Better Hearing in Norway: A Comparison of Two HUNT Cohorts 20 Years Apart

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Objective: To obtain updated robust data on a age-specific prevalence of hearing loss in Norway and determine whether more recent birth cohorts have better hearing compared with earlier birth cohorts.

Design: Cross-sectional analyzes of Norwegian representative demographic and audiometric data from the Nord-Trøndelag Health Study (HUNT)—HUNT2 Hearing (1996–1998) and HUNT4 Hearing (2017–2019), with the following distribution: HUNT2 Hearing (N=50,277, 53% women, aged 20 to 101 years, mean = 50.1, standard deviation = 16.9); HUNT4 Hearing (N=28,339, 56% women, aged 19 to 100 years, mean = 53.2, standard deviation = 16.9). Pure-tone hearing thresholds were estimated using linear and quantile regressions with age and cohort as explanatory variables. Prevalences were estimated using logistic regression models for different severities of hearing loss averaged over 0.5, 1, 2, and 4 kHz in the better ear (BE PTA4). We also estimated prevalences at the population-level of Norway in 1997 and 2018.

Results: Disabling hearing loss (BE PTA4 ≥ 35 dB) was less prevalent in the more recent born cohort at all ages in both men and women ($p < 0.0001$), with the largest absolute decrease at age 75 in men and at age 85 in women. The age- and sex-adjusted prevalence of disabling hearing loss was 7.7% (95% confidence interval [CI] 7.5 to 7.9) and 5.3% (95% CI 5.0 to 5.5) in HUNT2 and HUNT4, respectively. Hearing thresholds were better in the more recent born cohorts at all frequencies for both men and women ($p < 0.0001$), with the largest improvement at high frequencies in more recent born 60- to 70-year old men (10 to 11 dB at 3 to 4 kHz), and at low frequencies among the oldest.

Conclusions: The age- and sex-specific prevalence of hearing impairment has decreased in Norway from 1996–1998 to 2017–2019.

Key words: Aging, Audiometry, Cohort effect, Hearing, Hearing loss, ISO 7029, Prevalence, Restricted cubic splines.

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INTRODUCTION

Hearing loss is associated with serious communication and psychosocial problems and high healthcare costs (Cunningham & Tucci 2017). About 5% of the adult population in high-income countries have a disabling hearing loss, and this percentage increases to almost 50% among men older than 74 years (Stevens et al. 2013). Sense organ diseases, among which hearing loss is the most common, were the leading cause of years lived with disability (YLD) for the elderly in 2015 (GBD 2015 Disease and Injury Incidence and Prevalence Collaborators 2016). This emphasizes the importance of hearing healthcare and the need for preventive measures to minimize the time that people spend with disability.

The world's population is aging rapidly and unless an action is taken, WHO estimates that the number of people with disabling hearing loss globally could rise from 466 million in 2018 to 630 million by 2030 and potentially to over 900 million in 2050 (World Health Organization 2019). While the increase may affect the cost and size of the hearing healthcare service, the estimates are uncertain and empirical evidence for trends in the age-specific prevalence of hearing loss are scarce. While most studies suggest improvements in hearing ability among more recent cohorts of older adults in industrialized countries (Hoffman et al. 2010; Zhan et al. 2010; Hoffman et al. 2017; Hoff et al. 2018), the trends for younger individuals show mixed results (Shargorodsky et al. 2010; Henderson et al. 2011; Muhr et al. 2017; Su et al. 2017; Hoffman et al. 2019).

Policymakers need prevalence data for future planning of health and social care provision, and updated normative data on hearing thresholds (HTs) is important for clinicians. We analyzed two large cross-sectional, nationally representative hearing surveys of Norwegian adults, one recent and the other performed 20 years ago, to obtain robust data on the age-specific prevalence of hearing loss as well as normative percentile values of HTs, and to investigate potential changes between birth cohorts.

MATERIAL AND METHODS

Study Sample

HUNT Hearing consists of two hearing loss studies, HUNT2 Hearing (1996–1998) and HUNT4 Hearing (2017–2019). Each study was part of a large general health-screening study for the entire adult population of Nord-Trøndelag County in Norway, the Nord-Trøndelag Health Study (HUNT2 and HUNT4, respectively).

In HUNT2 hearing, 17 of the 24 municipalities in the county participated in the hearing examination. Two municipalities did not accept the invitation, and the population of six municipalities were examined by the main HUNT2 before the hearing study started. The participation rate averaged 67% across 16 of the 17 municipalities, and 41% in Levanger where the population was invited to the hearing examination after the main HUNT 2 (Engdahl et al. 2005). Audiometric data were collected from 50,277 participants with written consent, giving a total participation rate of 61% (Fig. 1).

HUNT4 hearing took part in the six larger municipalities (Levanger, Stjørdal, Steinkjer, Verdal, Nærøy, and Namsos),

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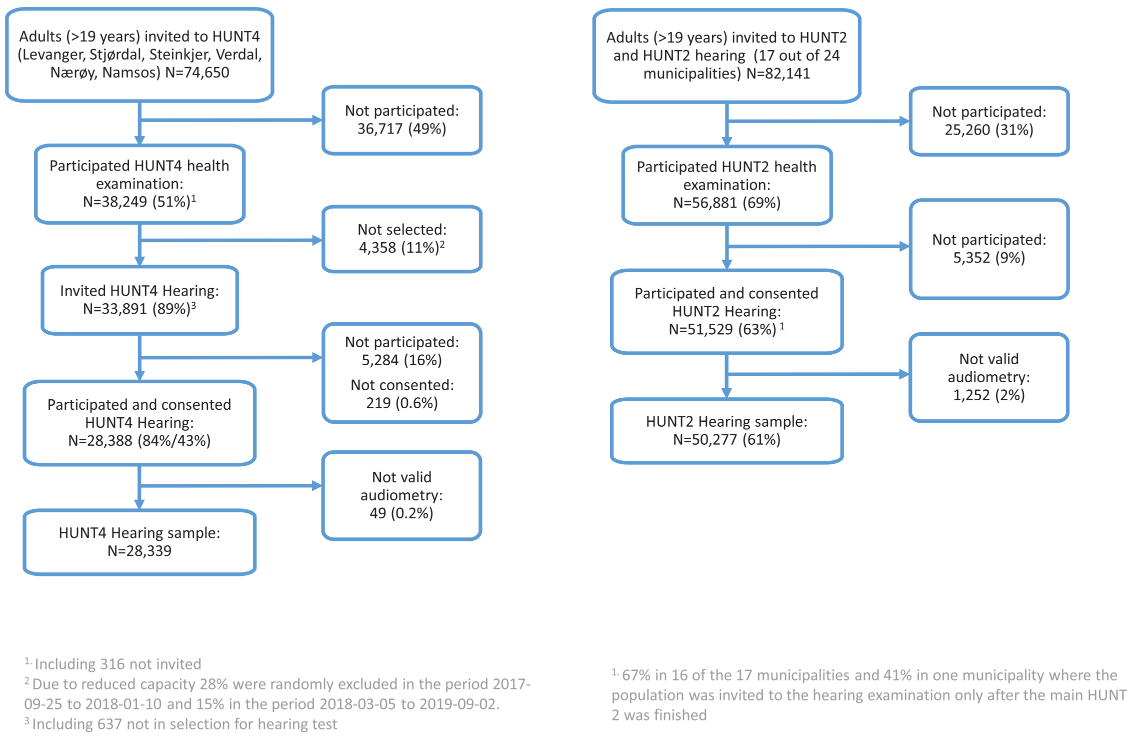

