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Occupational Noise Exposure, Hearing Loss, and Notched Audiograms in the HUNT Nord-Trøndelag Hearing Loss Study, 1996–1998

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Objectives/Hypothesis: To study the prevalence and usefulness of audiometric notches in the diagnosis of noise-induced hearing loss (NIHL).

Study Design: Audiograms and data on noise exposure from 23,297 men and 26,477 women, aged 20 to 101 years, from the Nord-Trøndelag Hearing Loss Study, 1996–1998.

Methods: The prevalence of four types of audiometric notches (Coles, Hoffman, Wilson) and 4 kHz notch were computed in relation to occupational noise exposure, age, sex, and report of recurrent ear infections.

Results: The prevalence of notches in the 3 to 6 kHz range (Wilson, Hoffman, and Coles) ranged from 50% to 60% in subjects without occupational noise exposure, and 60% to 70% in the most occupationally noise-exposed men. The differences were statistically significant only for bilateral notches. For 4 kHz notches, the prevalence varied from 25% in occupationally nonexposed to 35% in the most occupationally exposed men, and the differences were statistically significant for both bilateral and unilateral notches. For women, the prevalence of notches was lower than in men, especially for 4 kHz notches, and the differences between occupationally noise exposed and nonexposed were smaller. Recreational exposure to high music was not associated with notched audiograms.

Conclusions: The detection of bilateral notches and unilateral 4 kHz notches is of some value in diagnosing NIHL, especially in men.

Key Words: Noise, notched audiograms, occupation, noise-induced hearing loss.

Level of Evidence: 4

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INTRODUCTION

Noise is a known cause of hearing loss,[1] but noise in the workplace is probably a less-common cause of hearing loss than in the past, particularly in the Western world.[2–5] Reduced exposure to noise and better protective measures are likely responsible. Still, occupational noise-induced hearing loss (NIHL) is one of the most reported occupational diseases internationally.[5,6]

Hearing loss, however, is primarily associated with increasing age.[7] The median binaural hearing thresholds for the 3- to 6-kHz range for men increases from about 5 dB hearing level (HL) for a 30-year-old to about 33 dB HL for a 60-year-old according to International Organization for Standardization (ISO) 1999: 2013, Table B1.[7] Corresponding figures for women are 4 dB HL and 20 dB HL. Also, hearing loss varies greatly for individuals of the same age. In 60-year-old men, the range of hearing varies from 13 dB HL (10th percentile) to 61 dB HL (90th percentile). This individual variation is smaller in women than in men. Genetic factors may explain a large part of the variation,[8,9] perhaps as much as 40%.[10] For comparison, the expected hearing loss after exposure at 85 dBA unprotected through 40 years is 5 dB HL, and at 90 dBA is 12 dB HL for the 3 to 6 kHz range.[7] This means that the noise-related hearing loss one would expect to find among most noise-exposed workers in today's workplaces is modest compared to the effects of age-related hearing loss. It may therefore be difficult to distinguish between a noise-related and age-related hearing loss, particularly in older subjects.[11]

There are different guidelines for the definition of occupational hearing loss. Some definitions place emphasis on hearing loss in the 0.5 to 4 kHz area, because

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hearing loss in this frequency area is of greatest clinical significance in terms of spoken communication, whereas other definitions focus on the hearing loss in the 3 to 6 kHz range, because this range is the most susceptible to loud noise exposure. This makes it difficult to compare results across different studies.[11]

Audiometric notches have been used to distinguish between noise-induced and age-related hearing loss.[5,12] In the clinic, a notch is usually considered a strong indicator of NIHL. However, experts disagree on what is a real notch,[13,14] and a number of different notch definitions have been proposed.[15–19] In recent years, studies have shown that audiometric notches occur commonly in workers without loud occupational noise exposure.[14,20]

In a recent study of railway employees, audiometric notches were almost as common in workers without any occupational noise exposure (50%) as in occupationally noise exposed (60%); hence, the usefulness of notches to distinguish between occupationally mediated noise-induced and age-induced hearing loss may be limited.[21] The aim of this study is to examine the characteristics and associations of audiometric notches in relation to occupational noise exposure and other potentially mediating factors in another large Norwegian population.

MATERIALS AND METHODS

Study Population

The Nord-Trøndelag Hearing Loss Study (NTHLS) was conducted in Norway from 1996 to 1998 and was part of the Nord-Trøndelag Health Study (HUNT 2), a large, general health-screening study for the entire adult population of Nord-Trøndelag County. In the NTHLS, 17 of the 24 municipalities in the county participated in the hearing examination, consisting of pure-tone audiometry and the completion of two questionnaires (Hearing Q1 and Q2). The subjects ranged in age from 20 to 101 years (median = 48.0 years, mean = 50.2, standard deviation = 17.0). The participation rate was 67% except in one municipality where the population was invited to the hearing examination only after the main HUNT 2 was finished (participation rate 41%). Audiometric data were collected from 50,464 participants. Among these, 49,774 subjects had data available on the Hearing Q1, which is the sample used in this study. More detailed information about the study is found elsewhere.[4]

Study Variables

Hearing loss. Air-conduction hearing threshold levels were obtained using pure-tone audiometry at eight frequencies from 0.25 to 8 kHz in accordance with ISO 8253–1 (1989) as described in an earlier publication in the NTHLS.[22] We defined two pure-tone binaural threshold average summary measures: pure-tone average (PTA): $PTA_{0.5–4}$ at 0.5, 1, 2, and 4 kHz, and $PTA_{3–6}$ at 3, 4, and 6 kHz.

Audiometric notches. We used four different notch definitions.

Hoffman et al. defined a notch as present when "any threshold at 3, 4, or 6 kHz exceeds by 15 dB HL the average threshold in the low/middle frequencies, 0.5 and 1 kHz, and the threshold at 8 kHz is at least 5 dB HL better (lower) than the maximum threshold at 3, 4, or 6 kHz."[16] The Hoffman algorithm required a notch to be present on the audiograms of both ears in order for a person to be classified as having a notch,[20] but in this study we used both unilateral and bilateral definitions of Hoffman's notch, because all the other notch definitions were based on unilateral and bilateral notches.

