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Revisão Sistemática

Systematic Review of Interventions to Prevent Occupational Noise-Induced Hearing Loss – A Follow-up

Revisão sistemática de intervenções para prevenção da perda auditiva induzida por ruído ocupacional – uma atualização

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Descritores

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ABSTRACT

Purpose: To conduct a systematic review of the effectiveness of interventions to prevent occupational hearing loss, following up on the findings of the most recent version of Cochrane systematic review on the same topic. **Research strategy:** Searches were carried out in PubMed, Web of Science and Scopus databases. **Selection criteria:** The following interventions were considered: engineering/administrative controls; hearing protection devices (HPD); and audiological monitoring. **Data analysis:** For bias risk analysis, each study was assessed according to randomization, allocation, blinding, outcomes, other sources of bias. **Results:** 475 references were obtained. Of these, 17 studies met the inclusion criteria: one randomized, one interrupted time series, and 15 before and after studies. Most studies were conducted in industries; three in military and/or shooting training environments; one in an orchestra, and one in construction. Most studies showed a high risk of bias. Six studies found a reduction in short-term exposure to noise through engineering/administrative controls; one found a positive impact due to changes in legislation; five studies have found positive effects of HPD in reducing exposure to noise and of educational trainings in the use of HPD; lastly, two studies found a reduction in noise levels and an increase in the using of HPD due to the implementation of hearing conservation programs. **Conclusion:** All the studies concluded that the interventions used resulted in positive effects on hearing and/or on exposure to noise. Regarding long-term effects, most studies were limited to assessing immediate or short-term effects, reinforcing that studies including long-term follow-up be developed.

RESUMO

Objetivo: realizar uma revisão sistemática sobre a efetividade de intervenções para prevenção da perda auditiva induzida por ruído ocupacional, atualizando os achados da mais recente versão da revisão sistemática Cochrane do mesmo tema. **Estratégia de pesquisa:** As buscas ocorreram nas bases PubMed, Web of Science e Scopus. **Critérios de seleção:** Como intervenções, foram considerados: controles de engenharia/administrativos; dispositivos de proteção auditiva (DPA); vigilância auditiva e monitoramento audiológico. **Análise dos dados:** Para a análise de risco de viés, cada estudo foi avaliado de acordo com a adoção de randomização, alocação, cegamento, desfecho, outras fontes de viés. **Resultados:** Foram obtidas 475 referências no total. Destas, 17 estudos cumpriram os critérios de inclusão: um randomizado, um de série temporal interrompida e 15 de antes e depois. A maioria dos estudos foi realizada em indústrias; três em ambiente militar e/ou de treinamento de tiro; um em orquestra e outro em construção civil. A maioria dos estudos mostrou alto risco de viés. Seis estudos verificaram redução da exposição ao ruído a curto prazo por meio de controles de engenharia/administrativos; um verificou impacto positivo decorrente de mudança na legislação; cinco verificaram efeitos positivos dos DPA na diminuição da exposição ao ruído e dos treinamentos educacionais no uso do DPA; e dois encontraram redução dos níveis de ruído e aumento no uso do DPA decorrentes da implementação de programas de conservação auditiva. **Conclusão:** Todos os estudos analisados concluíram que as intervenções utilizadas resultaram em efeitos positivos sobre a audição e/ou sobre a exposição ao ruído. Em relação aos efeitos de longo termo, a grande maioria dos estudos limitou-se a avaliar efeitos imediatos ou de curto termo, reforçando que estudos incluindo follow-up de longo termo devem ser desenvolvidos.

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INTRODUCTION

We estimate that 4.1 million workers are exposed daily to noise levels that exceed the exposure limit recommended by the National Institute for Occupational Safety and Health (NIOSH), 85 dBA[1], and 22 million workers may be exposed to dangerous levels of noise annually[2]. Approximately 27.7 million individuals aged 20 to 69 years old in the United States live with noise-induced hearing loss (NIHL)[3], making noise a critical factor in the workplace for its health-related impacts.

NIHL remains the second most common self-reported occupational disease, despite several studies and regulations on the topic and interventions in the workplace[4]. In the period from 1981 to 2010, prevalence of occupational hearing loss was approximately 20%, varying between several industrial sectors in the United States[5]. Thus, due to the continuity of the high rate of NIHL and the potential to reduce noise exposure through prevention, many countries have implemented various preventive interventions[6]. However, it remains a challenge to select the most effective ones due to the variety of existing intervention strategies[7,8].

In 2017, the second update of the Cochrane review about the effectiveness of interventions to prevent hearing loss related to work[7,8] was published. The literature search was completed on October 3, 2016. The authors verified evidence of low or moderate quality in the interventions analyzed in the study (implementation of more strict legislation, components of hearing conservation programs, training for the proper fitting of hearing protectors) or even the lack of evidence on the effectiveness of these interventions to reduce exposure to noise or occupational hearing loss. The authors considered that the absence of conclusive evidence cannot be interpreted as evidence of ineffectiveness. On the contrary, they emphasize that new research is likely to have an important impact on conclusions[7,8].

