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RESEARCH ARTICLE

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No accelerated 20-year hearing decline after occupational noise exposure has ceased: The HUNT study

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Abstract

Objectives: It has been suggested that noise exposure can accelerate hearing decline after the noise exposure has ceased. We aimed to assess long-term hearing decline in persons with and without prior occupational noise exposure.

Methods: We conducted a population-based longitudinal study in Norway using the Trøndelag Health Study (HUNT) from 1996 to 1998 (baseline) and from 2017 to 2019 (follow-up). The sample included 1648 participants with baseline age ≥55 years (42% men, mean age 60 years) and <5 years occupational noise exposure after baseline. We analyzed the association between occupational noise exposure before baseline and mean hearing decline between 1998 and 2018 (20-year decline) at each frequency, adjusted for age, sex, education, and impulse noise exposure before baseline.

Results: Occupational noise exposure before baseline ($N = 603$) was associated with baseline hearing loss, but not with later accelerated 20-year decline, at any frequency. Noise-exposed persons had less subsequent 20-year decline at 3 kHz than did nonexposed. Restricting the noise-exposed group to persons who also had a baseline Coles notch (hearing thresholds at 3, 4, or 6 kHz of 10 dB or more compared with thresholds at 1 or 2 kHz and 6 or 8 kHz; $N = 211$), the exposed group showed less 20-year decline at both 3 and 4 kHz, as well as less accelerated 20-year decline at 8 kHz, compared with the nonexposed.

Conclusion: Our large long-term longitudinal study shows no increased risk of continuing hearing decline after occupational noise exposure has ceased. The finding supports a conclusion that ear damage stops when the noise exposure is ended.

KEYWORDS

ageing, hearing decline, longitudinal, noise, notch

1 | INTRODUCTION

Hearing loss is a common chronic disability. A recent large study from Norway showed a weighted population-based prevalence of disabling hearing loss (pure-tone average of 0.5–4 kHz in the better hearing ear of ≥35 dB hearing level) among adults of 5.9%.[1]

Occupational noise exposure is still an important risk factor for hearing loss. The risk of continuing hearing decline after noise exposure has ceased is, however, a complex issue. As described in a recent

review, there are few longitudinal human studies on this topic and the results are inconsistent.[2] One study using initial notches in the audiogram as the exposure variable showed an association with later accelerated low-frequency hearing decline.[3] Another study found a greater progression of hearing loss among military veterans compared with those expected from ISO7029.[4] On the other hand, two studies of occupational noise exposure showed no such relation.[5,6]

To assess the risk of continuing hearing decline after occupational noise exposure has ceased, the present large longitudinal study examines long-term hearing decline in persons with and without prior occupational noise exposure.

2 | METHODS

2.1 | Participants

The Trøndelag Health Study (HUNT) is one of the world's largest population-based health studies. HUNT started in 1984 and has been conducted in four waves (HUNT 1–4). The HUNT study has been described in detail previously.[7]

The second and fourth waves of HUNT (HUNT2 and HUNT4) included hearing investigations with pure tone audiometry: HUNT2 hearing (1996–1998) and HUNT4 hearing (2017–2019). HUNT2 hearing included 50,560 participants (participation rate 61%), and HUNT4 hearing included 28,388 participants (participation rate 43%). The HUNT hearing studies are described in detail.[1]

This longitudinal study included the 13,022 individuals who attended both HUNT hearing studies. Among these, we excluded persons with missing questionnaires ($N = 886$) or incomplete audiometry ($N = 54$). To assess the risk of continuing hearing decline after occupational noise exposure has ceased, we excluded persons <55 years of age at HUNT2 ($N = 10,282$), as well as persons reporting ≥ 5 years of occupational noise exposure after baseline ($N = 152$). Our final sample included 1648 persons. The study was approved by The Regional Committee for Medical Research Ethics (23178 HUNT Hearing). All participants in the HUNT study signed an informed consent form allowing the use of their data and samples for research.

