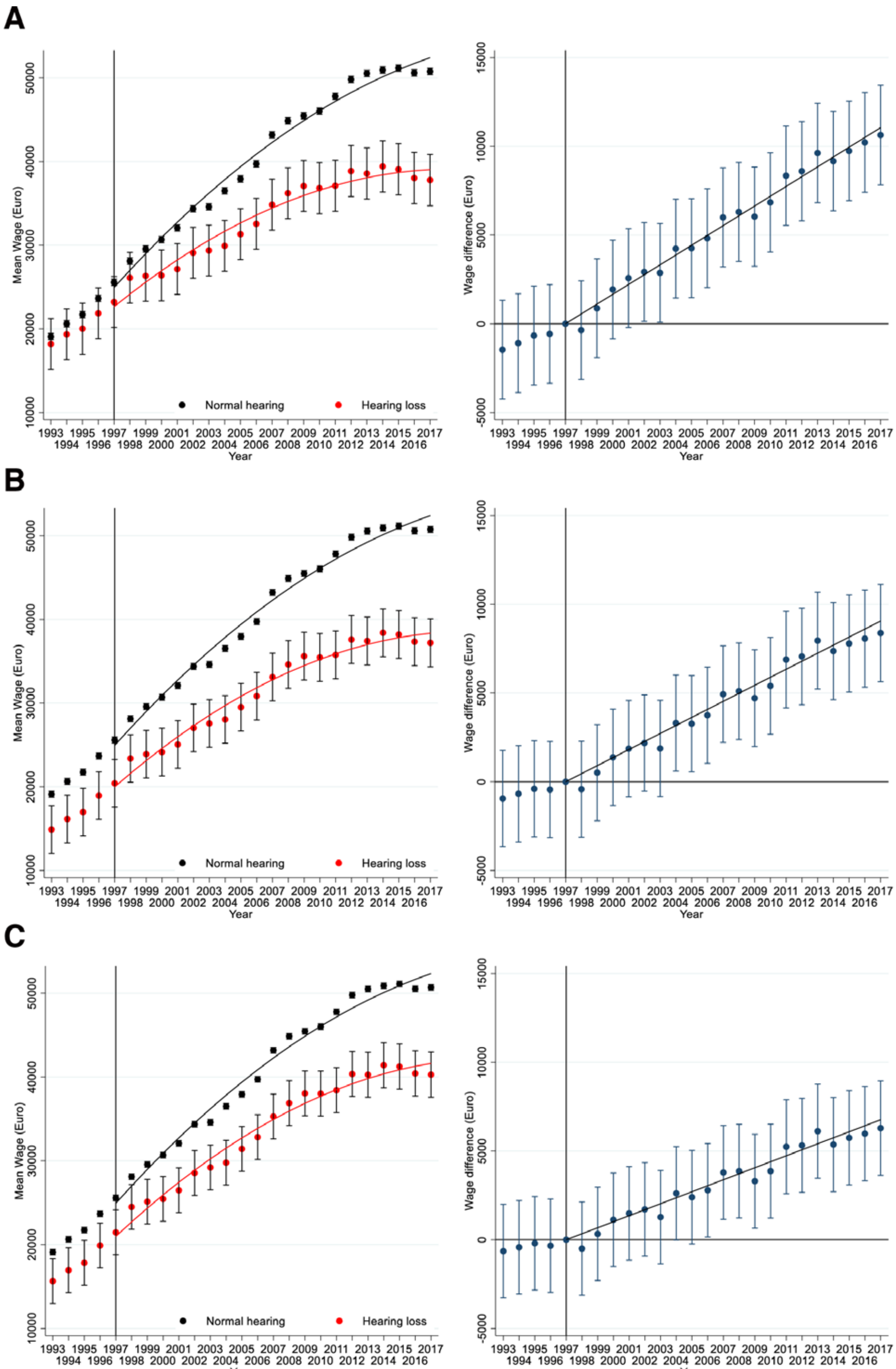

Fig. 1. Annual mean wage and yearly wage difference between study groups. Annual mean wage in Euro for both groups is shown to the left and annual wage difference between people with normal hearing and people with hearing loss is shown to the right. A, Crude numbers. B, The numbers are adjusted for age and sex. C, The numbers are adjusted for age, sex, and education. Solid lines represent results from the more parsimonious models with time fitted with a linear and a quadric term and a linear interaction term. In the right panel, we have equalized the earnings differentials at baseline.

the follow-up period. We observed no evidence of a pre-trend, with minimal changes noted before the baseline.

