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Effect of Noise Exposure on 1,382 Metallurgical Workers in Periodic Audiometric Evaluation: A Cohort Study

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Keywords
Hearing loss · Noise · Noise-induced hearing loss · Objective audiometry · Occupational exposure

Abstract
Introduction: Noise-induced hearing loss is the most preventable cause of auditory impairment. Periodic audiometric evaluations are essential to monitor the hearing health of noise-exposed workers. ***Objective:*** To compare the evolution of audiometric thresholds in the initial three evaluations at frequencies of 3, 4, and 6 kHz in groups of workers exposed or not to noise. ***Methods:*** In this historical cohort study, audiometric evaluations were obtained from male workers between 18 and 40 years of age at six different metallurgical companies in Brazil. The workers were separated into noise-exposed and non-noise-exposed groups. The mean thresholds for 3, 4, and 6 kHz were calculated for both ears at baseline and the first and second periodic evaluations. The nonparametric Wilcoxon test was used for statistical analysis. ***Results:*** A total of 1,382 metallurgical workers were evaluated (1,199 noise-exposed and 183 non-noise-exposed). There was a significant difference between baseline and the first periodic evaluation (right ear – effect size = 0.62; $p = 0.0030$ and left ear – effect size = 0.74; $p = 0.0063$) and between baseline and the second periodic evaluation (right ear – effect size = 0.85; $p = 0.004$ and left ear – effect size = 0.96; $p = 0.0002$). In the non-noise-exposed group, there was no difference between baseline and the first periodic evaluation (right ear – effect size = 0.18; $p = 0.2703$ and left ear – effect size = 0.12; $p = 0.7907$) and between baseline and the second periodic evaluation (right ear – effect size = 0.29; $p = 0.4475$ and left ear – effect size = 0.41; $p = 0.6381$). ***Conclusion:*** In noise-exposed workers, there was a significant worsening of audiometric thresholds between baseline and the initial periodic evaluation, but there was no difference between the two post-baseline evaluations. This shows that noise exposure can quickly affect hearing, despite protective measures.

Introduction

Noise-induced hearing loss (NIHL), the most preventable cause of auditory impairment, is responsible for 16% of disabling hearing loss in adults [Frederiksen

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et al., 2017; Le et al., 2017; Lie et al., 2016; McBride and Williams, 2001]. Despite preventive regulations and workplace interventions, NIHL is still the second most common occupational disease [Frederiksen et al., 2017; Le et al., 2017]. NIHL is irreversible [Frederiksen et al., 2017; Imam and Hannan, 2017; Kerr et al., 2017], manifests initially at the frequencies of 3, 4, and 6 kHz [Coles et al., 2000] and extends to adjacent frequencies as it progresses [Coles et al., 2000; Duarte et al., 2015; McBride and Williams, 2001]. It rarely leads to profound hearing loss, since it usually does not exceed 40 dB of hearing loss at low frequencies or 75 dB of hearing loss at high frequencies. Once noise exposure ceases, NIHL does not progress [Imam and Hannan, 2017; Le et al., 2017].

Periodic audiometric evaluations are essential for monitoring the hearing health of noise-exposed workers. An increase in audiometric thresholds over time could indicate that the hearing conservation measures implemented by a company have not been effective [Leshchinsky, 2018].

The present study aims to compare the progression of mean audiometric thresholds of 3, 4, and 6 kHz among metallurgical workers in the initial three worker examinations. This study also aims to assess the effects of hearing conservation measures on noise-exposed workers during the first 2 years on the job according to the mean increase in audiometric threshold at 3, 4, and 6 kHz.

Materials and Methods

Audiological evaluations performed between January 1999 and January 2016 were obtained from six different metallurgical companies in Southeastern Brazil.

All companies had implemented hearing conservation programs according to the National Noise and Hearing Conservation Committee guidelines. Metallurgical workers were divided in two different groups: (1) a noise-exposed group: workers exposed to ≥85 dB sound pressure for at least 8 h daily, who were issued earplug hearing protectors by each company as required by law; and (2) a non-noise-exposed group: workers exposed to ≤80 dB sound pressure for at least 8 h daily. The variation in the sound pressure level in each company between exposed and non-exposed workers was not statistically significant.

The audiometric evaluations were performed at a specialized center. The pure-tone audiometry procedure was performed by eight different speech therapists with ample experience in audiometric evaluation of occupational noise exposure. Prior to audiometry, all ears were examined to confirm there was no obstruction in the external ear canal or any other pathology.