2.2 | Measurements

2.2.1 | Exposure variables

We used the baseline questionnaire (HUNT2 in 1996–1998) to define a history of occupational noise exposure: this asked "Are you exposed to loud noises at work, or have you been exposed at work earlier in life, for periods as long as 3 months? «No, never; <5 h weekly; 5–15 h weekly, >15 h weekly». We constructed a categorical variable with three categories: no, never (reference category in all analyses); noise exposure ≤ 15 h weekly (some exposure); or noise exposure > 15 h weekly (high exposure). We coded missing ($N = 97$) as no exposure. We also created a dichotomous occupational noise exposure variable, defined as none versus any occupational noise exposure before 1998. This variable was investigated separately.

We also aimed to assess the association for noise-exposed persons who had a baseline notch. The second exposure variable was defined as occupational noise exposure before baseline and a Coles notch at baseline, compared with no occupational noise exposure before baseline and no baseline notch. The Coles notch is defined as hearing thresholds at 3, 4, or 6 kHz of 10 dB or more compared with those at 1 or 2 kHz and 6 or 8 kHz.[8] The criteria established by Coles et al. have been shown to correlate well with clinical assessments.[9]

2.2.2 | Outcome variable: Hearing threshold decline

Pure tone audiometry was conducted in line with ISO 8253-1 (International Organization for Standardization, 2010), with fixed frequencies at test frequencies 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz, utilizing 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 followed by the lower frequencies. The 1 kHz tone was repeated at the end, and if 10 dB or more improvement or worsening in threshold was discernible, the ear was retested until agreement to 5 dB or less was obtained. The maximum threshold that could be recorded was 100 dB for frequencies from 0.5 to 6 kHz, and 90 dB at 0.25 and 8 kHz. The minimum limit was set to −10 dB. Manual audiometry was offered to elderly or impaired subjects who were not able to follow the instructions for the automatic procedure. Hearing thresholds were defined relative to the hearing threshold levels of the population of otologically normal subjects aged 19–23 years in each wave.[1]

We defined hearing decline as the difference in hearing threshold between the baseline study and the follow-up study, at each frequency. We used the mean of both ears, which is regarded as a reliable measure. In other words, the 20-year hearing decline was continuously scored and investigated separately at each frequency (0.5, 1, 2, 3, 4, 6, and 8 kHz). Generally, occupations have diffuse noise exposures that do not result in asymmetrical hearing loss.[10]

2.2.3 | Covariates

We adjusted for age, sex, education, and impulse noise exposure as assessed at baseline. We used register data from Norwegian Statistics[11] to create a continuously scored variable on the educational level at baseline (primary school, secondary school, and higher education). We used the HUNT2 questionnaire to create a binary variable on impulse noise exposure before baseline. This asked "Are you more often than most people exposed to impulse noise, such as shooting" (yes vs. no). The category "don't know, maybe" and missing values were coded as no exposure. We did not adjust for exposure to music, since this exposure has not been associated with hearing loss in the HUNT cohort.[12] Further, the evidence in general for an effect of music listening through personal music players on hearing has been limited and of low quality.[13]

TABLE 1 Characteristics of the 1648 participants.