Mixed Linear Model Main Analysis • A more parsimonious model with a linear interaction term fitted the data well, both crude and when adjusting for covariates (Figs. 1A–C). We thus estimated annual change in income difference between people with and without hearing loss before age 40 with a linear interaction between hearing loss and time (Table 3). The model adjusted for age and sex (model B) showed that people with normal hearing had an income increase of 453 EUR (95% CI = 384 to 522) or 13.2% more per year than people with hearing loss. There was a greater effect among people with disabling hearing loss than for people with mild hearing loss (Table 3).

TABLE 1. Background data of the sample used for longitudinal analyses of differences in annual earnings over 20 yrs for people with and without hearing loss at baseline (age range 20 to 40 yrs), the HUNT2 study (1998), Norway

	Total Sample (N = 14,830)	Normal Hearing (N = 14,600)	Any Hearing Loss (N = 230)	Mild Hearing Loss (N = 176)	Disabling Hearing Loss (N = 54)
Mean hearing threshold at baseline (dBHL)	2.1	1.6	32.8	25.4	56.9
Mean age at baseline—mean (SD)	30.6 (5.6)	30.5 (5.6)	32.3 (5.3)	32.5 (5.5)	31.7 (5.0)
Mean annual income in EUR* at baseline (mean [SD])	25,461 (16,383)	25,496 (16,342)	23,240 (18,673)	24,857 (19,093)	17,969 (16,308)
Men, N (%)	6846 (46.2)	6720 (46.0)	126 (54.8)	95 (54.0)	31 (57.4)
Women, N (%)	7984 (53.8)	7880 (54.0)	104 (45.2)	81 (46.0)	23 (42.6)
Younger adults (<30 yr at baseline), N (%)	6956 (46.9)	6871 (47.1)	85 (37.0)	63 (35.8)	22 (40.7)
Older adults (>30 yr at baseline), N (%)	7874 (53.1)	7729 (52.9)	145 (63.0)	113 (64.2)	32 (59.3)
Low education, N (%)	9702 (65.4)	9518 (65.2)	184 (80.0)	137 (77.8)	47 (87.0)
High education, N (%)	5128 (34.6)	5082 (34.8)	46 (20.0)	39 (22.2)	7 (13.0)

**Income in Euro adjusted according to consumer price index inflated to 2017 values.*

Stratified Analyses • For men, the difference was 424 EUR (95% CI = 315 to 533) and for women 462 EUR (95% CI = 376 to 547). The model B difference in annual earnings was higher for younger adults (<30 years at baseline) than older adults (668 EUR [95% CI = 550 to 786] and 308 EUR [95% CI = 224 to 393], respectively), and higher in the group with lower (primary or secondary education) versus higher educational levels (427 EUR [95% CI = 357 to 497] and 83 EUR [95% CI = −90 to 256], respectively).

Model C presents the results from the mixed model analyses adjusted for education, as well as for age and sex. The difference in annual earnings growth between people with and without

TABLE 2. Wage difference at baseline in 1997 (in Euro, CPI-adjusted) between people with and without baseline hearing loss (before age 40), the HUNT2 study, Norway

	Model A			Model B			Model C		
	Wage Difference	95% CI		Wage Difference	95% CI		Wage Difference	95% CI	
Total sample	2153	–567	4874	4850	2328	7372	3850	6164	405
Men	2971	–907	6849	5531	1660	9403	4852	1210	8494
Women	3739	482	6996	4455	1203	7707	3054	185	5923
Younger adults (<30 yrs at baseline)	4558	344	8772	6103	2211	9995	5057	1479	8635
Older adults (≥30 yrs at baseline)	2096	–1489	5680	4205	871	7540	3479	439	6518
Higher education	–3611	–10,055	2833	2073	–3851	7996	2487	–3246	8220
Lower education	3607	790	6425	4973	2476	7470	4276	1862	6691

Model A crude model. Model B adjusted for age and sex and their interactions with time (Sex × Time, and Age × Time). Model C adjusted for age, sex, and education, and their interactions with time (Sex × Time, Age × Time, and Education × Time).
CI, confidence interval; CPI, consumer price index; Higher education, university <4 yrs and university ≥4 yrs; Lower education, primary education and secondary education.

TABLE 3. Mixed linear model results with income as dependent variable

	Model A			Model B			Model C		
Exposure Variable	Difference in Earnings	95% CI		Difference in Earnings	95% CI		Difference in Earnings	95% CI	
Any hearing loss									
Total sample	553	482	623	453	384	522	337	269	405
Men	619	508	730	424	315	533	323	216	430
Women	519	432	606	462	376	547	315	231	398
Younger adults (<30 yrs at baseline)	715	596	834	668	550	786	424	309	538
Older adults (≥30 yrs at baseline)	355	270	440	308	224	393	243	160	326
Higher education	217	41	393	83	–90	256	190	19	362
Lower education	465	395	535	427	357	497	371	302	441
Mild hearing loss	428	348	509	312	233	391	213	136	291
Disabling hearing loss	1008	863	1153	950	807	1092	772	633	912