Fig. 1. Flowchart.

representing about two thirds of the county with a target population of 74,650 invited subjects (Fig. 1). The smaller municipalities were excluded because of practical and financial reasons. Drop-in was offered for all residents and a few participants belonging to the smaller municipalities were attending and included in the sample (n = 316). The participation rate in main HUNT4 was 51%, resulting in 38,249 adults >19 years. Among these, 33,891 participants (89 %) were invited to attend HUNT4 hearing. Initially, all participants of the health examination were invited to the hearing test. In times with reduced capacity due to logistic matters, some of the participants were randomly excluded. Likewise, in times with better capacity, participants were allowed to complete a hearing test even if they were not invited (n = 637). Out of the invited participants to HUNT4 hearing, 28,388 (84%) participated with consent, resulting in a total participation rate of 43%. Audiometric data were available for 28,339 participants with written consent.

Longitudinal audiometric data were available for 12,964 participants participating in both HUNT2 and HUNT4 hearing.

Measurements

In short, both hearing studies included a questionnaire, otoscopy, and pure-tone audiometry.

HUNT4 hearing was run at two sites in parallel with two teams moving three times to cover together six sites. Each team consisted of one trained audiologist and two trained assistants. A questionnaire on subjective hearing loss, hearing aid use, tinnitus, occupational and nonoccupational noise exposure, and other hearing-related risk factors was distributed to all participants and filled out in the waiting room before the hearing examination.

Otoscopy • The otoscopic examination was conducted using hand-held light otoscope. Results were classified as normal, completely occluded ear canal, perforated ear drum, ear drum cannot be assessed, or other significant pathology of the outer ear or ear drum. Ear wax was not removed. Only 227 participants (0.8%) were not examined by otoscopy; these participants were not examined because of inadequate time.

Audiometry • Air conduction pure-tone audiometry was attained in one of three semiportable, dismountable sound attenuation booths (IAC Moduline System, 102 mm thick, $1450 \times 1450 \times 2100\,mm^3$) at each site placed in a room specially selected to avoid background noise. The background noise was measured for six randomly selected site/booth combinations: tests were made at four of the six sites. First, all three booths were tested at one site and then we tested only one booth per site at three sites. The ambient sound levels were well within the criteria in ISO 8253-1:2010 (International Organization for Standardization 2010) for test tones in the 0.25- to 8-kHz range.

The testing was conducted with three interacoustics audiometers type AD629 per site with TDH-39P supra-aural audiometric earphones equipped with standard PN51 cushions and plastic head band, each linked to a personal computer using the program Diagnostic Suite. Audiometry was conducted using a self-administered protocol, permitting three subjects to be examined simultaneously. The data were automatically stored on the PC in the database OtoAccess, and the audiogram was distributed to the test person with a short text generated automatically with a self-made macro in Excel based on the hearing loss severity. The audiometers were recalibrated according to ISO 389-1 (International Organization for Standardization 2017a) in a 6-cc coupler (IEC 60318-3:2014) every time they were moved (three times per audiometer), and were checked by the operators every day before audiometry.

The hearing examination lasted for approximately 12 min per subject including about 10 min for the audiometric test. Masking was not used. Bone conduction thresholds were not measured. HT levels (HTLs) were determined in accordance with ISO 8253-1 (International Organization for Standardization 2010), with fixed frequencies at the eight test frequencies 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz, using an automatic procedure ("press the button as soon as you hear a sound") with the ascending method first on the left, then on the right ear. The sequence of frequencies followed the order stated in ISO 8253-1, that is, starting at 1 kHz and going up in frequency and then the lower frequencies. The 1 kHz tone was repeated at the end, and if 10 dB or more improvement or worsening in HTL was discernible, the ear was retested until agreement to 5 dB or less was obtained. The maximum threshold that could be recorded was the 100-dB hearing level (HL) for the frequencies of 0.5 to 6 kHz, and 90 dB HL at 0.25 and 8 kHz. The lower limit was set to −10 dB HL. Manual audiometry was offered to elderly or impaired subjects who were not able to follow the instructions for the automatic procedure. The same ascending procedure as with automatic audiometry was applied. More than eight missing on 16 frequencies tested was regarded a "not valid" test and the participants were excluded (n = 49). Participants with any, but less than eight, missing frequencies were excluded list wise on a frequency to frequency basis (n = 50).

HUNT2 hearing was also run with two teams in parallel. Each team consisted of one trained audiologist and one or, on busy days, two trained assistants. One team operated in the five towns and stayed 4–6 months in each town and the other team traveled in rural areas, staying from a few days to two months at each place. A similar questionnaire as in HUNT4 was distributed to all participants and filled out in the waiting room before the hearing examination. Otoscopy was only offered a subsample of 6415 participants in parts of two of the studied municipalities, Namsos and Levanger. Air conduction pure-tone audiometry was attained in one of five semiportable, dismountable sound attenuation booths (Tegnér T-booth, 50 mm thick, $950 \times 1050 \times 2100\,mm^3$), IAC Moduline System, 102 mm thick, $1450 \times 1450 \times 2100$ mm) at each site. The testing was obtained with five Interacoustics audiometers type AD25 per site with TDH-39P supra-aural audiometric earphones equipped with standard MX 41/AR cushions and metallic head band, each linked to a personal computer. Audiometry was conducted using a self-administered protocol, permitting five subjects to be examined simultaneously. The audiometers were re-calibrated (ISO 389-1) (International Organization for Standardization, 1994) every six months, and were checked by the operators every day before audiometry. The audiometry session lasted for approximately 10 min per subject. Masking was not used. Bone conduction thresholds were not measured but Weber's test (256 Hz) was included. HTLs were determined with the same procedure as in HUNT4. The maximum threshold that could be recorded was 120 dB HL for the frequencies of 0.5 to 6 kHz, and 110 dB HL at 0.25 and 100 dB at 8 kHz. The lower limit was set to −10 dB HL. Detailed information about HUNT2 hearing is found elsewhere (Borchgrevink et al. 2005; Engdahl et al. 2005).

Differences Between HUNT2 and HUNT4 • The audiometric equipment in HUNT2 hearing and HUNT4 hearing was slightly different. At HUNT4, each site consisted of three attenuation booths, while at HUNT2 up to five booths were operated at each site. The sound attenuation booths in HUNT4 were larger and with somewhat better sound isolation than the ones used in HUNT2, especially at 0.25 kHz. Because it is likely that the background noise was somewhat higher in HUNT2 at and below 0.25 kHz, HTs at 0.25 kHz were excluded from the present analyses. In HUNT4, the TDH-39P earphones were equipped with PN51 cushions and plastic head band, while in HUNT2, MX41/AR cushions and a metal head band were used. Because the maximum threshold levels that were recorded were slightly higher in HUNT2 than in HUNT4, the maximum limits of the HUNT2 threshold levels were set to match HUNT4 for the present analyses. In HUNT4, all participants underwent otoscopy, while in HUNT2, this was only offered a subsample. In HUNT4, participants were informed of the test result at the site, while in HUNT2, no information of the results was provided to the participants by the audiometry team.

