

# BMJ Open Noise-induced hearing loss in a longitudinal study of Norwegian railway workers

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## ABSTRACT

**Objective:** The aim of this study was to analyse longitudinal data to assess the risk of noise-induced hearing loss (NIHL) in Norwegian railway workers.

**Design:** Longitudinal.

**Setting:** A major Norwegian railway company.

**Methods:** We examined data from the first and last audiograms for the period 1991–2014, from 9640 railway workers with varying occupational noise exposure and with an average observation period of 10 years. The course of hearing acuity in seven groups of railway workers (train drivers, conductors, bus drivers, traffic controllers, train maintenance workers, track maintenance workers and others) were compared with each other and with ISO standards (ISO 1999).

**Results:** The change in hearing threshold during the observation period was 2–3 dB in the 0.5–4 kHz range and 6–7 dB in the 3–6 kHz range adjusted for age and sex, for all occupational groups, which is slightly less than expected (8 dB) according to ISO 1999.

**Conclusions:** The risk of NIHL in Norwegian railway workers during the period 1991–2014 has been negligible.

## INTRODUCTION

Noise is a well-known cause of hearing loss in the workplace, and noise-induced hearing loss (NIHL) is one of the most reported occupational diseases in Norway and internationally.<sup>1–3</sup> Calculations show that workplace noise causes about 16% of hearing loss worldwide. The percentage is higher in developing countries (up to 23%), and lower in the Western world (10%).<sup>4 5</sup> Historically, the magnitude of exposure to noise in Norwegian workplaces and other developed countries was high and associated with severe hearing loss independent of other known risk factors.<sup>6</sup> This is no longer the situation.<sup>6</sup> Various preventive measures such as legislation, a Labour Inspection Authority, technical noise reduction measures and the use of personal protective equipment have led to much lower noise exposure level.<sup>2 7 8</sup>

## Strengths and limitations of this study

- Large longitudinal study with several occupational groups.
- High quality of the audiometries and of the exposure assessments.
- Lack of information of risk factors of hearing loss other than age, sex and occupational noise exposure, such as leisure time noise exposure, smoking, cholesterol, hypertension, diabetes, high cholesterol, etc.

Population surveys demonstrate that hearing loss is primarily associated with advanced age.<sup>9 10</sup> Men lose more of their hearing than women with age, regardless of noise exposure.<sup>11</sup> The hearing loss varies greatly from person to person, which could be due to many factors including genetics.<sup>12 13</sup> However, there is still a widespread perception that hearing loss due to occupational exposure to noise is very extensive.<sup>4</sup> For many years, Norwegian railway employees have been perceived to be at risk for developing NIHL.<sup>14</sup> In a recent cross-sectional study, we showed that train drivers and conductors have hearing threshold levels similar to those of persons not exposed to noise.<sup>14</sup> Among railway workers engaged in maintenance work on trains and tracks, there was a small but significant hearing loss of ~5 dB among the oldest compared with non-noise-exposed.<sup>15</sup> Since railway employees must have good health to become employed, we assumed that there could be a certain amount of selection into the profession that may have biased the result. Furthermore, both the aforementioned Norwegian railway studies were cross-sectional. The aim of this study was therefore to conduct a longitudinal study of hearing in the train staff to see if hearing loss among train drivers, conductors and train and track maintenance workers was larger than expected during the observation period.



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## METHOD

### The study group

The study participants were all railway employees who have been examined regularly at the occupational health service (OHS) of the Norwegian State Railway. Railway employees such as train drivers, conductors, traffic controllers and most of the railway maintenance workers are classified as safety personnel in accordance with a European Union regulation, and must therefore be medically certified at intervals of 1–5 years depending on their age. A hearing test is part of their medical examination. There are also health requirements for bus drivers, but these are less comprehensive than for railway personnel. To be included in the survey, at least two complete audiograms in the digital medical record were required. The first and last audiograms from the period 1991 to 2014 were used in the present study. Participants with incomplete audiograms (N=118) or an observation period of <1 year (N=243) were excluded from the analysis.