Longitudinal analyses of differences in annual earnings growth (in Euro, CPI-adjusted) over 20 yrs (1997–2017) between people with and without hearing loss at baseline (age range 20–40 yrs), the HUNT2 study, Norway. Model A crude model. Model B adjusted for age and sex and their interactions with time (Sex × Time, and Age × Time). Model C adjusted for age, sex, and education, and their interactions with time (Sex × Time, Age × Time, and Education × Time).
CI, confidence interval; CPI, consumer price index; Higher education, university <4 yrs and university ≥4 yrs; Lower education, primary education and secondary education.

hearing loss measured at baseline was somewhat smaller after adjusting for education (Table 3).

Occupational noise exposure could be a confounder: certain lower paying jobs may cause hearing loss due to occupational exposure and have lower earning potentials over time. We therefore conducted a supplementary analysis (not tabulated) adjusting for occupational noise exposure, which showed only a minor effect on the result.

Table 4 shows the relative change in income over 20 years between people with and without hearing loss at baseline. The relative change in income was 1.10 higher for people with normal hearing (model B).

DISCUSSION

Main Findings

People with hearing loss at baseline (before age 40) had a smaller increase in annual earning over time compared with people with normal hearing. The difference in annual increase in earnings over 20 years was greater among women than men, greater among younger than older adults, and greater among lower than higher educated persons (not statistically significant for education). Adjusting for education reduced the difference between people with and without hearing loss.

Comparison of the Results With Other Studies

Our study showed that people with normal hearing had a greater annual increase in income over a 20-year follow-up period compared with people with hearing loss before age 40. Relatively few studies have been performed to evaluate hearing loss and income. A recent systematic review on the association between hearing loss and income (Mossman et al. 2023) states that the available literature consistently supports an association between income and adult-onset hearing loss but is limited entirely to cross-sectional studies (Jung & Bhattacharyya 2012; Cruickshanks et al. 2015; Emmett & Francis 2015; Scholes et al. 2017; Glenister & Simmons 2019), with the directionality remaining unknown. It could, for instance, be that low income leads to hearing loss, as low income to some extent reflects low-paid blue-collar jobs with more occupational noise exposure that affects hearing negatively. On the other hand, one might also believe that it is hearing loss that results in low income, as hearing loss may lead to lower levels of education or poorer opportunities in the labor market.

A cross-sectional study in the United Kingdom from 2018 found that the odds of hearing loss were close to twice as high for men in the lowest income tertile versus the highest tertile (odds ratio (OR) = 1.77, 95% CI = 1.15 to 2.74) (Scholes et al. 2017). Emmet and Francis (2015) found that individuals with hearing loss had a 1.5 times higher odds of reporting low income compared with those with normal hearing (OR = 1.58, 95% CI = 1.16 to 2.15) (Emmett & Francis 2015). In another community-based cohort study of U.S. Hispanic/Latino groups from 2015, Cruickshanks et al. (2015) performed audiometric testing and collected self-reported information on income. They included adjustment for education in their analyses. The study showed that those with the highest income level were significantly less likely to have hearing loss than people with the lowest income (OR = 0.56, 95% CI = 0.29 to 0.73) (Cruickshanks et al. 2015).

The mentioned studies investigated hearing loss in different income groups, rather than income within groups of hearing level. People with hearing loss could have a poorer income growth because they have had occupations that caused the presence of hearing loss. However, we found no apparent pre-trend among the study groups in the years leading up to baseline of our analysis (Fig. 1).

Interpretation

The annual earnings variable used in this paper includes the yearly sum of wages and private business income. Sick leave wages and parental leave wages are included in the variable. Some individuals had one or several years of zero registered earnings. Reasons for this include nonemployment, disability, being a stay-at-home parent, or in full-time education. Several reasons could explain the difference in annual income growth over time between the two groups in the present study. One may speculate that a reason could be a greater number of years outside of working life for hearing impaired people, for example due to working part time, nonemployment or years with disability benefits. The difference in earnings growth may also be related to educational differences, a person having a poorer chance of climbing the career ladder, or the occupation itself having less of a career ladder to climb. People with hearing loss could have lower paying jobs at baseline and therefore lower earning potentials and growth potentials over time. This theory is supported by our analyses of wage differences at baseline between persons with and without hearing loss, as well as the analyses of yearly income growth as a percent change.