Diagnoses of Hearing Loss • Hearing loss-related disease diagnoses were obtained from the Norwegian Patient Registry (NPR). NPR provides The International Classification of Diseases, Tenth Edition (ICD-10 codes) from the specialist health services. We obtained all diagnoses of hearing loss (H90), noise-induced hearing loss (H833), and age-related hearing loss (H911) from year 2017 of all participants in HUNT4 hearing individually and aggregated over age groups of the target population of the six municipalities participating in HUNT4 hearing.

Self-Reported Hearing Loss • Data on self-reported hearing loss were obtained from questionnaire data in main HUNT2 and HUNT4: "Do you suffer from any long-term illness or injury of a physical or psychological nature that impairs your functioning in your everyday life? (Long-term means at least one year.)." "If Yes: Would you describe your function impairment as mild, moderate or severe?" With hearing loss being one of five different long-term illnesses or injuries. Self-reported hearing loss was obtained for all participants invited to HUNT hearing that took part in main HUNT, also the ones without hearing measures.

Data on Self-Reported Risk Factors for Hearing Loss • Data on self-reported exposures were obtained from the hearing questionnaires in HUNT2 and HUNT4 with the following questions:

- Have you daily, or almost daily, been exposed to any of this at work? Followed by a list of 9 (HUNT2) or 12 (HUNT4) noise sources *(no; one or more of the listed sources*).
- By loud noise, we mean noise which makes it difficult to have a conversation. Have you regularly been exposed to loud noise at your present or previous work? (No, never; <5 hr weekly; 5 to 15 hr weekly, >15 hr weekly).
- Have you, more often than most people, been exposed to impulse noise (explosions, shooting etc.)? (yes; no; don't know).
- How many hours per week do you use headphones or earphones? (<1 hr; 1 to 2 hr; 2 to 6 hr; >6 hr).
- Have you had recurrent ear infections? (yes; no; do not know).

Definition of HTs in dB • According to ISO 8253-1 (International Organization for Standardization 2010) the HT level (HTL) is the HL expressed in dB HL based on a reference zero value in ISO 389. The audiometers in HUNT2 and HUNT4 were calibrated according to ISO 389 (International Organization for Standardization 2017a) with the well-known calibration error at 6 kHz for the TDH-39P earphones (Engdahl et al. 2005). To compensate for this error, and to compensate for any systematic differences in calibration between audiometry in HUNT2 and HUNT4, we defined HTs expressed in dB relative to the median HTLs of the population of otologically normal subjects aged 19 to 23 years. Otologically normal subjects were defined as all participants with normal otoscopy, no recurrent ear infections, and no history of exposure to noise (answering "no" to the three above questions on noise exposure) and with less than 6 hours of earphone use per week. Otologically normal subjects in HUNT2 were defined in the subsample that underwent otoscopy (Engdahl et al. 2005).

Statistical Analyses

All analyses were conducted using Stata version 15.0.

Median HTLs of Otologically Normal Subjects in dB HL • Median HTLs of otologically normal subjects were estimated by linear interpolation in the mid-distribution function by the iquantile command in Stata weighting on sex in order for males and females to be represented in equal numbers (International Organization for Standardization 2017a).

Mean HTs • We modeled HTs averaged over both ears at each specific hearing frequency from 0.5 to 8 kHz by linear regression with age and cohort as explanatory variables separately for men and women. Age was modeled as a restricted cubic spline with five knots with default knot locations (5, 27.5, 50, 72.5, and 95th percentiles), because this created a better model fit than simpler models with age as a linear variable for all hearing frequencies tested (Likelihood-ratio test, $p < 0.001$). The knot locations correspond to 24, 39, 51, 64, and 79 years. To model age-specific cohort changes, an interaction term between cohort and the age function was included in the models. To account for dependency in the data because of participants participating in both surveys, cluster-robust standard errors were estimated using the vce (cluster) option in Stata with subjects' id as the cluster variable (Rogers 1994). Age- and cohort-specific mean values were estimated from the interaction models with the margins command in Stata with standard errors estimated by the vce (unconditional) method that accounts for clustering.

Percentile Values of HTs • We used quantile regression to estimate changes at multiple points in the distribution of HTs rather than only at the mean, as well as to estimate normative percentile values at selected percentiles. Age- and cohort-specific values at 10, 25, 50, 75, and 90th percentiles were estimated from the interaction models with the margins command in Stata with standard errors estimated by the delta method (Oehlert 1992).

Prevalence Estimates of Hearing Loss • We assessed hearing loss using the better ear HT averaged over frequencies 0.5, 1, 2, and 4 kHz on each ear (BE PTA4). First, we estimated prevalences for different severities of hearing loss using the criteria for classification by the Global Burden of Disease (GBD) (Stevens et al. 2013; Wilson et al. 2017) in 15 dB intervals from good hearing (<20 dB) in the better ear, to total impairment (≥95 dB) in the better ear. Second, we estimated prevalences of disabling hearing loss based on two different definitions: ≥35 dB as suggested by GBD (Stevens et al. 2013; Wilson et al. 2017) and >40 dB as recommended by the WHO (World Health Organization 2018). To adjust for the difference in age structure between the two cohorts, the different levels of hearing loss severity were modeled by logistic regression with age and cohort as explanatory variables. Cluster-robust standard errors were estimated. Age was modeled as a restricted cubic spline with four knots, and an interaction term between cohort and the age function was included to model age-specific cohort effects. Prevalence and difference in prevalence were predicted from the logistic models with the margins command in Stata with standard errors estimated by the unconditional method.

Representative Population Estimates of the Hearing Loss Prevalence • Representative population estimates of the hearing loss prevalence among adults >19 years of age in Norway was obtained using weights reflecting the age- and sex-specific population in Norway in 1996 and 2017 obtained from Statistics Norway (Statistics Norway 2019).

Evaluation of Possible Selection Bias • The potential selection effect due to attrition from main HUNT to HUNT Hearing was assessed by imputing HT values for all participants that took part in main HUNT and was invited to HUNT Hearing, but did not attend the hearing investigation. First, regression models were estimated in the sample with complete information predicting HTs based on sex, age, and self-reported hearing status. Second, these models were used to impute HTs for those with missing values. We further compared the fraction of subjects with a hearing loss-related disease diagnose registered in NPR in the sample of participants in HUNT4 hearing with that of the total target population in four age groups, 19 to 44, 45 to 67, 68 to 79, and above 79 years.

All statistical tests were two-tailed and calculated at a 95% confidence interval ($p < 0.05$). The significance level was set to 0.001 to allow for multiple testing.

Ethics

The Regional Committees for Medical and Health Research Ethics approved the study (23178 HUNT hørsel). The study met all requirements in accordance with the General Data Protection Regulation, and a Data Protection Impact Assessment was conducted. Only participants with written consent were included in the study.

