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Hearing protection field attenuation estimation systems and associated training for reducing workers' exposure to noise (Review)

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[Intervention Review]

Hearing protection field attenuation estimation systems and associated training for reducing workers' exposure to noise

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ABSTRACT

Background

Global Burden of Disease studies identify hearing loss as the third leading cause of years lived with a disability. Their estimates point to large societal and individual costs from unaddressed hearing difficulties. Workplace noise is an important modifiable risk factor; if addressed, it could significantly reduce the global burden of disease.

In practice, providing hearing protection devices (HPDs) is the most common intervention to reduce noise exposure at work. However, lack of fit of HPDs, especially earplugs, can greatly limit their effectiveness. This may be the case for 40% of users. Testing the fit and providing instructions to improve noise attenuation might be effective. In the past two decades, hearing protection fit-test systems have been developed and evaluated in the field. They are called field attenuation estimation systems. They measure the noise attenuation obtained by individual workers using HPDs. If there is a lack of fit, instruction for better fit is provided, and may lead to better noise attenuation obtained by HPDs.

Objectives

To assess: (1) the effects of field attenuation estimation systems and associated training on the noise attenuation obtained by HPDs compared to no instruction or to less instruction in workers exposed to noise; and (2) whether these interventions promote adherence to HPD use.

Search methods

We used CENTRAL, MEDLINE, five other databases, and two trial registers, together with reference checking, citation searching, and contact with study authors to identify studies. We imposed no language or date restrictions. The latest search date was February 2024.

Selection criteria

We included randomised controlled trials (RCTs), cluster-RCTs, controlled before-after studies (CBAs), and interrupted time-series studies (ITSs) exploring HPD fit testing in workers exposed to noise levels of more than 80 A-weighted decibels (or dBA) who use hearing protection devices. The unit 'dBA' reports on the use of a frequency-weighting filter to adjust sound measurement results to better reflect how human ears process sound. The outcome noise attenuation had to be measured either as a personal attenuation rating (PAR), PAR pass rate, or both. PAR pass rate is the percentage of workers who passed a pre-established level of sufficient attenuation from their HPDs, identified on the basis of their individual noise exposure.

Data collection and analysis

Two review authors independently assessed study eligibility, risk of bias, and extracted data. We categorised interventions as fit testing of HPDs with instructions at different levels (no instructions, simple instructions, and extensive instructions).

Main results

We included three RCTs (756 participants). We did not find any studies that examined whether fit testing and training contributed to hearing protector use, nor any studies that examined whether age, gender, or HPD experience influenced attenuation. We would have included any adverse effects if mentioned by the trial authors, but none reported them. None of the included studies blinded participants; two studies blinded those who delivered the intervention.

Effects of fit testing of HPDs with instructions (simple or extensive) versus fit testing of HPDs without instructions

Testing the fit of foam and premoulded earplugs accompanied by simple instructions probably does not improve their noise attenuation in the short term after the test (1-month follow-up: mean difference (MD) 1.62 decibels (dB), 95% confidence interval (CI) -0.93 to 4.17; 1 study, 209 participants; 4-month follow-up: MD 0.40 dB, 95% CI -2.28 to 3.08; 1 study, 197 participants; both moderate-certainty evidence). The intervention probably does not improve noise attenuation in the long term (MD 0.15 dB, 95% CI -3.44 to 3.74; 1 study, 103 participants; moderate-certainty evidence).

Fit testing of premoulded earplugs with extensive instructions on the fit of the earplugs may improve their noise attenuation at the immediate retest when compared to fit testing without instructions (MD 8.34 dB, 95% CI 7.32 to 9.36; 1 study, 100 participants; low-certainty evidence).

Effects of fit testing of HPDs with extensive instructions versus fit testing of HPDs with simple instructions

Fit testing of foam earplugs with extensive instructions probably improves their attenuation (MD 8.62 dB, 95% CI 6.31 to 10.93; 1 study, 321 participants; moderate-certainty evidence) and also the pass rate of sufficient attenuation (risk ratio (RR) 1.75, 95% CI 1.44 to 2.11; 1 study, 321 participants; moderate-certainty evidence) when compared to fit testing with simple instructions immediately after the test. This is significant because every 3 dB decrease in noise exposure level halves the sound energy entering the ear.

No RCTs reported on the long-term effectiveness of the HPD fit testing with extensive instructions.

Authors' conclusions

HPD fit testing accompanied by simple instructions probably does not improve noise attenuation from foam and premoulded earplugs. Testing the fit of foam and premoulded earplugs with extensive instructions probably improves attenuation and PAR pass rate immediately after the test. The effects of fit testing associated with training to improve attenuation may vary with types of HPDs and training methods. Better-designed trials with larger sample sizes are required to increase the certainty of the evidence.

