

# Use of double hearing protection for occupational noise attenuation: a systematic review

## Uso da dupla proteção auditiva na atenuação do ruído ocupacional: uma revisão sistemática

## El uso duplo de protectores auditivos para la reducción del ruido ocupacional: una revisión sistemática


*Francine Varlete Leopoldina Barcelos\** 

*Vitória Neves de Barros\** 

*Luciele Kauana Woide\** 

*Gabriely Quintana de Medeiros\** 

*Karina Mary de Paiva\** 

*Patricia Haas\** 

### Abstract

**Introduction:** Noise-Induced Hearing Loss (NIHL) is associated with continuous exposure to noise within the occupational environment and is the second most common disease among workers. **Objective:** To verify the effectiveness and benefit of using double hearing protection in attenuating occupational noise. Search Strategy: The search for scientific articles was carried out in the MEDLINE (Pubmed), LILACS, SciELO, SCOPUS and WEB OF SCIENCE databases, without restriction of language, period and location. To complement and avoid risk bias, a search for gray literature was performed on Google Scholar. **Methodology:** The systematic review was conducted in accordance with the Preferred Reporting

\* Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil.

#### Authors' contributions:

FVLB: responsible for preparing the research planning, collecting and analyzing studies and interpreting data, as well as writing the article.

VNB, LKW, GQM: participated in the analysis of studies, interpretation and analysis of the data obtained.

KMP: supported the planning of the study, guided data collection, as well as the study analysis.

PH: study advisor, support in study planning, orientation data, as well as supporting the analysis of the studies and writing of the article.

**E-mail for correspondence:** Patricia Haas - haaspatricia37@gmail.com

**Received:** 8/14/2023

**Accepted:** 10/05/2023

Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations. Studies that scored  $\geq 6$  points according to the qualitative scoring protocol proposed by Pithon et al. (2015). **Results:** Double hearing protection should be used when the use of a shell or plug type hearing protector does not provide enough attenuation to reduce noise in the work environment, but this sound attenuation by hearing PPE can be an obstacle to communication and spatial location, especially to workers who have some degree of PAIR. **Conclusion:** the use of double hearing protection can be a considerable strategy for protecting against hearing loss in controlled environments. New sound patterns for warning alarms, providing for the warning of accidents in an occupational environment where the combined use of hearing devices used in controlled environments and the implementation of broadband signals as a standard signal can be used as collective safety strategies.

**Keywords:** Personal Protective Equipment; Hearing Loss; Occupational Health; Occupational Risks.

## Resumo

**Introdução:** A Perda Auditiva Induzida por Ruído (PAIR) está associada à contínua exposição ao ruído dentro do ambiente ocupacional, é a segunda doença mais recorrente entre os trabalhadores. **Objetivo:** Verificar a efetividade e benefício do uso da dupla proteção auditiva na atenuação do ruído ocupacional. **Método:** A busca de artigos científicos foi realizada nas bases de dados MEDLINE (Pubmed), LILACS, SciELO, SCOPUS e WEB OF SCIENCE, sem restrição de idioma, período e localização. Para complementar e evitar viés de risco foi realizada uma busca por literatura cinzenta no Google Acadêmico. A revisão sistemática foi conduzida de acordo com as recomendações do Preferred Reporting Items for Systematic Reviews and Meta-Análises (PRISMA). Estudos que pontuaram  $\geq 6$  pontos de acordo com o protocolo de pontuação qualitativa proposto por Pithon et al. (2015). **Resultados:** A dupla proteção auditiva deverá ser utilizada quando o protetor auditivo tipo concha ou plug não fornecerem atenuação suficiente para diminuir o ruído no ambiente laboral, contudo, a atenuação sonora pelos EPI auditivos pode ser um obstáculo à comunicação e localização espacial, principalmente aos trabalhadores que possuem algum grau de PAIR. **Conclusão:** o uso da dupla proteção auditiva pode ser uma estratégia considerável para proteção de perdas auditivas em ambientes controlados. Novos padrões sonoros para alarmes de alerta, prevendo o aviso de acidentes em ambiente ocupacional em que o uso combinado dos dispositivos auditivos utilizados em ambientes controlados e a implantação dos sinais de banda larga como sinal padrão poderão ser utilizados como estratégias de segurança coletiva.

**Palavras-chave:** Equipamento de Proteção Individual; Perda Auditiva; Saúde Ocupacional; Riscos Ocupacionais.

## Resumem

**Introducción:** La pérdida de audición inducida por el ruido es asociada con la exposición continua el lo ambiente de trabajo y es la segunda enfermedad más común em los trabajadores. **Objetivo:** Verificar la eficacia y beneficio del doble uso de los protectores auditivos em la atenuación del ruido. **Método:** La revisión sistemática se realizó de acuerdo con las recomendaciones para revisiones sistemáticas y metanálisis (PRISMA). Los estudios que obtuvieron  $\geq 6$  puntos según el protocolo de puntuación cualitativa propuesto por Pithon et al. (2015). **Resultados:** La protección auditiva doble és utilizada cuando el uso de un protector auditivo tipo concha o enchufe no proporciona la atenuación suficiente para reducir el ruido em el ambiente de trabajo, pero esta atenuación del sonido por los EPP auditivos puede ser un obstáculo para la comunicación y la ubicación espacial, especialmente para los trabajadores con pérdida de audición. **Conclusión:** el uso de doble protección auditiva es una estrategia considerable em ambientes controlados y seguros. Nuevos padrones sonoros para alarmas de aviso de accidentes em un entorno laboral y la implementación de señales de banda ancha como señal estándar, pueden utilizarse como estrategias de seguridad colectiva.