RESULTS

Descriptive Data

In HUNT2 hearing, the participants ranged in age from 20 to 101 years (median = 49.0, mean = 50.1, standard deviation = 16.9) with 53% women. In HUNT4 hearing, the participants ranged in age from 19 to 100 years (median = 54.0, mean = 53.2, standard deviation = 16.9) with 56% women. Figure 2 shows the age distribution of the two cohorts illustrating that the

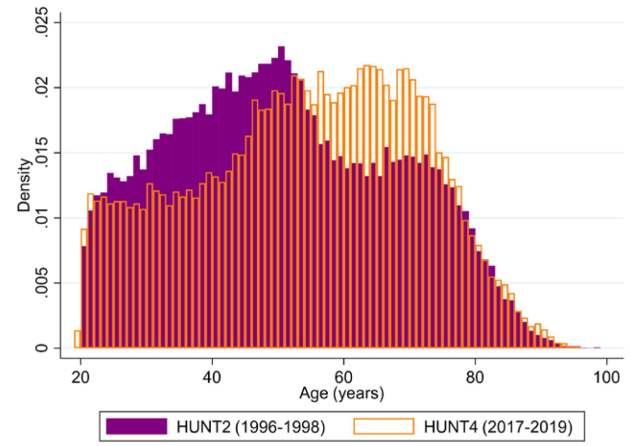

Fig. 2. Age distribution of the cohort in HUNT2 hearing (1996–1998) and HUNT4 hearing (2017–2019).

TABLE 1. Hearing Threshold Levels (dB HL) of Otologically Normal Subjects Aged 19 to 23 Served as Reference "Audiometric Zero" Values

Frequency (kHz)	0.5	1	2	3	4	6	8
HUNT2 (N = 101)	4.1	2.3	2.4	0.4	1.7	7.5	4.5
HUNT4 (N = 257)	2.7	1.0	0.4	0.3	0.9	6.6	4.3

participants in HUNT4 were slightly older. Compared with the general population of Nord-Trøndelag, young (<30 years) and elderly (>80 years) participants were under-represented.

HT Levels of Otologically Normal 19- to 23-Year-Old Subjects

The HTLs in dB HL of otologically normal 19- to 23-year-old participants in HUNT4 and HUNT2 that serve as reference values of "audiometric zero" are shown in Table 1. The reference values (HTLs in dB HL) in both cohorts were slightly higher than the reference for 0 dB HL at each frequency, with the largest discrepancies (up to 7.5 dB) at 6 and 8 kHz. The HTLs were similar in the two cohorts, differing by 2.0 dB or less at all frequencies with highest levels in HUNT2.

Mean HTs in dB

HTs were poorer in 1996 to 1998 than in 2017 to 2019 at all frequencies for both women and men ($p < 0.0001$, Fig. 3). Figure 4 shows an example of HT at 4 kHz for HUNT2 and HUNT4 as a function of age to illustrate that age is modeled as a restricted cubic spline. The figure shows the association between age and hearing, and age-specific differences between the two studies. There was a significant interaction between age and cohort at all frequencies in both men and women ($p < 0.0001$, Fig. 5). In women, the birth cohort effect increased as a function of age, with an increased rate above 60 years for all frequencies except for 8 kHz. In men, the birth cohort effect was largest at high frequencies at around 60 to 70 years (up to 10 to 11 dB at 3 to 4 kHz). While the difference at high frequencies leveled off in the elderly, the difference continues to increase at lower frequencies (0.5 and 1 kHz).

Percentile Values of HTs

HTs were better in the more recent born cohort at all different percentiles of the distribution ($p < 0.001$, Fig. 6).

Percentile values of HTs in dB averaged over both ears as a function of age in 5-year intervals are presented for the HUNT4 sample (n = 28,339) in Supplemental Digital Content 1, http://links.lww.com/EANDH/A664, and for a sample of otologically normal subjects of HUNT4 (n = 10,241) in Supplemental Digital Content 2, http://links.lww.com/EANDH/A665. All normative data are presented related to the median HT levels of otologically normal subjects aged 19 to 23 as a reference. To obtain values in dB HL obtained with TDH39 headphones and calibrated according to ISO 389 numbers in Table 1 should be added. The data of otologically normal subjects are comparable with levels modeled by ISO 7029 (International Organization for Standardization 2017b) but with some discrepancies, especially at 4 to 6 kHz (Fig. 7).

Prevalences of Hearing Loss

Overall, the prevalence of disabling hearing loss (BE PTA4 ≥ 35 dB) decreased significantly from 7.7% (95% CI 7.5 to 7.9) in HUNT2 to 5.3% (95% CI 5.0 to 5.5) in HUNT4, adjusted by age and gender. In women, the overall prevalence decreased from 5.8% (95% CI 5.5 to 6.0) to 4.3% (95% CI 4.0 to 4.5); in men from 10.0% (95% CI 9.6 to 10.3) to 6.5% (95% CI 6.1 to 6.8), adjusted by age (Tables 2 and 3). The prevalence decreased from 1996–1998 to 2017–2019 at all ages in both men and women (Fig. 8). The largest absolute decrease occurred at about 75 years in men and at 85 years in women. Prevalences for HUNT4 estimated in 5 year intervals are presented in table in Supplemental Digital Content 3, http://links.lww.com/EANDH/A666.

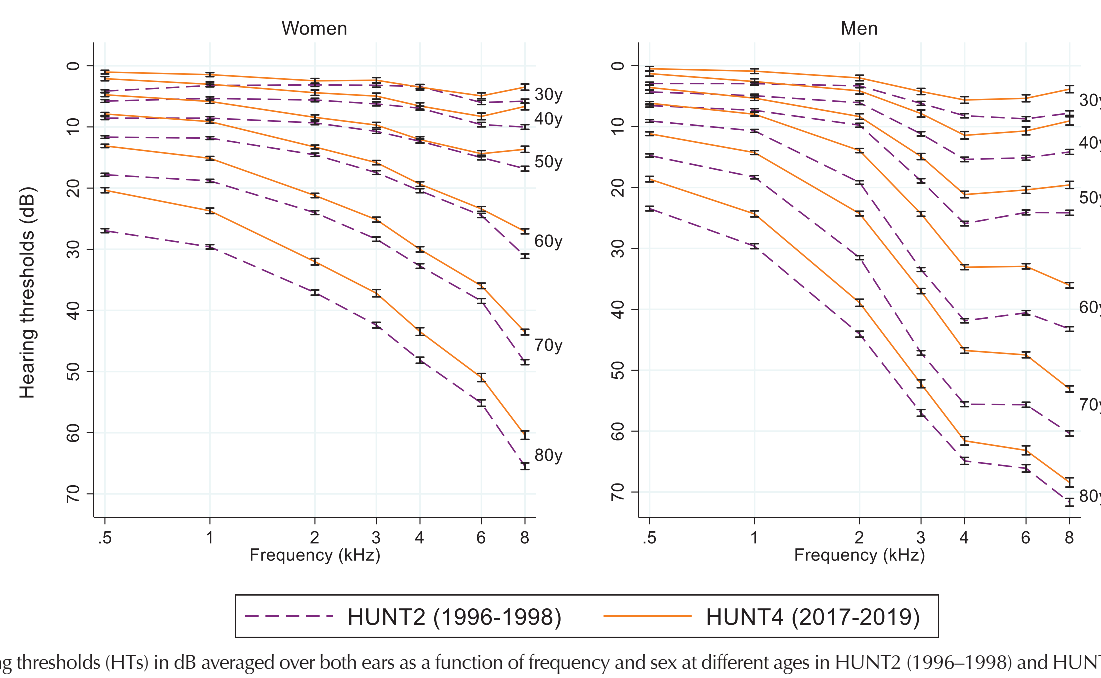

Fig. 3. Hearing thresholds (HTs) in dB averaged over both ears as a function of frequency and sex at different ages in HUNT2 (1996–1998) and HUNT4 (2017–2019). Error bars represents 95% CI. HTs are relative to median hearing threshold levels of otologically normal subjects aged 19 to 23 presented in Table 1.