Thus, since the aforementioned Cochrane review emphasized that new research could have a relevant impact on the topic, this study aimed to conduct a follow-up to the updated systematic review, compiling the most recent studies, evaluating the effectiveness of non-pharmacological interventions for preventing exposure to occupational noise or occupational hearing loss, compared to no intervention or alternative interventions.

RESEARCH STRATEGY

The study followed the criteria used by Tikka et al.[8] described below.

We performed literature searches on PubMed, Web of Science (Clarivate), and Scopus, including studies published between January 1, 2017, and May 1, 2019. The date of the last literature search used is May 1, 2019.

SELECTION CRITERIA

The study included the following designs: randomized clinical trials, non-randomized before and after studies, and interrupted time series.

We included studies with workers exposed to occupational noise (>80 dBA) and excluded studies of clinical interventions such as the use of antioxidants, magnesium, or other compounds, and literature review studies.

We considered the following interventions: engineering controls (reduction or elimination of the source of noise, change of materials, processes or layout of the workplace)[9]; administrative controls (changes in work practices, management policies, or worker behavior)[9]; hearing protection devices (HPD)[1]; hearing surveillance and audiological monitoring by audiometry[1]. Hearing Conservation Programs (HCP) aim to avoid permanent threshold shift (PTS), considered long-term effects, occurring after several years and prevented by implementation of engineering measures or administrative control, or by consistent use of HPD. These are interventions that reduce exposure to noise, thus decreasing hearing loss[10].

The outcome measures included were: effects on noise exposure and effects on hearing. As there are different rules for integrating noise levels over time (exchange rates of 3 and 5 dB) in different countries, we used those defined by the authors.

In the audiometry, audiometric measurements were included even when there was no protocol report, as it is an excessively restrictive criterion[7].

A meta-analysis was not performed due to methodological differences between the studies included.

DATA ANALYSIS

The guiding question of the study was: "Do the non-pharmacological interventions carried out with workers exposed to occupational noise or environments with noise levels above 80 dBA produce real effects on noise exposure and/or on the occupational hearing loss compared to no intervention or alternative interventions?".

The search strategy was formulated using the PICO chart (P - Patient, Problem or Population, I - Intervention, C - Comparison, O - Outcome (s) (for example, Health condition)[11], where:

- P - Workers exposed to occupational noise;
- I - Any non-pharmacological interventions for prevention of exposure to occupational noise or occupational hearing loss;
- C – Comparison with no intervention or alternative interventions;
- O - Effect on noise exposure and/or hearing loss.

Figure 1 describes the flowchart (carried out according to PRISMA[12]) of the review steps and the search strategy. After excluding duplicate articles, the authors analyzed titles and abstracts independently and excluded those not considered relevant. Then, we analyzed the full texts of the 29 articles initially selected, checking whether they met the inclusion and exclusion criteria. For each study included, we extracted data and assessed the risk of bias.

We analyzed the effect of an intervention on exposure to noise over time according to values provided by the authors of the selected studies, in the same way as the effects on hearing.