	Total sample *N* = 1648	No noise *N* = 1045	Any noise,[a] *N* = 603	Some noise, *N* = 412	High noise, *N* = 191	No notch, and no noise,[b] *N* = 830	Notch and noise, *N* = 192
Age in 1998, mean (range)	60 (55–77)	60 (55–77)	60 (55–76)	60 (55–76)	60 (55–73)	60 (55–76)	60 (55–71)
Men, *N* (%)	694 (42)	285 (27)	409 (68)	269 (65)	140 (73)	180 (22)	157 (82)
Coles notch in 1998, *N* (%)	403 (24)	211 (20)	192 (32)	118 (29)	74 (39)	–	–
Hearing threshold in 1998							
PTA 1 kHz, dB, mean (SD)	10.2 (10.2)	9.8 (9.8)	10.8 (10.9)	10.2 (10.4)	12.0 (12.0)	10.0 (9.6)	10.7 (10.7)
PTA 4 kHz, dB, mean (SD)	26.8 (19.4)	22.7 (16.9)	33.8 (21.2)	32.0 (21.2)	37.7 (20.8)	19.7 (15.0)	43.5 (19.8)
Hearing decline 1998–2018							
PTA 1 kHz, dB, mean (SD)	14.2 (12.1)	13.9 (11.8)	14.7 (12.6)	14.8 (12.7)	14.5 (12.4)	13.2 (11.1)	14.7 (12.3)
PTA 4 kHz, dB, mean (SD)	25.3 (13.6)	25.7 (13.3)	24.8 (14.1)	24.5 (14.2)	25.4 (13.4)	26.5 (13.6)	19.3 (14.6)
Higher education in 1998, *N* (%)	356 (22)	245 (23)	111 (18)	92 (22)	19 (10)	190 (23)	28 (15)
Impulse noise before 1998, *N* (%)	117 (7)	26 (2)	91 (15)	53 (13)	38 (20)	16 (2)	35 (18)

Note: The HUNT hearing study, Norway. Baseline study 1996–1998, follow-up study 2017–2019.

Abbreviation: PTA, pure-tone average.

[a]Any noise was defined as occupational noise exposure before 1998, some noise as exposure ≤ 15 h weekly, and high noise as exposure > 15 h weekly.

[b]Coles notch was defined as an audiometric notch at 3, 4, or 6 kHz in 1998.

2.3 | Statistical analyses

We analyzed data in Stata version 17.0. Statistical tests were calculated with 95% confidence intervals. The α level was set at 0.05 for all analyses. We used multiple linear regression analyses to assess the association between the two exposure variables (occupational noise exposure before baseline, or occupational noise exposure before baseline and a baseline notch) and later 20-year hearing decline at each frequency. We adjusted for age, sex, education, and impulse noise exposure.

Age was modeled as a restricted cubic spline with four knots to account for nonlinearity, which created a better model fit than models with age as a linear variable (likelihood-ratio test, $p < 0.001$). We also assessed the adjusted mean 20-year hearing decline for persons with or without prior exposure.

3 | RESULTS

3.1 | Participants

Table 1 displays the characteristics of the final sample ($N = 1648$). The sample included 42% men. The mean age at baseline was 60 years. Compared to persons without occupational noise exposure before baseline ($N = 1045$), the 603 noise-exposed persons included more men (68% vs. 27%) and fewer persons with higher education (18% vs. 23%). The prevalence of a Coles notch was 32% and 20% among persons with or without occupational noise exposure before 1998, respectively. Figure 1 presents the baseline hearing threshold levels (descriptive data, not adjusted) for the two exposure variables. The baseline hearing threshold levels were poorer among the noise-exposed persons than non-noise exposed.

