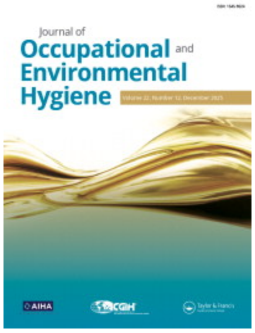

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: www.tandfonline.com/journals/uoeh20

Enhancing and sustaining noise attenuation from hearing protection devices: A mixed methods review of fit testing and instruction approaches

Wei Gong, Thais C. Morata & Alessandra G. Samelli

To cite this article: Wei Gong, Thais C. Morata & Alessandra G. Samelli (27 Jan 2026): Enhancing and sustaining noise attenuation from hearing protection devices: A mixed methods review of fit testing and instruction approaches, Journal of Occupational and Environmental Hygiene, DOI: 10.1080/15459624.2025.2602758

To link to this article: https://doi.org/10.1080/15459624.2025.2602758

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
https://doi.org/10.1080/15459624.2025.2602758

Taylor & Francis
Taylor & Francis Group

REVIEW ARTICLE

Enhancing and sustaining noise attenuation from hearing protection devices: A mixed methods review of fit testing and instruction approaches

Wei Gong[a], Thais C. Morata[a], and Alessandra G. Samelli[b]

[a]Division of Field Studies and Engineering, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio; [b]Department of Physical Therapy, Speech-Language-Hearing Sciences, and Occupational Therapy, Universidade de São Paulo, São Paulo, SP, Brazil

ABSTRACT

Extensive training has been shown to improve the effectiveness of hearing protection devices (HPDs) in reducing noise exposure for workers. This study aimed to (1) assess the evidence for short- and long-term effectiveness of HPD fit testing paired with extensive instructions and (2) identify the type and frequency of refresher instruction associated with maintaining its effectiveness. A literature search was completed on February 5, 2025. The inclusion criteria focused on uncontrolled before-and-after (UBA) studies that reported personal attenuation ratings (PARs) provided by HPDs in the field. A total of 23 UBA studies involving 5,575 workers were included, meta-analyses were performed when multiple comparable studies were located. For earplugs, retesting immediately after extensive training increased the mean PAR by 12.88 dB (13 studies) compared with the pre-intervention PARs without instructions. The improvement decreased to 8.84 dB (2 studies) within 6 months and further reduced to 4.46 dB (2 studies) at 12 months. For earmuffs, only one study reported increase in PARs of 5, 2, and 3 dB for immediate, short-term, and long-term assessment, respectively. Introducing extensive refresher training within a 6-month interval increased the mean PAR from earplugs by 1.53 dB (2 studies) compared with the post-intervention PAR retested immediately after extensive training, with a further increase of 3.45 dB (1 study) following annual extensive instruction. Simple refresher instructions within a 6-month interval maintained the PAR values (1 study). However, without any refresher training, the PAR decreased by 2.64 dB (2 studies) within 6 months and 3.09 dB (2 studies) over 6 months or longer. Refresher training may increase the probability that workers receive efficient protection from their HPDs. However, more high-quality studies could help inform the optimal type and frequency of refresher training.

KEYWORDS
Earmuff; earplug; hearing conservation program; hearing loss prevention; personal attenuation ratings (PARs); training

Introduction

Noise exposure has long been recognized as a common physical hazard in various industries and workplaces (Themann et al. 2023). It is the primary cause of preventable hearing loss among other health effects (Le et al. 2017). Worldwide, it is estimated that occupational noise exposure contributes to 16% of the cases of moderate or worse (>40 dB HL) hearing loss in adults (Nelson et al. 2005) and accounts for 7 million years lived with disability (YLDs) (95% CI 4.76 to 10.1, GBD 2019 Hearing Loss Collaborators 2021). The National Institute for Occupational Safety and Health (NIOSH) estimated that 22% of the United States (U.S.) workforce has a history of occupational noise exposure (Kerns et al. 2018), which was responsible for 11.2% (95% CI: 10.2 to 12.4) of YLDs due to hearing loss (Haile et al. 2024). While still high, globally, the burden of occupational noise-induced hearing loss has decreased from 1990 to 2019 by 1.72%, especially in countries from middle and lower social demographic indices (C. Liu et al. 2024).

Controlling the hazard at the source is recognized as the most effective and preferred approach to prevent occupational injury and illness (https://www.cdc.gov/niosh/noise/about/noise.html). However, a lack of emphasis on noise control and over-reliance on hearing protection are recognized factors that likely contribute to the continuing high burden of hearing

CONTACT Wei Gong yud9807@gmail.com Division of Field Studies and Engineering, National Institute for Occupational Safety and Health (NIOSH), Cincinnati, OH.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/15459624.2025.2602758. AIHA and ACGIH members may also access supplementary material at http://oeh.tandfonline.com.

loss among noise-exposed workers. (Themann and Masterson 2019). In the U.S., hearing protection devices are labeled with a Noise Reduction Rating (NRR) to indicate their potential for noise reduction (EPA 1979). The NRR is a laboratory-derived statistical estimate that does not accurately reflect attenuation achieved by an individual worker in the field. It has been shown repeatedly to overestimate real-world sound reductions (Themann and Masterson 2019). By measuring personal attenuation ratings (PARs) on each worker through hearing protector fit testing (HPFT) (Voix et al. 2022), one can ensure that workers are receiving effective attenuation from their HPDs.

The concept of HPFT has been around since the 1970s (Lempert and Edwards 1983). Advances in computer technology have enabled the development of portable and economical fit-test systems. Several commercial fit-test systems are available on the market, and these have seen gradual adoption by employers and occupational hearing testing companies (Voix et al. 2022).

Fit-test interventions are designed to help an individual worker properly fit their HPDs and achieve the necessary attenuation level with a particular protector. This is accomplished in part by providing the worker with instructions on how to choose, fit, and use HPDs. Recent studies report that HPD fit testing could help workers wear their HPDs correctly and improve the protectors' attenuation (Gong et al. 2021; Murphy et al. 2016). It may also help lower rates of hearing loss. Four facilities that used fit testing in their hearing conservation program achieved the lowest rates of hearing shift among the 14 participating sites within the same company (Sayler et al. 2018). A 2024 Cochrane systematic review reported that fit testing combined with extensive instructions can immediately reduce noise level at workers' ears following the test and associated training (Morata et al. 2024).

A few countries have published standards recommending (Argentina, Australia, Brazil, Italy, Russia, Uruguay, and Venezuela) or regulating (Canada, Germany, Malaysia, US DoD) the use of fit testing as part of hearing conservation interventions (Wells et al. 2023). In 2025, the US National Institute for Occupational Safety and Health (NIOSH) published a Science Policy Update recommending individual fit-testing for hearing protection devices (https://www.cdc.gov/niosh/docs/2025-104/pdfs/2025). This Update clarifies hearing protector recommendations in the 1998 NIOSH Criteria for a Recommended Standard – Occupational Noise Exposure.

There are still unanswered questions about the development and implementation of HPD fit-testing interventions. It remains unclear how long the effectiveness of extensive instructions can be maintained, whether instruction is necessary during follow-up fit tests, and if so, which type of instructions (extensive, simple, or none) and how often they would need to be provided to sustain the effectiveness of the intervention. In addition, the Cochrane review did not find any studies that evaluated whether fit testing and training contributed to the use of HPDs (Morata et al. 2024). These gaps in the evidence represent a critical barrier to implementing universal HPD fit testing in occupational settings (Murphy et al. 2023).

