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Indian J Occup Environ Med. 2019 Sep-Dec; 23(3): 121–125.
Published online 2019 Dec 16.
doi: 10.4103/ijoem.IJOEM_252_18: 10.4103/ijoem.IJOEM_252_18
PMCID: PMC6941339
PMID: 31920261

Effect of Combined Exposure to Noise and Vibration on Hearing

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Received 2018 Dec 1; Revised 2019 Jul 12; Accepted 2019 Aug 27.

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Abstract

Aim:

This study was conducted to examine the effect(s) of combined exposure to whole-body vibration (WBV) and noise in railway workers.

Methods:

In this historical cohort study, train drivers with combined exposure to WBV and impermissible noise as the case group (n = 85) and shunters with just exposure to impermissible noise as the control group (n = 30) were recruited. The hearing threshold at the conventional audiometric frequencies was measured in both the groups, and the standard threshold shift (STS) and hearing threshold shift at higher frequencies were calculated. Data were analyzed by SPSS version 20 using *t*-test, Chi-square, and paired *t*-test.

Results:

There was no significant difference between the groups for age of participants as well as work duration and body mass index. Increased hearing threshold was most frequently observed at 3000, 4000, and 6000 Hz. STS and hearing threshold shift at high frequencies were observed at 6.0% and 3.3%, and 8.2% and 26.7% in train drivers and shunters in the left ear, respectively, but these were not statistically significant.

Conclusion:

Despite the unauthorized exposure to noise and WBV of train drivers, the STS and hearing threshold shift at higher frequencies were not more prevalent compared with the shunters who were exposed only to impermissible noise levels; hence, no association was found between noise and vibration in this study.

Keywords: Hearing loss, noise, standard threshold shift, train drivers, whole-body vibration

Introduction

Noise is the most common physical hazard in the workplace, causing numerous health problems in human, notably noise-induced hearing loss (NIHL).[1] Second to presbycusis, NIHL is the most common sensorineural hearing loss in adults, constituting 16% of disabilities due to hearing loss.[2,3] It is estimated that nearly 500 million people are at risk of NIHL worldwide.[4]

The workers in many industrial and nonindustrial occupations notably construction, transportation, and railway industries are exposed to whole-body vibration (WBV), another important physical hazard. Vibration may be transferred to the whole body through surfaces such as soles (in standing position), buttocks (in sitting position), or supporting areas (in supine position).[5]

Human body response to WBV depends on the frequency, acceleration, and duration of the vibration. The more the frequency and duration of the vibration, the more is its adverse human health effects.[5] Combined exposure to noise and vibration is found in many occupational situations.[6]

There are limited studies on the effects of vibration on human hearing, either in isolation or in combination with noise. Some studies have shown synergistic effects of noise and vibration on hearing ability.[7,8,9] It may be related to the transfer of vibration into the internal ear, which may either have direct effect on the hearing ability or indirectly increase the individual susceptibility to NIHL.[10] However, such a relationship was not found in other studies, and even a survey by Izumi found a lower hearing threshold at frequency of 4 KHz in subjects with concurrent exposure to noise and vibration, suggesting an antagonistic effect of noise and WBV at this frequency.[11]

There are also debates over the influence of WBV *per se* on hearing loss. Some surveys reported that WBV in isolation may not cause hearing loss;[6,11] in contrast, a recent experimental study revealed that WBV standalone may induce hearing loss as well.[5]

This study was conducted to examine the effect(s) of combined exposure to WBV and noise in railway workers in Yazd, Iran.

METHODS

This historical cohort study was conducted on railway workers in Yazd (a central province in Iran) during summer and autumn 2015. The cases had combined exposure to WBV and impermissible noise, that is, exposure to noise levels ≥85 dBA in the workplace,[12] and workers with exposure to impermissible noise without exposure to WBV were considered as the control group.

The Census method was used, and after applying inclusion and exclusion criteria, all eligible individuals were enrolled in the study. Inclusion criteria were as follows: work experience of at least 1 year and presence of a preplacement audiogram as the baseline. In the absence of such an audiogram, the first available one in medical records was considered as the baseline. The exclusion criteria were as follows: history of head injury with loss of consciousness, familial or congenital hearing loss, diabetes mellitus, hyperlipidemia, hypothyroidism, hyperthyroidism, renal diseases, otologic problems (including middle ear inflammation, tympanic membrane perforation, and cerumen impaction), conductive hearing loss, taking ototoxic drugs such as loop diuretics and aminoglycosides, and age >50 years.