### Noise exposure

A noise exposure assessments programme by dosimetry (Casella dBadge CEL-350) was conducted by the OHS in the railway company by a certified occupational hygienist.<sup>14 15</sup> The 8 hour noise exposure level was 70–80 dB(A) in train drivers, 70–85 dB(A) in train conductors and with peak levels of 130 dB(C) while shunting of trains and 115 dB(C) while blowing the whistle on the platform or using the signal horn of the train. For the train and track maintenance workers, the daily exposure level was 75–90 dB(A) with an average level of 85–86 dB(A) and with peak exposures of 130–140 dB(C). The use of hearing protection is mandatory at high exposure levels, so the actual exposure to the ear is substantially lower for the maintenance workers. For traffic controllers, the exposure is estimated to be below 70 dB (A), for bus drivers in the range 70–75 dB (A) and for ‘others’ the exposure levels are not known.

### Hearing examination

The audiometric testing was performed by specially trained nurses in the OHS of the railway company using Madsen Xeta Otometrics pure tone audiometry with TDH-39P headphones in a soundproof booth. The procedure of the Labour Inspection Authority, which is equivalent to ISO 8253-1,<sup>16</sup> was used for testing at frequencies 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz. The audiometers were calibrated every second year according to the requirements of the equipment provider.

### Statistics

Data from the medical records on age, occupation and sex were used together with audiometric data from the first and last audiograms recorded.

Occupations were classified into seven main groups: (1) Train drivers, (2) train conductors, (3) traffic

controllers, (4) bus drivers and (5) track and (6) train maintenance workers. Participants with other types of occupations were classified as (7) ‘others’.

The average hearing threshold for the better ear of 0.5, 1, 2 and 4 kHz and of 3, 4 and 6 kHz for both the first and the last audiograms were calculated. The better ear for each frequency was used to be comparable with the reference values in ISO. (The better ear refers to the best result of each frequency for the left or right ear). The hearing thresholds for the various occupational groups were then compared with each other. The time between the first and last audiometric examinations was calculated, as were the individual permanent threshold shifts (PTS) during the observation period, calculated as the difference between the second and the first audiometric results. We calculated PTS both unadjusted and adjusted for age, sex and duration of the observation period (UNIANOVA procedure in SPSS) and these scores were compared between occupational groups and with the ISO standard, annex A, calculated by the algorithms given in ISO 1999.<sup>11</sup>

Results from the first and last audiograms for the mean value of 3–6 kHz were eventually compared to reference values from ISO 1999:2013, Annex B2.<sup>11</sup> The Annex B2 is based on a Norwegian reference sample not exposed to noise.<sup>9</sup> Age-specific and sex-specific grouped data for the median and 90th centile for the better ear were used since these statistics were reported in the reference material.

Some of the participants had changed jobs during the observation period or were observed for a short period. Therefore, we also conducted a sensitivity analysis in which we reanalysed the data excluding those with an observation period of <3, 6, 9 and 12 years and those who had changed jobs to see if this affected the results.

We analysed the data using the IBM SPSS Statistics V.23.

## RESULTS

We obtained data from the medical records of 10 001 employees with at least two audiograms. Of these, 118 participants had incomplete audiograms and 243 had an observation period of <1 year and were excluded from the analysis. Our study group therefore consisted of 1088 women and 8552 men, most of whom were Caucasians. Their mean age was 38.3 years (SD 9.9) at the first audiometric examination and 48.8 years (SD 10.7) at the second one.