Fig. 4. Hearing thresholds (HTs) in dB averaged over both ears at 4 kHz as a function of age with age modeled as a cubic spline for HUNT2 (1996–1998) and HUNT4 (2017–2019). Shaded areas represent 95% CI. Dots represent mean levels at each year of age. HTs are relative to median hearing threshold levels of otologically normal subjects aged 19 to 23 presented in Table 1.

The weighted population-based prevalence of hearing loss ≥35 dB HL in adults older than 19 years in Norway was 7.5% (95% CI 7.3 to 7.7) in 1997 and 5.9% (95% CI 5.7 to 6.1) in 2018. The corresponding prevalences of hearing loss >40 dB were 5.2% (95% CI 5.0 to 5.4) and 3.9% (95% CI 3.7 to 4.0), respectively.

Self-Selection

Self-reported hearing loss among participants that participated in main HUNT and was invited to HUNT hearing but did not attend the hearing investigation (11% in HUNT2 and 16% in HUNT4) was slightly higher than among HUNT hearing participants. The age-adjusted frequency of severe self-reported hearing loss among nonparticipants was 10.4 and 10.5% in HUNT2 and HUNT4, respectively, while the corresponding numbers among participants were 9.2 and 8.9 %. The estimated prevalence of hearing loss (≥35 dB) in the complete sample after imputing values for HTs in nonparticipants was 8.2 and 6.0% as compared to 7.7 and 5.3% in the sample with participants only.

The fraction of subjects with hearing loss-related disease diagnoses registered in NPR in the sample of participants in HUNT4 hearing were 0.4, 2.7, 7.5, and 15.8% in the age-groups,

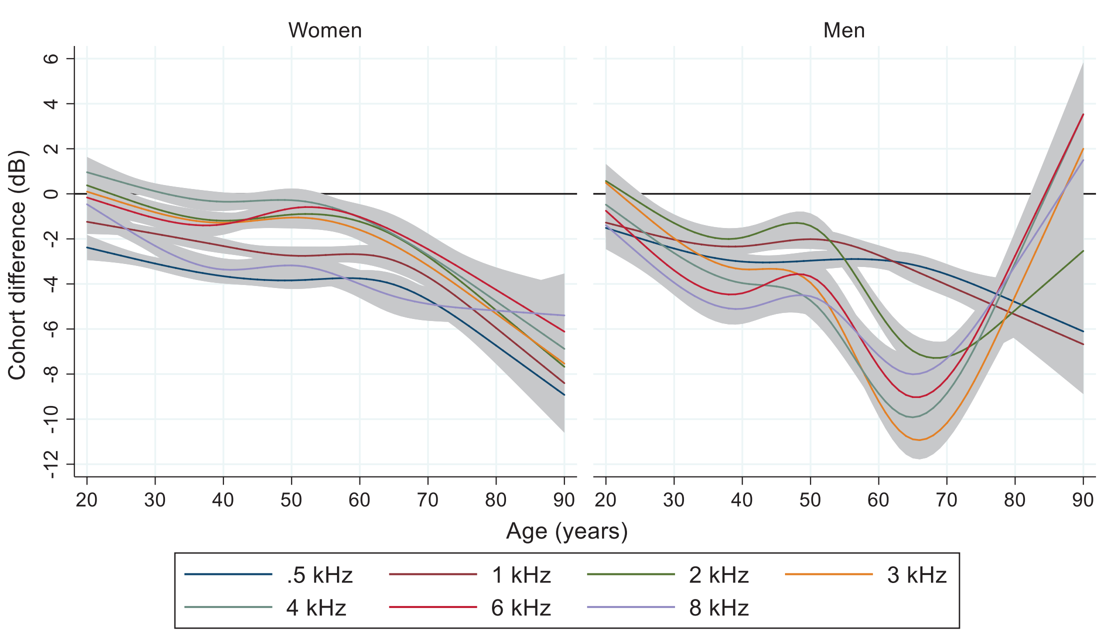

Fig. 5. Mean cohort difference in dB of hearing thresholds (HTs) between HUNT2 (1996-1998) and HUNT4 (2017-2019) as a function of age for different frequencies. Shaded areas represent 95% CI.

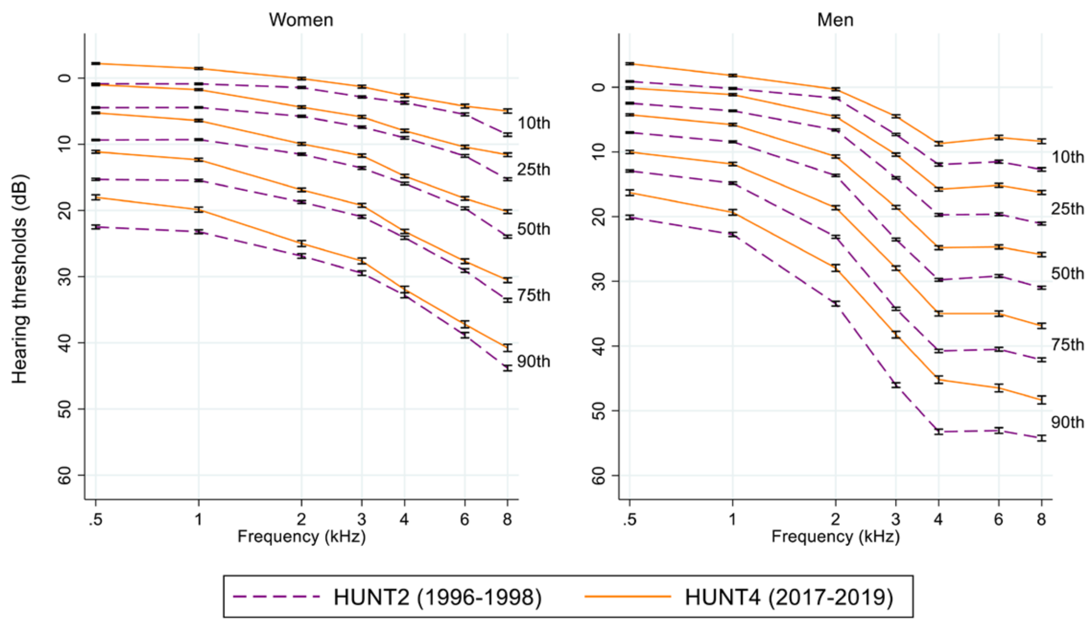

Fig. 6. Age adjusted percentiles of hearing thresholds (HTs) in dB averaged over both ears as a function of frequency for HUNT2 (1996–1998) and HUNT4 (2017–2019). HTs are relative to median hearing threshold levels of otologically normal subjects aged 19 to 23 presented in Table 1.