The three initial audiometric evaluations of each worker were analyzed: baseline and the first and second periodic evaluations. Baseline was considered the worker's first exam after hiring and prior to beginning job functions. The post-baseline exams are referred to as Exam 1 and Exam 2.

Table 1. Distribution of workers exposed to noise in each company

Company	Non-noise-exposed	Noise-exposed
1	26 (14.20%)	138 (11.50%)
2	31 (16.93%)	196 (16.35%)
3	18 (9.83%)	180 (14.97%)
4	15 (8.19%)	181 (15.12%)
5	44 (24.04%)	224 (18.66%)
6	49 (26.77%)	280 (23.37%)
Total	183 (100%)	1,199 (100%)

The following calibrated audiometers were used in the evaluations: a Madsen Midimate 622 (GN Otometrics, Taastrup, Denmark) and an Interacoustics AD 29 (Interacoustics, Assens, Denmark). Audiometry evaluations were performed according to the following parameters: (I) air conduction at frequencies from 0.25 to 8 kHz; (II) bone conduction was tested at 0.5 to 4 kHz if the airway thresholds were altered; and (III) speech recognition threshold and speech intelligibility index.

Inclusion Criteria

The inclusion criteria were male metallurgical workers who underwent at least three audiometric evaluations (baseline, Exam 1, and Exam 2) with 14 h of hearing rest prior to each evaluation and who had normal baseline results. Workers under 41 years of age at the time of baseline examination were included, since the effects of aging and other associated comorbidities are not common in this age group, in order to avoid any bias during the analysis of auditory thresholds.

Exclusion Criteria

Workers with incomplete audiological evaluations, conductive hearing loss, complaints of tinnitus, any known chronic disease (hypertension, diabetes mellitus, autoimmune diseases, infectious diseases, or immunodeficiencies) or whose examinations were performed for any reason other than that described above were excluded.

We also excluded workers for whom Exam 1 occurred more than 2 years after baseline; workers for whom Exam 1 occurred less than 6 months after baseline; workers for whom Exam 2 occurred more than 3 years after baseline; and workers for whom Exam 2 occurred less than 6 months after Exam 1.

For each worker, the mean values were calculated for tonal frequency threshold at 3, 4, and 6 kHz in the left and right ears for each exam. Tonal thresholds between 0.25–2 and 8 kHz were not considered in the statistical analysis of this study. The exposed and non-exposed groups were compared at baseline and the first and second periodic exams with the Mann-Whitney test. Statistical analysis was performed using the non-parametric Wilcoxon test. Results were considered statistically significant at $p < 0.05$.

Table 2. Mean and standard deviation of 3, 4, and 6 kHz frequency threshold results in the first three audiometric evaluations, stratified by laterality and company