**Palabras clave:** Equipo de protección personal; Pérdida de la audición; Salud laboral; Riesgos laborales.

## Introduction

Noise is defined as a persistent sound emission that can spread slowly causing discomfort and impacting the healthy auditory system function. This continuous exposure to high levels of noise can cause hearing loss, which is known as Noise-Induced Hearing Loss (NIHL).<sup>1</sup> NIHL is irreversible sensorineural and usually bilateral hearing loss, whose progression can be avoided, and its cause is associated with long periods of permanence in noisy environments, usually within work environments.<sup>2</sup> In general, it does not exceed 40 dBHL at low frequencies and 75 dB at high frequencies, and when exposure to noise ceases, NIHL tends not to progress.<sup>3</sup> A continuous exposure to sound intensity greater than 85 dB is the principal factor that causes NIHL, making it the second most self-reported occupational disease mainly in workers exposed to industrial noise.<sup>2</sup> Loss of auditory discrimination and sound localization can be associated with the degree of NIHL; however, NIHL impacts can go beyond the auditory symptoms and reach the vestibule, causing work accidents, insomnia, irritability, and arterial hypertension.<sup>4</sup>

In the United States, approximately 27.7 million individuals are affected by NIHL, and one estimates that 25% of the Brazilian working class may present some degree of NIHL.<sup>5,6</sup> Noise is considered a high risk for occupational hearing loss when the level of sound pressure and the time of exposure exceed the limits established in regulatory occupational health and medicine standards, such as the exposure limits set in NR15, through Ordinance No. 3.214/1978, which establishes the Tolerance Limits (TL) for exposure to continuous or intermittent noise, and for impact noise.<sup>7</sup> In Brazil, issues related to NIHL are described in labor legislation, in order to ensure the integrity of workers' hearing health.<sup>8</sup>

NIHL is considered one of the compulsory notifiable diseases, present in the Notifiable Diseases Information System (Sinan), which aims to map the profile of individuals with NIHL and subsequently, using this data, develop public measures for hearing health care.<sup>9</sup> Furthermore, public health policies recommend source noise reduction, provision of personal protective equipment (PPE) and hearing protection devices (HPDs), and detection of hearing changes through audiological monitoring.<sup>10</sup>

Adherence to the use of hearing protectors occurs mainly among companies and its acceptance in the market refers to its low cost; however, even though the equipment functions as an acoustic barrier, preventing noise from reaching the cochlea, there is the need for strategies that are consistent with occupational risks and the implementation of administrative strategies for noise control.<sup>11</sup> Double hearing protection stands out as a possible strategy for increasing hearing protection, as the combined use of two hearing protectors, earmuffs or earplugs, could result in gains of up to 15 dB.<sup>12</sup> Studies indicate that this strategy may reduce users' sound perception and discrimination and, therefore, should only be used in cases of extreme sound exposure, with noise levels above 105 dBHL.<sup>13,14,15</sup>

Based on the above, this research aims to verify the effectiveness of using double hearing protection in attenuating occupational noise, aiming to answer the following guiding question: Does the combined use of personal protective equipment have a positive effect on workers exposed to high sound pressure levels?

## Method

### *Protocol and registration*

This review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) recommendations.<sup>16</sup> The analyses were performed using the RevMan 5 ® program. The searches for scientific articles were conducted by two independent researchers on the electronic MEDLINE (Pubmed), LILACS, SciELO, SCOPUS, WEB OF SCIENCE and BIREME databases, without restrictions on language, period, and location. To complement and avoid risk of bias, a search for gray literature was carried out on Google Scholar. The research was structured and organized based on the PICOS framework, which stands for Population, Intervention, Comparison, Outcome, and Studies, where: population of interest or health problem (P) corresponds to patients; intervention (I) refers to the use of double protection; comparison (C) corresponds to PPE; outcome (O) corresponds to hearing protection, and studies (S) refer to clinical trials.

### *Search strategy*

The descriptors were selected from Health Sciences Descriptors (DeCS) and Medical Subject

Heading Terms (MeSH), given their wide use by the scientific community to index articles on the PubMed database. The combination of descriptor and Boolean operator was used as a search strategy: (Hearing loss) and (double hearing protection). The search took place in a concentrated manner in May 2023. To complement the review, a search for gray literature was carried out on Google Scholar.

### Eligibility Criteria

Studies without restrictions on language, period, and location were included. Table 1 represents the inclusion and exclusion criteria used in this research. Studies that obtained a score greater than or equal to 6 points were included, according to the protocol for qualitative scoring proposed by Python et al.