Table 1 shows an overview of age, gender, occupation and hearing thresholds for the first and last audiometry. There was a significant predominance of men in all groups, but to a lesser extent for conductors, traffic controllers and ‘others’. Conductors were younger and bus drivers were older at the first audiogram. Age was similar at the last audiometric examination for all but for conductors who were younger. The observation time between the first and last examination was significantly

Table 1 Background data

|                                     | Train driver | Train conductor | Bus driver  | Train maintenance | Track maintenance | Traffic controller | Others      | Total       |
|-------------------------------------|--------------|-----------------|-------------|-------------------|-------------------|--------------------|-------------|-------------|
| Number                              | 1568         | 1319            | 713         | 1506              | 2132              | 554                | 1848        | 9640        |
| First audiometry                    | 1454         | 1254            | 712         | 1339              | 1936              | 659                | 2283        | 9640        |
| Age, mean (years)                   |              |                 |             |                   |                   |                    |             |             |
| First audiometry                    | 37.1         | 33.0            | 44.1        | 39.5              | 38.2              | 38.0               | 40.2        | 38.3        |
| Last audiometry                     | 47.8         | 43.7            | 50.8        | 50.1              | 50.6              | 49.7               | 49.2        | 48.8        |
| Sex (% men)                         |              |                 |             |                   |                   |                    |             |             |
| First audiometry                    | 96.6         | 65.0            | 93.8        | 96.3              | 98.6              | 77.3               | 82.7        | 88.7        |
| Last audiometry                     | 95.4         | 65.0            | 93.8        | 96.4              | 98.5              | 79.7               | 85.7        | 88.7        |
| Daily noise exposure, dB(A)         |              |                 |             |                   |                   |                    |             |             |
| $L_{Aeq, 8h}$                       | 70–80        | 70–85           | 70–75       | 85–86             | 85–86             | <70                | unknown     |             |
| Better ear $HTL_{346}$ , dB (SD)    |              |                 |             |                   |                   |                    |             |             |
| First audiometry                    | 10.2 (9.8)   | 8.0 (7.6)       | 16.8 (13.1) | 14.5 (12.1)       | 12.7 (11.6)       | 10.3 (9.9)         | 13.6 (11.5) | 12.3 (11.2) |
| Last audiometry                     | 17.3 (14.1)  | 14.1 (12.5)     | 22.0 (15.1) | 22.3 (15.8)       | 22.0 (15.9)       | 17.5 (13.6)        | 19.3 (14.5) | 19.3 (14.9) |
| Better ear $HTL_{0.5124}$ , dB (SD) |              |                 |             |                   |                   |                    |             |             |
| First audiometry                    | 6.7 (5.8)    | 5.7 (4.9)       | 11.1 (7.2)  | 9.7 (7.1)         | 8.3 (6.6)         | 6.9 (5.8)          | 8.9 (6.3)   | 8.1 (6.5)   |
| Last audiometry                     | 9.6 (7.5)    | 8.3 (7.2)       | 13.2 (8.3)  | 13.2 (8.8)        | 12.2 (8.9)        | 9.7 (7.7)          | 11.3 (7.7)  | 11.1 (8.2)  |

Sex, age, occupational noise exposure and hearing by occupation (mean 3, 4 and 6 kHz and mean 0.5, 1, 2 and 4 kHz, better ear).  $HTL$ , hearing threshold.

shorter for the bus drivers (6.7 years) compared to the other occupational groups (10–12 years). Hearing thresholds also varied between the various occupational groups with the best hearing thresholds for conductors and the poorest for bus drivers.

Table 2 shows the change in unadjusted and adjusted hearing threshold shifts by sex, age and occupation for the 8570 participants with the same profession throughout the study. Men lost more hearing than women during the observation period in the 3–6 kHz range ( $PTS_{346}$ ), but not for the 0.5–4 kHz range ( $PTS_{0.5124}$ ). Age was a strong predictor for PTS. The PTS for the youngest age group, below 36 years, was much lower than for the oldest one. The impact on hearing loss by occupation was much smaller. The change was 2–3 dB in the 0.5–4 kHz range and 6–7 dB in the 3–6 kHz range for all occupational groups. Traffic controllers had the lowest change in hearing thresholds and the difference was 0.8 dB better than the most affected group, track maintenance workers, for 0.5–4 kHz and 1.3 dB for the 3–6 kHz range ( $p < 0.05$ ).

We also calculated the expected hearing thresholds for each participant according to the algorithms in ISO 1999, Annex A.<sup>11</sup> The mean expected change in hearing threshold for the observation period was 4.0 dB for the 0.5–4 kHz range and 8.0 dB for the 3–6 kHz range, that is, slightly higher than observed for all the occupational groups ( $p < 0.001$ ).