Company	Ear	Baseline		Exam 1		Exam 2		Effect size 1 *NNE/NE*	Effect size 2 *NNE/NE*	Effect size 3 *NNE/NE*
		NNE	NE	NNE	NE	NNE	NE			
1	right	9.77 (10.72)	9.98 (10.11)	9.98 (10.53)	10.55 (10.11)	10.05 (10.71)	10.68 (10.11)	*0.21/0.57*	*0.28/0.70*	*0.07/0.13*
	left	9.97 (11.51)	11.01 (10.51)	10.01 (11.62)	11.78 (10.51)	10.31 (11.72)	11.94 (10.51)	*0.04/0.77*	*0.35/0.93*	*0.31/0.16*
2	right	9.83 (10.62)	9.88 (10.12)	10.03 (10.52)	10.49 (10.12)	10.10 (10.53)	10.57 (10.12)	*0.20/0.61*	*0.27/0.69*	*0.07/0.08*
	left	10.01 (11.31)	10.91 (10.31)	10.12 (11.41)	11.95 (10.31)	10.41 (10.31)	12.15 (10.31)	*0.11/1.04*	*0.40/1.24*	*0.29/0.20*
3	right	9.91 (10.95)	9.94 (10.02)	9.99 (10.58)	10.57 (10.02)	10.15 (10.59)	10.71 (10.02)	*0.08/0.63*	*0.24/0.77*	*0.16/0.14*
	left	10.08 (11.08)	11.12 (10.08)	10.17 (11.88)	11.99 (10.08)	10.53 (10.08)	12.18 (10.08)	*0.09/0.87*	*0.45/1.06*	*0.36/0.15*
4	right	9.86 (10.83)	10.02 (10.23)	10.03 (10.49)	10.62 (10.23)	10.17 (10.63)	10.81 (10.23)	*0.17/0.60*	*0.31/0.79*	*0.14/0.19*
	left	10.04 (11.33)	11.09 (10.33)	10.19 (11.53)	11.78 (10.33)	10.51 (10.33)	12.13 (10.33)	*0.15/0.69*	*0.47/1.04*	*0.32/0.35*
5	right	9.94 (10.78)	9.93 (10.18)	10.02 (10.48)	10.56 (10.18)	10.16 (10.48)	10.68 (10.11)	*0.08/0.63*	*0.22/0.75*	*0.14/0.14*
	left	10.05 (11.22)	11.13 (10.22)	10.21 (11.65)	11.73 (10.22)	10.38 (10.22)	12.14 (10.22)	*0.16/0.60*	*0.33/1.01*	*0.17/0.41*
6	right	9.81 (10.89)	9.86 (10.09)	9.95 (10.54)	10.38 (10.09)	10.11 (10.67)	10.77 (10.18)	*0.14/0.52*	*0.30/0.91*	*0.16/0.39*
	left	10.02 (11.17)	11.14 (10.17)	10.14 (11.57)	11.83 (10.17)	10.36 (10.17)	12.28 (10.09)	*0.12/0.69*	*0.34/1.14*	*0.24/0.45*
Any	right	9.83 (10.88)	9.8 (10.96)	10.01 (10.51)	10.42 (10.88)	10.12 (10.62)	10.65 (10.17)	*0.18/0.62*	*0.29/0.85*	*0.11/0.23*
	left	10.03 (11.77)	11.11 (11.87)	10.15 (11.56)	11.85 (11.91)	10.44 (11.61)	12.07 (10.95)	*0.12/0.74*	*0.41/0.96*	*0.29/0.22*

NE, noise-exposed workers; NNE, non-noise-exposed workers. Standard deviations are in parentheses. Effect size 1: difference between mean of thresholds Exam 1 and baseline. Effect size 2: difference between mean of thresholds Exam 2 and baseline. Effect size 3: difference between mean of thresholds Exam 2 and Exam 1.

Results

Of the 1,382 included workers, 1,199 were in the noise-exposed group and 183 were in the non-noise-exposed group. A total of 4,146 exams were analyzed. The distribution of workers according to company and noise exposure is presented in Table 1.

Based on the date of the baseline evaluation, the mean age of the exposed workers was 25.7 years and the mean age of the non-exposed workers was 26.5 years. Both groups were subdivided into two age groups: first, from 18 to 30 years old, and second, from 31 to 40 years old. Most patients belonged to the first subgroup (81.09% in the non-exposed group and 75.72% in the exposed group). The second subgroup presented the minority of patients included in this study (19.67% in the non-exposed group and 24.27% in the exposed group).

The baseline exam and the first and second periodical exams were compared between exposed and non-exposed groups. There was no significant difference between the exposed (mean threshold of 10.45 dB) and non-exposed groups (mean threshold of 9.83 dB) at baseline ($p = 0.125$). There was a significant difference between the two groups in the first periodic exam (mean threshold of 10.08 dB in the non-noise-exposed group and 11.13 dB in the noise-exposed group, $p = 0.003$) and second periodic exam (mean threshold of 10.13 dB in the non-noise-exposed group and 11.36 dB in the noise-exposed group, $p = 0.002$). The average elapsed time between baseline and Exam 1 was 8.75 months. Exam 2 occurred on average 19.45 months after baseline. The average time between Exam 1 and Exam 2 was 10.70 months.

Table 2 presents the mean (and standard deviation) and the effect size results for the non-exposed and exposed groups, respectively, regarding the 3, 4, and 6 kHz frequency thresholds at baseline, Exam 1, and Exam 2 according to company.