**Table 1.** Overview of articles included

Author/ Year/ Place of publication/ Journal	Objective	Sample	Method	Results	Conclusion
Brungart DS, Kordik AJ, Simpson BD; 2004. @Ohio (EUA) - J Acoust Soc Am.	To analyze the effects of double hearing protection on the localization of multiple speech sources.	Six participants participated in the study (five men and one woman) with normal hearing thresholds and aged between 21 and 24 years. Subjects were tested without hearing protectors, with a single type of protector, and with double protection, wearing foam earplugs under earmuffs.	Study type: Clinical trial@Speech intelligibility tests were applied at 30dB above each participant's hearing threshold. Simultaneous sentences, target sentences, and masked sentences from male and female speakers were presented, from the same loudspeaker (non-spatial test) or two different ones (spatial test). The task was to identify the corresponding color and number in the sentence messages and whether it came from a loudspeaker on the left or right. There were four blocks, each referring to a hearing protection level, consisting of 15 spatial and 15 non-spatial tests.	Left-right discrimination was almost 100% correct when without a hearing protector or when wearing a single type of hearing protector; however, when wearing double protection, there was a 60% of reduction in correct answers. Nevertheless, there was a 69% of improvement in speaker distinction in localization tests when wearing double protection.	Despite the reduction in localization ability, the study shows that individuals with double hearing protection are still capable, even if to a reduced extent, of distinguishing the speakers in speech intelligibility tests.
Simpson BD, Bolia RS, Mckinley RL, Brungart DS; 2005. Ohio (EUA). - Hum. Factors@	To evaluate the HPDs impact on sound localization when wearing double hearing protection.	Seven participants (three men and four women) aged 18 to 39 years with normal hearing thresholds, according to the American@National Standards Institute [ANSI, 1997], and normal vision.	Study type: Clinical trial@ Individuals were positioned in front of a sphere with 277 speakers together with 4 LEDs. Participants had to identify the target LED while other randomly distributed LEDs with a sound signal acted as distractors. The test was divided into blocks of increasing difficulty, with increase in the number of distractors. Tests were carried out under four conditions; no HPD, foam earplugs, circumaural earmuffs, @and foam earplugs along with@circumaural earmuffs.	Without the use of HPDs, the response time remained constant as the test demand increased; during the use of earplugs, there was a moderate difference in searching time; in the case of earmuffs, a greater difference was observed in the target search time, and in the use of double hearing protection, there was a significant difference compared to the other conditions, suggesting that the auditory cue was disrupted during use.	The use of hearing protectors can obstruct significantly the passage of sound, which may vary according to the type of hearing protector worn. In the case of double protection, the localization of visual stimuli was severely affected due to the non-localization of the sound.@@

Author/ Year/ Place of publication/ Journal	Objective	Sample	Method	Results	Conclusion
Laroche C, Giguère C, Vaillancourt V, Marleau C, Cadieux MF, Laprise-Girard K, et al.; 2021. @ Ottawa (CA) - MDPI Journal.	To explore the effects of HPDs and safety helmets on the localization of broadband and tonal alarms by means of two experiments. The former analyzed the effects of passive hearing protection, while the latter analyzed the effects of level-dependent hearing protection.	The first experiment included a sample of 72 participants (34 women and 38 men) with normal hearing thresholds and aged between 18 and 39 years. The second experiment had a sample of 72 individuals (57 women and 15 men).	Study type: Clinical trial@ Participants were positioned in the middle of a loudspeaker sphere with 8 loudspeakers arranged uniformly over 360°, which emitted a background noise of 80dBHL while performing a simple task to identify the alarm. Subjects, with passive or level-dependent HPDs, were tasked with identifying the loudspeaker that sounded the alarm.	The broadband alarm localization was identified more easily compared to the tonal one. Passive hearing protectors had the greatest impact on localizing the alarm. The safety helmet had a much smaller impact compared to hearing protectors, but combined use may have a slight impact on sound localization in a horizontal plane.	Regarding sound localization in noisy workplaces, broadband alarms should be prioritized and double hearing protection should be avoided, with passive or level-dependent devices being the best options. Safety helmets had minimal effect on the task.

Source: Brungart DS et al. (2004), Simpson BD et al. (2005), Laroche C et al. (2021).