After taking written informed consent from all the participants, data including demographic features, work duration, smoking, alcohol use, medical history, exposure to noise outside the workplace, and drug history were gathered using a questionnaire. After measuring the height and weight and otoscopic examination for the existence of cerumen or tympanic membrane perforation, audiometric evaluation was done using a diagnostic audiometer (AC 40; Madsen, Denmark) in an acoustic chamber meeting ANSI 2004 criteria.[13] The hearing threshold was measured separately for each ear at the frequencies of 0.5, 1, 2, 3, 4, 6, and 8 kHz for air condition and at 0.5, 1, 2, 3, and 4 kHz for bone conduction in both the groups. Then, the standard threshold shift (STS) was calculated according to the Occupational Safety and Health Administration (OSHA) regulations[14] at 2, 3, and 4 kHz compared with the baseline audiogram. Because high frequencies (i.e., 3, 4, and 6 kHz) are affected by noise earlier than other conventional frequencies, the mean hearing thresholds in these frequencies in the last audiogram were also compared with the corresponding mean thresholds in the baseline audiogram. The hearing threshold shift ≥10 dB was then considered as STS in high frequencies.[15]

Finally, from 110 train drivers, 85 were enrolled in the study; 25 were excluded (15 due to age more than 50 years and 10 due to other causes such as diabetes mellitus and conductive hearing loss). In the control group, from a total of 36 shunters, 30 were enrolled in the study.

Workplace noise and WBV levels were extracted from the result of measurements routinely performed in the railway industry by industrial hygiene professionals for industrial monitoring.

The values for vibration acceleration were measured at X-, Y-, and Z-axes using vibration-level-meter (Bruel and Kejear 2231) according to ISO 2631-1:1997 standard[16] (number of measurement, N = 4). X-axis shows the direction of the travel, Y-axis indicates the side-to-side direction, and Z-axis represents the vertical direction.

The sum of overall weighted acceleration in the X-, Y-, and Z-axes (a_V) was calculated according to ISO 2631-1:1997 standard.

Taking into account that all measurements must be reported for 8-h daily exposure to vibration,[17] the results were converted accordingly by WBV calculator,[18] and then they were compared with Directive 2002/44/EC of the European Parliament and the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration); that is, exposure action level of 0.5 m/s^2 and 8-h exposure limit value of 1.15 m/s^2, respectively.[19]

Data were analyzed using SPSS version 20 (SPSS Inc., IBM, Chicago, IL, USA). Student's *t*-test was used for the comparison of the mean hearing thresholds between baseline and the last audiograms in each ear. The prevalence of STS and significant hearing threshold shift at high frequencies were compared between the groups by Chi-square test. Paired *t*-test was used for the comparison of the mean hearing threshold of the right and left ears in any group. *P* value less than 0.05 was considered as statistically significant.

The study was the result of a residency thesis in occupational medicine, and the protocol was approved by the medical ethics committee of Shahid Sadoughi University of Medical Sciences.

Results

The mean age of the groups was not significantly different (33.27 ± 3.50 years vs. 34.10 ± 3.69 years, respectively). Likewise, there was no significant difference for work duration between the groups (9.29 ± 2.12 years vs. 8.50 ± 3.51 years, respectively). Table 1 shows the demographic features of the study groups.

As it can be seen in Table 2, according to Directive 2002/44/EC of the European Parliament,[19] daily exposure value for train drivers was above the limit action value (i.e., A (8) = 0.5 m/s^2).

The average of the weighted equivalent level on the scale A (LAeq) for the train driver group was 84.2 dB (A), and for the shunter group, it was 83.6 dB (A). The mean duration between the first and the current audiograms was 4 years in both the groups.

The mean hearing thresholds of train drivers in baseline and the next audiograms as well as the amount of worsening of hearing thresholds across frequencies of 0.5–8 kHz for the right and left ears are shown in Figures 1 and 2, respectively. As presented, the mean hearing threshold of the recent audiograms has been significantly increased across all the frequencies tested compared with the baseline.

The corresponding results for the right and left ears of the shunters are presented in Figures 3 and 4, respectively. As shown, the hearing thresholds have been increased across all the frequencies tested, but they were not statistically significant for 0.5 kHz and 1 kHz in both ears.