There was a significant difference of auditory thresholds in the exposed group between baseline examination (mean thresholds in the right ear of 9.80 dB and mean thresholds in the left ear of 11.11 dB) and Exam 1 (mean thresholds in the right ear of 10.42 dB, $p = 0.0030$; and mean thresholds in the left ear of 11.85 dB, $p = 0.0063$). There was also a significant difference between baseline exam and Exam 2 (mean thresholds in the right ear of 10.65 dB, $p = 0.0004$; and mean thresholds in the left ear of 12.07 dB, $p = 0.0002$). There were no differences between Exam 1 and Exam 2 neither for the right ear nor for the left ear ($p = 0.5620$ and $p = 0.5151$, respectively; Table 3).

There was no significant difference of auditory thresholds in the non-exposed group for baseline exam (mean thresholds in the right ear of 9.83 dB and mean thresholds in the left ear of 10.03 dB) and Exam 1 (mean thresholds in the right ear of 10.51 dB, $p = 0.2703$; and mean thresholds in the left ear of 10.15 dB, $p = 0.7907$). We found no differences of auditory thresholds in the baseline exam compared to the Exam 2 in the non-exposed group (mean thresholds in the right ear of 10.12 dB, $p = 0.4475$; and mean thresholds in the left ear of 10.44 dB, $p = 0.6381$).

Table 3. Comparison of audiometric evaluations according to the mean results for 3, 4, and 6 kHz frequencies classified by laterality

Company	Ear	Baseline vs. Exam 1		Baseline vs. Exam 2		Exam 1 vs. Exam 2	
		NNE, *p*	NE, *p*	NNE, *p*	NE, *p*	NNE, *p*	NE, *p*
1	right	0.4478	0.0043	0.2653	0.0033	0.6708	0.8515
	left	0.4147	0.0029	0.1123	0.0016	0.6759	0.6788
2	right	0.5821	0.0015	0.7670	0.0030	0.1546	0.5487
	left	0.2888	0.0041	0.0810	0.0050	0.1783	0.3238
3	right	0.9952	0.0018	0.3341	0.0001	0.7055	0.7752
	left	0.7907	0.0090	0.0689	0.0001	0.2550	0.5371
4	right	0.2183	0.0052	0.1783	0.0011	0.3910	0.7514
	left	0.2953	0.0043	0.2703	0.0022	0.6381	0.8444
5	right	0.4688	0.0032	0.1068	0.0024	0.5848	0.5729
	left	0.9628	0.0013	0.5137	0.0035	0.4595	0.7085
6	right	0.6564	0.0026	0.1564	0.0024	0.8330	0.1893
	left	0.9988	0.0039	0.3577	0.0058	0.1783	0.2364
All	right	0.2703	0.0030	0.4475	0.0004	0.2653	0.5620
	left	0.7907	0.0063	0.6381	0.0002	0.5821	0.5151

NE, noise-exposed workers; NNE, non-noise-exposed workers.

We also found no significant difference between Exam 1 and Exam 2 for the right and left ears ($p = 0.2653$ and $p = 0.5821$, respectively). The results for each company are similar (Table 3).

Discussion/Conclusion

Worker health is greatly affected by NIHL, including lost productivity and reduced quality of life [Pawlaczyk-Luszczynska et al., 2013]. At the end of the 20th century, the USA, Europe, and Brazil began implementing measures to protect noise-exposed workers [Daniell et al., 2006; Rabinowitz et al., 2003; Duarte et al., 2015].

Age and comorbidities cause hearing thresholds to worsen regardless of noise exposure [Le et al., 2017]. The present study excluded workers over 40 years of age at baseline, as well as workers with diabetes, hypertension, as well as autoimmune and infectious diseases.

Workers from six metallurgical industries were evaluated. The difference in sample size among the exposed and non-exposed groups was due to two factors. The sector employing the largest number of employees in the included companies is the production line, in which workers are exposed to noise. Women, although not included in this study, are mostly employed in the administrative and human resources sectors of these companies.

Measures to control the sound pressure level and use of ear protectors are essential to reduce the damage caused by noise. Ear discomfort, the occlusion effect, and aesthetic issues impede the use of hearing protection during the entire workday [Daniell et al., 2006]. Government regulations require the use of hearing protection in noisy environments. None of the evaluated companies could provide statistical data confirming the proper use of hearing protection by all noise-exposed workers. Each company controls its own sound exposure level. Since, the risk of hearing loss increases significantly with each 3-dB increase in noise exposure [Coles et al., 2000; McBride and Williams, 2001; Le et al., 2017], it was necessary for the exposed group to have an exposure level of 85 dB for 8 h per day for a homogenous sample.