### Risk of bias

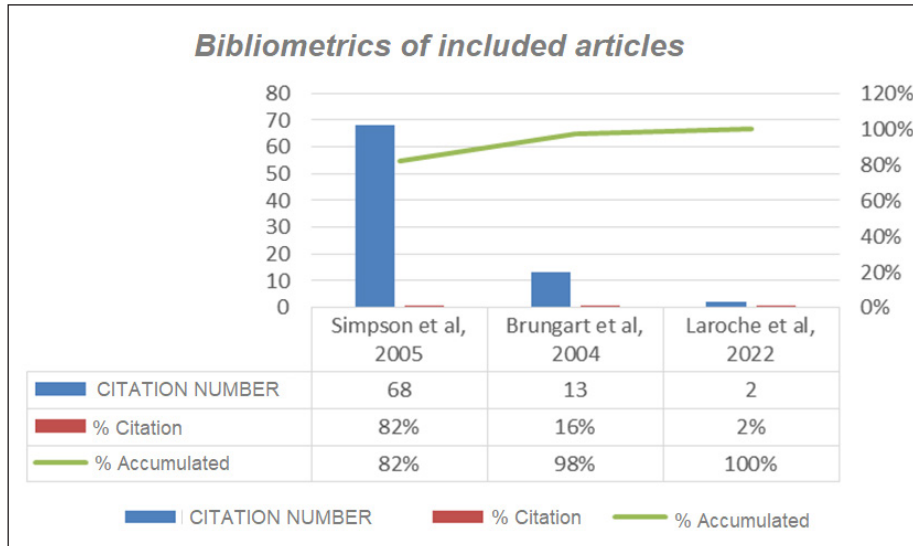
The quality of the methods used in the included studies was assessed independently by the reviewers, in accordance with the PRISMA recommendation.<sup>16</sup> The evaluation prioritized the clear description of information. At this point, a blind review was carried out by masking the names of authors and journals to avoid any potential bias and conflict of interest.

### Exclusion Criteria

Letters to the editor, guidelines, literature reviews, narrative reviews, systematic reviews, meta-analysis, and abstracts were excluded. Studies that were unavailable in full were also excluded (Table 1).

### Data analysis

For the study eligibility process, data were extracted by means of a specific form for systematic review created by three researchers using Microsoft Excel®, and the extracted data were added to the software by one of the researchers and then checked by another researcher. Initially, data were selected according to the title; then, the abstracts were analyzed and only those that were potentially eligible were selected. Based on the abstracts, the articles were selected for full reading and those that met all the pre-determined criteria to answer the guiding question were selected. Bibliometrics of the selected articles was performed, represented by a diagram of the accumulated frequency with insertion of values as a percentage of citation, aiming to evaluate the accumulated effect of the included articles (Figure 1).



**Figure 1.** Diagram of the accumulated frequency analysis of the bibliography of included articles.

## Method of study selection

Initially, the three eligibility reviewers calibrated themselves with each other to conduct the systematic review. After calibration and clarification of doubts, the titles and abstracts were examined independently by eligibility reviewers, who knew the names of the authors and journals. Studies outside the proposed scope, case reports, letters to the editor and/or editorial office, literature reviews, indexes, summaries, systematic reviews, and meta-analysis were excluded. Subsequently, the preliminary eligible studies had their full text obtained and evaluated (Table 1).

### Collected data

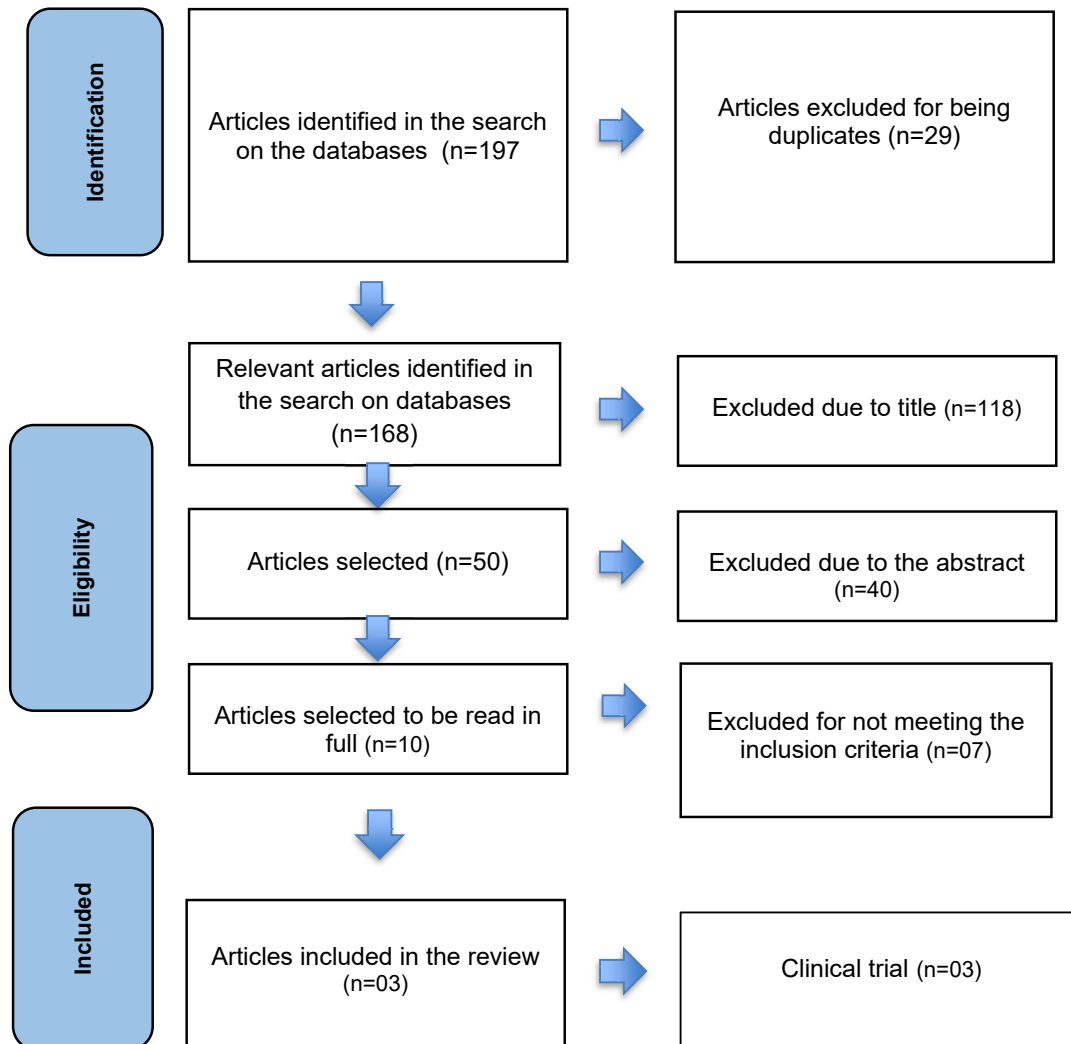
After screening, the text of the selected article was reviewed and extracted in a standardized manner by three authors under the supervision of an eligibility judge, identifying year of publication, location of research, language of publication, type, sample, method, result, and conclusion (Table 1).