The Coles notch was defined as a high-frequency notch when the hearing threshold level at 3 and/or 4 and/or 6 kHz is at least 10 dB HL greater than the thresholds at 1 or 2 kHz and at 6 or 8 kHz.[20]

The 4-kHz notch was defined as hearing thresholds at 2 and 8 kHz that are both at least 10 dB HL lower than (better than) the threshold at 4 kHz.[18]

The Wilson audiometric notch was defined as thresholds at 2 and 8 kHz that are both at least 10 dB HL lower than (better than) the threshold at the notch frequency of interest (3, 4, or 6 kHz).[19]

Exposures. Occupational noise exposure was assessed by several questionnaire items. One of them was assumed to tap loud noise at work in general ("Are you exposed to loud noises at work, or have you been exposed at work earlier in life for periods as long 3 months?" scored from Never = 0 to >15 hours per week = 3.). Ten items specified different types of noisy working places, such as "mechanical/workshop industry" and "building/construction," each scored "no" = 0 or "yes" = 1. Nine other items, specifying various sources of occupational noise such as "staple gun, hammering" and "machine room," were also scored 0 or 1. A single occupational noise indicator was generated as an unweighted sum of the general occupational noise item, the noisy working place items, and the items pertaining to sources of occupational noise. The unweighted sum has been shown to explain the variance of hearing loss almost as well as an optimally weighted sum of the same noise items.[23] The occupational noise sum score, with a range from 0 to 22, was categorized as 0: no reported occupational noise, 1 to 4: some occupational noise, and >4: high occupational noise exposure.

Exposure to music was assessed by three questionnaire items: "playing in a brass band or other type of band" and "been to discotheques" was scored "no" = 0, "perhaps or don't know" = 1, or "yes" = 2. Going to rock concerts or other places with loud music more frequently than once a month both were scored the same way. Using a Walkman or other type of "pocket disco" with ear phones was scored as "never/rarely" = 0, "1 to 2 hours per week" = 1, "3 to 6 hours per week" = 2, and "more than 6 hours per week" = 3. The three items were summed into a single music sum score that was further categorized as no exposure to music (original sum score = 0), some exposure to music (sum score 1–2), and high exposure to music (sum score >2). Exposure to impulse noise (e.g., explosions, shooting) and recurrent ear infections since childhood were scored using "no" = 0, "perhaps or don't know" = 1, or "yes" = 2. The items on the questionnaire are described in detail elsewhere.[4] Missing values at single items were treated as absence of exposure.

Statistics

The data analysis was performed with SPSS IBM Statistics version 22 (IBM, Armonk, NY). Groups were compared using the χ^2 test for categorical variables and analysis of variance for continuous variables. Sex and age adjustments were performed in SPSS using the UNIANOVA procedure. Logistic regression was used for the multivariable analysis of categorical variables.

RESULTS

Audiometric data and data on noise exposure were obtained from 49,774 subjects, which is the sample used in this study. Table I gives an overview of the study population. The majority of the participants reported no exposure to occupational noise. Also, men were much more likely to report "some" and/or "high" noise exposure

TABLE I.
Background Data Related to Occupational Noise Exposure.

	Occupational Noise Exposure			
	No	Some	High	*P*
Men				
No.	6,142	12,589	4,566	
Age, yr, mean (SD)*	49.5 (17.5)	50.4 (16.6)	49.8 (15.9)	<.001
Mean hearing threshold, dB, binaural, 3, 4, and 6 kHz†	27.7 (27.3, 28.1)	31.4 (31.1, 31.6)	35.0 (34.6, 35.5)	<.001
Mean hearing threshold, dB, binaural, 0.5, 1, 2, and 4 kHz†	16.6 (16.3, 16.8)	18.5 (18.4, 18.7)	20.8 (20.5, 21.1)	<.001
Women				
No.	20097	6046	334	
Age, yr, mean (SD)*	51.0 (17.6)	46.9 (15.3)	50.8 (17.7)	<.001
Mean hearing threshold, dB, binaural, 3, 4, and 6 kHz†	20.6 (20.4, 20.8)	20.9 (20.5, 21.2)	22.5 (21.1, 23.9)	<.01
Mean hearing threshold, dB, binaural, 0.5, 1, 2, and 4 kHz†	15.4 (15.2, 15.5)	15.6 (15.3, 15.8)	16.7 (15.6, 17.8)	<.05

*Analysis of variance.
†UNIANOVA adjusted for age (95% confidence interval).
SD = standard deviation.

compared to women. There was a dose-response relationship between the reported occupational noise exposure and hearing thresholds in men. The age-adjusted differences in average hearing thresholds between those who reported no noise exposure and those who reported high noise exposure were 7.4 dB HL for the binaural mean of 3, 4, and 6 kHz, and 4.2 dB HL for the binaural mean of 0.5, 1, 2, and 4 kHz. The corresponding differences in hearing thresholds in women were 1.9 dB and 1.3 dB, respectively.

Table II shows the prevalence of unilateral and bilateral notches. The prevalence of notches in the 3 to 6 kHz range (Wilson, Hoffmann, and Coles) varied from 50% to 60% in men without an occupational noise exposure to 60% to 70% in the most exposed men. The differences were statistically significant only for bilateral notches. For 4 kHz notches the prevalence varied from 25% in occupationally nonexposed to 35% in the most highly exposed men, and the differences were statistically significant for both bilateral and unilateral notches. The prevalence of notches was lower for women than for men, especially for 4 kHz notches, and the differences between occupational noise exposed and nonexposed were smaller and less clear than in men.

Women with some noise exposure had a higher prevalence of bilateral Wilson, Coles, the 4 kHz notch, and unilateral Coles and the 4 kHz notch than the nonexposed. For women who reported a high noise exposure, the prevalence of notches were similar to the prevalence of the nonexposed except for the unilateral Coles notch, which was significantly lower in the highly exposed ones.

The prevalence of bilateral notches appears to increase up until the age of approximately 50 years in men and then to decrease. In women, the prevalence of bilateral Wilson and Coles notches are highest among the young and then decrease gradually, especially after 50 years of age (Table III).