We then examined whether participants who had changed jobs during the observation period ( $N=1070$ ) had a different hearing loss than those who had not changed jobs ( $N=8570$ ). The hearing deterioration for the 3–6 kHz range was 6.8 dB for those who had changed jobs when corrected for age, gender and duration of the observation period and 7.1 dB for those who had not changed jobs. The difference was not statistically significant ( $p=0.275$ ).

Some of the survey participants had a short observation period, which might have affected the results. We therefore conducted stepwise sensitivity analyses by removing those with a shorter observation period than 3, 6, 10 and 12 years. With a longer observation period, the change in hearing threshold became greater, but the differences between the groups remained small and practically unchanged with the lowest change in hearing threshold for traffic controllers and the highest for track maintenance workers.

We also compared hearing for the various occupational groups with the ISO 1999 norms (figure 1). The median hearing thresholds in male train drivers and conductors were similar to the ISO reference values, while the 90th centile was somewhat better. The same was the case for traffic controllers. Train and track maintenance workers had a median value that was 3–4 dB higher than the ISO value for all age groups. Their 90th centile values were similar to the ISO values for ages below 50 years, and somewhat higher for ages 50 years and older.

**Table 2** Crude and adjusted mean PTS from the first to last hearing examination by sex, age and occupation

|                    | Number | Crude<br>PTS <sub>346</sub> , dB<br>(95% CI) | PTS <sub>0.5124</sub> , dB<br>(95% CI) | Adjusted<br>PTS <sub>346</sub> , dB<br>(95% CI) | PTS <sub>0.5124</sub> , dB<br>(95% CI) |
|--------------------|--------|--|--|---|--|
| Sex                |        |  |  |   | †                                      |
| Women              | 976    | 3.1 (2.6 to 3.7) <sup>Ref</sup>              | 1.8 (1.4 to 2.1) <sup>Ref</sup>        | 5.7 (5.2 to 6.2) <sup>Ref</sup>                 | 2.9 (2.6 to 3.2) <sup>Ref</sup>        |
| Men                | 7594   | 7.5 (7.3 to 7.7) <sup>***</sup>              | 3.2 (3.1 to 3.3) <sup>***</sup>        | 7.2 (7.0 to 7.3) <sup>***</sup>                 | 3.0 (2.9 to 3.1)                       |
| Age (years)‡       |        |  |  |   | §                                      |
| <36                | 2096   | 2.4 (2.1 to 2.8) <sup>Ref</sup>              | 0.9 (0.7 to 1.2) <sup>Ref</sup>        | 4.4 (4.0 to 4.7) <sup>Ref</sup>                 | 1.7 (1.5 to 1.9) <sup>Ref</sup>        |
| 36 to 44           | 2119   | 6.5 (6.1 to 6.9) <sup>***</sup>              | 2.6 (2.3 to 2.8) <sup>***</sup>        | 5.6 (5.3 to 5.9) <sup>***</sup>                 | 2.2 (2.0 to 2.4) <sup>***</sup>        |
| 44–50              | 2121   | 9.6 (9.2 to 10.0) <sup>***</sup>             | 4.1 (3.9 to 4.3) <sup>***</sup>        | 8.0 (7.7 to 8.3) <sup>***</sup>                 | 3.5 (3.2 to 3.7) <sup>***</sup>        |
| >50                | 2234   | 9.3 (8.9 to 9.7) <sup>***</sup>              | 4.4 (4.1 to 4.6) <sup>***</sup>        | 9.9 (9.5 to 10.2) <sup>***</sup>                | 4.6 (4.4 to 4.8) <sup>***</sup>        |
| Occupation         |        |  |  |   | ¶                                      |
| Traffic controller | 522    | 7.1 (6.3 to 7.9) <sup>Ref</sup>              | 2.8 (2.3 to 3.2) <sup>Ref</sup>        | 6.3 (5.7 to 7.0) <sup>Ref</sup>                 | 2.4 (1.9 to 2.8) <sup>Ref</sup>        |
| Train driver       | 1322   | 7.6 (7.2 to 8.1)                             | 3.3 (3.0 to 3.6)                       | 6.8 (6.3 to 7.2)                                | 3.0 (2.7 to 3.3)                       |
| Train conductor    | 1173   | 5.7 (5.2 to 6.2)                             | 2.5 (2.2 to 2.8)                       | 7.1 (6.6 to 7.5)                                | 3.1 (2.8 to 3.4)                       |
| Bus driver         | 696    | 5.0 (4.3 to 5.7) <sup>**</sup>               | 2.0 (1.5 to 2.4)                       | 6.8 (6.2 to 7.4)                                | 2.6 (2.2 to 3.0)                       |
| Train maintenance  | 1292   | 7.4 (6.9 to 7.9)                             | 3.3 (3.0 to 3.6)                       | 7.0 (6.6 to 7.4)                                | 3.1 (2.8 to 3.4)                       |
| Track maintenance  | 1888   | 9.0 (8.6 to 9.3) <sup>*</sup>                | 3.8 (3.5 to 4.0) <sup>**</sup>         | 7.6 (7.2 to 7.9) <sup>**</sup>                  | 3.2 (3.0 to 3.5) <sup>*</sup>          |
| Others             | 1677   | 5.6 (5.2 to 6.1) <sup>*</sup>                | 2.6 (2.4 to 2.9)                       | 6.8 (6.4 to 7.2)                                | 3.1 (2.8 to 3.3)                       |
| Total              | 8570   |  |  |   |  |