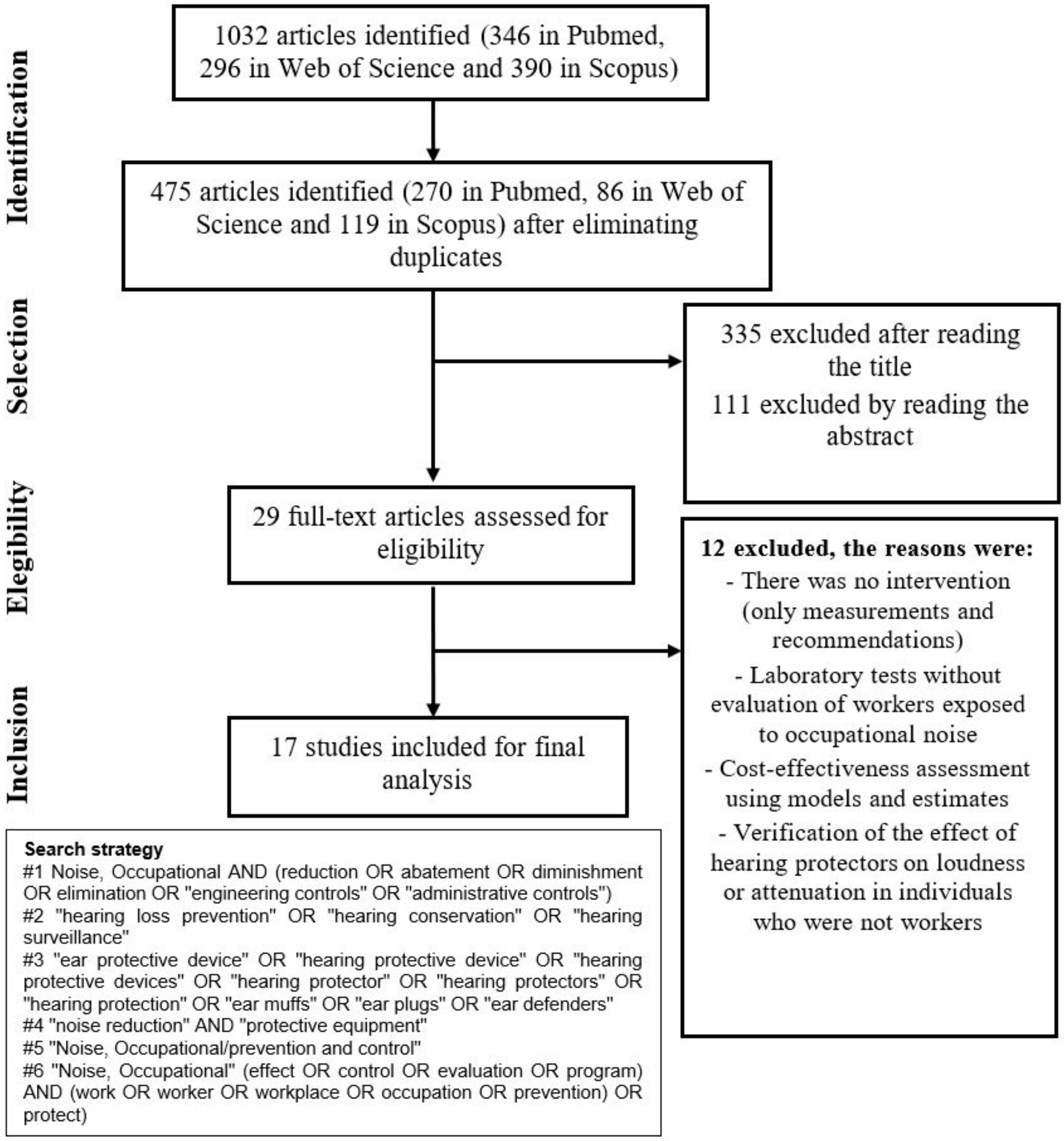

Figure 1. Search strategy (publication date limit between January 2017 and May 2019) and PRISMA flowchart of the review steps.

For the risk of bias analysis, we used the Cochrane[13] tool, which evaluates each study included according to the adoption of randomization, allocation concealment, blinding of participants, blinding of outcome evaluators, incomplete outcomes, selective outcome reporting, and other sources of bias. The assessment of each item was: (-) high risk of bias; (+) low risk of bias; (?) bias uncertain. The final classification (conclusion on the risk of bias for that study) was given by the most frequent sign observed among all categories.

During the process, when possible, we resolved discrepancies by peer discussion; when this was not possible, a third author was involved in the decision.

RESULTS

This research resulted in 475 references (270 in Pubmed, 86 in Web of Science, and 118 in Scopus), excluding duplicates. The screening of references for eligibility found 29 full articles. Seventeen of these studies met the inclusion criteria. The studies excluded by the abstract were categorized into themes (Table 1). Most studies (47.7%) dealt with identification of the risk caused by noise, i.e., through hearing thresholds or measurement of noise levels. The studies identified hearing changes in individuals exposed to noise, noise levels above the level of activity, or inconsistent use of HPD; however, none of them carried out interventions to modify what was found, so we excluded them from the present review. We also excluded studies that examined attenuation/preference/comfort of HPD (19%); assessed knowledge, attitudes, and motivation for using HPD (10.8%); studied predictors for hearing loss and use of HPD (7.2%); and evaluated headphones, exposure to non-occupational noise, influence of HPD on the voice, head trauma, metabolic and cardiac diseases, extra-auditory effects of noise, among others (15.3%).

Table 1. Themes and main variables of the studies excluded by the abstract

Theme	N (%)	Main variables studied
Risk identification	53 (47,7)	Hearing thresholds (conventional audiometry and high frequencies), TTS, PTS, OAE, auditory evoked potentials, use of HPD, noise exposure levels.
HPD attenuation/ preference/comfort study	21 (19,0)	Laboratory measures of HPD attenuation, speech discrimination/warning signs/localization in noise, computational models for developing HPD/methods for measuring HPD performance, use of training for HPD fitting.
Knowledge, attitudes, and motivation for using HPD	12 (10,8)	Beliefs, values, knowledge, attitudes about the importance of using HPD, regarding noise and hearing loss. Educational interventions to change habits and attitudes.
Predictors for hearing loss and use of HPD	8 (7,2)	Age, gender, noise exposure levels, exposure time, non-use of HPD, PTS, TTS, OAE, efferent system, tinnitus, interpersonal factors, among others.
Others	17 (15,3)	Headphones, exposure to non-occupational noise, influence of HPD on the voice, head trauma, metabolic and cardiac diseases, extra-auditory effects of noise, among others.

Legend: N – number of studies; TTS – temporary threshold shift; PTS – permanent threshold shift; OAE – otoacoustic emissions; HPD – hearing protection device.

Characterization of the studies included

Table 2 shows the characteristics of the studies included and their bibliographic references. One study used a randomized design[14] and another, an interrupted time series[15]. The remaining 15 studies carried out before and after studies.