In spite of the higher prevalence of STS and hearing threshold shift at high frequencies for both the ears in train drivers compared with the shunters, this was not statistically significant [Table 3].

Discussion

In this study, STS and hearing threshold shift at higher frequencies were more prevalent in both the ears in the group with combined exposure to noise and vibration (train drivers) than the group with isolated noise exposure (shunters), but the difference was not statistically significant.

There are limited and inconclusive studies on the effects of combined exposure to the noise and vibration on hearing threshold in the real workplace circumstances. Silva and Mendes (2005) evaluated the effects of combined exposure to vibration and noise in 141 bus drivers. Despite significant WBV exposure levels (0.85 m/s^2) and exposure to noise level of 83.6 dBA, no association was found between vibration and noise on hearing threshold.[20] In a study by Nasir and Rampal (2011), which evaluated the contributing factors for inducing hearing loss in Malaysian airport personnel, the prevalence of hearing loss was 2.2 times greater in workers exposed to vibration compared with the nonexposed ones (adjusted odds ratio = 2.2, 95% confidence interval: 1.1–4.3).[21] Similarly, another study showed that the amount of sensorineural hearing loss was more than what was anticipated based on merely noise exposure; it was attributed to the exposure to vibration.[22]

Most studies regarding the effects of WBV on hearing, either isolated or in combination with noise, are human or animal studies with inconclusive results.

The findings of the studies conducted between 1983 and 1992 on volunteer participants demonstrated synergistic effects of vibration and noise.[8,18] In brief, the methodology of these studies was exposure to sinusoidal vibration at Z-axis at 2.01–10 Hz and acceleration of 2–2.65 m/s^2, or stochastic vibration at 1.4–11.2 Hz with or without exposure to 60–98 dBA white noise, for 11–16 min, 2–5 times consecutively. Ten to 370 participants with a mean age of 22.5–23.8 years, a mean weight of 37.8–72.2 kg, and a mean height of 179.7–180.7 cm were evaluated in these studies.

In contrast, in a research by Morita, isolated exposure to vibration with a frequency of 17 Hz for 30 min resulted in improved hearing threshold in the participants, but combined exposure to vibration and noise had a synergistic impact, with more transient threshold shift compared with the noise exposure in isolation.[23]

More recent experimental surveys done between 2006 and 2013 showed no synergistic effects for combined exposure to WBV and noise.[11,23,24] In a research by Izumi, in contrast to isolated noise exposure, WBV alone resulted in no significant TTS. While TTS was found in the exposure to both vibration and noise, this was not more than noise exposure alone. It was even reported that combined exposure to noise and vibration may result in lower hearing threshold shift at frequency of 4 kHz, and vibration may have an antagonistic effect against noise at this frequency.[11]

In another survey (2013), 19 subjects with normal hearing were exposed to combined WBV at Z-axis at a frequency of 5 Hz with an acceleration amplitude of 2.12 m/s^2 and 96 dBA sound for 18 min; TTS was then evaluated by performing distortion product otoacoustic emission (DPOAE) both before and after the intervention. This study showed a significantly higher TTS for combined exposure to WBV and noise especially for higher frequencies. The highest TTS rate was observed at 3984 Hz, but no synergism was found between WBV and noise.[24] Dornella *et al*. concluded that WBV *per se* does not lead to hearing threshold shift, and the shift seen after the combined exposure is the result of noise exposure.[25]

An old study by Coles *et al*. in 1965 showed minor hearing threshold shift after exposure to WBV at 15 Hz and some evidence for reduced noise-induced TTS by vibration.[26] Similarly, the results of the animal experimental studies are conflicting, even for the cochlear histologic findings and the frequencies affected by WBV. In a research by Moussavi-Najarkola *et al*., the DPOAE amplitude of the rabbits exposed to WBV was significantly higher than the controls, especially at the mid- to high frequencies compared with low frequencies ($P < 0.05$). In addition, the results were not different for the right and left ears.[5] Histologic evaluation of the inner ear revealed hydropic degenerative changes of the inner hair cells of WBV-exposed subjects.[27]

In another survey conducted on guinea pigs with different exposure times to WBV, vibration resulted in inner ear alterations in all groups. These changes often initiate at the apical cochlear inner hair cells and spread to the basilar cochlear region and are proportionate to the exposure time length. Hence, the study concluded that inner ear damage caused by sinusoidal vibration may deteriorate hearing ability especially at low and middle frequencies.[28]

The effect of vibration on hearing may be due to the transfer of vibration to the inner ear, which could directly affect the hearing ability or may increase subject's susceptibility to NIHL,[10] but we did not find a which study measured the exact amount of WBV really reaching the inner ear.