## Clinical outcome

The clinical outcome of interest consisted of verifying the benefits of the combined use of HPDs as a strategy to prevent NIHL. Articles which did not adopt the defined approach were not included in the systematic review sample.

## Results

Initially, 197 articles were selected for the sample, and 168 remained after exclusion due to repetition; then, the titles and abstracts were analyzed and 158 works were excluded for not being within the scope of the research proposal. Ten articles were then sent for final analysis with full reading, and three of them were included in this research (Figure 2). The three studies selected are clinical trials. The databases were consulted based on the chosen descriptors, and the obtained results are shown in Figure 2.



**Figure 2.** Flowchart of article search and analysis.

### Study design and main findings

Three clinical trials were included in the research. Brungart et al.<sup>13</sup> carried out a clinical trial to examine the effects of double hearing protection on the ability to discriminate multiple speech sources in  $n=6$  military personnel (five men and one woman) with normal hearing thresholds and aged between 21 and 24 years, at the Air Force Research Laboratory Auditory Localization Facility, in Ohio. Speech intelligibility tests were applied 30 dB above each participant's hearing threshold, presenting simultaneous sentences, target sentences, and masked sentences from male and female speakers, from the same loudspeaker (non-spatial test) or two different ones (test space), also evaluating the

speech signal identification and localization. The task consisted of identifying the corresponding color and number in the sentence messages and which loudspeaker was activated, left or right, evaluated in four blocks, each block referring to a level of hearing protection. The authors observed that in comparative tests between the use of double hearing protection and the use of simple hearing protection, double hearing protection should be adopted at noise levels greater than 100 dBA, and the use of a single hearing protection device can facilitate sound identification and localization.

The study by Simpson et al.<sup>14</sup> sought to evaluate the impact of HPDs on sound localization during the use of double hearing protection in  $n=7$



participants (three men and four women) aged 18 to 39 years with normal hearing thresholds, according to the American National Standards Institute – ANSI,<sup>15</sup> and with normal vision. The tests were carried out at the Air Force Research Laboratory Auditory Localization Facility at Wright-Patterson Air Force Base, in Ohio. The individuals were positioned in a sphere with 277 speakers together with four LEDs with the aim of identifying the target with and without the use of HPDs, while other visual signals, randomly distributed, acted as distractors with a sound signal. The test was divided into blocks with increasing difficulty, with increase in the number of distractors, in four conditions: no hearing protectors, foam earplugs, earmuffs, and foam earplugs combined with earmuffs. Without the use of hearing protectors, the response time remained constant as the test progressed; with the use of earplugs, there was a greater difference in the increase in target search time, and with the use of double protection, noise source localization and head movement to identify alerts were compromised. The conclusion was that the localization of auditory cues was extremely difficult with double hearing protection due to impairment in spatial location caused by it.

The clinical trial by Laroche et al.<sup>16</sup> explored the effects of HPDs and safety helmets on the ability to localize broadband alarms and tonal sound alarms from two experiments. The former analyzed the effects with and without passive hearing protection and the use of a safety helmet, while the latter sought the effects of level-dependent hearing protection that has technology to reduce background noise. The first experiment included a sample of  $n=72$  participants (34 women and 38 men) with normal hearing thresholds and aged between 18 and 39 years. These participants were required to locate the signals of heavy vehicle security alarms (tonal signal and broadband signal) while performing a task exposed to a background noise field of 80 dBA. In the second experiment, with a sample of  $n=72$  individuals (57 women and 15 men), participants were tested with and without hearing protection, with the use of a helmet and level-dependent hearing protection. In general, the results showed that the location of the broadband signal alarm can be identified more easily compared to tonal signal alarm; passive ear protectors had better results for sound localization, while the safety helmet demonstrated an insignificant impact

in relation to earmuffs, but the combined use of the helmet and hearing protectors had a small change in the localization of the sound source. However, the double hearing protection had the worst results for front/back localization, with and without the use of a protective helmet. Therefore, the authors point out that broadband alarms should be prioritized and double hearing protection should be avoided, with passive or level-dependent devices being the best options.