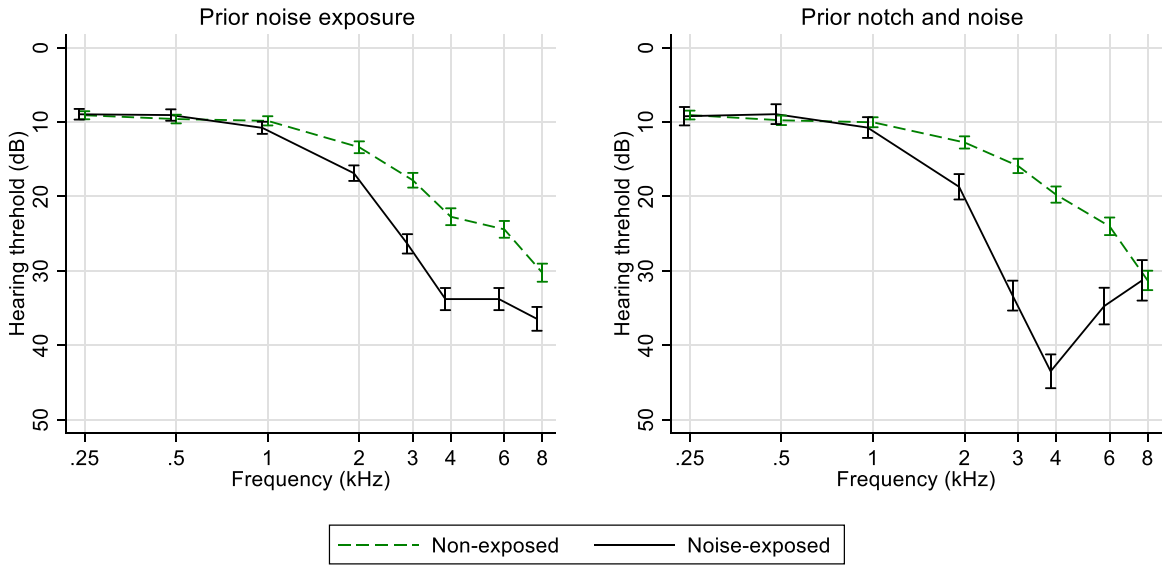

FIGURE 1 Mean baseline hearing threshold levels (not adjusted) for persons with or without occupational noise exposure before baseline. The HUNT hearing study, Norway. Baseline study 1996–1998. Error bars are 95% confidence intervals. Prior noise exposure is defined as occupational noise exposure before baseline (yes/no). Prior notch and noise are defined as occupational noise exposure before baseline and a baseline Coles notch at 3, 4, or 6 kHz (reference category no occupational noise exposure before baseline and no baseline notch). [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 The association between occupational noise exposure before 1998 and hearing threshold in 1998.

Linear regression coefficients in dB with 95% confidence intervals							
	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
No noise exposure ($N = 1045$)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Any noise exposure ($N = 603$)	0.4 (−0.7 to 1.4)	1.3 (0.2–2.5)	2.2 (0.8–3.6)	3.4 (1.7–5.0)	3.1 (1.4–4.9)	3.2 (1.3–5.0)	1.5 (−0.5 to 3.5)
Some noise exposure[a] ($N = 412$)	0.3 (−0.9 to 1.4)	1.0 (−0.2 to 2.2)	1.9 (0.4–3.5)	2.5 (0.7–4.3)	2.4 (0.5–4.3)	2.7 (0.7–4.7)	1.6 (−0.6 to 3.8)
High noise exposure[a] ($N = 191$)	0.7 (−0.9 to 2.3)	2.2 (0.6–3.9)	3.0 (0.9–5.1)	5.5 (3.0–7.9)	5.0 (2.3–7.7)	4.2 (1.5–7.0)	1.3 (−1.8 to 4.3)

Note: The HUNT hearing study, Norway. Baseline study 1996–1998.

Linear regression coefficients in dB with 95% confidence intervals for separate models at each frequency adjusted for age, sex, education, and impulse noise assessed in 1998.

[a]Occupational noise exposure before 1998 was assessed as a categorical variable with three categories: No, never (reference category in all analyses), noise exposure ≤ 15 h weekly (some exposure), or noise exposure > 15 h weekly (high exposure).

3.2 | Regression analyses

3.2.1 | Occupational noise exposure before baseline and hearing threshold at baseline

Compared with no occupational noise exposure before baseline, occupational noise exposure before baseline was associated with a poorer hearing threshold at baseline, at 1–6 kHz, and especially at 3 and 4 kHz and for the highly exposed group (>15 h/week) (Table 2).

3.2.2 | Occupational noise exposure before baseline and subsequent 20-year hearing decline

Occupational noise exposure before baseline (yes vs. no) was not associated with a later accelerated 20-year decline, at any frequency. Persons with occupational noise exposure before baseline had less subsequent 20-year hearing decline at 3 kHz compared with nonexposed (Table 3).