19 to 44, 45 to 67, 68 to 79, and above 79 years. The corresponding fractions of subjects in the total target population of HUNT4 hearing were 0.5, 2.9, 8.7, and 16.1%.

DISCUSSION

HTs were better in more recent born birth cohorts at all frequencies for both men and women, with the largest difference in men. The difference was varied by sex, age, and hearing frequency. At high frequencies, the difference was particularly pronounced in 60- to 70-year old men, while at low frequencies, the difference was the highest above age 80. Disabling hearing loss was less prevalent in the more recent born birth cohorts at all ages in both men and women, with the largest absolute decrease at age 75 in men and age 85 in women. The age-adjusted prevalence of disabling hearing loss was nearly halved in the most recent born birth cohort in both men and women.

The present study has several strengths. It is based on data from a two-large cohorts representative of the general population of Nord-Trøndelag county. Hearing is measured by means of pure-tone audiometry, often described as a gold standard for hearing loss assessment. In many respects, Nord-Trøndelag is

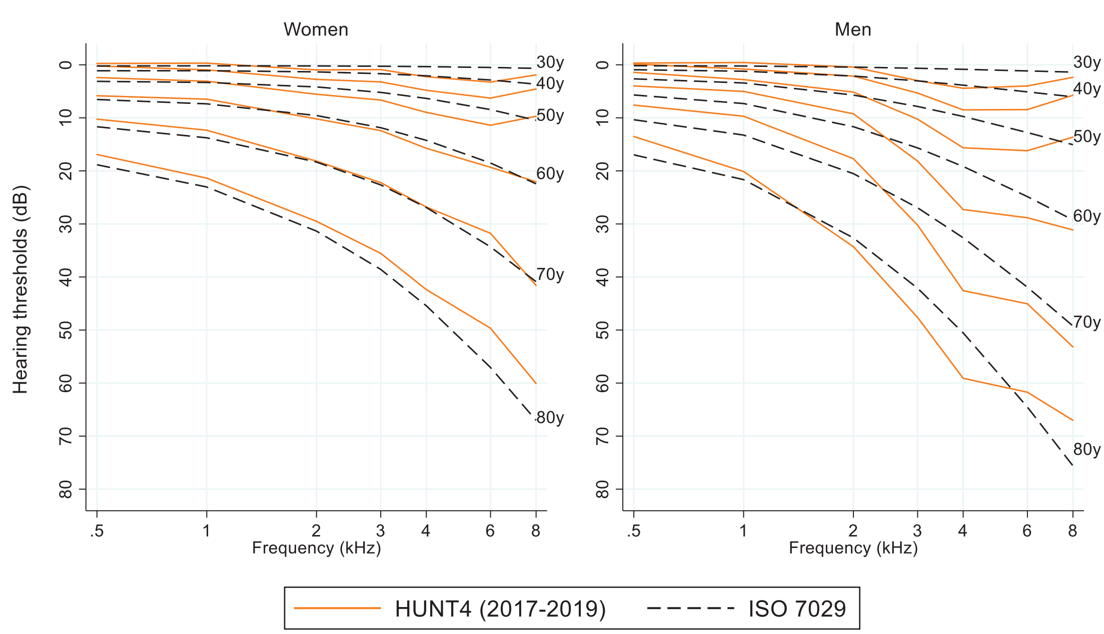

Fig. 7. Age adjusted median levels of hearing thresholds (HTs) in dB averaged over both ears as a function of frequency for HUNT4 (2017–2019) screened for otologically normal subjects (n = 10,241) compared with values of ISO 7029. HTs are relative to median hearing threshold levels of otologically normal subjects aged 19 to 23 presented in Table 1.

TABLE 2. Prevalence of Hearing Impairment by Severity*, Age, and Sex for HUNT2 (1996–1998)

	Impairment category:	Prevalence (%) Unilateral	Mild	Moderate	Moderately severe	Severe	Profound/ deaf	Any loss	Disabling			
	Age	<20 and ≥35 dB	20–34 dB	35–49 dB	50–64 dB	65–79 dB	≥80 dB		≥35 dB	95% CI	>40 dB	95% CI
Women	20–44 yrs	0.6	1.1	0.2	0.1	0.1	0.0	2.2	0.3	0.2–0.4	0.2	0.1–0.3
	45–64 yrs	1.5	8.9	1.3	0.2	0.1	0.1	10.5	1.6	1.4–1.8	0.9	0.8–1.1
	>64 yrs	1.5	34.4	14.7	3.4	0.8	0.3	56.5	19.2	18.3–20.0	12.5	11.8–13.2
	Age adjusted	1.2	12.8	4.4	1.0	0.3	0.1	19.6	5.8	5.5–6.0	3.7	3.5–3.9
	Norway 1997	1.0	11.5	5.2	1.6	0.3	0.1	19.9	7.3	7.1–7.6	5.0	4.8–5.2
Men	20–44 yrs	1.0	1.7	0.2	0.1	0.0	0.1	3.3	0.5	0.3–0.6	0.3	0.2–0.5
	45–64 yrs	1.7	16.9	3.1	0.5	0.1	0.0	21.0	3.5	3.2–3.8	2.0	1.8–2.2
	>64 yrs	1.6	38.2	23.3	7.6	0.9	0.2	73.2	32.2	31.0–33.3	22.2	21.2–23.3
	Age adjusted	1.4	17.0	7.4	2.2	0.3	0.1	28.3	10.0	9.6–10.3	6.7	6.4–7.0
	Norway 1997	1.3	12.4	5.5	1.9	0.2	0.1	21.4	7.7	7.4–8.1	5.4	5.1–5.7
Total	20–44 yrs	0.7	1.3	0.2	0.1	0.1	0.0	2.7	0.4	0.3–0.5	0.3	0.2–0.3
	45–64 yrs	1.6	12.7	2.1	0.4	0.1	0.1	15.4	2.5	2.3–2.7	1.4	1.3–1.6
	>64 yrs	1.5	36.3	18.7	5.3	0.8	0.3	64.3	25.2	24.4–25.9	16.9	16.3–17.6
	Age, sex adjusted	1.3	14.8	5.8	1.6	0.3	0.1	23.7	7.7	7.5–7.9	5.1	4.9–5.3
	Norway 1997	1.1	11.9	5.4	1.7	0.3	0.1	20.6	7.5	7.3–7.7	5.2	5.0–5.4

Severities of hearing loss using the criteria for classification by the GBD based on better ear pure-tone average over 0.5, 1, 2, and 4 kHz (BE PTA4).
CI indicates confidence interval; GBD, Global Burden of Disease.