## Discussion

NIHL is the second most common disease among workers,<sup>3,4,17</sup> and the studies included in this research sought to evaluate the effectiveness of wearing double hearing protection, as well as its impact on the localization of sound signals present in the work environment.

The combined use of double hearing protection is recommended when sound pressure levels are greater than 100 or 105 dBA; the attenuation gain can vary from 4 and 35 dB SPL, and this value will depend on the PPE quality.<sup>12,19</sup> The attenuation for the combined use of PPE should not be the sum of each individual value; when earmuff + earplug are worn simultaneously, 5 dB should be added to the highest noise reduction rating (NRR) value of the corresponding PPE.<sup>12,20</sup> The authors of the studies included in this research indicate that the use of double protection may interfere with speech intelligibility and sound localization, which may cause work accidents or expose the professional to dangerous situations. The gain in attenuation value in PPE occurs due to the occlusion effect, when there is mechanical coupling between the hearing protectors and physical contact with the epithelium and bones of the ear canal, together with the air volume between the two devices.<sup>12,21</sup> The authors also suggest that the use of hearing protectors can cause a decrease in auditory perception, mainly due to the impact on communication between the ears (interaural attenuation), which may restrict head movements towards the sound signal to localize it.<sup>12</sup>

In the United States, the National Institute for Occupational Safety and Health (NIOSH) advises that when wearing earmuff or earplug does not provide sufficient attenuation to reduce noise in the work environment, double protection should be adopted considering a gain between 5 and 10





dB in the attenuation level.<sup>12,19,22</sup> Thus, this value may occur from the combined use of HPDs, such as earmuffs and earplugs, aiming to prevent hearing loss.<sup>23</sup> However, double hearing protection can impair the perception of the spatial plane, caused by the occlusion effect, and may prevent the recognition of simultaneous speakers in the work environment.<sup>13</sup>

Sound attenuation by HPDs can be an obstacle to communication and spatial localization, especially for those workers who have some degree of NIHL,<sup>23</sup> as double hearing protection may impair auditory intelligibility. In this sense, the study by Laroche et al.<sup>16</sup> suggests that, as hearing loss is common in workplaces where hearing protectors are necessary, more studies should be carried out on individuals with hearing loss with inclusion of other safety equipment and the cognitive recruitment necessary to perform tasks in this scenario. Nevertheless, it is possible to choose PPE that provide mitigation for the function performed and also preserve the communication capacity.<sup>24</sup>

The three studies included in this research show that double attenuation is effective in relation to noise perception, but the lack of user training in relation to HPDs could cause a decrease in the protector efficiency given that the attenuation calculation is carried out based on the values in the Approval Certificate (AC) provided by the manufacturer of these HPDs.<sup>19</sup> Monitoring the engineering and/or administrative sectors, training professionals for the use of PPE and HPDs, and implementing hearing conservation program (HCP) are essential strategies that, used alone or in combination, can influence positively hearing health and/or the exposure to noise.<sup>18</sup>

The use of HPDs may limit the recognition of some warning signs, especially in the horizontal plane. The findings of Laroche et al.<sup>16</sup> indicate that broadband alarms have better results in localization tests compared to tonal alarms, suggesting that this measure should become a priority in worker safety actions. The ability to detect and recognize alarms is crucial for workers, especially in warning signals that are emitted from a distance, allowing workers to show better reaction time if the alarm is activated.<sup>25</sup> The use of HPDs can also cause confusion in spatial localization, as front/back localization.<sup>16</sup> It can be seen in the literature that no hearing protector maintains the same performance for sound localization as in the open-ear situation, except

in the right-left horizontal localization, where the earmuff had worse results.<sup>19,26</sup> This corroborates the findings of the study by Simpson et al.,<sup>14</sup> which infers that individuals who wear earplugs have greater sound perception and are more likely to protect themselves from danger, and that the use of earmuffs may compromise sound localization due to difficulty moving the head to localize the sound source.