The limitation of our study was unavailability of pre-employment audiograms in some cases, hence, we considered the first available audiogram in the medical records as the baseline audiogram for the comparison. While most experimental studies evaluated the effects of sinusoidal vibration, we assessed the combined interaction of WBV and noise on human body in the real field wherein the complex vibration pattern is more common than the sinusoidal pattern. Furthermore, this study was designed as historical cohort, while previous researches had a cross-sectional design.

In our study, despite the unauthorized exposure of train drivers to noise and WBV, the STS and hearing threshold shift at higher frequencies were not more prevalent compared with shunters who were exposed only to impermissible noise levels; hence, no interaction was found between noise and vibration in this study. Further prospective research in the real workplaces using advanced audiometric methods such as otoacoustic emission and auditory brainstem response is recommended.

Institution and Ethics approval and informed consent

This study approved by the ethics committee of Shahid Sadoughi University of Medical Sciences. An informed consent was obtained from each participant.

Financial support and sponsorship

This study was supported by Research Deputy of Shahid Sadoughi University of Medical Sciences.

Conflicts of interest

There are no conflicts of interest.

Acknowledgement

This study was the result of a residency thesis in occupational medicine, Shahid Sadoughi University of Medical Sciences.

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Figures and Tables

Table 1

Demographic features of the study groups

	Case	Control	*P*
Age (years)	33.27±3.50	34.10±3.69	**0.27**
Work duration (years)	9.29±2.12	8.50±3.51	**0.14**
Body mass index (kg/m^2)	26.49±3.80	26.83±3.73	**0.65**
Smoking [*n* (%)]	7 (8.2)	0 (0)	**0.19**

Data are presented as mean±standard deviation

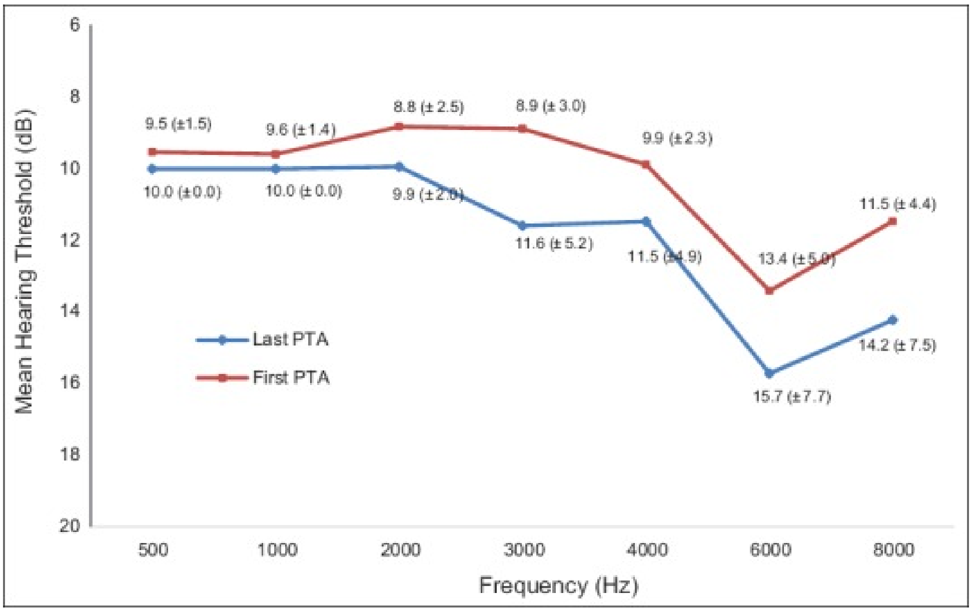
Table 2

Vibration acceleration values and daily exposures of train drivers (total daily exposure=6 h)

	X-axis	Y-axis	Z-axis	aV[†]	Daily vibration exposure
*a (m/s^2)	0.24	0.43	0.80	0.99	-
[‡]A (8) (m/s^2)	o. 29	0.52	0.69	-	**0.69**