Better ear. Same occupation at the first and last audiograms.

\*p<0.05; \*\*p<0.01; \*\*\*p<0.001.

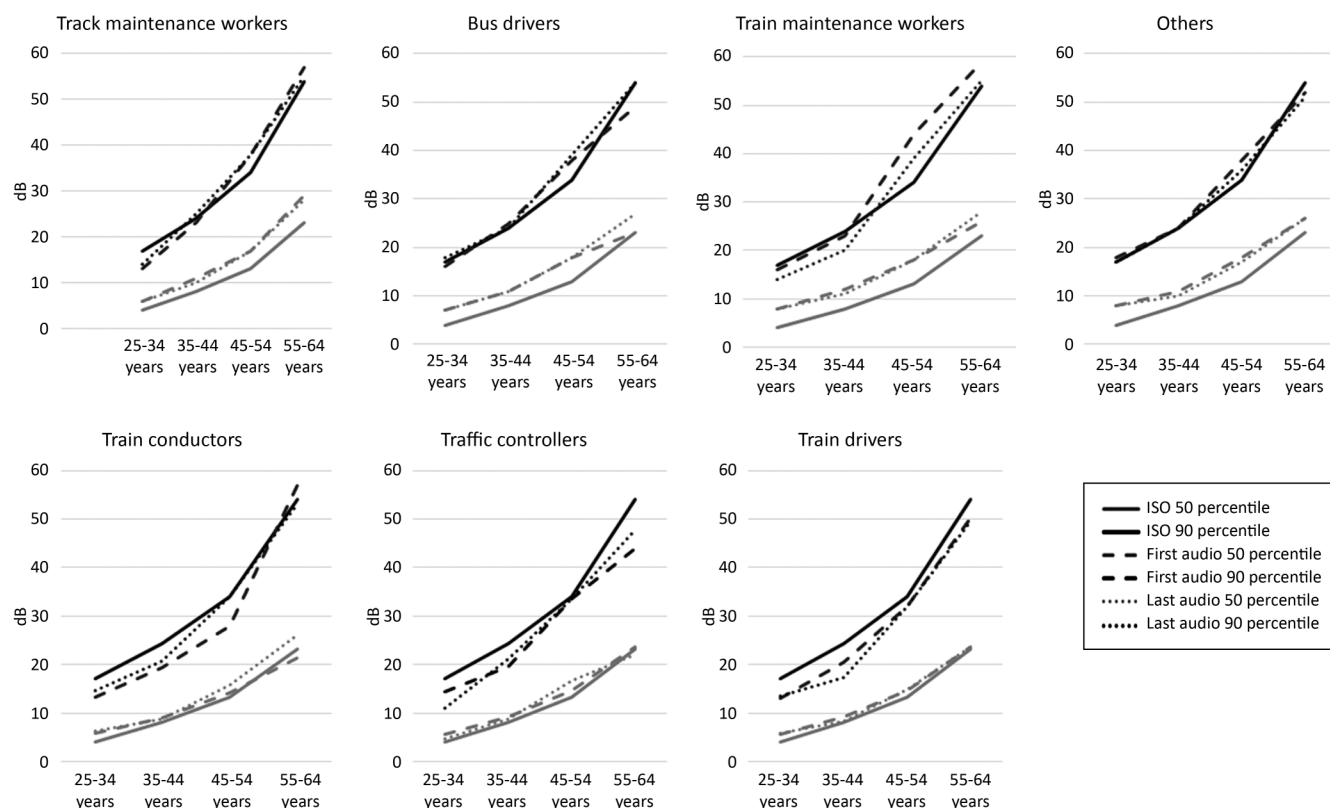
†Adjusted for age, duration of follow-up and occupation.