The literature presents several pieces of research regarding hearing protection in military personnel and aircraft pilots, also highlighting how important auditory system integrity is, given that any impediment, deficiency, or distortion can lead to non-identification, erroneous identification, impairment in recognition or localization of threats, in addition to impaired understanding of orders.<sup>27,28,29</sup> Eventually, in environments where warning signs are used, the intensity of these alarms may exceed exposure limit values by at least 5 dB,<sup>23</sup> which would not be favorable to hearing loss prevention strategies. Regarding the use of double hearing protection in military personnel, Simpson et al.<sup>14</sup> conclude that the occlusion effect can reduce sound spatial perception drastically, and that, although the combined use of PPE is common in the armed forces, the loss of discrimination of speech signals would be a disadvantage in wearing double hearing protection. It is important to highlight that this population has a significant number of professionals at hearing risk and, therefore, the number of studies found with this population is justified; besides, new studies should be performed in order to understand the exposure impacts, focusing on the development of appropriate prevention and interventions strategies.<sup>18</sup>

The study by Brungart et al.<sup>13</sup> included in this research states that individuals with double hearing protection are still capable, even if minimally, of discriminating between the target speaker and other speakers in speech intelligibility tests; however, such results may be related to the reduced sample size and the environment where the tests were carried out, which does not portray the worker's reality. Finally, the position of a sound source in relation to the listener may have a positive effect on the warning signal localization accuracy and the performance in identifying and localizing broadband alarms compared to tonal alarms, inferring that the former should become a priority as safety measure.<sup>16</sup>

## Conclusion

Health problems resulting from exposure to noise may affect all workers who are subjected to high sound pressure levels, and it is known that NIHL is irreversible and its worsening is progressive. The use of double hearing protection can be a good strategy to avoid hearing loss in controlled environments, such as military training and shooting ranges, and places with assisted practices.

Earplugs had the best performance with regard to sound localization in the tests of all included articles. It is also necessary to implement new sound standards for warning alarms, considering accident warnings at the work environment. However, the lack of comfort associated with the use of hearing protectors can affect the adherence to their use in a strong manner and, therefore, their effectiveness in preventing NIHL. More training strategies should be adopted, and also the review of labor legislation and safety strategies that can lead to better mitigation performance by these devices. Targeting strategies focused on occupational health, in which the combined use of hearing devices used in controlled environments and the implementation of broadband signals as a standard signal, can be used as collective safety strategies.

## Referências

1. Cunha AP, Cortes DA, Ferreira GR. Perda Auditiva Induzida por Ruído Ocupacional. *Revista Multidisciplinar: HUMANIDADES & TECNOLOGIA EM REVISTA (FINOM)*, Minas Gerais, v. 15, n. 13, p. 495-510, abr. 2019. ISSN: 1809-1628.
2. Ding T, Yan A, Liu K. What is noise-induced hearing loss? *Br. J. Hosp. Med.* 2019 Sep 2;80(9):525–9. Doi: <https://doi.org/10.12968/hmed.2019.80.9.525>
3. Silva VAR, Mitre EI, Crespo AN. Is noise-induced hearing loss still a public health problem after decades of legislation? *Braz J Otorhinolaryngol.* 2020 Nov; 86(6): 665–6. Doi: <https://doi.org/10.1016/j.bjorl.2020.04.00>
4. Hillesheim D, Zucki F, Rogia SM, Paiva KM. Dificuldade auditiva autorreferida e exposição ocupacional a agentes otoagressores: um estudo de base populacional. *Cad. Saúde Pública.* 2021; 37(10): e00202220. DOI: 10.1590/0102-311x00202220.
5. MINISTÉRIO DA SAÚDE - Secretaria de Atenção à Saúde. Departamento de Ações Programáticas Estratégicas. Perda auditiva induzida por ruído (Pair). Brasília: Ed. do Ministério da Saúde; 2006. Disponível em: [https://bvsms.saude.gov.br/bvs/publicacoes/protocolo\\_perda\\_auditiva.pdf](https://bvsms.saude.gov.br/bvs/publicacoes/protocolo_perda_auditiva.pdf)
6. Hoffman HJ, Dobie RA, Losonczy KG, Themann CL, Flamme GA. Declining Prevalence of Hearing Loss in US Adults Aged 20 to 69 Years. *JAMA Otolaryngol Head Neck Surg.* 2017 Mar 1; 143(3): 274. DOI: 10.1001/jamaoto.2016.3527
7. Ministério do Trabalho e Emprego (MTE). Portaria nº 3.214, de 08 de junho de 1978. Brasília, DF, Seção 1.
8. Maia LMSV. Análise da perda auditiva induzida pelo ruído em agricultores da comunidade dos municípios da região de Campo Mourão - PR – projeto piloto: analysis of noise-induced hearing loss in farmers of the community of municipalities in the region of Campo Mourão-PR pilot project. 2023. 46 p. Tese (Doutorado) - Curso de Mestrado em Inovação Tecnológica, Desenvolvimento de Equipamentos, Tecnologias e Sistemas Eletrônicos, Universidade Tecnológica Federal do Paraná (UTFPR), Campo Mourão, 2023.
9. Hillesheim D, Gonçalves LF, Batista D, Correa D, Goulart ML, Zucki F. Perda auditiva induzida por ruído no Brasil: descrição de 14 anos de notificação. *Audiol Commun Res.* 2022; 27: 1-6. DOI: 10.1590/2317-6431-2021-25851.
10. Basu S, Aggarwal A, Dushyant K, Garget S. Occupational noise induced hearing loss in India: a systematic review and meta-analysis. *Indian J Community Med.* 2022; 47(2): 166. DOI: 10.4103/ijcm.ijcm\_1267\_21.
11. Giannella AS, Fiorini AC. Capítulo 27: Ações de Proteção para Prevenção de Perdas Auditivas Relacionadas ao Trabalho. In: *Tratado de Audiologia.* 2ª ed. Rio de Janeiro: Guanabara Koogan; 2015. p. xx-xx. ISBN: 978-85-277-2744-0.
12. Técnico R. Dupla Proteção: revisão bibliográfica, legislação em outros países e resultados de ensaios no Brasil. 2020. Disponível em: [https://issuu.com/animaseg/docs/relat\\_rio\\_da\\_tecnico\\_-\\_dupla\\_protecao\\_-\\_cb32](https://issuu.com/animaseg/docs/relat_rio_da_tecnico_-_dupla_protecao_-_cb32)
13. Brungart DS, Kordik AJ, Simpson BD. The effects of single and double hearing protection on the localization and segregation of spatially-separated speech signals (L). 2004 Oct 1;116(4):1897–900. Doi: <https://doi.org/10.1121/1.1786812>
14. Simpson BD, Bolia RS, McKinley RL, Brungart DS. The Impact of Hearing Protection on Sound Localization and Orienting Behavior. *Hum Factors.* 2005 Mar; (1): 188-98. DOI: 10.1518/0018720053653866.
15. ANSI: American National Standards Institute. ANSI S3.5-1997: methods for the calculation of the speech intelligibility Index. New York, NY: Acoustical Society of America; 2012.
16. Laroche C, Giguère C, Vaillancourt V, Marleau C, Cadieux MF, Laprise-Girard K, et al. Effect of Hearing and Head Protection on the Localization of Tonal and Broadband Reverse Alarms. *Hum Factors.* 2021 Feb 17. DOI: 10.1177/0018720821992223.
17. Samelli AG, Matas CG, Gomes RF, Morata TC. Revisão sistemática de intervenções para prevenção da perda auditiva induzida por ruído ocupacional – uma atualização. *Codas.* 2020; 33(4): e20190189. DOI: 10.1590/2317-1782/20202019189.
18. Moher, D., Shamseer, L., Clarke, M. et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev* 4, 1 (2015). <https://doi.org/10.1186/2046-4053-4-1>
19. Guida HL, Taxini CL, Gonçalves CG, Valenti VE. Evaluation of hearing protection used by police officers in the shooting range. *Braz J Otorhinolaryngol.* 2014; 80: 515-21.