Persons with occupational noise exposure before baseline and a baseline notch had a less 20-year decline at both 3 and 4 kHz, as well as less accelerated decline at 8 kHz, compared with persons without prior noise exposure and notch. Figure 2 illustrates adjusted mean 20-year hearing decline for persons with or without exposure, at each specific frequency.

4 | DISCUSSION

4.1 | Main findings

Occupational noise exposure before baseline (yes vs. no) was associated with baseline hearing loss, but not with later accelerated 20-year hearing decline, at any frequency. Noise-exposed persons had, however, less subsequent 20-year decline at 3 kHz than nonexposed. Persons with occupational noise exposure before baseline combined with a baseline notch had a less 20-year hearing decline at both 3 and 4 kHz, as well as less accelerated 20-year decline at 8 kHz, compared with nonexposed.

4.2 | Comparison of the results with other longitudinal studies

Our study showed no association between a history of occupational noise exposure and later accelerated hearing decline, at any frequency. This complies with prior studies of elderly persons with prior occupational noise exposure. Hederstierna and Rosenhall[5] studied persons at 70 and 75 years of age (5 years follow-up), showing no differences in hearing decline between previous noise-exposed (62 men, 22 women) and nonexposed (96 men, 158 women). Similar results were reported by Lee et al.,[6] who followed 188 men aged 60–81 years at entry for 3–12 years (mean 6 years).

TABLE 3 The association between occupational noise exposure before 1998 and hearing decline from 1998 to 2018.

Linear regression coefficients in dB with 95% confidence intervals	0.5 kHz Reference	1 kHz Reference	2 kHz Reference	3 kHz Reference	4 kHz Reference	6 kHz Reference	8 kHz Reference
Noise before 1998							
No noise exposure (*N* = 1045)							
Any noise exposure (*N* = 603)	0.1 (−1.1 to 1.3)	−0.2 (−1.5 to 1.1)	−0.5 (−1.9 to 0.9)	**−1.6 (−3.0 to −0.1)**	−0.5 (−2.0 to 1.0)	−1.3 (−2.9 to 0.4)	−0.3 (−2.1 to 1.5)
Some noise exposure[a] (*N* = 412)	0.1 (−1.2 to 1.4)	0.2 (−1.2 to 1.6)	−0.6 (−2.1 to 1.0)	−1.3 (−2.9 to 0.2)	−0.7 (−2.3 to 1.0)	−1.3 (−3.2 to 0.5)	−0.5 (−2.4 to 1.6)
High noise exposure[a] (*N* = 191)	0.3 (−1.5 to 2.1)	−1.1 (−3.0 to 0.8)	−0.4 (−2.5 to 1.7)	−2.1 (−4.2 to 0.1)	−0.0 (−2.3 to 2.3)	−1.1 (−3.6 to 1.5)	0.2 (−2.5 to 2.9)
Noise and notch[b]							
No noise and no notch (*N* = 830)							
Noise and notch (*N* = 192)	−0.2 (−2.1 to 1.7)	0.2 (−1.8 to 2.2)	0.8 (−1.4 to 3.1)	**−4.8 (−7.2 to −2.3)**	**−8.4 (−10.9 to −5.8)**	−0.8 (−3.7 to 2.0)	6.5 (3.4–9.5)

Note: The HUNT hearing study, Norway. Baseline study 1996–1998, follow-up study 2017–2019. Bold values indicate $p < 0.05$.

Linear regression coefficients in dB with 95% confidence intervals for separate models at each frequency adjusted for age, sex, education, and impulse noise assessed in 1998.

[a]Occupational noise exposure before 1998 was assessed as a categorical variable with three categories: no, never (reference category in all analyses), noise exposure ≤ 15 h weekly (some exposure), or noise exposure > 15 h weekly (high exposure).