Because age, gender, and noise exposure seem to be associated with the prevalence of notches, we analyzed the odds of notches for both unilateral and bilateral notches for men and women separately (Tables (IV–VII)), unadjusted and adjusted for covariates such as impulse noise, exposure to music, recurrent ear infection and age. Unilateral audiometric notches had a weak association with noise exposure in men (Table IV) but not in women (Table V). There was a significant dose-response relationship for bilateral notches in men (Table VI) but not in women (Table VII). In general the associations between impulse noise (both recreational and occupational exposures) and notches were similar to those for occupational noise exposure and notches. Exposure to music was not related to the prevalence of notches, and histories of recurrent ear infections resulted in a slightly reduced odds ratios of notches in men and women.

DISCUSSION

In this study we found that audiometric notches occur commonly in the Nord-Trøndelag County population, both in occupationally noise-exposed and nonexposed residents. Occupational noise exposure was associated with an increased prevalence of bilateral notches but only for unilateral 4 kHz notches in men. For women the association between notches and occupational exposure to noise was less clear. One explanation may be that women reported noise exposure much less than men, and the hearing loss associated with exposure to occupational noise was smaller than in men.

The associations between bilateral notches and occupational noise exposure are consistent, with NIHL being typically bilateral, and that a unilateral hearing loss is inconsistent with an occupationally mediated NIHL.[5,12]

A history of recreational exposure to loud music, such as playing in a band or going to rock concerts, was not associated with notched audiograms. This is in line with other studies showing no link between music and hearing loss.[22,24]

TABLE II.
Prevalence of Audiometric Notches (%) in One or Both Ears in Relation to Occupational Noise Exposure and Sex.

	Occupational Noise Exposure					
	No		Some*		High*	
	Unilateral	Bilateral	Unilateral	Bilateral	Unilateral	Bilateral
Men (N = 23,297)						
Wilson notch	34.7	16.2	34.8	21.1†	36.5	23.4†
Hoffman notch	34.3	19.7	34.7	26.7†	34.6	30.9†
4 kHz notch	19.5	5.2	22.4†	9.2†	24.9†	11.0†
Coles notch	37.7	22.6	36.9	28.3†	38.7	31.1†
Women (N = 26,477)						
Wilson notch	28.8	8.1	30.0	10.3†	26.3	9.6
Hoffman notch	28.1	8.6	28.0	9.3	25.1	8.4
4 kHz notch	8.2	1.0	9.3‡	1.4‡	8.4	0.9
Coles notch	33.5	11.8	35.0§	14.2†	27.5§	15.0

*Pearson χ^2 test. Noise exposure: some versus no and high versus no.
†$P < .001$.
‡$P < .01$.
§$P < .05$.

The prevalence of notches in this study was quite similar to those among railway workers, where an association between occupational noise exposure and the occurrence of notches was found.[21] The prevalence of the 4 kHz notches in our study was similar to that of military veterans described by Wilson[18] and Wilson and McArdle.[19] However, the prevalence of the Wilson notch was slightly higher in our study. Both studies revealed that unilateral notches are more common than bilateral ones. Wilson et al. did not have any occupational noise exposure data available in their study, but they described their subjects' hearing as fairly normal as compared with a US reference population.[25]

This study has several strengths and weaknesses. One of the major strengths is that it is derived from a large population-based study where the hearing data were collected in a uniform manner (same sound-treated booths, headphones, and audiometric equipment) according to a standard protocol. The study also collected information about recurrent ear infections, impulse noise, and exposure to loud music, which has made it possible to adjust for these factors in the analysis. The impact of these adjustments was, however, limited. One weakness is that information on noise exposure was obtained using a questionnaire at the time of the exam without a more thorough noise exposure history that could have

TABLE III.
Prevalence of Unilateral and Bilateral Audiometric Notches in Relation to Age and Sex.

	Wilson Notch		Hoffman Notch		4 kHz Notch		Coles Notch	
	Unilateral	Bilateral	Unilateral	Bilateral	Unilateral	Bilateral	Unilateral	Bilateral
Men, age, yr (N = 23,297)								
<25	37.4	15.9	27.5	9.5	17.7	3.6	40.4	22.2
25–34	38.3	18.2	33.6	14.8	20.0	4.6	40.6	26.2
35–44	37.7	23.4	35.5	24.1	22.9	9.2	39.5	30.5
45–54	36.3	26.7	35.5	33.9	26.3	13.0	37.1	34.8
55–64	34.9	22.3	34.7	35.2	25.8	11.7	36.7	29.6
65–74	31.3	14.0	36.1	26.7	19.8	6.3	35.1	20.3
>74	25.6	9.8	33.7	20.1	14.0	3.7	31.4	14.1
Women, age, yr (N = 26,477)								
<25	34.9	11.1	23.5	5.7	8.8	0.8	39.4	15.2
25–34	34.3	11.5	25.3	7.4	9.6	0.8	38.4	16.4
35–44	34.1	11.3	29.1	9.3	9.6	1.2	38.8	15.3
45–54	33.0	10.0	31.7	10.3	9.8	1.8	37.2	14.5
55–64	27.2	7.1	29.8	10.4	9.1	1.0	31.9	11.5
65–74	19.4	4.1	26.6	8.2	6.5	0.6	25.4	6.5
>74	15.2	3.0	25.0	6.9	3.3	0.6	20.3	4.1

Data are presented as percentages.

TABLE IV.
Binary Logistic Regression for Men of the Odds of Unilateral Audiometric Notches Associated With Occupational Noise Exposure, Impulse Noise, Music, Ear Infections, and Age.