We found that 29.5% of the studies took place in the United States, 17.6% in Iran, and 11.8% in China. The remainder (41.1%) comprised several other countries with only one study each (Belgium, Canada, Denmark, Malaysia, Poland, Sweden, and Thailand).

Regarding context or scenario, most studies (70.6%) were carried out in industrial environments and/or contexts; three in a military and/or shooting training environment (17.6%); one in an orchestra (5.9%) and another one in civil construction (5.9%).

Sample size varied from three to 18,672 workers in nine studies, totaling 19,710 participants, with an average of 2,190. The others evaluated: 1,157 areas of a paper towel industry[15]; a Computer Numerical Command (CNC) industry[16]; a grain crusher[17]; three heavy equipment[18]; 11 compressed air pistols[19]; 14 metal fabrication facilities[20]; more than 700,000 dosimetry measures[21]; and four firearms[22].

As for interventions, two studies evaluated HPD using the MIRE technique[23,24]; two evaluated training for the proper fitting of HPD[25,26], including post-intervention and follow-up measures. Six studies carried out engineering control intervention, including changes, improvements or maintenance of equipment, isolation of machines, and noisy areas[16-19,22,27]. One study also performed administrative control[22] and another compared the attenuation performance of two acoustic shells for orchestra musicians[27]. Four studies evaluated HCPs[15,20,28,29], including administrative and engineering controls, use of HPD, and training of workers. Sayler et al.[20] also evaluated the relationship between cost and effectiveness of an HCP. Bourchom et al.[14] evaluated the impact of using HPD during use of firearms. Fallah Madvari et al.[30] used an educational model for workers, addressing the importance of using HPD. One of the studies assessed the impact of implementing a review of the Mine Safety and Health Administration (MSHA) noise regulation that established an action level of 85 dBA, 5 dB exchange rate for sound pressure levels (SPL) between 80 and 130 dBA and harmonized requirements for HCPs[21].

Effects of the intervention

Engineering and administrative controls: short-term noise reduction results

We included six of the studies in this category[16-19,22,27].

Behar et al.[27] evaluated the average attenuation of two acoustic shells for three different orchestral instruments. The total attenuation was 9.2 dBA for the first shell and 5.9 dBA for the second, with a statistically significant difference.

Khairai et al.[16] developed a case study in a factory comparing noise levels before and after the improvements made. The average initial noise level was 95.8 dBA, with all machines turned off. After maintenance of the pneumatic system, noise was reduced to 55.5 dBA. With the machines turned on, noise decreased from 109.3 dBA to 95.2 dBA, after six machines were brought together in an area covered by a plastic curtain.

Murphy et al.[22] verified the effects of engineering control (firearm noise suppressor) and administrative control (low-speed ammunition) on SPLs produced by different weapons. Suppressors reduced peak sniper pressure levels by 17–26 dB, equivalent energy levels by 9–21 dB, and overall sound power level by 2–23 dB. The levels of the rifle without suppression showed a difference of 1 to 2 dB depending on the ammunition, while the other type of rifle had between 12 dB and 20 dB of difference between the two ammunition speeds.

Prieve et al.[19] compared the noise reduction offered by advanced compressed air guns compared to conventional guns and found a significant reduction in sound pressure level ranging from 3.3 to 17.7 dBA.

Saleh et al.[18] compared SPLs inside three heavy equipment operator cabins before and after installation of sound damping mats (SDMats), obtaining a significant reduction of 5.6-7.6 dBA in the maximum acceleration configurations.

Tanas et al.[17] verified the effectiveness of structural modifications carried out in a grain crusher, measuring noise

Table 2. Characteristics of the studies included and their risk of bias (n = 17).

Study / Study country	Design	Participants / Context or scenario of the study	Interventions	Results	Risk of Bias
Aliabadi et al., 2018 (Iran)	Non-randomized before and after study	Factory workers with different noise characteristics; two industrial factories in western Iran n = 50 (25 in each factory)	Intervention: workers wearing 5 types of earmuffs. Each protector sample was tested for 50 individuals and F-MIRE measurements were repeated three times. Comparison: "Outside" vs. "Inside" the hearing protection device (HPD).	Difference in noise level outside vs. inside the protectors at low and high frequencies. The attenuation values of hearing protectors were lower than those of the laboratory noise reduction classifications (p <0.05) for workers exposed to low-frequency noise; and higher for workers exposed to high-frequency noise (p <0.05).	-/-/-/-/+/+/? Conclusion: (-) high risk
Behar et al., 2018 (Canada)	Non-randomized before and after study	Musicians in an orchestra; Toronto orchestra pit (Four Seasons Center) n = 3	Intervention: engineering noise control. Two acoustic shells were evaluated at the same time - two dosimeters in each shell (front and back - the difference was expressed in "attenuation") - 45° in front of the musician. One instrument at a time. Two tests for each instrument. Comparison: "front" vs. "behind" the shell.	Total attenuation: 9.2 dBA (Manhasset shell) and 5.9 dBA (Wenger shell) (p-value = 0.006).	-/-/-/-/+/+/? Conclusion: (-) high risk
Biabani et al., 2017 (Iran)	Non-randomized before and after study	Workers of different occupations exposed to noise in work environment; Hamadan University of Medical Sciences laboratory n = 30	Intervention: workers wearing 3 types of earmuffs. Each protector sample was tested for 30 individuals and the MIRE measurements were repeated three times. Comparison: with and without goggles.	Typical safety goggles can reduce average PAR by approximately 2.5 dB (p <0.05). The variability in PAR values between individuals, intra-individuals, and between hearing protectors was not statistically significant (p> 0.05).	-/-/-/-/+/+/? Conclusion: (-) high risk
Bourchom et al., 2018 (Thailand)	Randomized clinical trial	Thai military service recruits randomly assigned to 2 groups: not wearing hearing protection and using silicone protectors; military shooting training n = 60	Intervention: use of HPD. Control: workers who have not used HPD.	Immediately after the shooting, those who did not wear hearing protection had a higher rate of SNHL than the other group, at high frequency (53.2% vs. 0%, p <0.05). On the 3rd day, hearing thresholds were gradually improved at all frequencies, except 6,000 Hz. On the 7th day, three recruits (10%) from the group without hearing protection still had SNHL on the audiogram, 12 individuals (40%) had abnormal function of external hair cells detected by DPOAEs.	+/?/-/-/+/+/? Conclusion: (+) low risk