PLAIN LANGUAGE SUMMARY

Do earplug fit tests plus training on how to fit earplugs help people who work in noisy environments?

Key messages

• Earplug fit testing paired with simple instructions for properly fitting earplugs probably does not improve noise reduction.

• Earplug fit testing paired with extensive instructions probably improves protection against noise compared to receiving no instructions or simple instructions.

Why are noisy work environments a problem?

Noise exposure at work is associated with serious health conditions, from hearing loss and tinnitus (ringing or buzzing sounds in the ears without an external source), to injuries and heart/blood vessel problems. Hearing protection devices (HPDs) – such as earplugs and earmuffs – are commonly used to reduce people's noise exposure at work. Especially for earplugs, it is well-known that many workers struggle to insert them properly into the ear canal. Ill-fitting earplugs will not protect one's hearing sufficiently.

What are hearing protection fit-test systems?

Hearing protection fit-test systems are technologies that measure the extent to which noise is reduced (attenuated) at the ear for a person wearing earplugs or another hearing protection device.

What did we want to find out?

We wanted to find out if hearing protection fit testing plus training to wear earplugs (or other protection devices) properly is effective at reducing noise experienced by workers, and whether they continued to wear earplugs consistently. We also wanted to find out if people's age, gender, earplug type, and experience of using hearing protection devices made any differences to the effectiveness of fit testing and training.

What did we find?

We found 3 studies involving 756 participants. They examined the effects of giving people simple or extensive instructions for fitting their hearing protection devices (all the studies used foam or premoulded earplugs) together with fit tests that measured how much noise was reduced. We did not find any studies that examined whether fit testing and training promoted consistent hearing protection use, nor any studies that examined whether age, gender, or hearing protection experience influenced noise reduction.

Main results

• Earplug fit testing accompanied by simple instructions probably does not improve personal attenuation ratings (PAR) from foam and premoulded earplugs compared to no instructions.

• Fit testing with extensive instructions probably improves workers' protection against noise, measured immediately after the test and training, compared to having no or simple instructions. An increase in protection of about 3 dB will halve the sound's power at the ear, increasing the protective effect of earplugs.

• The effects of fit testing may depend on the type of hearing protection device and training methods.

• None of the included studies measured or reported harmful effects from fit testing and training, and we did not think it was likely we would find any.

What are the limitations of the evidence?

We have moderate to low confidence in the evidence. Our confidence was reduced because the studies were small, and we had concerns about how participants were allocated to groups.

How up-to-date is the evidence?

The evidence is current to February 2024.

SUMMARY OF FINDINGS

Summary of findings 1. Effects of instructions versus no instructions for fit testing HPDs

Population: workers exposed to noise using earplugs
Setting: industry
Intervention: fit testing of earplugs with **extensive or simple** instructions
Comparison: fit testing of earplugs without instructions

Outcomes	Anticipated absolute effects* (95% CI)		№ of participants (studies)	Certainty of the evidence (GRADE)	Comments
	PAR with fit testing of earplugs without instructions	Effect on PAR with fit testing of earplugs with instructions			
PAR (dB) at short-term follow-up: range 1 month to 4 months after **simple instructions**	The mean PAR (dB) at short-term follow-up was **25.92** dB at 1-month and **24.39** dB at 4-month follow-up.	1 month: MD **1.62 dB higher** (0.93 lower to 4.17 higher) 4 months: MD **0.40 higher** (2.28 lower to 3.08 higher)	285 (1 RCT)	⊕⊕⊕⊝ Moderate[a]	Fit testing of earplugs with **simple instructions** probably has no or little effect on PAR (dB) in the short term compared to no instructions.
PAR (dB) at long-term follow-up: mean 12 months after **simple instructions**	The mean PAR (dB) at long-term follow-up was **26.19 dB**	MD **0.15 dB higher** (3.44 lower to 3.74 higher)	103 (1 RCT)	⊕⊕⊕⊝ Moderate[a]	Fit testing of earplugs with **simple instructions** probably has no or little effect on PAR (dB) in the long term compared to no instructions.
PAR (dB) at immediate follow-up after **extensive instructions**	The mean PAR (dB) at immediate follow-up was **5.54** dB	MD **8.34 dB higher** (7.32 higher to 9.36 higher)	100 (1 RCT)	⊕⊕⊝⊝ Low[b]	Fit testing of premoulded earplugs with **extensive instructions** may improve PAR (dB) at immediate follow-up compared to no instructions.
PAR pass rate (%)	No studies measured or reported PAR pass rate.				
Adverse effects	No studies measured or reported adverse effects.				
Proportion of workers who wear HPDs	No studies measured or reported the proportion of workers who wear hearing protectors.				