The 2024 Cochrane review (Morata et al. 2024) located not only three randomized controlled trials (RCTs, with 756 participants) but also 17 uncontrolled before-and-after (UBA) articles with complete datasets (Table A1). Among them, two articles (Casali and Park 1991; Park and Casali 1991) reported one UBA study. In addition, one randomized controlled trial (Federman et al. 2021) had a UBA component. Given their methodological design limitations, the results from the UBA studies supported the discussion but not the conclusions. The Cochrane review authors (Morata et al. 2024) noted, however, that despite their higher risk of bias (compared with RCT studies), UBA studies (given their design) can provide additional insight in scenarios when information from RCTs is limited.

Conducting an evidence synthesis that includes UBA studies allows one to map the scope and depth of research on a particular topic while identifying gaps, clarifying concepts, and informing future research directions. The primary goals of this mixed method review were to (1) assess the evidence for the effectiveness of HPD fit testing associated with extensive instructions, specifically examining both short- and long-term effectiveness; and (2) identify the type and frequency of refresher instructions most strongly associated with maintaining the effectiveness of HPD fit testing associated with extensive instructions. The secondary goal was to evaluate the impact of fit testing effectiveness on adherence to hearing protector use.

Methods

This mixed methods review combined the framework of a scoping review with key features of a systematic review. A scoping review delineates the coverage and focus of a body of literature with a synthesis of evidence (Munn et al. 2018). It also allows the identification of the nature of a broad field of evidence and evaluates whether a systematic review or meta-analyses are feasible. The key features of a systematic review include framing the question in a structured and explicit way; using a comprehensive, transparent, and reproducible search of the literature; and conducting the quality assessment of included studies (Khan et al. 2003).

The PICO (Population, Intervention, Comparison, and Outcome) model was used to guide the formulation of the research questions, development of search strategies, and characterization of studies or meta-analyses as in Morata et al. 2024. In this model, the population was defined as workers exposed to noise who use HPDs, the intervention involved fit testing with different formats of instructions, the comparison included various instruction formats, and the outcome was PAR, the PAR pass rate, or the rate of HPD use.

Systematic literature search

A systematic search was performed on Medline, Embase, PsycINFO, the Cochrane Central Register of Controlled Trials; CINAHL) (Cumulative Index to Nursing and Allied Health Literature), Scopus, NIOSHTIC-2 (National Institute for Occupational Safety and Health), ClinicalTrials.gov, and World Health Organization (WHO) International Clinical Trials Registry Platform. The search strategy employed was consistent with that reported in a previous Cochrane review (Morata et al. 2024). There were no restrictions on language, publication year, or publication status. Citations were imported into EndNote, where duplicates were removed. The databases were last searched on February 5, 2025.

Selection criteria

The inclusion criteria were (1) UBA studies involving fit-tested workers who used HPDs and were exposed to noise levels of more than 80 dBA; (2) studies that reported noise attenuation levels provided by various types of HPDs used by workers; (3) studies involving fit testing procedures and different formats of instructions for workers on how to properly select and fit HPDs. The primary outcome was noise attenuation measured either as a PAR and/or PAR pass rate. PAR pass rate is the percentage of workers who passed an established level of sufficient attenuation from their HPDs, determined based on their individual noise exposure levels. The secondary outcome was the HPD use rate, defined as the percentage of workers who used HPD during their work shift.

Eligible studies were selected in two stages. First, the 17 UBA studies identified in the previous Cochrane review (Morata et al. 2024) were automatically included. The last search of the Cochrane review was February 29, 2024. Second, search results from February 29, 2024 to February 5, 2025 were imported to the web-based software Covidence. Two review authors (WG, TM) independently screened the title and abstracts of all studies identified from the new search. The same two authors then conducted full-text screening. Any discrepancies between reviewers were resolved by discussion or by consulting a third review author (AS).

Data extraction and analysis

One review author extracted study characteristics using the same data collection form from the previous Cochrane Review (Morata et al. 2024) and entered data in a Microsoft Excel (Microsoft Excel for Microsoft 365 MSO, Version 2402) spreadsheet to perform a meta-analysis using a random-effects model (Neyeloff et al. 2012). The second review author spot-checked data entry for accuracy against the study report. For dichotomous outcomes, risk ratios (RRs) were calculated for PAR pass rate and the rate of HPD use. For continuous outcomes, mean differences (MDs) were used for PAR. The sample mean and standard deviation (SD) were estimated as described by Wan et al. (2014) when studies reported only sample size, median, range, and/or interquartile range.

All training formats reported in the included studies were categorized into two levels: extensive and simple. Extensive training was defined as any format of training that includes individualized instruction, while simple training was defined as any training format without an individualized instruction component. Initially, all workers underwent pre-intervention fit testing, and the first PAR was recorded as pre-intervention PAR. Subsequently, some workers took a post-intervention retest after receiving an extensive and/or simple instruction either immediately (same day), in the short-term (up to 6 months), or in the long-term (beyond 6 months). This retested PAR was recorded as the post-intervention PAR. Later, a follow-up fit test was conducted among those who had completed the post-intervention test to obtain follow-up PAR values; this follow-up fit test could include or exclude refresher training. The refresher training was also categorized as either extensive or simple instruction.

To assess the effectiveness of HPD fit testing with extensive instruction, the post-intervention PARs were compared with the pre-intervention PARs. This comparison allows for an evaluation of how long the effectiveness of extensive instructions is maintained.

To determine whether refresher instruction was necessary to maintain the effectiveness of extensive instruction, the follow-up PARs were compared with the post-intervention PAR values obtained immediately after extensive instruction. This comparison also allows evaluation of which type of refresher instruction (extensive, simple, or none) would be most effective and how often it would need to be provided to maintain the effectiveness of extensive instruction.

In addition, the rate of HPD use among workers was compared between the pre-and post-intervention fit testing, as well as between follow-up and the post-intervention fit testing. This comparison aims to examine whether HPD fit testing accompanied by instruction enhances adherence to HPD use.

The data were pooled from studies deemed sufficiently homogenous in terms of intervention, participants, and settings. A meta-analysis was performed with random-effects model, if more than one study provided useable data in any single comparison. Statistical significance alpha levels were set at 0.05.

Assessment of risk of bias and quality of evidence

The authors aimed to use the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool to assess the risk of bias in the eligible UBA studies (Sterne et al. 2024). If the evidence allowed, the five considerations (risk of bias, inconsistency, imprecision, indirectness, and publication bias) of the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) method was employed to assess the certainty of a body of evidence as it related to the studies that contributed data for the pre-specified outcomes.

Results

Characteristics of included studies

The latest search yielded 284 references in total. During the title and abstract screening, 277 were not eligible for inclusion. The remaining seven articles underwent full-text review, and one was excluded because of incomplete data. This process resulted in 6 recent UBA studies being added to 17 UBA studies (reported in 18 articles) identified in the 2024 Cochrane review (Morata et al. 2024). A total of 23 UBA studies with completed datasets were included in this review (Figure 1, Table A1). No RCT studies were found. Workers from 14 studies (Table A1) who did not achieve the desired PAR during the initial fit tests and/or with incorrect fit skill received an intervention followed by follow-up fit tests. In contrast, workers from nine studies (Table A1) underwent initial and follow-up fit tests regardless of the PAR levels they achieved at their initial tests.

Of 5,575 workers who were recruited in the 23 UBAs, a total of 4,629 workers were eligible and participated in the initial fit test to obtain their pre-intervention PARs. Of these, 4,184 received extensive instructions and were fit tested to estimate their post-intervention PARs. Among them, 3,374 were retested on the same day when they received extensive instructions, 456 were tested within 6 months after receiving extensive instructions, and 351 were tested more than 6 months later. In addition, 1,275 took a third test to estimate their follow-up PARs, either within 6 months or beyond 6 months after their second test.