Legend: HPD – hearing protection device; DPOAEs - Distortion product otoacoustic emissions; F-MIRE - *Field Microphone-in-real-ear*; PTS – permanent threshold shift; N – number of studies; SPL - Sound pressure level; PAR - Personal attenuation rating; SNHL - Sensorineural hearing loss; HCP - hearing conservation program; BASNEF – "Beliefs, Attitudes, Subjective Norms and Enable Factors". The signs in the last column are presented in order of the categories of bias assessed, as described in the Methods. The conclusion was obtained by the most frequent signal; (-) high risk of bias; (+) low risk of bias; (?) uncertain bias.

Table 2. Continued...

Study / Study country	Design	Participants / Context or scenario of the study	Interventions	Results	Risk of Bias
Collée et al., 2019 (Belgium)	Non-randomized before and after study n = 18,672	Military personnel from the Belgian military service; Occupational Medicine Service and Belgian Defense Medical Expertise Center.	Intervention: hearing conservation program (HPC). Control: before HCP implementation.	For each annual increment, average hearing thresholds at 3, 4, and 6 kHz increased by 0.08 dB and this number decreased (was less positive) by 0.18 dB per year.	-/-/-/-/?/+/? Conclusion: (-) high risk
Fallah Madvari et al., 2019 (Iran)	Non-randomized before and after study n = 100	Workers of different occupations exposed to noise; tile industry	Intervention: training with the BASNEF Education Model (n = 50). Control: untrained colleagues (n = 50).	Before intervention, the time of use of HPD in both groups was 0.5 hours and noise exposure was 89 dBA. After intervention, the time of using HPD increased in the intervention group, noise exposure was 80 dBA, and for the control group, without training, the same amount of time using HPD resulted in 89 dBA of exposure.	-/-/-/-/+/+/? Conclusion: (-) high risk
Frederiksen et al., 2017 (Denmark)	Non-randomized before and after study 11 Danish industries with high noise levels n = 271	Workers of different occupations exposed to noise;	Intervention: hearing conservation program (HCP). Control: before HCP implementation.	Average noise levels decreased from 83.9 dBA to 82.8 dBA. For workers exposed to more than 85 dBA, use of HPD increased from 70.1 to 76.1%.	?/?/-/-/-/+/? Conclusion: (-) high risk
Gong et al., 2019 (China)	Non-randomized before and after study n = 335	Workers of different occupations exposed to noise; four factories in eastern China	Intervention: training for the proper fitting of HPD. Comparison: pre-intervention, post-intervention, and six-month follow-up.	Significant improvement was shown in post-intervention PARs ($p < 0.05$), as well as PARs from the follow-up visit ($p < 0.05$). Comparing follow-up visit PARs to post-intervention PARs, good sustainability was demonstrated in two factories ($p > 0.05$), while a significant decline ($p < 0.05$) was observed in another.	-/-/-/-/?/+/? Conclusion: (-) high risk
Khairai et al., 2018 (Malaysia)	Non-randomized before and after study Comparison: Before and after improvements.	Case study; CNC industry	Intervention: engineering control to reduce noise in the CNC stripping process.	Initial average noise level with all machines turned off was 95.8 dBA. After the leaking pneumatic system was resolved, noise was reduced to 55.52 dBA. Average noise level with all machines in operation was 109.34 dBA. After six machines were brought together in one area and it was covered with a plastic curtain, noise was reduced to 95.21 dBA.	-/-/-/-/+/+/? Conclusion: (-) high risk

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Table 2. Continued...