TABLE 3. Prevalence of hearing impairment by severity*, age, and sex for HUNT4 (2017–2019)

	Impairment category	Prevalence (%) Unilateral	Mild	Moderate	Moderately severe	Severe	Profound/ deaf	Any loss	Disabling			
	Age	<20 and ≥35 dB	20–34 dB	35–49 dB	50–64 dB	65–79 dB	≥80 dB		≥35 dB	95% CI	>40 dB	95% CI
Women	20–44 yrs	0.4	0.8	0.2	0.0	0.0	0.0	1.6	0.3	0.1–0.4	0.2	0.1–0.3
	45–64 yrs	1.1	7.9	1.2	0.2	0.0	0.0	9.6	1.4	1.2–1.6	0.8	0.6–0.9
	>64 yrs	1.2	32.0	11.1	2.1	0.2	0.2	48.4	13.8	12.9–14.8	8.2	7.4–9.0
	Age adjusted	0.9	11.7	3.4	0.6	0.1	0.1	16.9	4.3	4.0–4.5	2.5	2.3–2.7
	Norway 2018	0.8	10.9	4.6	1.0	0.2	0.1	17.6	5.9	5.6–6.2	3.7	3.4–3.9
Men	20–44 yrs	1.0	1.7	0.2	0.1	0.0	0.1	3.3	0.2	0.1–0.4	0.1	0.0–0.2
	45–64 yrs	1.7	16.9	3.1	0.5	0.1	0.0	21.0	1.6	1.3–1.9	0.8	0.6–1.0
	>64 yrs	1.6	38.2	23.3	7.6	0.9	0.2	73.2	22.1	20.9–23.3	14.9	13.9–16.0
	Age adjusted	1.1	14.3	4.8	1.3	0.3	0.0	21.9	6.5	6.1–6.8	4.3	4.0–4.6
	Norway 2018	1.0	11.9	4.3	1.3	0.3	0.1	18.7	5.9	5.6–6.3	4.1	3.8–4.4
Total	20–44 yrs	0.7	1.3	0.2	0.1	0.1	0.0	2.7	0.2	0.2–0.3	0.1	0.1–0.2
	45–64 yrs	1.6	12.7	2.1	0.4	0.1	0.1	15.4	1.5	1.3–1.7	0.8	0.7–0.9
	>64 yrs	1.5	36.3	18.7	5.3	0.8	0.3	64.3	17.5	16.8–18.3	11.2	10.5–11.8
	Age, sex adjusted	1.0	12.9	4.1	0.9	0.2	0.1	19.3	5.3	5.0–5.5	3.3	3.1–3.5
	Norway 2018	0.9	11.4	4.4	1.2	0.2	0.1	18.2	5.9	5.7–6.1	3.9	3.7–4.0

Severities of hearing loss using the criteria for classification by the GBD based on better ear pure-tone average over 0.5, 1, 2 and 4 kHz (BE PTA4).
CI indicates confidence interval; GBD, Global Burden of Disease.

a representative of Norway regarding geography, economy, industry and sources of income, age distribution, morbidity, and mortality (Krokstad et al. 2013). However, the county has no large cities, and the mean levels of education are slightly lower than the national averages. We believe Nord-Trøndelag to be a representative of Norway also in terms of hearing loss being at the country average in the number of hearing aids dispensed per inhabitants adjusted for age and sex (Balteskard 2017). The same audiometric procedure was followed for both birth cohorts, and the minor differences in audiometers, use of cushions for the earphones, and change of headband from metal to plastic should not impose systematic differences (Poulsen 2010). The HTLs of otologically normal young reference populations were slightly different in the two cohorts, although not exceeding the uncertainty of the audiometric equipment (International Organization for Standardization 2010). To overcome this systematic methodological

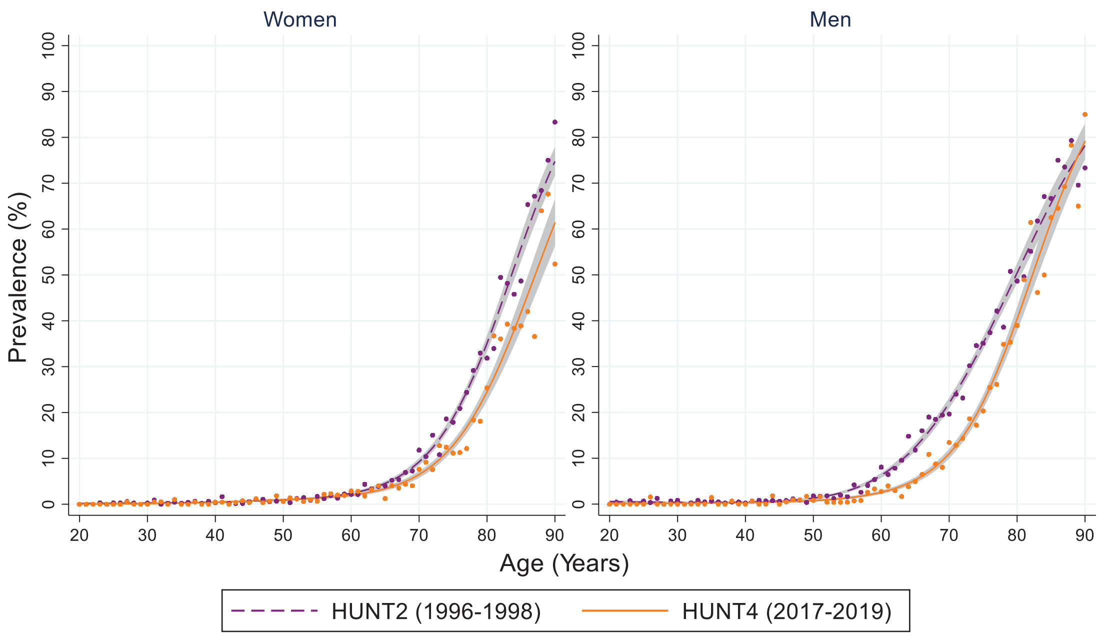

Fig. 8. Prevalence of disabling hearing loss according to the definition by the Global burden of disease study (GBD) with better ear pure-tone average (0.5, 1, 2 and 4 kHz) ≥35 dB. Prevalence is predicted from a logistic regression model. Shaded areas represent 95% CI. Dots represent point prevalences at each year of age.

difference, the HTs were defined relative to otologically normal young reference populations in both surveys. Thus, it is unlikely that the improved hearing should be attributable to changes in the procedure. One exception is that the background noise of the last study was lower due to improvements in the sound isolation of the hearing booths probably only affecting HTs at low frequencies (0.5 kHz) and at low sound levels. At 0.5 kHz, we thus expect the improvement in hearing from HUNT2 to HUNT4 to be larger in the lower part of the level distribution, but this was not found. Even if background noise affected the prevalence of mild hearing loss, there is no reason to believe that the prevalence estimates of disabling hearing loss were affected by differences in background noise. Because we did not clean ears based on otoscopy results, the fact that otoscopy was offered to all HUNT4-participants and only to a subsample of HUNT2 should not have influenced the differences between the two studies.