	Wilson Notch cOR (95% CI)	Hoffman Notch cOR (95% CI)	4 kHz Notch cOR (95% CI)	Coles Notch cOR (95% CI)	Wilson Notch aOR (95% CI)	Hoffman Notch aOR (95% CI)	4 kHz Notch aOR (95% CI)	Coles Notch aOR (95% CI)
Occupational noise exposure								
No	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
Some	1.11 (1.04, 1.19)	1.21 (1.13, 1.29)	1.26 (1.17, 1.36)	1.12 (1.04, 1.20)	1.10 (1.02, 1.18)	1.17 (1.09, 1.25)	1.23 (1.14. 1.33)	1.11 (1.03, 1.19)
High	1.29 (1.18, 1.40)	1.34 (1.23, 1.47)	1.50 (1.37, 1.65)	1.35 (1.23, 1.47)	1.22 (1.12, 1.34)	1.26 (1.15, 1.38)	1.40 (1.27, 1.54)	1.30 (1.18, 1.43)
Impulse noise								
No	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)†
Perhaps	1.19 (1.09, 1.30)	1.12 (1.02, 1.23)	1.21 (1.10, 1.34)	1.10 (1.00, 1.21)	1.12 (1.02, 1.22)	1.13 (1.02, 1.24)	1.16 (1.05. 1.27)	1.02 (0.92. 1.12)
Yes	1.20 (1.10, 1.30)	1.20 (1.10, 1.30)	1.25 (1.15, 1.36)	1.18 (1.08, 1.28)	1.18 (1.09, 1.28)	1.19 (1.09, 1.30)	1.21 (1.10, 1.32)	1.14 (1.05, 1.25)
Music								
No	1 (Ref)*	1 (Ref)*	1 (Ref)†	1 (Ref)*	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Some	1.14 (1.07, 1.22)	0.84 (0.78, 0.90)	0.97 (0.90, 1.04)	1.18 (1.10, 1.26)	0.98 (0.91, 1.06)	0.94 (0.87, 1.02)	0.96 (0.89, 1.04)	1.01 (0.93, 1.08)
High	1.21 (1.11, 1.32)	0.70 (0.64, 0.76)	0.87 (0.79, 0.96)	1.21 (1.10, 1.33)	1.01 (0.92, 1.12)	0.91 (0.82, 1.01)	0.94 (0.84, 1.05)	1.01 (0.91, 1.12)
Recurrent ear infections								
No	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)‡	1 (Ref)†	1 (Ref)†	1 (Ref)‡
Perhaps	0.96 (0.85, 1.09)	0.98 (0.86, 1.12)	0.96 (0.84, 1.10)	1.05 (0.92, 1.20)	0.91 (0.80, 1.03)	0.96 (0.84, 1.10)	0.91 (0.79, 1.05)	1.00 (0.88, 1.14)
Yes	0.95 (0.88, 1.03)	0.91 (0.84, 0.98)	0.95 (0.87, 1.03)	0.94 (0.86, 1.02)	0.88 (0.81, 0.95)	0.89 (0.82, 0.97)	0.90 (0.82, 0.98)	0.87 (0.80, 0.94)
Age group, yr								
<25	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
25–34	1.10 (0.96, 1.27)	1.50 (1.30, 1.73)	1.18 (1.00, 1.39)	1.13 (0.98, 1.31)	1.08 (0.94, 1.25)	1.43 (1.24, 1.66)	1.12 (0.95, 1.32)	1.10 (0.95, 1.27)
35–44	1.21 (1.06, 1.39)	2.02 (1.75, 2.32)	1.50 (1.28, 1.75)	1.22 (1.06, 1.41)	1.20 (1.05, 1.38)	1.93 (1.67, 2.23)	1.43 (1.21, 1.68)	1.19 (1.03, 1.38)
45–54	1.23 (1.07, 1.40)	2.66 (2.31, 3.07)	1.93 (1.65, 2.26)	1.22 (1.06, 1.40)	1.22 (1.06, 1.41)	2.53 (2.18, 2.94)	1.84 (1.56, 2.16)	1.20 (1.04, 1.39)
55–64	1.02 (0.88, 1.17)	2.65 (2.28, 3.07)	1.83 (1.56, 2.16)	1.01 (0.87, 1.17)	1.00 (0.86, 1.16)	2.47 (2.11, 2.89)	1.71 (1.44, 2.03)	0.98 (0.84, 1.15)
65–74	0.71 (0.62, 0.82)	2.22 (1.92, 2.57)	1.19 (1.01, 1.41)	0.73 (0.63, 0.84)	0.70 (0.60, 0.81)	2.05 (1.75, 2.40)	1.11 (0.93, 1.32)	0.71 (0.60, 0.82)
>74	0.50 (0.42, 0.58)	1.67 (1.42, 1.96)	0.76 (0.62, 0.92)	0.53 (0.45, 0.62)	0.49 (0.41, 0.58)	1.55 (1.31, 1.84)	0.71 (0.58, 0.87)	0.52 (0.44, 0.62)

Wald χ^2 test.
*$P < .001$.
†$P < .05$.
‡$P < .01$.
aOR = adjusted odds ratio (adjusted for other covariates); CI = confidence interval; cOR = crude odds ratio.

involved objective measurements of noisy environments. This leaves open a risk for random misclassification, which may have biased the results in favor of the null hypothesis, but we believe that such a possible bias is at worst moderate. A possible systematic misclassification, where people who know they have a hearing loss tend to over-report noise exposure, also cannot be ruled out. Such an effect will inflate the observed effects of noise and counteract the effect of random misclassification. Also, the standard clinical TDH 39 headphones were used for audiometry, which may have given rise to a +5 to +6 dB HL error in the threshold registration at 6 kHz,[15] although such an effect is by no means certain. Furthermore, in this cross-sectional study, we cannot exclude a certain amount of respondents' self-selection bias for attendance at the examination, but we do not believe that this possibility has provided systematic errors of importance, because most HUNT participants attended the study for reasons unrelated to the hearing exam.

Our aim was to study four well-established types of notches. However, we cannot safely conclude that our results are fully valid for all possible definitions of notches. For instance, deeper or otherwise more strictly

TABLE V.
Binary Logistic Regression for Women of the Odds of Unilateral Audiometric Notches Associated With Occupational Noise Exposure, Impulse Noise, Music, Ear Infections, and Age.