[b]Occupational noise exposure before baseline and a baseline Coles notch at 3, 4, or 6 kHz (reference category no occupational noise exposure before baseline and no baseline notch).

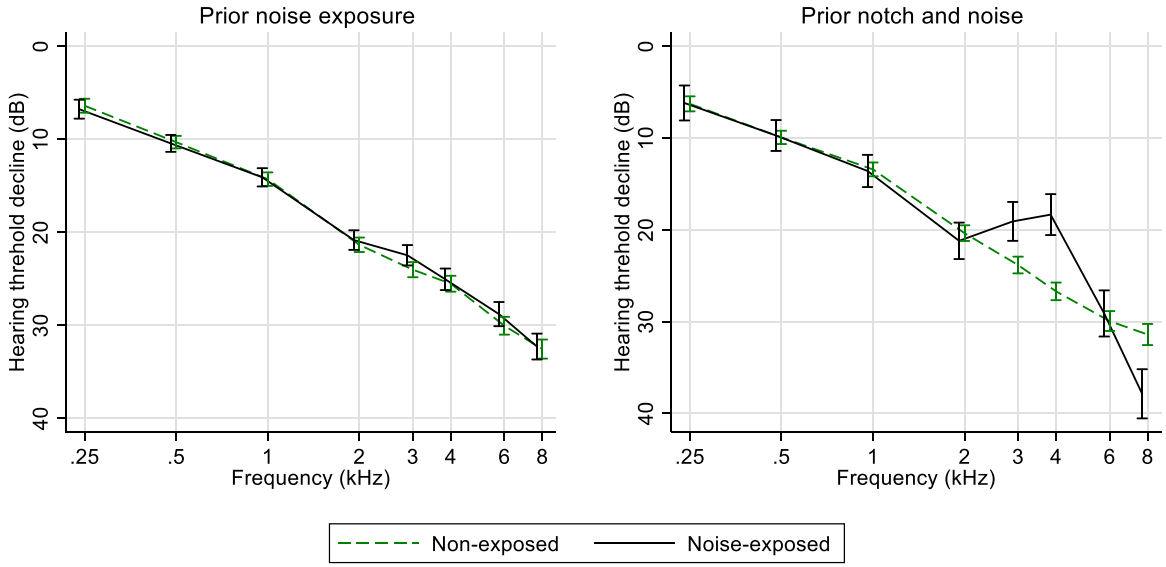

FIGURE 2 Adjusted mean hearing decline 1998–2018 among persons with or without occupational noise exposure before baseline. Adjusted mean hearing decline was predicted from linear regression analyses at each frequency adjusted for age, sex, education, and leisure noise. The HUNT hearing study, Norway. Baseline study 1996–1998, follow-up study 2017–2019. Error bars are 95% confidence intervals. Prior noise exposure is defined as occupational noise exposure before baseline (yes/no). Prior notch and noise are defined as occupational noise exposure before baseline and a baseline Coles notch at 3, 4, or 6 kHz (reference category no occupational noise exposure before baseline and no baseline notch). [Color figure can be viewed at wileyonlinelibrary.com]

Both studies, like this study, showed poorer baseline hearing thresholds among the noise-exposed than the nonexposed.

On the other hand, a study of 29 former military personnel found a greater progression of hearing loss among the military personnel compared with those expected from ISO7029 (2017).[4] The same author had previously re-analyzed data from a study from 1971[14] on military veterans and compared their progression with ISO7029, reporting a greater progression of hearing loss at 1 kHz.[2] Finally, a partly cross-sectional study reported greater low-frequency hearing decline between the ages of 70 and 75 years among persons with prior high-level noise exposure than for those with prior low-level noise.[15]

The present study also evaluated a history of occupational noise exposure combined with a baseline audiometric notch. Still, there was no association with later accelerated low-frequency hearing decline. In contrast, a study that evaluated initial notches among 203 elderly men measured twice in 15 years found an accelerated loss at 2 kHz.[3] The study did not include a history of occupational noise exposure before baseline.