As in most observational studies, falling response rates have been experienced in more recent study waves, and thereby the possibility of selection of a healthier population in the most recent birth cohort cannot be ruled out. Those who failed to attend HUNT had a somewhat less healthy lifestyle and somewhat poorer health than those who did attend (Langhammer et al. 2012), so some of the registered improvements in health condition shown by our data may be an effect of increasing selection. Especially, the high attrition rate for the youngest and oldest part of the sample might imply a risk of recruitment bias regarding HTs. The hearing examination, however, was only a small part of the health examination program, and represents just one out of many important reasons why each subject chose to participate or not. Accordingly, a strong self-selection toward inflated or deflated hearing loss is unlikely. As to foreign citizens, the hearing questionnaire was only in Norwegian, but language is not regarded an important reason for nonparticipation, as Nord-Trøndelag is the county in Norway with the lowest number of people with foreign citizenship.

The attrition from the main health examination to the hearing investigation is more likely to affect the prevalence of hearing loss, and imputation indicated that this self-selection slightly deflated hearing loss prevalence. However, the underestimation of the true prevalence was similar in the two cohorts with a minimal effect on the comparison of the two cohorts. Furthermore, register data indicated that the number of hearing-related diagnosis was only slightly lower in the population of participants in HUNT4 hearing compared with the total target population.

With measures at only two time points we cannot derive the pattern of the change, the point at when hearing started to improve, or how it changed. Using the data to forecast future hearing status of the population is limited.

The hearing improvement in the more recent born cohort is in agreement with other studies that suggest cohort improvements in hearing ability among adults (Hoffman et al. 2010; Zhan et al. 2010; Hoffman et al. 2017; Hoff et al. 2018). A recent Swedish study found the prevalence of mild hearing loss (>25 dB) among 70-year-old subjects to decline from 53 to 28% in men and from 37 to 23% in women over a study period from 1971 to 2017 (Hoff et al. 2018). This relative size of the decline is comparable to the size of the decline in our study, although over a longer period. A comparable size of decline was also found in the United States, with lower odds having a mild hearing loss (>25 dB) in 1959–1962 compared to that in 1999–2004 (Hoffman et al. 2010, 2012). The decline expressed as odds ratio (OR) was 0.56 in men and 0.66 in women aged 25 to 64 years, and it was 0.59 in men and 0.56 in women aged 65 to 74 years. The decline continued for the period 1993 to 2008, with an OR of 0.87 per 5 years in men and 0.94 in women, corresponding to 0.57 and 0.78 over a 20-year period.

Many factors could influence the changing prevalence of hearing loss over time or across birth cohorts. On the one hand, workplace noise may have been reduced, treatment of ear disorders may have become better and health in general has been improved, which may all have led to lower incidence of hearing loss. On the other hand, some widespread behavioral changes could have led to an increase—and some may particularly affect the young, including a higher usage of headphones (World Health Organization 2015), which may worsen hearing (Herrera et al. 2016; Widen et al. 2017). The decline in age-specific prevalence of hearing loss among the elderly found in one previous study was to some degree explained by changes in educational attainment, but not by occupational noise, leisure noise, and ear infections (Zhan et al. 2011). However, the study was small, had a relatively short time-span of 10 years, and considered only a few risk factors. That a reduction in noise exposure may explain parts of the reduction seems plausible: we found an improvement that was particularly pronounced within noise-frequencies, 3 to 6 kHz, in 60- to 70-year-old men. Noise-induced hearing loss in the industry has been reduced in recent decades because of hearing conservation programs (Johansson & Arlinger 2001). It is only within the past 40 years that serious efforts to reduce excessive noise at work sites have been initiated (Thurston 2013), and regulations to limit workers' exposure to loud sounds with limits of 85 dB were implemented in Norway in 1982. While 65 years old in 2018 spent most of their working life after 1982, 65 years old in 1997 spent a major part of their working life before 1982, when hearing protector devices was less in use.

The present study shows a small improvement in hearing in the more recent born birth cohorts among younger adults aged 20 to 30. Previous studies of younger individuals show mixed results, probably because of the small variation in hearing loss among adolescents, and, as already discussed, care should be taken when evaluating milder hearing losses when hearing is examined under suboptimal conditions, such as mobile audiometric test booths. Small variations in background noise make a greater difference when evaluating populations with superior hearing. Swedish evidence, based on hearing screening at the military service conscription examination, suggests that the prevalence of moderate hearing loss at high frequencies (≥35 dB at 3 to 6 kHz) in 18-year-old males decreased from 1971 to 2004 (Muhr et al. 2017). At the same time, they found large fluctuations in the prevalence of mild hearing loss (25 to 35 dB), especially at 6 kHz. American studies show mixed results with respect to time trends: one study of 12- to 17-year-old subjects suggested decreased prevalence between 1966–1970 and 1988–1994, while there were no changes between 1988–1994 and 2005–2010 (Hoffman et al. 2019). Other studies conclude that there has been a temporary rise in hearing loss from 1988 to the mid-2000s (Shargorodsky et al. 2010; Henderson et al. 2011) and then a decline toward 2010 (Su and Chan 2017). A study of young 17- to 25-year-old adults beginning employment at a multisite US corporation between 1985 and 2004 showed a small decrease in prevalence over the 20-year period (OR = 0.96) (Rabinowitz et al. 2006). Improvement in hearing among younger adults may indicate that higher usage of earphones among young subject has been of minor importance. Supporting this, the epidemiological evidence for an effect of music listening on HTs is limited (le Clercq et al. 2016), and no effects of frequent use of personal audio devices (mainly Walkman and Discman) or regular attendance to discotheques or rock concerts on HTs were found in the HUNT2 hearing study (Tambs et al. 2003).

Hearing loss prevalence defined using HTLs in dB HL presumes correct use of reference values for the audiometry, the "audiometric zero" values. Levels calibrated according to ISO 389 highly deviated from zero in our reference population of young otologically normal subjects. We have no explanation to the particularly large deviance at 6 and 8 kHz, but this finding is consistent with discrepancies between normal HTs and "audiometric zero" that have been reported previously at these particular frequencies (Lutman et al. 1994). When available, we therefore support to use HTLs from a reference population of young otologically normal subjects as "audiometric zero." This is especially important when prevalences are to be compared between studies using different methodologies. If the present study had used "audiometric zero" derived directly from ISO 389, the age- and sex-adjusted prevalence of disabling hearing loss (≥ 35 dB HL) in HUNT2 would have been estimated to 10.4% instead of 7.9%. We therefore believe previously reported prevalence numbers to be slightly overestimated (Borchgrevink et al. 2005). An alternative explanation for the difference in HTLs between the HUNT reference populations and ISO 389 could be that HT levels of the young otologically normal population has increased because the ISO reference levels were established. This is speculative as the reference levels in ISO 389, which were based on 15 studies from 1950 to 1960 from five countries (Weissler 1968), were small and with major shortcomings in representativeness and description of subject selection. It has previously been argued that ISO 389 do not necessary represent the thresholds of otologically normal young subjects in general (Lutman and Davis 1994).

CONCLUSIONS

The age- and sex-specific prevalence of hearing impairment decreased in Norway from 1996–1998 to 2017–2019.

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