	Wilson Notch cOR (95% CI)	Hoffman Notch cOR (95% CI)	4 kHz Notch cOR (95% CI)	Coles Notch cOR (95% CI)	Wilson Notch aOR (95% CI)	Hoffman Notch aOR (95% CI)	4 kHz Notch aOR (95% CI)	Coles Notch aOR (95% CI)
Occupational noise exposure								
No	1 (Ref)*	1 (Ref)	1 (Ref)†	1 (Ref)‡	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Some	1.10 (1.04. 1.18)	1.01 (0.94, 1.07)	1.16 (1.05, 1.28)	1.13 (1.06, 1.20)	0.99 (0.92, 1.05)	0.98 (0.92, 1.05)	1.07 (0.96,	1.01 (0.95, 1.08)
High	0.90 (0.70. 1.16)	0.85 (0.66, 1.10)	1.02 (0.69, 1.51)	0.78 (0.61, 1.01)	0.89 (0.69, 1.15)	0.84 (0.65, 1.09)	1.00 (0.68, 1.49)	0.78 (0.60, 1.01)
Impulse noise								
No	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Perhaps	1.12 (0.95, 1.33)	1.12 (0.95, 1.32)	1.33 (1.04, 1.69)	1.17 (0.99, 1.38)	1.05 (0.88, 1.24)	1.15 (0.97, 1.36)	1.25 (0.98, 1.60)	1.10 (0.93, 1.30)
Yes	1.07 (0.82, 1.40)	1.19 (0.92, 1.54)	1.17 (0.79, 1.73)	1.07 (0.82, 1.39)	1.07 (0.82, 1.40)	1.23 (0.95, 1.60)	1.15 (0.77, 1.70)	1.08 (0.83, 1.40)
Music								
No	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Some	1.39 (1.30, 1.49)	0.90 (0.84, 0.96)	1.25 (1.12, 1.39)	1.41 (1.32, 1.51)	0.96 (0.89, 1.04)	0.93 (0.86, 1.01)	1.08 (0.96, 1.22)	0.99 (0.91, 1.07)
High	1.58 (1.45, 1.71)	0.84 (0.77, 0.92)	1.26 (1.11, 1.44)	1.56 (1.44, 1.70)	1.04 (0.94, 1.15)	0.95 (0.86, 1.06)	1.11 (0.95, 1.31)	1.04 (0.94, 1.15)
Recurrent ear infections								
No	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Perhaps	1.02 (0.90, 1.16)	1.02 (0.89, 1.16)	1.19 (0.98, 1.45)	1.03 (0.91, 1.17)	0.94 (0.83, 1.08)	1.01 (0.89, 1.15)	1.12 (0.92, 1.36)	0.95 (0.84, 1.08)
Yes	1.04 (0.98, 1.11)	1.00 (0.93, 1.07)	0.98 (0.88, 1.09)	1.00 (0.94, 1.07)	0.97 (0.90, 1.03)	1.00 (0.93, 1.07)	0.93 (0.83, 1.03)	0.93 (0.87, 0.99)
Age group, yr								
<25	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡	1 (Ref)‡
25–34	0.98 (0.87, 1.11)	1.13 (0.99, 1.29)	1.11 (0.91, 1.35)	0.98 (0.87, 1.11)	0.99 (0.88, 1.12)	1.13 (0.99, 1.30)	1.12 (0.92, 1.37)	0.99 (0.87, 1.12)
35–44	0.97 (0.86, 1.09)	1.42 (1.25, 1.62)	1.11 (0.92, 1.35)	0.97 (0.86, 1.10)	0.98 (0.87, 1.11)	1.41 (1.23, 1.61)	1.16 (0.95, 1.42)	0.99 (0.87, 1.12)
45–54	0.90 (0.80, 1.01)	1.65 (1.45, 1.87)	1.14 (0.94, 1.38)	0.89 (0.79, 1.00)	0.91 (0.79, 1.04)	1.60 (1.39, 1.84)	1.22 (0.99, 1.51)	0.90 (0.79, 1.03)
55–64	0.64 (0.57, 0.73)	1.51 (1.32, 1.72)	1.04 (0.85, 1.28)	0.65 (0.57, 0.73)	0.65 (0.56, 0.75)	1.45 (1.24, 1.68)	1.13 (0.90, 1.42)	0.66 (0.57, 0.76)
65–74	0.39 (0.35, 0.45)	1.23 (1.07, 1.41)	0.73 (0.59, 0.90)	0.43 (0.38, 0.49)	0.40 (0.34, 0.46)	1.18 (1.01, 1.37)	0.79 (0.63, 1.01)	0.43 (0.38, 0.50)
>74	0.29 (0.25, 0.34)	1.11 (0.96, 1.28)	0.35 (0.27, 0.46)	0.31 (0.27, 0.36)	0.29 (0.25, 0.34)	1.06 (0.90, 1.25)	0.39 (0.29, 0.52)	0.31 (0.27, 0.37)

Wald χ^2 test.
*$P < .01$.
†$P < .05$.
‡$P < .001$.
aOR = adjusted odds ratio (adjusted for other covariates); CI = confidence interval; cOR = crude odds ratio.

defined notches might prove to be somewhat more strongly associated with noise exposure.

The age-adjusted difference in hearing threshold among the occupationally most highly noise-exposed in this study is moderate, between 7 and 8 dB HL in the 3 to 6 kHz range for men and only 1 to 2 dB HL for women, compared to the hearing loss of those who reported no noise exposure. The finding of a moderate effect of noise on hearing loss generally in this population seems to correspond with the small differences in prevalence of notches between the occupationally noise-exposed and the nonexposed adults, in particular for women. It is important to note that other possibilities have not been ruled out, including individual differences to susceptibility to hearing loss from noise exposure and the failure to account for many other sources of noise exposure across the lifespan of the study participants.

It is comforting to learn that the moderate differences found in hearing loss between the occupationally noise exposed and nonexposed is the situation in today's working life in Norway and probably also in many other countries in the Western world. The underlying reason is probably due to increased awareness of the damage that can result from very loud noise exposure and,

TABLE VI.
Binary Logistic Regression for Men of the Odds of Bilateral Audiometric Notches Associated With Occupational Noise Exposure, Impulse Noise, Music, Ear Infections, and Age.