Study / Study country	Design	Participants / Context or scenario of the study	Interventions	Results	Risk of Bias
Neitzel et al., 2018 (Sweden)	Interrupted time series	Four Swedish paper towel factories;	Intervention: hearing conservation program (HCP).	Noise levels have decreased in Swedish paper factories over time. Results of the focus group indicated that use of HPD increased over time. Approximately 50% of workers in the four factories evaluated were exposed to a limit equal to or greater than 8h of noise exposure of 85 dBA at the end of the study period in 2010.	-/-/-/-/?/?/?
		n = 1,157 areas	Control: before HCP implementation.		Conclusion: (-) high risk
Liu et al., 2018 (China)	Non-randomized before and after study	Workers of different occupations exposed to noise; Chinese textile factory;	Intervention: training for the proper fitting of HPD.	Immediate and residual effects of training obtained by workers in the attenuation of HPD were observed and also effects of training in improving attenuation after a period of daily use.	-/-/-/-/?/+/?
		N = 189	Comparison: pre-intervention, post-intervention, and follow-up for six and twelve months.		Conclusion: (-) high risk
Murphy et al., 2018 (United States of America)	Non-randomized before and after study	Four firearms; outdoor shooting center (Rose Lake) and hunting field (Rudyard)	Intervention: engineering control for noise reduction (firearm noise suppressor) and administrative control (low-speed ammunition).	Firearm noise suppressors tend to reduce peak sound pressure in the sniper's ears by 17–26 dB, reduce equivalent energy levels by 9–21 dB, and reduce overall sound pressure level by 2–23 dB. Levels of the unexpressed Savage rifle showed a difference of 1 to 2 dB depending on the ammunition, while Remington rifles had between 12 dB and a difference of 20 dB between the two ammunition speeds.	-/-/-/-/+/+/?
		N = 5 shootings			Conclusion: (-) high risk
			Comparison: Before and after improvements.		
Prieve et al., 2017 (United States of America)	Non-randomized before and after study	Different compressed air guns; ten areas for manufacturing research and development environments	Intervention: engineering control for noise reduction (advanced air guns with noise suppression).	17 of 21 comparisons of advanced air guns with conventional air guns exhibited statistically significant noise level reductions ranging from 3.3 to 17.7 dBA, while only three comparisons showed significant increases, the largest being 1.8 dBA. Advanced noise-reducing air guns engineering controls can be highly effective to reduce exposure to occupational noise.	-/-/-/-/+/+/?
		n = 11			Conclusion: (-) high risk
			Comparison: conventional air guns.		

Legend: HPD – hearing protection device; DPOAEs - Distortion product otoacoustic emissions; F-MIRE - *Field Microphone-in-real-ear*; PTS – permanent threshold shift; N – number of studies; SPL - Sound pressure level; PAR - Personal attenuation rating; SNHL - Sensorineural hearing loss; HCP - hearing conservation program; BASNEF – "Beliefs, Attitudes, Subjective Norms and Enable Factors". The signs in the last column are presented in order of the categories of bias assessed, as described in the Methods. The conclusion was obtained by the most frequent signal; (-) high risk of bias; (+) low risk of bias; (?) uncertain bias.

Table 2. Continued...

Study / Study country	Design	Participants / Context or scenario of the study	Interventions	Results	Risk of Bias
Roberts et al., 2017 (United States of America)	Non-randomized before and after study	Noise dosimetry measures from 1979 to 2014; Mining Health and Safety Administration n = more than 700,000	Implementation of the review of the MSHA noise regulation in 2000.	Global noise levels in mines have decreased. However, this decrease was not uniform across all mining sectors.	-/-/-/-/?/+/? Conclusion: (-) high risk
Saleh et al., 2017 (United States of America)	Non-randomized before and after study	Heavy equipment (roller, crane, and motor grader); International Union of Operating Engineers training center n = 3	Intervention: engineering control to reduce noise. Comparison: Before and after installing sound-damping mats (SDMats).	SPLs inside the cabins of the heavy equipment operator were significantly reduced by 5.6 - 7.6 dBA in the maximum acceleration configuration after installing the SDMats (p <0.01).	-/-/-/-/+/+/? Conclusion: (-) high risk
Sayler et al., 2017 (United States of America)	Non-randomized before and after study	Metal fabrication facilities operated by a single company; n = 14	Intervention: hearing conservation program (HCP). Control: before implementation of the hearing conservation program (relating cost and effectiveness).	Higher expenditures for training and HPD fitting tests were significantly associated with a reduction in the prevalence of PTS. Higher expenditure on training was also related to a lower prevalence of hearing loss and rates of high-frequency hearing loss.	-/-/-/-/+/+/? Conclusion: (-) high risk
Tanas et al., 2018 (Poland)	Non-randomized before and after study	Case study - Grain crusher; grain crusher operator workstation	Intervention: engineering control for noise reduction in a grain crusher. Comparison: Before and after improvements.	The structural modifications introduced reduced noise level by 3 dBA for the frequencies of the hopper component related to vibration of the hopper (180 Hz) and support structure of the crusher (240 to 480 Hz). The level of these components determines the noise level at the operator's workstation for the average grain filling conditions. Total noise level in the shredder operator has been reduced by 2.6 dBA.	-/-/-/-/+/+/? Conclusion: (-) high risk

Legend: HPD – hearing protection device; DPOAEs - Distortion product otoacoustic emissions; F-MIRE - *Field Microphone-in-real-ear*; PTS – permanent threshold shift; N – number of studies; SPL - Sound pressure level; PAR - Personal attenuation rating; SNHL - Sensorineural hearing loss; HCP - hearing conservation program; BASNEF – "Beliefs, Attitudes, Subjective Norms and Enable Factors". The signs in the last column are presented in order of the categories of bias assessed, as described in the Methods. The conclusion was obtained by the most frequent signal; (-) high risk of bias; (+) low risk of bias; (?) uncertain bias.

levels before and after improvements. Total noise level for the operator was reduced by 2.6 dBA.