Seventeen studies were conducted in manufacturing facilities, with 11 located in China, two in the United States, with one each from Canada, Taiwan, Korea, and Japan. In addition, one study took place at the U.S. Department of Defense, two were in the U.S. Marine Corps, and one was at an energy distribution company in Canada. Furthermore, two studies were performed at a public university in Brazil (Table A1). All workers reported being exposed to noise at work. Fourteen studies documented noise exposure levels ranging from 80 to 107 dBA, while some peak levels from rifles reached up to 160 dB SPL. Only five studies provided detailed descriptions of noise measurement methods and results (Murphy et al. 2016; Gong et al. 2021; Zhong et al. 2023; J. Liu et al. 2024; Shu et al. 2025). The ages of participants, reported by 16 studies, ranged from 18 to 69 years old (Table A1). Three studies included only male participants, one study primarily included female workers, and 17 studies reported a predominance of male participants (Table A1).

Eight studies used the real-ear attenuation at threshold (REAT, ISO 2018) method to estimate PAR values, while the remaining 15 studies used the microphone in the real-ear (MIRE, ANSI 2018) method (Table A1). Only one study measured PAR levels for canal caps, two studies tested earmuffs, and the remaining studies tested different types of earplugs, including foam, pre-molded, and push-to-fit earplugs (Table A1).

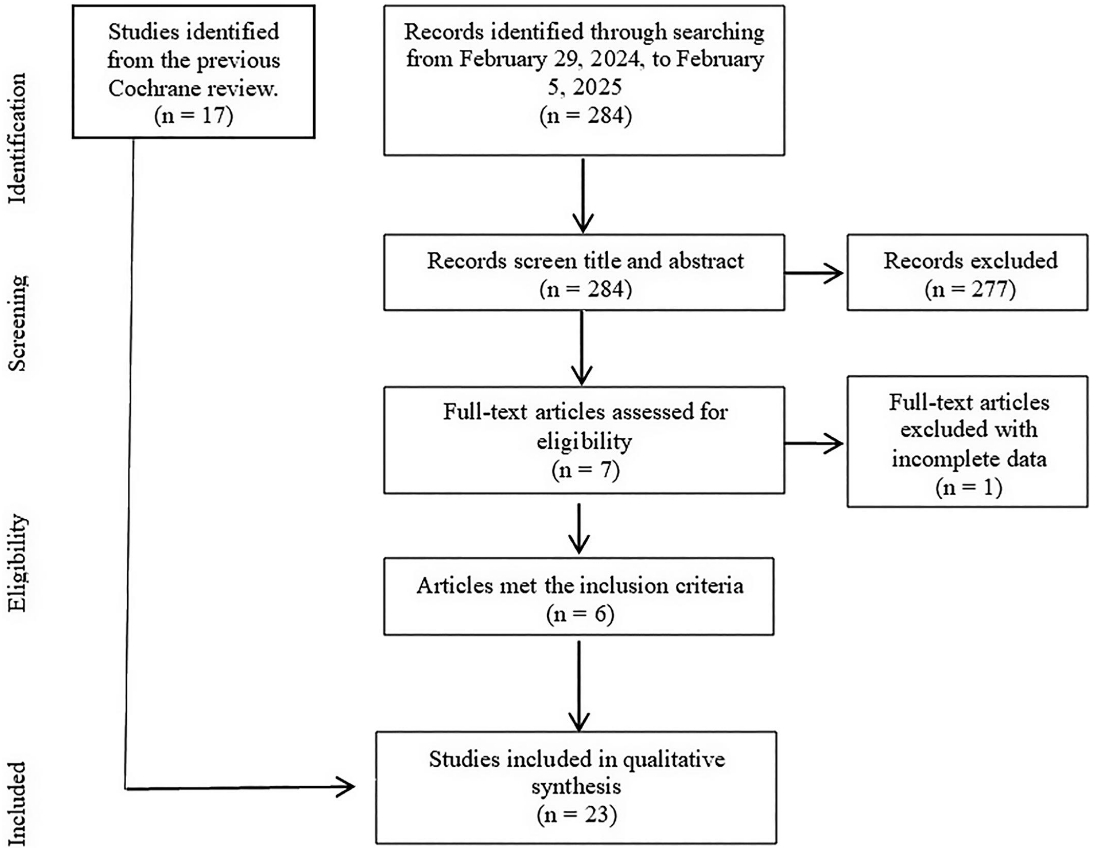

Figure 1. Prisma flowchart for screening process conducted for the mixed method review.

Three types of training format were defined: extensive, simple, and no instruction. To evaluate the effectiveness of intervention, 14 studies compared no instruction with extensive instruction (Table A1); three studies compared extensive instruction with simple instruction—specifically, HPD manufacturers' package instruction in two studies (Assunção et al. 2019; Takada et al. 2020) and group instruction in one study (Tsukada and Sakakibara 2008). In addition, one study reported the intervention effect of a short video instruction (simple), expert-fit instruction (extensive), or integrated video training and expert-fit instruction (extensive), compared with no instruction (Federman et al. 2021).

Twenty-one studies (Table A1) measured the immediate effects of fit testing combined with instruction. Eight studies assessed short-term effects, while four studies measured long-term effects (Table A1). Eight studies evaluated the effect of follow-up fit testing with refresher training weekly (Martin et al. 2019), biannually (Assunção et al. 2019), or over a period within 6 months (Tsukada and Sakakibara 2008; Gong et al. 2019; Y. Liu et al. 2020; Lü Lin et al. 2022) or in 12 months or more (Murphy et al. 2016; Y. Liu et al. 2020; Fu et al. 2024). In addition, Kim et al. provided annual individualized instruction to earplug users for four consecutive years to evaluate the effect of annual training (Kim et al. 2019). Only one study examined whether fit testing with instructions contributed to the use of hearing protection (Tsukada and Sakakibara 2008).

Regarding the assessment of risk of bias and quality of evidence, it is important to note that all the UBA studies identified in this review reported only one pre-intervention outcome measurement and one post-intervention outcome measurement for each participant. While the ROBINS-I tool is particularly relevant for UBA studies, it is not appropriate for those that rely on single pre- and/or post-intervention outcome measurements for each participant. Such studies are typically judged to be at serious or critical risk of bias because it is impossible to determine whether pre-post changes are due to the intervention rather than other factors (Sterne et al. 2024). Furthermore, UBA studies are observational in nature and focus solely on subjects who underwent the intervention. As a result, they usually warrant downgrading from low to very low quality according to the GRADE handbook (Schünemann et al. 2013). Therefore, all included studies were judged to be at serious risk of bias, which resulted in very low quality of evidence and should be considered with caution.

Effects of fit testing of HPD with extensive instructions

Immediate effects

Compared with the pre-intervention PARs without instructions, earplug users experienced an immediate post-intervention PAR increase of 12.88 dB (95% CI: 10.09 to 15.66; 12 studies, $Z = 9.87$, $p < 0.00001$), and the PAR pass rates improved with a risk ratio (RR) of 1.60 (95% CI: 1.13 to 2.27; 7 studies, $Z = 3.69$, $p = 0.0002$). For earmuff users, the post-intervention PAR increased by 5.00 dB (95% CI: 3.99 to 6.01; 1 study, $Z = 15.48$, $p < 0.00001$), and the PAR pass rate improved with an RR of 1.14 (95% CI: 1.07 to 1.21; 1 study, $Z = 9.72$, $p < 0.00001$).

When compared with the pre-intervention PARs with simple instructions, the post-intervention mean PARs for earplugs increased by 5.06 dB (95% CI: 3.99 to 6.01; 3 studies, $Z = 9.72$, $p < 0.00001$), and the PAR pass rate rose with an RR of 1.13 (95% CI: 1.06 to 1.19; 3 studies, $Z = 4.01$, $p < 0.0001$).