	Wilson Notch cOR (95% CI)	Hoffman Notch cOR (95% CI)	4 kHz Notch cOR (95% CI)	Coles Notch cOR (95% CI)	Wilson Notch aOR (95% CI)	Hoffman Notch aOR (95% CI)	4 kHz Notch aOR (95% CI)	Coles Notch aOR (95% CI)
Occupational noise exposure								
No	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
Some	1.44 (1.33, 1.57)	1.61 (1.49, 1.75)	1.93 (1.70, 2.19)	1.43 (1.32, 1.55)	1.41 (1.30, 1.54)	1.51 (1.39, 1.64)	1.87 (1.64, 2.13)	1.40 (1.29, 1.52)
High	1.77 (1.59, 1.96)	2.08 (1.89, 2.30)	2.46 (2.12, 2.85)	1.81 (1.64, 2.00)	1.61 (1.44, 1.80)	1.82 (1.64, 2.02)	2.22 (1.91, 2.59)	1.66 (1.49, 1.84)
Impulse noise								
No	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
Perhaps	1.34 (1.20, 1.48)	1.30 (1.18, 1.44)	1.34 (1.16, 1.53)	1.31 (1.18, 1.45)	1.22 (1.09, 1.36)	1.29 (1.16, 1.43)	1.23 (1.06, 1.42)	1.18 (1.06, 1.31)
Yes	1.31 (1.20, 1.44)	1.45 (1.32, 1.58)	1.42 (1.26, 1.60)	1.31 (1.20, 1.44)	1.25 (1.13, 1.38)	1.38 (1.26, 1.52)	1.30 (1.15, 1.48)	1.23 (1.12, 1.35)
Music								
No	1 (Ref)	1 (Ref)*	1 (Ref)*	1 (Ref)†	1 (Ref)	1 (Ref)†	1 (Ref)	1 (Ref)
Some	1.08 (1.00, 1.17)	0.70 (0.65, 0.75)	0.83 (0.74, 0.92)	1.12 (1.04, 1.21)	0.93 (0.86, 1.02)	0.90 (0.82, 0.98)	0.88 (0.78, 0.99)	0.96 (0.88, 1.04)
High	1.04 (0.94, 1.16)	0.49 (0.44, 0.55)	0.68 (0.58, 0.79)	1.15 (1.04, 1.27)	0.91 (0.81, 1.03)	0.85 (0.75, 0.95)	0.87 (0.73, 1.02)	0.99 (0.88, 1.10)
Recurrent ear infections								
No	1 (Ref)	1 (Ref)‡	1 (Ref)	1 (Ref)	1 (Ref)†	1 (Ref)†	1 (Ref)	1 (Ref)†
Perhaps	0.91 (0.78, 1.06)	0.98 (0.85, 1.13)	0.92 (0.75, 1.13)	0.96 (0.83, 1.11)	0.82 (0.70, 0.96)	0.93 (0.80, 1.07)	0.85 (0.69, 1.05)	0.87 (0.75, 1.00)
Yes	0.98 (0.90, 1.08)	0.88 (0.80, 0.96)	0.98 (0.87, 1.11)	0.96 (0.88, 1.05)	0.89 (0.80, 0.97)	0.85 (0.78, 0.94)	0.90 (0.79, 1.03)	0.86 (0.79, 0.94)
Age group, yr								
<25	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
25–34	1.23 (1.03, 1.48)	1.90 (1.54, 2.35)	1.35 (0.97, 1.88)	1.33 (1.12, 1.57)	1.14 (0.95, 1.37)	1.74 (1.41, 2.16)	1.20 (0.86, 1.68)	1.24 (1.04, 1.47)
35–44	1.77 (1.49, 2.11)	3.95 (3.23, 4.84)	2.96 (2.17, 4.03)	1.72 (1.46, 2.02)	1.65 (1.38, 1.98)	3.61 (2.94, 4.44)	2.65 (1.93, 3.63)	1.62 (1.37, 1.92)
45–54	2.13 (1.79, 2.53)	7.31 (5.98, 8.93)	4.71 (3.47, 6.38)	2.08 (1.77, 2.44)	1.95 (1.63, 2.33)	6.56 (5.33, 8.08)	4.17 (3.05, 5.69)	1.96 (1.65, 2.32)
55–64	1.54 (1.28, 1.84)	7.72 (6.29, 9.49)	4.13 (3.02, 5.63)	1.48 (1.26, 1.75)	1.37 (1.13, 1.66)	6.67 (5.38, 8.27)	3.47 (2.51, 4.78)	1.37 (1.14, 1.63)
65–74	0.75 (0.62, 0.91)	4.74 (3.85, 5.82)	1.86 (1.34, 2.57)	0.77 (0.65, 0.91)	0.67 (0.55, 0.81)	4.04 (3.25, 5.02)	1.55 (1.11, 2.17)	0.70 (0.58, 0.84)
>74	0.45 (0.36, 0.56)	2.87 (2.29, 3.58)	0.99 (0.68, 1.44)	0.44 (0.36, 0.53)	0.40 (0.32, 0.51)	2.51 (1.99, 3.18)	0.85 (0.57, 1.25)	0.41 (0.33, 0.50)

Wald χ^2 test.
*$P < .001$.
†$P < .01$.
‡$P < .05$.
aOR = adjusted odds ratio (adjusted for other covariates); CI = confidence interval; cOR = crude odds ratio.

hence, implementation of better hearing protection measures. Hearing losses due to noise in the workplace today are smaller than in the past. In our railway study we found a mean hearing loss of 3 to 4 dB in the 3 to 6 kHz range compared with the controls,[26] as compared to 7 to 8 dB HL in the present study.

Audiometric notches occur commonly both in the occupationally noise exposed and nonexposed in today's workplaces, even among the youngest men and women below 25 years of age. This makes it difficult to validly diagnose NIHL. Still, however, notches are emphasized in guidelines for the diagnosis of NIHL,[5,12] and by some regarded as evidence of NIHL.[27,28] Others have pointed out that audiometric notches should not be regarded as sufficient evidence for NIHL.[15,20,21,29]

This study shows that bilateral notches are associated with occupational noise exposure, with a stronger association in men than in women (Table II). Unilateral 4-kHz notches were also associated with a high noise exposure. For unilateral notches in the 3 to 6 kHz range, there was hardly any or only a weak association between noise exposure and audiometric notches. Because

TABLE VII.
Binary Logistic Regression for Women of the Odds of Bilateral Audiometric Notches Associated With Occupational Noise Exposure, Impulse Noise, Music, Ear Infections, and Age.