‡Mean age of the follow-up period by quartiles.

§Adjusted for sex, duration of follow-up and occupation.

¶Adjusted for age, sex and duration of follow-up.

PTS, permanent threshold shift.



**Figure 1** Hearing thresholds by age and occupation at the first and last audiometric examinations compared to reference values from ISO 1999, Annex B2 (Norwegian Reference values). Grouped 50 and 90 centile.



For bus drivers and 'others', the median value was 3–4 dB higher than the ISO value and similar for the 90th centile.

We made equivalent comparisons for women with findings (not shown) similar to those in men.

## DISCUSSION

In this study, we have found that train drivers, conductors and traffic controllers in a Norwegian railroad company had hearing similar to non-noise-exposed references, as of ISO 1999, Annex B2.<sup>11</sup> Bus drivers and track and train maintenance workers had slightly worse hearing: 1–2 and 2–3 dB higher hearing threshold for the 0.5–4 and 3–6 kHz range, respectively, compared to the same reference group. The change in hearing threshold over a 10-year period was very similar, however, 2–3 dB for the 0.5–4 kHz range and 6–7 dB for the 3–6 kHz range, which is slightly less than expected from ISO 1999:2013. Overall findings indicate that hearing loss due to noise exposure at work has been negligible for all groups in the observation period. This is perhaps not the case for track maintenance workers, who had slightly more deterioration in hearing than the traffic controllers. We did find, as expected, that age and sex were important predictors for change in the hearing threshold.<sup>11</sup>

The results of this study confirm the results of previous studies that train drivers and conductors have a hearing similar to that of a reference material.<sup>14 17 18</sup> Their noise exposure is probably too low (<85 dB(A)) to give any NIHL. Also, studies of other occupational groups with similar noise exposure reveal comparable results. For example, a 7-year follow-up study of firefighters exposed to a daily noise exposure level in the range 57–85 dB(A) found a less than expected decline in hearing.<sup>19</sup> Furthermore, in construction workers followed for 4 years and with a daily noise exposure level of more than 90 dB(A), only a small deterioration in hearing was revealed.<sup>20</sup>

At the baseline and follow-up registrations, we found a 2–4 dB higher age-adjusted and sex-adjusted hearing threshold in the 3–6 kHz range among train and track maintenance workers compared to traffic controllers. One explanation may be that hearing loss has occurred before the initial audiogram. The hearing thresholds in the maintenance workers for the 90th centile were lower than the ISO norms for the 30-year-old participants and higher than the ISO norms for the 60-year-old participants. This finding is in line with a cross-sectional survey<sup>15</sup> which may indicate that maintenance workers aged more than 50 years got a NIHL before 1991, possibly due to less focus on hearing protection at that time. A major part of noise-induced hearing loss appears to occur during the first 10–15 years of exposure, and subsequently the hearing loss seems to follow the age-related and sex-related hearing loss as in non-noise exposed.<sup>6 11</sup> This may explain why the change in hearing during the observation period for track

maintenance and train maintenance workers was similar to that of the other occupational groups.