No study examined whether fit testing with extensive training could immediately affect the rate of HPD use.

Short-term effects

Compared with the pre-intervention PARs without instructions, the 6-month post-intervention visits (Gong et al. 2019; Y. Liu et al. 2020) showed an increase in the mean PAR from earplugs of 8.84 dB (95% CI −3.70 to 21.38; 2 studies, $Z = 8.96$, $p < 0.00001$), while the PAR from earmuffs increased by 2 dB (95% CI 0.53 to 3.47; $Z = 2.67$, $p = 0.008$). PAR pass rates for earplugs also increased (Gong et al. 2019), with an RR of 2.08 (95% CI 1.74 to 2.50; 1 study, $Z = 7.88$, $p < 0.00001$). Overall, the short-term improvements in mean PAR were observed to be lower than the immediate effects.

Compared with the pre-intervention PARs with simple instruction, retests at 3-week (Park and Casali 1991) and 2-month intervals (Tsukada and Sakakibara 2008) showed increases in the mean PAR for earplugs, earmuff, and canal cap of 6.22 dB (95% CI 1.19 to 11.26; 2 studies, $Z = 2.42$, $p = 0.02$), 1.60 dB (95% CI −2.7 to 9.97; 1 study, $Z = 9.21$, $p < 0.00001$), and 3.50 dB (95% CI −2.7 to 9.97; 1 study, $Z = 1.06$, $p = 0.29$), respectively. In addition, the rate of earplug use increased from 46% to 66% over the 2-month period following the training (Tsukada and Sakakibara 2008). At a 1-month follow-up visit, 26 of 37 workers from a printing enterprise self-reported that they increased the use of HPD when exposed to noise in their work shift (Lü Lin et al. 2022).

Long-term effects

In the 12-month retest (Kim et al. 2019; Y. Liu et al. 2020), an increase in the mean PAR of 4.46 dB (95% CI −15.86 to 7.32; 2 studies, $Z = 2.79$, $p = 0.005$) for earplugs was observed when comparing post-intervention PAR with pre-intervention PAR. However, this increase was smaller than the retest conducted within 6 months (8.84 dB) and significantly less than the immediate retest following extensive instructions (12.88 dB) (Figure 2). No study examined whether fit testing combined with extensive training could affect the long-term rate of HPD use, nor did any study compare the post-intervention PARs from simple instruction with the pre-intervention PARs.

Figure 2 shows the immediate, short-term, and long-term effectiveness of fit testing of earplugs with extensive instruction when compared with pre-intervention fit testing without instruction.

Effects of fit testing of HPD with refresher instruction

Short-term effects

The follow-up fit test, along with extensive refresher instruction within 6 months (Assunção et al. 2019; Martin et al. 2019), increased the mean PAR values of earplugs by 1.53 dB (95% CI 0.99 to 2.06; 2 studies, $Z = 5.25$, $p < 0.00001$) when compared with the post-PAR immediate retest following extensive instructions. The PAR pass rates for earplugs remained stable (Assunção et al. 2019), with an RR of 0.97 (95% CI 0.43 to 2.71; 1 study, $Z = 0.29$, $p = 0.77$).

Interestingly, simple refresher instruction at the follow-up fit test did not show changes either in PAR values (mean difference 0.65 dB, 95% CI −3.75 to 5.10; 1 study, $Z = 0.55$, $p = 0.58$) or the PAR pass rate (RR 0.86, 95% CI 0.32 to 2.32; 1 study, $Z = 0.96$, $p = 0.34$).

However, a follow-up fit test conducted alone without refresher instruction within 6 months (Tsukada and Sakakibara 2008; Gong et al. 2019; Y. Liu et al. 2020; Lü Lin et al. 2022) indicated that the mean PAR values for earplugs decreased by 2.64 dB (95% CI −0.44 to 5.71; 4 studies, $Z = 2.51$, $p = 0.005$), while the mean PAR values for earmuff decreased by 2 dB (95% CI 0.81 to 3.19; 1 study, $Z = 3.29$, $p = 0.001$; Liu and Yang 2018).

Long-term effects

The follow-up fit test conducted with extensive refresher instruction after 12 months (Kim et al. 2019)

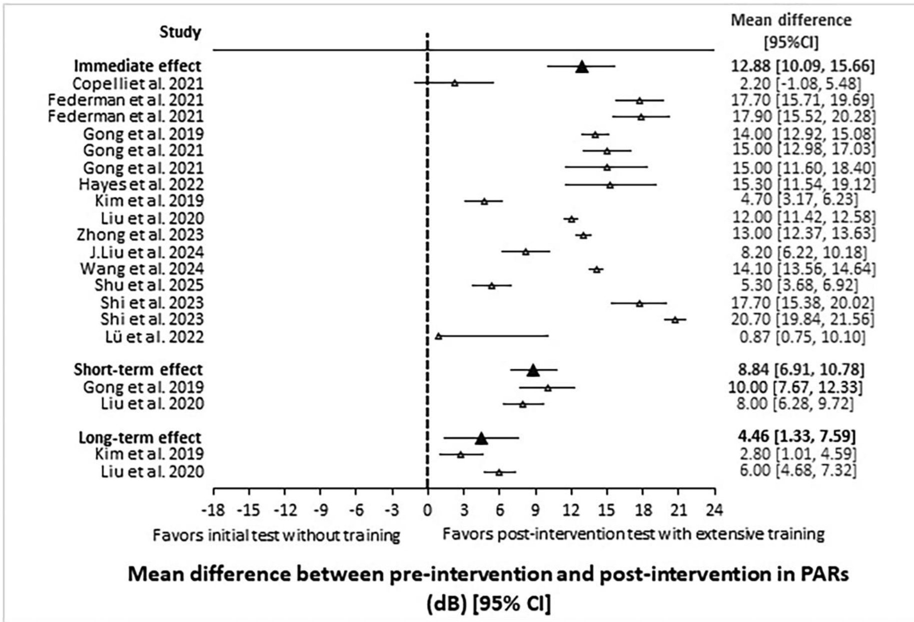

Figure 2. Mean differences in personal attenuation rating (PAR) values between results of the pre-intervention PARs without instruction and post-intervention PARs with extensive instruction at immediate, short-term, and long-term retests. The larger solid triangles represent the overall effect for each timeframe and the small open triangles indicate the effect for individual studies.

revealed an increase in the mean PAR values of earplugs of 3.45 dB (95% CI 2.01 to 4.88; $Z = 5.16$, $p < 0.0001$) when compared with the immediate retest following extensive instructions. No study examined the long-term effects of a follow-up fit test with simple refresher instruction.

In contrast, the follow-up fit test conducted without refresher instruction after 1 year led to a decrease in the mean PAR for earplugs by 3.09 dB (95% CI −2.19 to 8.37; 2 studies, $Z = 1.82$, $p = 0.07$, Kim et al. 2019; Y. Liu et al. 2020) when compared with the post-intervention PAR with extensive instruction. PAR pass rates for earplugs also decreased (Liu and Yang 2018), with a RR of 0.64 (95% CI 0.16 to 2.59; $Z = 1.82$, $p = 0.07$). For earmuffs, the mean PAR decreased by 1 dB (95% CI −0.78 to 2.78; 1 study, $Z = 1.10$, $p = 0.27$; Liu and Yang 2018). However, none of these decreases were statistically significant.

Figure 3 illustrates the short-term and long-term effectiveness of fit tests for earplugs with or without refresher instruction, in comparison with the retest immediately after extensive instruction.