	Wilson Notch cOR (95% CI)	Hoffman Notch cOR (95% CI)	4 kHz Notch cOR (95% CI)	Coles Notch cOR (95% CI)	Wilson Notch aOR (95% CI)	Hoffman Notch aOR (95% CI)	4 kHz Notch aOR (95% CI)	Coles Notch aOR (95% CI)
Occupational noise exposure								
No	1 (Ref)*	1 (Ref)	1 (Ref)†	1 (Ref)*	1 (Ref)†	1 (Ref)	1 (Ref)	1 (Ref)
Some	1.35 (1.22, 1.49)	1.10 (0.99, 1.21)	1.47 (1.14, 1.90)	1.29 (1.18, 1.41)	1.17 (1.05, 1.29)	1.06 (0.96, 1.18)	1.32 (1.01, 1.71)	1.11 (1.01, 1.21)
High	1.17 (0.80, 1.70)	0.93 (0.63, 1.38)	0.92 (0.29, 2.90)	1.20 (0.88, 1.65)	1.15 (0.79, 1.69)	0.93 (0.62, 1.38)	0.85 (0.27, 2.68)	1.19 (0.86, 1.64)
Impulse noise								
No	1 (Ref)*	1 (Ref)	1 (Ref)	1 (Ref)‡	1 (Ref)‡	1 (Ref)	1 (Ref)	1 (Ref)†
Perhaps	1.18 (0.91, 1.53)	1.07 (0.82, 1.39)	1.40 (0.74, 2.64)	1.21 (0.97, 1.52)	1.02 (0.78, 1.33)	1.09 (0.83, 1.43)	1.27 (0.67, 2.41)	1.07 (0.84, 1.35)
Yes	1.94 (1.39, 2.71)	1.40 (0.96, 2.04)	2.34 (1.09, 5.00)	1.65 (1.20, 2.26)	1.82 (1.29, 2.56)	1.44 (0.99, 2.10)	2.27 (1.06, 4.87)	1.57 (1.14, 2.17)
Music								
No	1 (Ref)*	1 (Ref)*	1 (Ref)	1 (Ref)*	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Some	1.57 (1.42, 1.75)	0.83 (0.74, 0.93)	1.27 (0.96, 1.67)	1.62 (1.47, 1.77)	0.91 (0.81, 1.03)	0.90 (0.79, 1.03)	1.23 (0.89, 1.68)	0.97 (0.87, 1.08)
High	1.76 (1.55, 2.00)	0.83 (0.72, 0.95)	0.86 (0.58, 1.28)	1.78 (1.59, 2.00)	0.94 (0.81, 1.10)	1.05 (0.88, 1.24)	0.97 (0.61, 1.56)	0.99 (0.87, 1.14)
Recurrent ear infections								
No	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)	1 (Ref)
Perhaps	0.91 (0.73, 1.13)	0.94 (0.76, 1.17)	0.94 (0.52, 1.69)	0.92 (0.76, 1.11)	0.81 (0.65, 1.01)	0.94 (0.76, 1.16)	0.89 (0.50, 1.61)	0.81 (0.67, 0.98)
Yes	1.12 (1.01, 1.25)	0.92 (0.82, 1.02)	1.11 (0.84, 1.47)	1.05 (0.96, 1.15)	1.01 (0.91, 1.12)	0.92 (0.82, 1.02)	1.05 (0.80, 1.39)	0.94 (0.86, 1.03)
Age group, yr								
<25	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*	1 (Ref)*
25–34	1.03 (0.86, 1.25)	1.36 (1.07, 1.72)	1.11 (0.58, 2.10)	1.08 (0.91, 1.28)	1.01 (0.84, 1.22)	1.37 (1.08, 1.75)	1.06 (0.56, 2.03)	1.07 (0.90, 1.27)
35–44	1.00 (0.84, 1.20)	1.85 (1.47, 2.33)	1.63 (0.90, 2.97)	0.99 (0.85, 1.17)	0.98 (0.81, 1.18)	1.89 (1.49, 2.40)	1.61 (0.86, 3.00)	0.99 (0.83, 1.17)
45–54	0.85 (0.71, 1.02)	2.18 (1.74, 2.74)	2.35 (1.31, 4.20)	0.89 (0.76, 1.05)	0.81 (0.66, 0.99)	2.19 (1.71, 2.80)	2.40 (1.27, 4.52)	0.88 (0.73, 1.05)
55–64	0.53 (0.43, 0.64)	2.15 (1.70, 2.72)	1.36 (0.72, 2.55)	0.61 (0.51, 0.72)	0.49 (0.39, 0.62)	2.14 (1.65, 2.77)	1.44 (0.72, 2.86)	0.60 (0.49, 0.73)
65–74	0.26 (0.21, 0.33)	1.55 (1.22, 1.97)	0.71 (0.36, 1.43)	0.28 (0.23, 0.34)	0.25 (0.19, 0.32)	1.54 (1.18, 2.01)	0.78 (0.37, 1.65)	0.28 (0.23, 0.35)
>74	0.18 (0.14, 0.23)	1.24 (0.96, 1.61)	0.74 (0.35, 1.54)	0.16 (0.13, 0.21)	0.17 (0.13, 0.23)	1.24 (0.93, 1.64)	0.82 (0.37, 1.80)	0.16 (0.12, 0.21)

Wald χ^2 test.
*$P < .001$.
†$P < .05$.
‡$P < 0.01$.
aOR = adjusted odds ratio (adjusted for other covariates); CI = confidence interval; cOR = crude odds ratio.

there is no gold standard for what is NIHL, it is not possible to calculate the sensitivity and specificity for NIHL for the various notches in this material, only for being exposed to noise, which is different from NIHL. Therefore, it is not possible on the basis of this study to determine the type of notch criteria that are superior for the diagnosis of NIHL. With a high prevalence rate of NIHL, or where the aim is to prevent or to detect an injury early, a notch with high sensitivity may be preferable. With a low prevalence rate of NIHL, a high specificity may become more important.