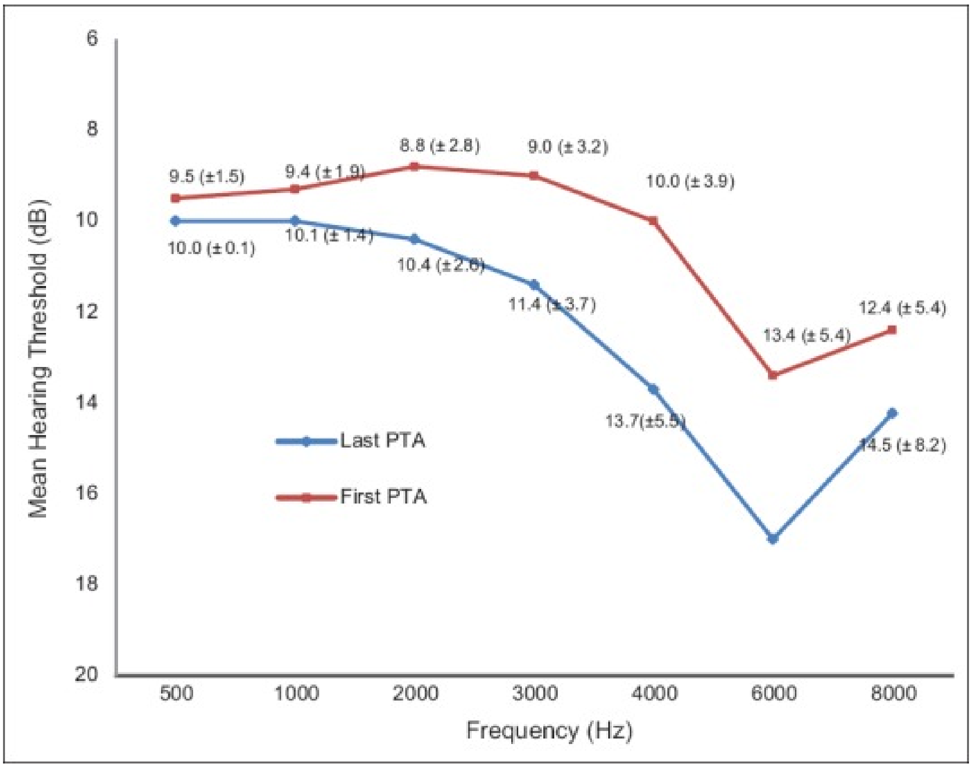
*a: Acceleration value. [†]aV: Sum of overall weighted acceleration in the X-, Y-, and Z-axes. [‡]A (8): daily exposure

Figure 1



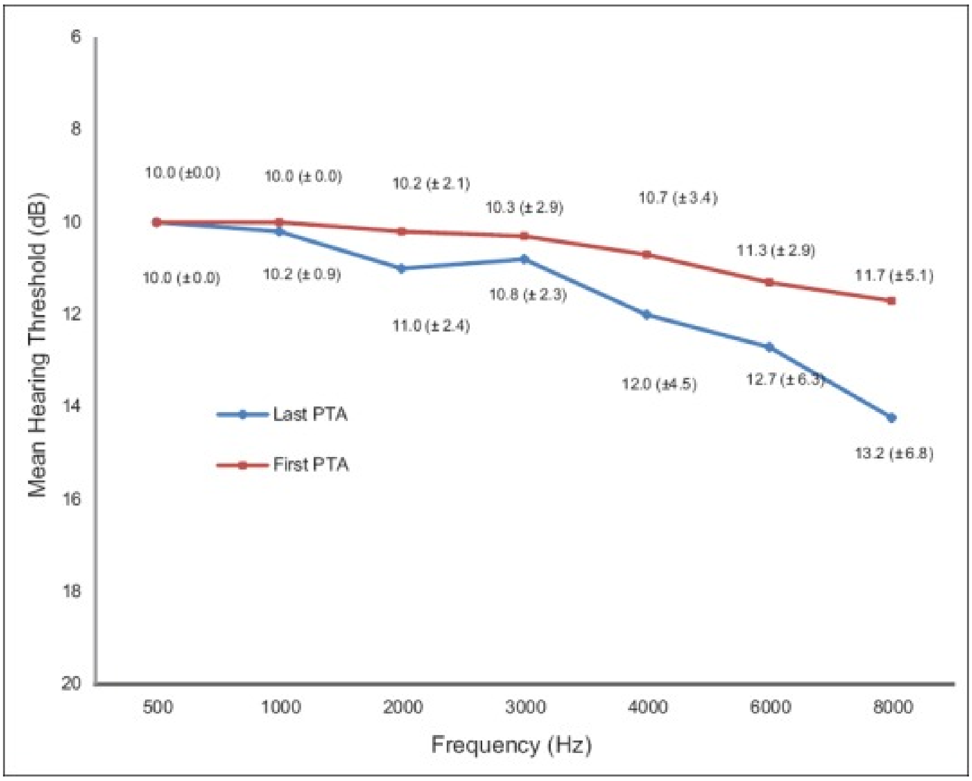
Comparison of the baseline and the last audiograms in the right ear of train drivers