Discussion

Effects of fit testing of HPD with extensive instructions

This mixed method review of 23 UBA studies revealed that providing extensive instructions immediately followed by fit testing achieved the greatest increase in PAR values and PAR pass rates for earplugs, compared with the pre-intervention PARs from fit testing without instruction. The increase in mean PAR (MD 12.88 dB; 95% CI: 10.03 to 15.66) is greater than that reported in the Cochrane review (MD 8.34 dB; 95% CI: 7.32 to 9.36). One possible explanation for this difference is that 14 UBA studies only provided intervention for workers who failed to achieve the desired PAR and/or with inappropriate use of HPDs, indicating that the pre-intervention PAR values for these workers were relatively lower than those in the randomized controlled trials (RCTs) analyzed in the Cochrane review (Morata et al. 2024). However, the increase in PAR levels is consistent regardless of the difference in the study design and rigor.

When there was a time interval of 1 week to 17 months between the extensive training and the post-intervention fit tests, a longer time interval between the instructions and the fit test was associated with lower attenuation. An exception was noted in the Park and Casali (1991) study, where workers received extensive instructions before a 3-week experimental period and were fit tested once a week. Their 3-week post-intervention mean PARs for earplugs improved by 12 dB compared with their pre-intervention PARs (Park and Casali 1991). This increase was even greater than the immediate effects observed in the randomized controlled trial (RCT) study (Federman et al. 2021). Beyond the different study designs, a possible explanation is that frequent fit testing (once a week) may enhance the effectiveness of extensive instruction.

For earmuffs, one study (Liu and Yang 2018) observed improvements in mean post-intervention PAR values at

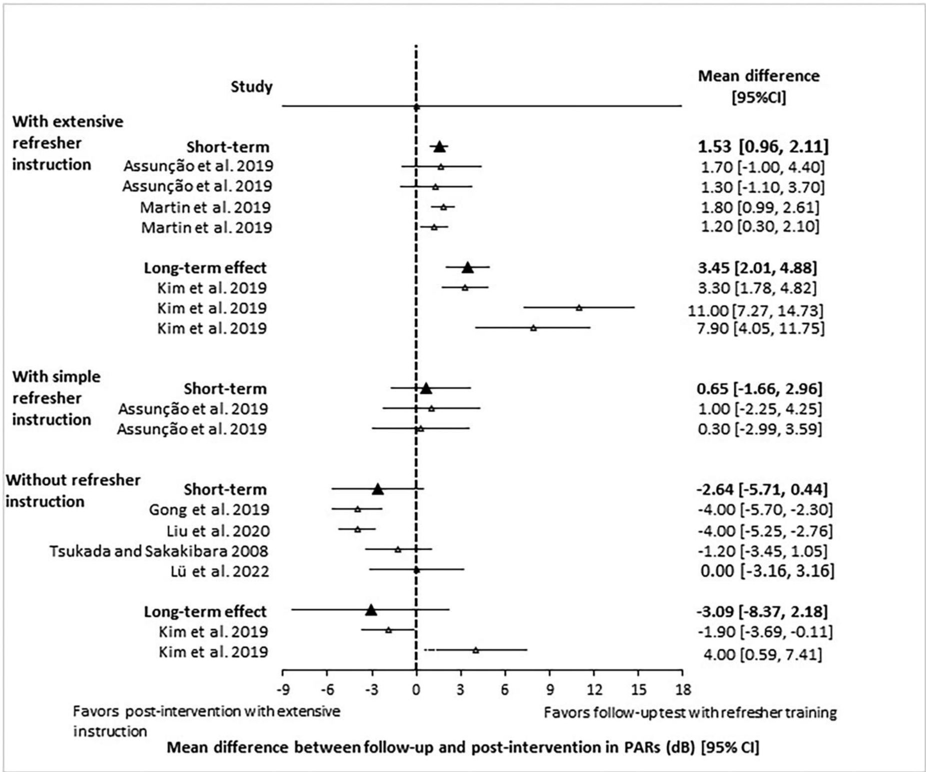

Figure 3. Mean differences in personal attenuation rating (PAR) values between results of the follow-up test with or without refresher training and that of retest immediately after extensive instructions. The large solid triangles represent the overall effect for each timeframe and the small open triangles indicate the effect for individual studies.

immediate, 6-month, and 12-month tests after participants received extensive instruction. The results, along with those from earplugs, consistently show that an interval of 6 months or more between instructions and fit testing significantly reduces the increase in PAR values from baseline. This finding indicates that providing extensive instruction immediately followed by a fit test leads to the greatest improvement in PAR values or pass rates. Conversely, longer intervals between instructions and fit testing (whether 6 or 12 months) are associated with a lower increase in attenuation. This suggests that a follow-up fit test is necessary after workers have demonstrated their ability to receive effective protection following extensive training.

One study reported a change in the rate of earplug use, showing an increase from 4% to 66% over 2 months following extensive training (Tsukada and Sakakibara 2008). In another study, workers indicated that they increased their earplug usage after initial fit tests; however, the rate of HPD use was not reported (Lü Lin et al. 2022). A 2024 study found that 138 out of 192 workers removed their earplugs during their initial visit for conversations or equipment checks; however, this number decreased to only 94 workers citing the same reasons after 17 months of their fit testing and instructions (Fu et al. 2024). These findings suggest that measuring the rate of HPD use may not comprehensively assess the impact of HPD fit testing since workers are generally required to wear HPDs when exposed to hazardous noise. Neitzel and Seixas (2005) noted that construction workers who reported "always" using HPDs in high noise environments actually wore them only one-third of the time when their noise exposure exceeded 85 dBA. Addressing factors contributing to nonuse—such as communication, comfort, and convenience—could enhance the consistency of HPD usage. Alternative metrics like HPD wearing duration, frequency of removal, or comfort levels may serve as better indicators for assessing consistent HPD use.

Effects of fit testing of HPD with refresher instruction

Evidence from two uncontrolled studies (Assunção et al. 2019; Martin et al. 2019) indicated that when the same subjects received extensive refresher instructions (either weekly or biannually), the mean post-training PAR improved by an average of 1.53 dB compared with the previous post-intervention PAR (95% CI: 0.99 to 2.06). In another study, annual fit testing combined with extensive instructions for 172 workers over 2 years and 30 workers over 4 years resulted in a mean PAR increase of 3.45 dB (95% CI: 2.01 to 4.88) at the 4th year test, compared with the post-intervention PAR values measured immediately after extensive training at the first year (Kim et al. 2019).

Extensive instructions can be time-consuming. Murphy et al. (2016) reported that training sessions lasted between 3 and 7 min, while Gong et al. (2021) noted that the duration of fit testing combined with extensive training varied from 5 to 30 min, depending on the number of times workers needed to be trained, refitted, and retested. In contrast, group training, video presentations, or written instructions typically require less time and fewer resources than the individualized extensive instruction. One study provided a 10-minute hearing health education and HPD training for groups of 8 to 16 U.S. Marine Corps recruits (Kulinski et al. 2024). This group training combined a standardized script, visual inspection, and immediate feedback from an occupational audiology staff member who provided recruits with the necessary skills to properly insert their HPDs. The study authors found a significant immediate increase of 14.6 dB in post-intervention PAR, with a slight decrease at 1-month follow-up, yet still above pre-intervention levels. The study indicates that implementing small-group training at large-scale in-processing events, where resource constraints may limit one-on-one intervention, could be considered a viable option for refresher instruction (Kulinski et al. 2024).

This mixed method review found that providing follow-up fit testing with simple refresher instruction at 6-month intervals allows workers to achieve the same level of protection as they did with initial extensive training. Therefore, this review suggests that simple instruction could serve as an alternative intervention to maintain the effectiveness of extensive instruction once workers are proficient in selecting and wearing hearing protection devices correctly. However, no studies have examined the long-term effects (beyond 6 months) of follow-up using refresher simple instruction.