The frequencies of 3, 4, and 6 kHz are the most affected by noise [Thurston, 2013; Tikka et al., 2017; Yankaskas et al., 2017]. This study evaluated the workers in the first 2 years of exposure. The frequencies of 0.25–2 and 8 kHz were not considered in the statistical analysis because they are later affected in noise-exposed patients [Duarte et al., 2015; Pelegrin et al., 2015; Le et al., 2017; Tikka et al., 2017]. Since only the 3, 4, and 6 kHz frequencies are early affected by noise [Coles et al., 2000; McBride and Williams, 2001; Kirchner et al., 2012], they were targeted in this study.

The noise-exposed and non-noise-exposed groups are similar at the baseline exam ($p = 0.125$), despite the small size in the group of non-exposed workers. Only a minor-

ity of administrative workers was evaluated in these companies. In both groups, the results were maintained when analyzed according to company. The same difference in mean tonal thresholds between the right and left ears was also observed.

The averages of the auditory thresholds obtained were similar during the study for both groups. However, there was a tendency for the thresholds to increase. After statistical analysis, we observed significant differences among noise-exposed workers. We found differences between the baseline examination and Exam 1 and Exam 2 (however, it was not statistically different between Exam 1 and Exam 2). Differently, there were no significant differences between the three examinations of unexposed workers.

The mean frequency results were similar throughout the examination period in both groups, with a tendency for the threshold to increase. However, when the statistical analysis was completed, there were differences between the groups. There were no significant differences between the three exams of non-exposed workers. However, a significant difference was found between baseline and Exams 1 and 2 (but no difference between Exams 1 and 2) in the exposed group. Despite the significant difference in the thresholds between the exposed and non-exposed workers, the difference does not achieve 1 dB (Table 2), therefore, it is clinically difficult to observe in the first three audiometric examinations. We observed that, among the noise-exposed workers, the effect size was small between baseline examination and Exam 1 (0.62 dB in the right ear), and the effect size was larger between the baseline examination and Exam 2 (0.96 dB in the left ear). Among the non-noise-exposed workers, the effect size was found to be small between baseline examination and Exam 2 (0.41 dB in the left ear). Further comparison between Exam 1 and Exam 2 revealed a small effect size of 0.29 dB for both groups (exposed and non-exposed workers) in the left ear.

The small difference found in the periodic examinations of exposed workers can be explained by the activation of a self-defense mechanism (for example, the use of hearing protectors) after the beginning of the exposure, which reduced the progressive changes of hearing thresholds. This effect would be similar to the protective effect triggered by a non-ototoxic dose of aminoglycoside administered prior to an ototoxic dose of the same antibiotic.

Noise has been identified as a likely factor in hearing impairment. Although there were no baseline differences between the exposed and non-exposed groups, after noise exposure onset, there was a significant difference between the groups for both the first and second periodic exams.

Performing periodic audiometric evaluations is considered a good method for monitoring the success of hearing conservation measures. Worsening audiometric thresholds in an employee over time are a sign that the company's measures are not functioning properly. Hearing is considered to have worsened when an increase of more than 10 dB is found between evaluations in the mean results for three consecutive frequencies, such as 3, 4, and 6 kHz. The difference, on average, was less than 10 dB in the subsequent evaluations. Thus, it cannot be stated that these workers' hearing continued to worsen, but rather that the initial noise exposure probably damaged the exposed workers' ears, despite the fact that hearing protection measures are required by law.

There was a significant worsening of audiometric thresholds in noise-exposed workers between baseline and the initial periodic exams, although there was no difference between the post-baseline evaluations. This statistically significant worsening of audiometric thresholds suggests that the companies' hearing conservation measures have not been completely effective.

Statement of Ethics

This study was approved by the Institutional Review Board of the University of Campinas (0810.0.146.000–11). The research and ethics committee determined that a specific consent form was unnecessary for this study. The included patients were being followed up at a university service and had previously given consent to the use of their data for research as long as their identity is preserved.

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Drs. Vagner Antonio Rodrigues da Silva and Alexandre Caixeta Guimarães drafted the manuscript and acquired, analyzed, and interpreted the data. Drs. Henrique Furlan Pauna and Joel Lavinsky drafted the manuscript and revised it critically for important intellectual content, and provided final approval of the final draft. Drs. Agrício Nubiato Crespo and Arthur Menino Castilho contributed substantially to the study design and approved the final draft.

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