Figure 2



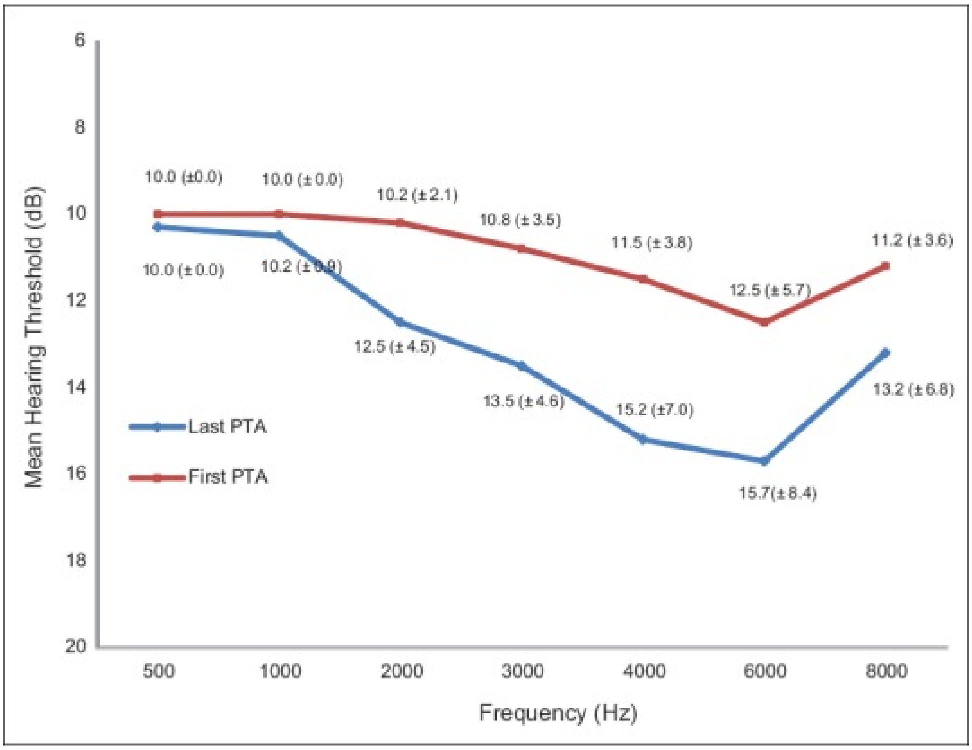
Comparison of the baseline and the last audiograms in the left ear of train drivers

Figure 3



Comparison of the baseline and the last audiograms in the right ear of shunters

Figure 4



Comparison of the baseline and the last audiograms in the left ear of shunters

Table 3

Comparison of the prevalence of STS and hearing threshold shift at high frequencies in the study groups

		Train driver *n* (%)	Shunter *n* (%)	OR	95% CI	*P*
Standard threshold shift	Right ear	4 (4.7)	1 (3.3)	1.43	0.10-3.51	0.40
	Left ear	5 (6.0)	1 (3.3)	1.81	0.22-2.65	0.20
Hearing threshold shift at high frequencies	Right ear	4 (4.7)	1 (3.3)	1.43	0.16-3.51	0.74
	Left ear	7 (8.2)	2 (6.7)	1.29	0.12-3.98	0.68

STS=Standard threshold shift, OR=Odds ratio, CI=Confidence interval

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