In contrast, the follow-up fit test without refresher instruction resulted in a decrease in the mean PAR for both earplugs (Kim et al. 2019; Y. Liu et al. 2020) and earmuffs (Liu and Yang 2018) over 6 months to 1 year. This finding confirms that periodic follow-up fit testing with some forms of refresher instruction is necessary after workers have demonstrated their ability to achieve effective protection following extensive training.

Limitations

Because of the high bias present in the UBA studies included in this review, no definitive conclusions can be drawn regarding the type and frequency of refresher instruction needed. In addition, the effectiveness of training—both short-term and long-term—is likely influenced by noise exposure levels. This is especially relevant for workers exposed to a noise level of 85 dBA or lower, as they may not need as much attenuation from their HPDs during daily work as they did after extensive training.

Furthermore, publication bias may have influenced our evaluation of the effects of extensive instruction from four UBA studies that were partially funded by the manufacturer of one of the systems used as an intervention. This funding source may have had an interest in publishing studies that demonstrate a preventive effect of fit testing for HPDs (Liu and Yang 2018; Gong et al. 2019; Y. Liu et al. 2020; Gong et al. 2021).

Conclusions

Implications for practice

The findings from this mixed method review indicate that providing extensive training can immediately enhance the noise attenuation offered by HPDs, aligning with the results reported in the Cochrane review published in early 2024. However, this initial increase in effectiveness tends to diminish over time. Fortunately, implementing periodic follow-up fit testing, along with either extensive or simple refresher instruction, can help maintain—and in some cases even improve—the effectiveness of the initial training. In other words, periodic follow-up fit testing with refresher training is beneficial for workers who demonstrate their ability to achieve effective protection.

From a practical perspective, biannual, annual, or biennial training would be more feasible than weekly sessions. However, few high-quality studies have evaluated the effects of periodic refresher instruction or the maintained effects of such instructions. These findings align with a previous Cochrane review (Tikka et al. 2017), which noted a limited number of studies examining the effectiveness of refresher training. Further research is likely to have an important impact and could modify the conclusions reached in this review.

Implications for research

Future randomized controlled trials (RCTs) could examine the need for optimal time intervals between tests with extensive instruction and periodic testing combined with refresher instructions. This mixed methods review indicates that periodic fit testing of HPDs with extensive or simple refresher instruction could help maintain the achieved attenuation from HPDs. To support this finding, RCTs of high or moderate quality could offer greater certainty to enhance the implementation of the intervention in workplace settings. Future studies also could use hierarchical clusters of noise exposure levels in the data analysis to better evaluate the training effects across different time frames.

For an HPD fit-testing strategy to be widely accepted in industry, it is important to identify its key elements and develop an efficient implementation model. In addition, addressing factors that contribute to nonuse of HPDs—such as communication, comfort, and convenience—could improve the consistency of hearing protector use. Other outcomes, such as HPD wearing time, frequency of removal, and comfort levels, may also serve as valuable indicators for assessing consistency in HPD use.

As noted in the Cochrane review (Morata et al. 2024), two variables have not yet been explicitly investigated: the effect of experience with HPD use and past training history.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Generative artificial intelligence (AI) statement

The authors used the CDC Chatbot (large language model GPT-4o mini) to review this submission for grammar, clarity, conciseness, and consistency to enhance its readability and academic tone.

Funding

This work was sponsored by intramural research funds from the National Institute for Occupational Safety and Health, USA.

ORCID

Wei Gong http://orcid.org/0000-0002-8449-759X
Thais C. Morata http://orcid.org/0000-0002-0320-9649
Alessandra G. Samelli http://orcid.org/0000-0002-7164-8942

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

References

[ANSI] American National Standard Institute. 2018. Performance criteria for systems that estimate the attenuation of passive hearing protectors for individual users. ANSI (ANSI S12.71).

Assunção CHdC et al. 2019. Longitudinal evaluation of a hearing protector fit training program. Med Lav. 110(4): 304–311. https://doi.org/10.23749/mdl.v110i4.8214

Casali JG, Park MY. 1991. Real-ear attenuation under laboratory and industrial test conditions as provided by selected hearing protectors. Proc Hum Factors Soc. 35(15):1110–1114. https://doi.org/10.1177/154193129103501519

Chiu CC, Wan TJ. 2020. Individual fit testing of hearing-protection devices based on microphones in real ears among workers in industries with high-noise-level manufacturing. Int J Environ Res Public Health. 17(9):3242. https://doi.org/10.3390/ijerph17093242

Copelli F et al. 2021. Field attenuation of foam earplugs. Saf Health Work. 12(2):184–191. https://doi.org/10.1016/j.shaw.2020.09.006

EPA. 1979. Federal Regulation 44 (190), 40CFR 211 Part 211, Noise labeling requirements for hearing protectors. Environmental Protection Agency, Government Publication Office. p. 130–156. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-G/part-211

Federman J, Duhon C. 2016. The viability of hearing protection device fit-testing at Navy and Marine corps accession points. Noise Health. 18(85):303–311. https://doi.org/10.4103/1463-1741.195806

Federman J, Karch SJ, Duhon C. 2021. How hearing conservation training format impacts personal attenuation ratings in US Marine Corps Training Recruits. Int J Audiol. 60(2): 151–159. https://doi.org/10.1080/14992027.2020.1811407

Fu S, Huang L, Zhong X et al. 2024. Association between personal attenuation rating with types of earplugs and noise exposure levels in a textile factory in China. Int J Audiol. 10:1–7. https://doi.org/10.1080/14992027.2024.2396028

GBD 2019 Hearing Loss Collaborators. 2021. Hearing loss prevalence and years lived with disability, 1990-2019: findings from the Global Burden of Disease Study 2019. Lancet. 397(10278):996–1009. https://doi.org/10.1016/S0140-6736(21)00516-X

Gong W et al. 2019. Evaluating the effect of training along with fit testing on foam earplug users in four factories in China. Int J Audiol. 58(5):269–277. https://doi.org/10.1016/S0140-6736(21)00516-X

Gong W, Zhang J, Liu X, Ding E, Zhu B. 2021. Verifying earplug attenuation and evaluating the effectiveness of one-on-one training along with earplug fit testing at nine facilities in China. Am J Ind Med. 64(9):771–780. https://doi.org/10.1002/ajim.23270

Haile LM et al. 2024. Hearing loss prevalence, years lived with disability, and hearing aid use in the United States from 1990 to 2019: findings from the Global Burden of Disease Study. Ear Hear. 45(1):257–267. https://doi.org/10.1097/AUD.0000000000001420

Hayes ME et al. 2022. Improving hearing protection device noise attenuation through fit testing in an occupational health clinic. Workplace Health Saf. 70(4):196–204. https://doi.org/10.1177/21650799211067927

ISO. 2018. International Organization for Standardization. Acoustics—hearing protectors—part 1: subjective method for the measurement of sound attenuation. ISO 4869-1:2018. ISO.