Legislation

Only one of the studies dealt with legislation[21].

After reviewing the MSHA noise regulation, analyzing more than 700,000 dosimetry measurements from 1979 to 2014, Roberts et al.[21] found that total noise level in mines decreased from 84.4 dBA to 79.9 dBA, although it was not uniform across all mining sectors.

Results of reducing noise exposure: Hearing protection devices and short- and medium-term training

Five studies addressed the results of reducing exposure to noise[23-26,30].

Aliabadi et al.[23] evaluated five earmuffs in 50 participants through repetition of three F-MIRE measurements in each individual. The attenuation values of the HPD measured in octave bands were lower than noise reduction levels established in the laboratory, for low frequencies ($p < 0.05$); for high frequencies, these values were higher than those obtained in the laboratory ($p < 0.05$).

Biabani et al.[24] evaluated three earmuffs with and without goggles in 30 participants, repeating the MIRE measurements three times. Safety goggles reduced average personal attenuation rating (PAR) by approximately 2.5 dB ($p < 0.05$).

Fallah Madvari et al.[30] used an educational training model, comparing the trained group with the untrained group. After the six-week intervention, the time of use of the HPD increased from 0.5 hours to 6.66 (± 1.40) in the intervention group and 0.83 (± 0.85) in the control group, reducing noise exposure from 89 dBA to 80 dBA in the first group.

Liu et al.[25] conducted training for the proper fitting of HPD in 189 workers in the textile industry, assessing attenuation before, immediately after, and after 6 and 12 months. The objective was to obtain information about the current situation of hearing protection, including field attenuation of HPD in workers, effects of training to improve attenuation and attention to hearing health, as well as the motivation for use of earmuffs in an environment with high temperatures. An increase in attenuation provided by HPDs was observed after training.

Gong et al.[26] conducted training for the proper fitting of earplugs in four factories, measuring personal attenuation rating (PAR) before, immediately after, and after six months. There was a statistically significant improvement after the intervention, and in the follow-up in most factories.

Results of reduced exposure to noise or changes in hearing: Hearing Conservation Programs

Two studies evaluated the effectiveness of HCPs through the effects on hearing and one of them also related effectiveness to the cost of the program. Sayler et al.[20] showed that higher investments in training and tests to assess attenuation levels were significantly associated with a reduction in the prevalence of hearing threshold shifts, with a lower prevalence of hearing loss and hearing loss in high frequencies, in a ten-year follow-up.

Bourchom et al.[14] evaluated 60 military personnel divided into two groups, with and without the use of HPD. Immediately after training shots, those who did not use HPD showed a greater threshold shift at high frequencies, compared to the group that used HPD (53.2% vs. 0%, $p < 0.05$). After three days, the hearing thresholds gradually improved in all frequencies, except 6,000 Hz. After one week, three individuals (10%) in the group that did not use HPD still showed lower hearing threshold.

Collée et al.[29] evaluated 18,672 military people before and after implementation of an HCP. They concluded that, for each one-year increment, average hearing thresholds for pure tone audiometry at 3, 4, and 6 kHz increased by 0.08 dB, and this degree of worsening was reduced by 0.18 dB per year after HPD.

Two studies have evaluated effectiveness of HPDs through their effects on noise exposure. Frederiksen et al.[28] evaluated 271 workers from different occupations, before and after implementation of the program. They found that average noise levels decreased from 83.9 dBA to 82.8 dBA. For workers exposed to noise levels above 85 dBA, there was an increase in use of HPD from 70.1 to 76.1%. Neitzel et al.[15] compared the SPL measurements of four facilities before and after implementation of the HPD, noting that there was a decline in noise levels over time and an increase in use of hearing protection. However, approximately 50% of workers were exposed to SPL greater than or equal to 85 dBA for eight hours.

Risk of bias

Sixteen of the 17 studies analyzed were classified as presenting a high risk of bias (94.1%) and one study[14], the only one to adopt randomization (Table 2), presented a low risk (5.9%). Fifteen studies did not perform allocation concealment (88.2%) and two did not provide enough information to conclude (11.8%). None of the studies carried out blinding of participants, nor outcome evaluators. In the outcomes, 11 studies did not have data loss (64.7%), five provided insufficient information to judge incomplete outcomes (29.4%), one presented loss of participants without explanation (5.9%); 16 reported outcomes according to what was proposed (94.1%) and one study did not provide enough information to conclude the risk assessment (5.9%). We could not determine the presence of other sources of bias for any of the studies.