Diagnosing NIHL should primarily be based on a measured hearing loss in series of audiograms in combination with a comprehensive noise-exposure history. Only together with such information, a finding of bilateral audiometric notches, such as the Wilson, Hoffman, Coles, or the 4 kHz notch, or a unilateral 4 kHz notch, is indicative of NIHL.

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BIBLIOGRAPHY

1. World Health Organization. Occupational Noise: Assessing the Burden of Disease From Work-Related Hearing Impairment at National and Local Levels. Geneva, Switzerland: World Health Organization; 2004.
2. Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The global burden of occupational noise-induced hearing loss. *Am J Ind Med* 2005;48: 446–458.
3. Dobie RA. The burdens of age-related and occupational noise-induced hearing loss in the United States. *Ear Hear* 2008;29:565–577.
4. Engdahl B, Tambs K, Borchgrevink HM, Hoffman HJ. Screened and unscreened hearing threshold levels for the adult population: results from the Nord-Trondelag Hearing Loss Study. *Int J Audiol* 2005;44:213–230.
5. European Agency for Safety and Health at Work. Noise in Figures. Luxembourg: Office for Official Publications of the European Communities; 2005.
6. European Agency for Safety and Health at Work. Workshop on the occupational burden of disease. 2014.
7. International Organization for Standardization. ISO 1999: 2013. Acoustics—estimation of noise-induced hearing loss. Geneva, Switzerland: International Organization for Standardization; 2013:24.
8. Gates GA, Couropmitree NN, Myers RH. Genetic associations in age-related hearing thresholds. *Arch Otolaryngol Head Neck Surg* 1999;125: 654–659.
9. Raynor LA, Pankow JS, Miller MB, et al. Familial aggregation of age-related hearing loss in an epidemiological study of older adults. *Am J Audiol* 2009;18:114–118.
10. Kvestad E, Czajkowski N, Krog NH, Engdahl B, Tambs K. Heritability of hearing loss. *Epidemiology* 2012;23:328–331.
11. Rabinowitz PM. The public health significance of noise-induced hearing loss. In: Le Prell CG, Henderson D, Fay RR, Popper AN, eds. Noise-Induced Hearing Loss. New York, NY: Springer; 2012:13–25.
12. Kirchner DB, Evenson E, Dobie RA, et al. Occupational noise-induced hearing loss. *J Occup Environ Med* 2012;54:106–108.
13. McBride DI, Williams S. Audiometric notch as a sign of noise induced hearing loss. *Occup Environ Med* 2001;58:46–51.
14. Osei-Lah V, Yeoh L. High frequency audiometric notch: an outpatient clinic survey. *Int J Audiol* 2010;49:95–98.
15. Coles RR, Lutman ME, Buffin JT. Guidelines on the diagnosis of noise-induced hearing loss for medicolegal purposes. *Clin Otolaryngol Allied Sci* 2000;25:264–273.
16. Hoffman HJ, Ko CW, Themann CL, Dillon CF, Franks JR. Reducing noise-induced hearing loss (NIHL) to achieve US healthy people 2010 goals. *Am J Epidemiol* 2006;163:S122.
17. Rabinowitz PM, Galusha D, Slade MD, Dixon-Ernst C, Sircar KD, Dobie RA. Audiogram notches in noise-exposed workers. *Ear Hear.* 2006;27: 742–750.
18. Wilson RH. Some observations on the nature of the audiometric 4000 Hz notch: data from 3430 veterans. *J Am Acad Audiol* 2011;22:23–33.
19. Wilson RH, McArdle R. Characteristics of the audiometric 4,000 Hz notch (744,553 veterans) and the 3,000, 4,000, and 6,000 Hz notches (539,932 veterans). *J Rehabil Res Dev* 2013;50:111–132.
20. Nondahl DM, Shi X, Cruickshanks KJ, et al. Notched audiograms and noise exposure history in older adults. *Ear Hear* 2009;30:696–703.
21. Lie A, Skogstad M, Johnsen TS, Engdahl B, Tambs K. The prevalence of notched audiograms in a cross-sectional study of 12,055 railway workers. *Ear Hear* 2015;36:e86–e92.
22. Tambs K, Hoffman HJ, Borchgrevink HM, Holmen J, Samuelsen SO. Hearing loss induced by noise, ear infections, and head injuries: results from the Nord-Trondelag Hearing Loss Study. *Int J Audiol* 2003;42:89–105.
23. Tambs K, Hoffman HJ, Borchgrevink HM, Holmen J, Engdahl B. Hearing loss induced by occupational and impulse noise: results on threshold shifts by frequencies, age and gender from the Nord-Trondelag Hearing Loss Study. *Int J Audiol* 2006;45:309–317.
24. Lie A, Skogstad M, Johannessen HA, et al. Occupational noise exposure and hearing: a systematic review. *Int Arch Occup Environ Health* 2016; 89:351–372.
25. Wilson RH, Noe CM, Cruickshanks KJ, Wiley TL, Nondahl DM. Prevalence and degree of hearing loss among males in Beaver Dam cohort: comparison of veterans and nonveterans. *J Rehabil Res Dev* 2010;47:505–520.
26. Lie A, Skogstad M, Johnsen TS, Engdahl B, Tambs K. A cross-sectional study of hearing thresholds among 4627 Norwegian train and track maintenance workers. *BMJ Open.* 2014;4:e005529.
27. Anino JO, Afullo A, Otieno F. Occupational noise-induced hearing loss among workers at Jomo Kenyatta International Airport, Nairobi. *East Afr Med J* 2010;87:49–57.
28. Hsu TY, Wu CC, Chang JG, Lee SY, Hsu CJ. Determinants of bilateral audiometric notches in noise-induced hearing loss. *Laryngoscope* 2013; 123:1005–1010.
29. Dobie RA. In reference to determinants of bilateral audiometric notches in noise-induced hearing loss. *Laryngoscope* 2013;123:E129.