20. Fernandes RME, Serra GPP, Filho SSC, Melo GSV, Mesquita ALA. Avaliação da proteção auditiva para ruído emitido por helicóptero. *Rev Eng Tecnol*. 2018; 2(10): 60-71.
21. Luan Y, Sgard F, Nelisse H, Dautres O. A finite element model to predict the double hearing protector effect on an in-house acoustic test fixture. *J Acoust Soc Am*. 2022 Mar; 151(3): 1860-74. DOI: 10.1121/10.0009835.
22. NIOSH, The National Institute For Occupational Safety And Health. Practical Guide for Preventing Occupational Hearing Loss: provide hearing protection. Provide Hearing Protection. (base de dados na internet) 2023. Disponível em: <https://www.cdc.gov/niosh/topics/noise/preventoccnoise/provide.html>.
23. Suter AH. Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis. *AIHA J*. 2002 Nov; 63(6): 768-789. DOI: 10.1080/15428110208984768.
24. Abel SM, Odell P. Sound attenuation from earmuffs and earplugs in combination: maximum benefits vs. missed information. *Aviat Space Environ Med*. 2006 Sep; 77(9): 899-904. PMID: 16964737.
25. Alali K, Casali JG. Auditory backup alarms: distance-at-first-detection via in-situ experimentation on alarm design and hearing protection effects. *Work*. 2012; 41: 3599-607. PMID: 22317269. DOI: 10.3233/WOR-2012-0671-3599.
26. Talcott KA, Casali JG, Keady JP, Killion MC. Azimuthal auditory localization of gunshots in a realistic field environment: effects of open-ear versus hearing protection-enhancement devices (HPEDs), military vehicle noise, and hearing impairment. *Int J Audiol*. 2012 Feb; 51 Suppl 1: S20-S30. DOI: 10.3109/14992027.2011.631591.
27. Lee K, Casali JG. Development of an auditory situation awareness test battery for advanced hearing protectors and TCAPS: detection subtest of DRILCOM (detection-recognition/identification-localization-communication). *Int J Audiol*. 2016 Dec; 56(sup1): 22-33. DOI: 10.1080/14992027.2016.1256505.
28. Fostick L, Fink N. Situational Awareness: the effect of stimulus type and hearing protection on sound localization. *Sensors (Basel)*. 2021 Oct 24; 21(21): 7044. DOI: 10.3390/s21217044.
29. Snapp HÁ, Millet B, Schaefer-Solle N, Rajguru SM, Ausili SA. The effects of hearing protection devices on spatial awareness in complex listening environments. *PLoS One*. 2023; 18(1): e0280240. DOI: 10.1371/journal.pone.0280240.



This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.