Khan KS, Kunz R, Kleijnen J, Antes G. 2003. Five steps to conducting a systematic review. J R Soc Med. 96(3):118–121. https://doi.org/10.1177/014107680309600304

Kerns E, Masterson EA, Themann CL, Calvert GM. 2018. Cardiovascular conditions, hearing difficulty, and occupational noise exposure within U.S. industries and occupations. Am J Ind Med. 61(6):477–491. https://doi.org/10.1002/ajim.22833

Kim JW, Yang S, Chung I, Lee MY. 2019. The effect of earplug training on noise protection. Ann Occup Environ Med. 31(1):e34. https://doi.org/10.35371/aoem.2019.31.e34

Kulinski D et al. 2024. Evaluation of hearing conservation in-processing procedures at a US marine corps accession point. Perspect ASHA SIGs. 9(6):1683–1690. https://doi.org/10.1044/2024_PERSP-24-00125

Le TN, Straatman LV, Lea J, Westerberg B. 2017. Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. J Otolaryngol Head Neck Surg. 46(1):41. https://doi.org/10.1186/s40463-017-0219-x

Lempert BL, Edwards RG. 1983. Field investigations of noise reduction afforded by insert-type hearing protectors. Am Ind Hyg Assoc J. 44(12):894–902. https://doi.org/10.1080/15298668391405913

Liu C et al. 2024. The burden of occupational noise-induced hearing loss from 1990 to 2019: an analysis of global burden of disease data. Ear Hear. 45(5):1138–1148. https://doi.org/10.1097/AUD.0000000000001505

Liu J et al. 2024. Measurement and evaluation of personal attenuation rating before and after the training of the noise-exposed workers wearing foam earplugs. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 42(8):589–593. Chinese. https://doi.org/10.3760/cma.j.cn121094-20230817-000

Liu Y, Yang M. 2018. Evaluating the effect of training along with fit testing on earmuff users in a Chinese textile factory. J Occup Environ Hyg. 15(6):518–526. https://doi.org/10.1080/15459624.2018.1456662

Liu Y, Gong W, Liu X, Li L. 2020. Evaluating the effect of training along with fit testing on premolded earplug users in a Chinese petrochemical plant. Ear Hear. 41(4):838–846. https://doi.org/10.1097/AUD.0000000000000803

Lü Lin ZJ, Jinping X, Rong Z, Bei G, Jingyi S. 2022. Analysis on factors affecting protective effects effect of hearing protectors for noise workers in a printing enterprise. Chinese J Indus Med. 35(4):369–371. Chinese. https://doi.org/10.13631/j.cnki.zggyyx.2022.04.029

Martin L, Negrini A, Gaudreau MA et al. 2019. Earplug personal attenuation rating (PAR) in noise-exposed workers: evolution over a five weeks follow-up. Paper presented at: 26th International congress on sound and vibration July 7-11; Montreal, Canada.

Morata TC et al. 2024. Hearing protection field attenuation estimation systems and associated training for reducing workers' exposure to noise. Cochrane Database Syst Rev. 5(5):CD015066. https://doi.org/10.1002/14651858.CD015066.pub2

Munn Z et al. 2018. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol. 18(1):143. https://doi.org/10.1186/s12874-018-0611-x

Murphy WJ, Flamme GA, Vause NL. 2023. Overcoming barriers to hearing protector fit testing–outcomes of the international hearing protector fit-testing symposium. Proc Mtgs Acoust. 53(1):002005. https://doi.org/10.1121/2.0001936

Murphy WJ, Themann CL, Murata TK. 2016. Hearing protector fit testing with off-shore oil-rig inspectors in Louisiana and Texas. Int J Audiol. 55(11):688–698. https://doi.org/10.1080/14992027.2016.1204470

Neitzel RL, Seixas N. 2005. The effectiveness of hearing protection among construction workers. J Occup Environ Hyg. 2(4):227–238. https://doi.org/10.1080/15459620590932154

Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. 2005. The global burden of occupational noise-induced hearing loss. Am J Ind Med. 48(6):446–458. https://doi.org/10.1002/ajim.20223

Neyeloff JL, Fuchs SC, Moreira LB. 2012. Meta-analyses and Forest plots using a Microsoft Excel spreadsheet: step-by-step guide focusing on descriptive data analysis. BMC Res Notes. 5(1):52. https://doi.org/10.1186/1756-0500-5-52

Park MY, Casali JG. 1991. A controlled investigation of in-field attenuation performance of selected insert, earmuff, and canal cap hearing protectors. Hum Factors. 33(6):693–714. https://doi.org/10.1177/001872089103300606

Sayler SK, Rabinowitz PM, Cantley LF, Galusha D, Neitzel RL. 2018. Costs and effectiveness of hearing conservation programs at 14 US metal manufacturing facilities. Int J Audiol. 57(sup1):S3–S11. https://doi.org/10.1080/14992027.2017.1410237

Schünemann H, Brożek J, Guyatt G, Oxman A, editors. 2013 Oct. GRADE handbook for grading quality of evidence and strength of recommendations. The GRADE Working Group. [accessed 2025 Dec 31]. https://gdt.gradepro.org/app/handbook/handbook.html

Shi HX et al. 2023. Analysis of verification results of protective effects of hearing protectors in different industries. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 41(5):333–337. Chinese. https://doi.org/10.3760/cma.j.cn121094-20211026-00516.

Shu L et al. 2025. The protective effect of wearing hearing protection devices in noise-induced hearing loss and its potential influencing factors in the Chinese adult population. Sci Total Environ. 964:178507. https://doi.org/10.1016/j.scitotenv.2025.178507

Sterne JAC, Hernán MA, McAleenan A, Reeves BC, Higgins JPT. 2024. Chapter 25: assessing risk of bias in a non-randomized study [last updated October 2019]. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane handbook for systematic reviews of interventions version 6.5. Cochrane. www.training.cochrane.org/handbook

Takada MM et al. 2020. Training in the proper use of earplugs: an objective evaluation. Work. 65(2):401–407. https://doi.org/10.3233/WOR-203092

Tikka C et al. 2017. Interventions to prevent occupational noise-induced hearing loss. Cochrane Database Syst Rev. 7(7):CD006396. https://doi.org/10.1002/14651858.CD006396.pub4

Themann CL, Masterson EA. 2019. Occupational noise exposure: a review of its effects, epidemiology, and impact

with recommendations for reducing its burden. J Acoust Soc Am. 146(5):3879–3905. https://doi.org/10.1121/1.5134465
Themann CL, Masterson EA, Peterson JS, Murphy WJ. 2023. Preventing occupational hearing loss: 50 years of research and recommendations from the National Institute for Occupational Safety and Health. Semin Hear. 44(4):351–393. https://doi.org/10.1055/s-0043-1769499
Tsukada T, Sakakibara H. 2008. A trail of individual education for hearing protection with an instrument that measures the noise attenuation effect of wearing earplugs. Ind Health. 46(4):393–396. https://doi.org/10.2486/indhealth.46.393
Voix J, Smith P, Berger EH. 2022. Field fit testing and attenuation-estimation procedure. In: Meinke DK, Berger EH, Neitzel RL, Driscoll DP, Bright K, editors. The noise manual. 6th ed. American Industrial Hygiene Association (AIHA). p. 255–301.
Wan X et al. 2014. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol. 14(1):135. https://doi.org/10.1186/1471-2288-14-135
Wang YN et al. 2024. Study on the fit testing for the workers wearing hearing protection device in machinery manufacturing enterprises. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 42(1):16–21. Chinese. https://doi.org/10.3760/cma.j.cn121094-20220909-00451
Wells LL et al. 2023. Standards and regulations for hearing protector fit testing – outcomes of the international hearing protector fit-testing symposium. Proc Mtgs Acoust. 53(1):002001. https://doi.org/10.1121/2.0001843
Zhong X et al. 2023. Research on the protective effect of hearing protective device for workers exposed to noise in a motor manufacturing enterprise. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 41(11):814–818. Chinese. https://doi.org/10.3760/cma.j.cn121094-20220815-00402

Appendix

Table A1. Characteristics of included studies (ordered alphabetically by first author's last name and publication year).