DISCUSSION

As we have observed, most articles included were studies of the before and after type, which was also verified in the systematic review of 2017[7]. Distribution of the countries in which they were developed is quite heterogeneous, with representatives in America, Asia, and Europe. Several countries around the world have been seeking to develop studies and implement laws and recommendations in an attempt to reduce the incidence of NIHL, achieving varying levels of success[6,31], and showing the growing concern with this global problem.

Regarding the scenario of the studies, most were carried out in industrial environments and/or contexts, but there were also studies developed in the military and civil construction environments. These types of occupations are among those with a higher risk of hearing damage in the number of workers exposed[4,31,32], which justifies a greater number of studies with these populations.

The sample sizes of the 17 studies varied widely; nine studies evaluated workers (average of 2,190 individuals). The smallest sample had three orchestra musicians[27], and the largest included 18,672 military personnel[29], numbers that are lower than those observed in the 2017 systematic review[7]. The remaining eight studies evaluated equipment, firearms, air pistols, industrial areas, and dosimetry, among others[21].

As for the effects of the interventions analyzed in the present review, six studies[16-19,22,27] sought to assess the impact of engineering and administrative controls on noise. Interventions included the acoustic shells for orchestra[27]; maintenance of the pneumatic system and use of plastic curtain[16]; use of firearm noise suppressors and low-speed ammunition[22]; replacement of conventional compressed air guns with others with noise reduction[19]; installation of sound-absorbing mats in heavy equipment[18]; and structural modifications in a grain crusher[17]. All studies found reduced exposure to noise in the short term through pre- and post-intervention assessment, comparing absolute noise levels, but none of them evaluated this effect over the long term, similar to what we observed in the 2017 review[7].

Only one study sought to verify the effects of legislation over time (1979 to 2014) on noise levels present in mines, after reviewing the MSHA regulation in 2000[21]. This study found a positive impact of the change in regulation on the levels present in mines, although this reduction was not homogeneous for all sectors. We observed similar findings by Tikka et al.[7], who suggested that a reduction in noise levels resulting indirectly from changes in legislation is probably mediated by engineering controls, which can have a positive impact in reducing noise exposure.

Five studies evaluated the effects of the reduction in noise exposure caused by hearing protection devices and training for proper use of HPD in the short and medium term[23-26,30]. To assess effects of HPD on reducing noise exposure, the studies used the following measures: verification of HPD attenuation by the F-MIRE[23] technique; verification of attenuation of earmuff in the presence and absence of goggles with the MIRE technique, identifying whether attenuation could be negatively impacted by concomitant use of goggles[24]; verification of the time of use of the HPD comparing groups that have or have not undergone educational training[30]; and verification of training effectiveness for the proper fitting of HPD by measuring the attenuation of HPD before, immediately after, after 6 and/or 12 months[25,26]. Studies have found that when HPD is used correctly there is a potential to reduce noise exposure, and that educational training for motivating use and guiding on correct fitting has a positive impact on HPD attenuation and/or on the time of use during the working day. We did not find studies on the long-term effects of these interventions.

Regarding risk of bias, 16 studies of the 17 analyzed were classified as high risk (94.1%) and one study[14], the only one to adopt randomization, presented low risk (5.9%). These findings are supported by the discussion of Lie et al.[33] about studies of exposure to noise being generally inferior in quality to population studies, since the latter tend to be of very good quality regarding possible confounding or modifying factors, such as smoking, heart disease, and blood pressure. Considering this information, we highlight that the studies included in this review do not mention possible confounding factors, which contributes to the increased risk of bias.

Based on the findings, we noted that the body of evidence is composed of studies with a high risk of bias, emphasizing the need to develop more research in this area, using more judicious methodologies, seeking to reduce the risk of bias and improve the quality of studies on intervention to prevent hearing loss.

Our interest in carrying out this update was to reproduce the methodology proposed by the original systematic review[7], bringing consistency and validity to this research. However, widening the search to other databases and languages could expand the studies included in the current review. As a further contribution of this review, we can also highlight the identification of gaps and issues that still need clarification through new research, which provides better quality evidence, favoring advancement of interventions to prevent hearing loss due to noise exposure.

CONCLUSION

This study found no substantial differences regarding what was verified in the systematic review by Tikka et al[7].

All the studies analyzed concluded that the interventions used (change in legislation, engineering and/or administrative controls, use/training for use of HPD, implementation of HCP), isolated or combined, had positive effects on hearing and/or noise exposure. As for long-term effects, the vast majority of studies have been limited to assessing immediate or short-term effects concerning hearing and/or noise exposure. This reinforces the suggestion by Tikka et al.[7] that studies including long-term follow-up should be developed to provide more conclusive evidence on this issue.

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Authors contributions

AGS: participation in the idealization of the study, collection, analysis, and interpretation of data and writing of the article. CGM: participation in the collection, analysis, and interpretation of data and writing of the article. RFG: participation in the idealization of the study, collection, analysis, and interpretation of data and writing of the article. TCM: participation in the idealization of the study, collection, analysis, and interpretation of data and writing of the article.