4.2.1 | Experimental animal studies

A few experimental animal studies have also reported continuing hearing decline after noise exposure has ceased.[16–18] For example, one study observed a substantial, ongoing deterioration of cochlear neural responses in the noise-exposed mice compared with the nonexposed,[16] a second study reported a worsened synaptopathy in the noise-exposed mice.[17]

4.3 | Interpretations of the findings

4.3.1 | Ceiling effect at frequencies with initial increased thresholds

Our study showed that persons with prior occupational noise exposure had less subsequent hearing decline at 3 kHz than nonexposed. Our study also showed that the noise-exposed group had an increased hearing threshold at baseline, especially at 3 kHz. This agrees with prior studies, including longitudinal studies of initial hearing threshold that is not necessarily assessed as a notch or related to noise exposure.[6,19] As discussed in prior studies, this finding could relate to a ceiling effect at frequencies with increased thresholds and pre-existing damage.[6,19] The exact hearing threshold level in which the ceiling effect occurs is however not clearly defined.

4.3.2 | Accelerated low-frequency hearing decline

We can only speculate about the inconsistent findings on accelerated hearing decline after noise exposure has ceased. Different results can be related to different study designs, materials, and methods, including different exposure variables and covariates. The study of former military personnel[4] evaluated younger persons with better hearing, which could explain some of the differences. The study was, however, small (n = 29), did not have its own reference group, and the participants had claimed compensation for noise-induced hearing loss 5–20 years after the end of military service, which might have introduced selection bias.

It has been questioned whether the notches in Gates' study reflect true noise-induced hearing loss.[20] Notches are common among persons who are not exposed to noise,[21] which was also shown in this study. Further, it cannot be excluded that the association between a notch and later hearing decline could be hampered by selection problems and regression to the mean. The adequacy of the methods to assess the relationship between the baseline value and subsequent change depends on the number of data waves, the availability of information on measurement error, and the variability of change between individuals.[22] Using a notch as the exposure variable could introduce a larger threat to internal validity compared to using a history of occupational noise exposure.

We believe our large long-term study had enough power to reveal an association. We cannot exclude, however, that our noise-exposed group experienced a ceiling effect at low frequencies during follow-up, which could have counteracted a potential accelerated hearing decline. As such, our results may not apply to younger noise-exposed persons with better baseline low-frequency hearing thresholds after noise exposure has ceased. However, the baseline low-frequency hearing thresholds in the present study were not poor (Table 1, Figure 1), and there were no marked differences between the groups. To sum up, we believe this study adds important support to the hypothesis that there is no continuing hearing decline after noise exposure has ended.

4.4 | Strengths and limitations

Strengths include the standardized audiometric measurements, good confounder control with prospective measurements, a long observation time, and a large data set in which the population is representative of the entire country.[8] We also had data on noise exposure after baseline, which allowed us to exclude persons reporting substantial noise exposure during follow-up.

An important weakness was that we had only two measurements, which did not allow for mixed-effects modeling. Also, a better design would include a high number of younger persons who had ceased occupational noise exposure, to avoid a possible ceiling effect. However, it would be difficult to realize such a design.

5 | CONCLUSION

Our large long-term study shows no accelerated hearing decline among persons with prior occupational noise exposure compared with nonexposed. This indicates that there is little risk of continuing hearing decline after occupational noise exposure has ceased. Our study did not, however, include younger adults. We believe our study adds important support to a conclusion that hearing damage stops when the noise exposure is ended.

AUTHOR CONTRIBUTIONS

The manuscript has been read and approved by all authors. All authors made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, and (3) final approval of the version to be submitted.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John D. Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS APPROVAL AND INFORMED CONSENT

The study was approved by the Regional Committee for Medical Research Ethics (23178 HUNT Hearing). All participants in the HUNT study signed an informed consent form allowing the use of their data and samples for research.

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