Reference	Participants	Intervention	Comparison	Outcome
Assunção et al. 2019	Workers at a public university $N = 67$ Noise exposure levels: not reported Age: 48.53 ± 8.48 years Gender: 90% male HPDs: foam and premolded earplugs Brazil	Pre-training: simple instructions-manufacturers' package instruction Post-training: extensive instructions Refresher-training: simple and extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Post extensive instruction *vs.* pre-simple instruction: immediate effects Simple refresher instruction *vs.* post-extensive instructions: short-term effects	PAR; PAR pass rate
Chiu and Wan 2020	Manufacturing $N = 50$ Noise exposure levels: not reported Age: no reported Gender: 100% male HPDs: foam earplugs Taiwan	Pre-training: no instructions Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR pass rate
Copelli et al. 2021	Manufacturing $N = 30$ Noise exposure levels: not reported Age: not reported Gender: 100% male HPDs: foam earplugs Canada	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: yes Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects	PAR
Federman and Duhon 2016	U.S. Marine Corps $N = 320$ Noise exposure levels: 160 dB impulse Age: not reported Gender: not reported HPDs: foam earplugs USA	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects	PAR pass rate
Federman et al. 2021	U.S. Marine Corps $N = 341$ Noise exposure levels: 160 dB impulse Age: not reported Gender: not reported HPDs: foam earplugs USA	Pre-training: simple instructions-short video Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects	PAR; PAR pass rate

(*Continued*)

Table A1. Continued.

Reference	Participants	Intervention	Comparison	Outcome
Fu et al. 2024*	Manufacturing $N = 192$ Noise exposure levels: 85–99 dBA Age: 44.35 ± 5.25 years Gender: 14.6% male HPDs: foam earplugs China	Pre-training: no instructions. Post-training: extensive instructions Refresher-training: no instruction Intervention provided to all workers: no Fit testing technology: MIRE	No refresher instructions *vs.* extensive instructions: long-term effects	PAR pass rate
Gong et al. 2019	Manufacturing $N = 335$ Noise exposure levels: 90–98 dBA Age: 18–59 years Gender: 57% male HPDs: foam earplugs China	Pre-training: no instructions. Post-training: extensive instructions. Refresher-training: no instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate and short-term effects No refresher instruction *vs.* extensive instructions: short-term effects	PAR; PAR pass rate
Gong et al. 2021	Manufacturing $N = 503$ Noise exposure levels: 80–100 dBA Age: 38 ± 11 years Gender: 93% male HPDs: foam and premolded earplugs China	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects	PAR; PAR pass rate
Hayes et al. 2022	Workers at the U.S. Department of Defense $N = 100$ Noise exposure levels: ≥85 dBA Age: mean 33.9 years Gender: 81% male HPDs: foam and premolded earplugs USA	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects	PAR; PAR pass rate
Kim et al. 2019	Manufacturing $N = 172$ Noise exposure levels: not reported Age: mean 51 years Gender: 82% male HPDs: foam earplugs Korea	Pre-training: no instructions. Post-training: extensive instructions Refresher training: no and extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate and long-term effects Extensive refresher instruction *vs.* extensive instructions: long-term effects No refresher instruction *vs.* extensive instructions: long-term effects	PAR
Liu and Yang 2018	Manufacturing $N = 189$ Noise exposure levels: >95 dBA Age: not reported Gender: 57% male HPDs: earmuffs China	Pre-training: no instructions. Post-training: extensive instructions Refresher-training: no instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate, short-term, and long-term effects No refresher instruction *vs.* extensive instructions: short-term and long-term effects	PAR
J. Liu et al. 2024*	Manufacturing $N = 94$ Noise exposure levels: 80.1–94.3 dBA Age: 36.76 ± 11.48 years Gender: 95.7% male HPDs: foam earplugs China	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR
Y. Liu et al. 2020	Manufacturing $N = 774$ Noise exposure levels: 90–95 dBA Age: 18–59 dBA Gender: 95% male HPDs: premolded earplugs China	Pre-training: no instructions. Post-training: extensive instructions Refresher-training: no instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate, short-term, and long-term effects No refresher instruction *vs.* extensive instructions: short-term and long-term effects	PAR

(*Continued*)

Table A1. Continued.

Reference	Participants	Intervention	Comparison	Outcome
Lü Lin et al. 2022*	Manufacturing $N = 37$ Noise exposure levels: 83.7–86.6 dBA Age: 37.0 ± 8.4 years Gender: 91.9% male HPDs: foam and premolded earplugs China	Pre-training: no instructions. Post-training: extensive instructions Refresher-training: no instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects No refresher instruction *vs.* extensive instructions: short-term effects	PAR; PAR pass rate
Martin et al. 2019	Manufacturing $N = 18$ Noise exposure levels: not reported Age: 49.1 ± 8.36 years Gender: 94% male HPDs: foam and push-to-fit earplugs Canada	Pre-training: simple instructions-manufacturers' package instruction Post-training: extensive instructions Refresher training: extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Extensive refresher instruction *vs.* extensive instructions: short-term	PAR
Murphy et al. 2016	Manufacturing $N = 126$ Noise exposure levels: 87–100 dBA Age: 20–69 years Gender: 96% male HPDs: foam and premolded earplugs USA	Pre-training: no instructions. Post-training: extensive instructions Refresher-training: no instructions Intervention provided to all workers: no Fit testing technology: REAT	Extensive instructions *vs.* no instructions: immediate effects No refresher instruction *vs.* extensive instructions: long-term	PAR pass rate
Park and Casali 1991	Manufacturing $N = 46$ Noise exposure levels: 87.8–106.4 dBA Age: mean 37.9 years Gender: not reported HPDs: foam and premolded earplugs, earmuffs, canal caps USA	Pre-training: simple instructions. Post-training: extensive instructions Intervention provided to all workers: yes Fit testing technology: REAT	Extensive *vs.* simple instructions: short-term effects	PAR
Shi et al. 2023*	Manufacturing $N = 639$ Noise exposure levels: 81% >80 dBA Age: predominance between 20 and 40 years Gender: predominance male HPDs: foam and premolded earplugs China	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR
Shu et al. 2025*	Manufacturing $N = 862$ Noise exposure levels: >80 dBA Age: 60% between 31 and 50 years Gender: 82.5% male HPDs: foam earplugs China	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR
Takada et al. 2020	Workers at a public university $N = 140$ Noise exposure levels: not reported Age: mean 49 years Gender: 89% male HPDs: foam and premolded earplugs Brazil	Pre-training: simple instructions. Post-training: extensive instructions Intervention provided to all workers: yes Fit testing technology: MIRE	Extensive *vs.* simple instructions: immediate	PAR; PAR pass rate
Tsukada and Sakakibara 2008	Manufacturing $N = 68$ Noise exposure levels: >80 dBA Age: 35.5 ± 9.1 years Gender: 100% male HPDs: foam and premolded earplugs Japan	Pre-training: simple instructions. Post-training: extensive instructions Refresher-training: no instructions Intervention provided to all workers: yes Fit testing technology: REAT	Extensive *vs.* simple instructions: immediate and short-term effects No refresher instruction *vs.* extensive instructions: short-term	PAR; PAR pass rate HPD use rate

(*Continued*)

Table A1. Continued.

Reference	Participants	Intervention	Comparison	Outcome
Wang et al. 2024*	Manufacturing $N = 485$ Noise exposure levels: 80.2–95.0 dBA Age: 60.5% between 25 and 44 years Gender: predominance male HPDs: premolded earplugs China	Pre-training: simple instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR
Zhong et al. 2023	Manufacturing $N = 179$ Noise exposure levels: 80.1–94.4 dBA Age: not reported Gender: 60% male HPDs: premolded earplugs China	Pre-training: no instructions. Post-training: extensive instructions Intervention provided to all workers: no Fit testing technology: MIRE	Extensive instructions *vs.* no instructions: immediate effects	PAR

*Articles were identified through a search covering the period from March 1, 2024, to February 5, 2025.
HPD: hearing protection device; MIRE: microphone in the real-ear, PAR: personal attenuation rating; REAT: real-ear attenuation at threshold.