The difference in annual increase in earnings, comparing people with and without hearing loss measured before age 40, was

TABLE 4. Relative change in income over 20 yrs (1997–2017) between people with and without hearing loss at baseline (before age 40), the HUNT2 study, Norway

	Model A			Model B			Model C		
	Relative Change	95% CI		Relative Change	95% CI		Relative Change	95% CI	
Total	1.23	1.15	1.32	1.10	1.02	1.19	1.06	0.99	1.15
Men	1.22	1.12	1.32	1.08	0.99	1.18	1.04	0.96	1.14
Women	1.19	1.04	1.37	1.11	0.97	1.30	1.06	0.95	1.22
Younger adults (<30 yrs at baseline)	1.19	1.01	1.45	1.09	0.91	1.35	1.00	0.85	1.20
Older adults (≥30 yrs at baseline)	1.15	1.08	1.23	1.09	1.01	1.18	1.06	1.00	1.15
Higher education	1.16	1.00	1.37	0.97	0.81	1.19	0.99	1.05	1.20
Lower education	1.20	1.12	1.30	1.15	1.08	1.23	1.12	0.83	1.22

Model A crude model. Model B adjusted for age and sex and their interactions with time (Sex × Time, and Age × Time). Model C adjusted for age, sex, and education, and their interactions with time (Sex × Time, Age × Time, and Education × Time).

CI, confidence interval; Higher education, university <4 yrs and university ≥4 yrs; Lower education, primary education and secondary education.

somewhat greater for women than for men. This may be related to a tendency of women to spend more time outside of working life than men. Women often take on a larger part of child-rearing responsibilities and it has previously been shown that there is a stronger association between hearing loss and receiving disability pension for women compared with men (Jørgensen et al. 2022a, b). There is often a higher proportion of women in occupations with high levels of social interaction, for instance in social work or among health workers. These are occupations in which hearing loss would give a negative impact and it may be part of the explanation of women having a higher risk of receiving disability pay compared with men. The sex difference was however small and disappeared after adjustment for education.

When it comes to age, younger adults with hearing loss have been found to have a higher risk of receiving disability pension compared with older adults with hearing loss (Jørgensen et al. 2022a, b). The present study shows that the difference in annual earnings was higher for younger adults than older adults.

It is possible to regard educational level as either a mediator or a confounder when studying hearing loss and income. It has been shown that people with hearing loss have a lower level of education compared with people with normal hearing (Idstad & Engdahl 2019). Higher education gives greater chances of higher earnings, in this case acting as a mediator between hearing loss and income. However, lower education may be a marker of lower socioeconomic position. Lower socioeconomic position affects the chance both of having a hearing loss and of having lower income and could therefore be a confounder of the association between hearing loss and income. In addition, low education also increases the chance of having a blue-collar occupation with noise exposure that affects hearing. When studying the effect of a specific variable in a statistical model, the variable should not be adjusted for if it acts as a mediator. However, if a variable is a confounder, it should be adjusted for (Schisterman et al. 2009). For this reason, we used two models of analysis; one where we adjusted for education and one in which we did not. When looking at the difference in change in earnings over time adjusted for education (as well as for sex and age), we found a somewhat smaller difference in income growth between people with and without hearing loss. As it is possible to view education as either a mediator or a confounder, it is likely that the "real" difference in income growth is found somewhere between the results of the two models of analysis.

Further studies are needed to fully explain the causes of the difference in increase in earnings between people with hearing loss and normal hearing. But it is apparent that hearing loss has implications when it comes to income and therefore socioeconomic position. Our findings highlight the need for increased workplace interventions for people with hearing loss, for example by enhancing office acoustics, adjusting the layout of offices and conference rooms, using assistive technology, and making available access to professional sign-language interpreters.

Strengths and Limitations of the Study

A large population-based design is a major strength of our study. It was performed in Trøndelag county, considered representative of Norway in terms of geography, industry, economy, income sources, age distribution, morbidity, and mortality (Krokstad et al. 2013), however, it does not include any large cities. Participation rates in the HUNT study and other health surveys are often lower among subgroups, such as lower socioeconomic groups (Harald et al. 2007) and subgroups with poorer physical or mental health.

Pure-tone audiometry, which is recognized as the gold standard for assessing hearing levels, was used to measure the participants' hearing. We had access to data on income based on information from SSB, providing accurate and objective income information. For the data points on income that were registered as 0, however, we did not have the exact reason for lack of income.

As hearing levels were measured at baseline it is possible that some of the participants in the control group developed a hearing loss during the follow-up period, which could cause an underestimation of the income results for this group and, thus, diminish the true effect size.

We did not have a way of clarifying whether the participants' hearing losses were prelingual or postlingual. A prelingual hearing loss could influence language development and there might be a difference between people with a prelingual hearing loss and people with a postlingual hearing loss in terms of their occupational trajectories.

CONCLUSION

The results of this large population-based follow-up study indicate that people with normal hearing have increased growth in earnings over time compared with people with hearing loss. The findings highlight the need for increased interventions in the workplace for people with hearing loss.

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