Another explanation for the hearing threshold being higher in maintenance workers than the train drivers, conductors and traffic controllers may be selection into the work. For some of the maintenance workers, a medical certification including requirements of hearing is mandatory. For bus drivers and 'others', the same stringent health requirements are not applied, and they have hearing thresholds similar to the maintenance workers. Furthermore, their level of occupational noise exposure is too low to lead to any significant hearing loss.<sup>11</sup> Still, they had a hearing threshold on the first and last audiograms and a change in the hearing threshold in the observation period similar to that of the train and track maintenance workers.

The main strengths of this study are the high number of participants and the longitudinal study design with a long mean follow-up time of 10 years. The mandatory health requirements every 1–5 year of train drivers, conductors and traffic controllers ensure a close to 100% participation rate. This does not apply to the other occupational groups and may lead to a lower participation rate, but we do not believe that this has affected the results substantially.

Furthermore, we judge the audiometry data to be of good quality. We also have noise exposure data from a comprehensive measurement programme. An unprotected daily noise exposure of 85–86 dB (A), such as in the maintenance workers, will lead to an expected NIHL in the 3–6 kHz range of about 4 dB after 10 years of exposure and 5 dB after 40 years of exposure according to the ISO norms.<sup>11</sup> Since the use of hearing protection is common in maintenance workers during noisy operations, the actual daily noise exposure level is considerably lower, which probably explains why the hearing loss due to noise exposure is negligible.

This study also has some limitations. Data on duration of employment, exposure to leisure noise sources such as shooting, noisy hobbies, participation in concerts, use of personal music players and the use of chainsaws and other noisy tools are missing in this study. Some studies suggest that these factors may be detrimental to hearing.<sup>21–23</sup> With the exception of shooting, most epidemiological evidence suggests that the impact of leisure noise sources is of minor importance to hearing.<sup>7</sup> We do not believe that confounding due to the lack of such information has affected the results of this study to any significant extent.

We did not have access to data of the participants on smoking, cardiovascular disease, hypertension, diabetes, high cholesterol, etc. Some studies show that these factors may affect hearing, but the results are conflicting and in most high quality studies the effects of these factors on hearing are small.<sup>7 24</sup> Moreover, there is no reason to believe that these factors are more prevalent in any of the occupational groups compared to the others. We therefore do not believe that this has affected the results appreciably.

Ethnicity and social group may also affect hearing. People with an African-American background lose less of their hearing than Caucasians and the same applies to those with high compared to low socioeconomic status.<sup>7</sup> In Norway, the railway employees are mainly Caucasians, and social group differences are small between the groups we have studied. We believe that a possible impact of these factors is negligible to the results.

The findings in this study may be valid for Norwegian conditions where the work environment could be good, compared to the conditions in other countries. The Norwegian State Railways has traditionally had a high focus on work, environment and safety and on occupational health. Thus, hearing may develop differently in railway workers in other countries with a poorer working environment and a higher noise exposure.<sup>4 5</sup>

## CONCLUSION

The aim of the study was to determine whether train drivers, conductors and maintenance workers in the Norwegian State Railway are at risk for developing NIHL. This study, with a mean observation period of 10 years during the period 1991–2014, reveals that this is probably not the case. The oldest train and track maintenance workers may, on average, have a small NIHL contracted before 1991.

**Contributors** TSJ has provided data from the OHS and has been involved in the drafting of the manuscript. AL and MS have written the first draft of the manuscript. BE and KT have given valuable advice on the manuscript and statistics. All authors have given substantial contributions to the conception and design, acquisition of the data, analysis and interpretation of the data, drafting and revision of the article and final approval of the version to be published. All authors have contributed to the research and the final document according to the ICMJE guidelines.

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