***The effect on PAR in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group.

CI: confidence interval; **MD:** mean difference; **PAR:** personal attenuation rating

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: we are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.

Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.

Very low certainty: we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect.

[a]Downgraded by one level due to imprecision: fewer than 400 participants.
[b]Downgraded by two levels due to study limitations: lack of information on randomisation and imprecision due to fewer than 400 participants.

Summary of findings 2. Effects of extensive instructions versus simple instructions for fit testing HPDs

Population: workers exposed to noise using HPDs
Setting: military
Intervention: fit testing of foam earplugs with extensive instructions
Comparison: fit testing of foam earplugs with simple instructions

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	№ of participants (studies)	Certainty of the evidence (GRADE)	Comments
	PAR with fit testing of foam earplugs with simple instructions	Effect on PAR with fit testing of foam earplugs with extensive instructions				
PAR (dB) - Fit testing of foam earplugs (immediate)	The mean PAR (dB) - Fit testing of foam earplugs was 25.2 dB	MD 8.62 **dB higher** (6.31 higher to 10.93 higher)	-	321 (1 RCT)	⊕⊕⊕◯ Moderate[a]	Fit testing of earplugs with extensive instructions probably improves PAR (dB) (immediate effect) compared to simple instructions.
PAR pass rate (%) - Fit testing of foam earplugs (immediate)	50.5%	**88.1%** (72.6 to 100.0)	**RR 1.75** (1.44 to 2.11)	321 (1 RCT)	⊕⊕⊕◯ Moderate[a]	Fit testing of foam earplugs with extensive instructions probably increases PAR pass rate (%) (immediate effect) compared to simple instructions.
Adverse effects	No studies measured or reported adverse effects.					
Proportion of workers who wear HPDs	No studies measured or reported the proportion of workers who wear hearing protectors.					

*__The effect on PAR in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: confidence interval; **MD:** mean difference; **PAR:** personal noise attenuation; **RR:** risk ratio.

GRADE Working Group grades of evidence
High certainty: we are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: we are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.

Low certainty: our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect.

Very low certainty: we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect.

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[a]Downgraded by one level due to imprecision: fewer than 400 participants.

BACKGROUND

Noise is an environmental agent that impacts several aspects of health and well-being. High noise levels can cause irreversible damage to hearing and trigger other auditory symptoms, including tinnitus and hyperacusis (noise sensitivity or reduced tolerance to sound) (Nelson 2005). Less intense noise levels can cause annoyance, sleep disturbance, negative cardiovascular and immunological outcomes, and other stress-mediated effects in both children and adults (Basner 2014; Morata 2005). Noise has long been recognised as an occupational hazard, even before industrialisation, and evidence of the burden on society it represents has continued to accumulate over time (ACGIH 2018; Teixeira 2021). Noise-induced hearing loss, increased injury risk (ACGIH 2018), and cardiovascular disease are three of the noise-related adverse work conditions receiving increased attention (Teixeira 2021).

A 2021 systematic review conducted as part of the Global Burden of Disease (GBD) initiative examined population-representative surveys on hearing loss prevalence from 1990 to 2019 (GBD 2019 Hearing Loss Collaborators). It estimated that 1.57 billion (1570 million) people (95% confidence interval (CI) 1.51 to 1.64) globally had hearing loss in 2019 alone, which corresponds to one in five individuals (20.3%, 95% CI 19.5 to 21.1). Differences in prevalence between countries were attributed to disparities in healthcare access and quality, but also to the prevalence of occupational noise exposure. By 2019, 7 million years lived with disability (YLDs) (95% CI 4.76 to 10.1) were attributable to occupational noise exposure. The GBD study group has identified noise-reduction strategies as one of the urgently needed multidisciplinary actions to improve hearing health care (GBD 2019 Hearing Loss Collaborators).

The relevance of hazardous noise exposure in the workplace to the prevalence of acquired hearing loss has been recognised for decades (ISO 2013; Nelson 2005; WHO 1997). This recognition prompted not only research but also the development and implementation of public health policy, and early intervention and prevention programmes (Suter 2017; Themann 2019). Numerous countries require workplaces from different economic sectors (including manufacturing/industry, utilities, transportation, the military, construction, agriculture, and mining) to comply with governmental regulatory requirements to control hazardous noise exposures and implement hearing conservation programmes (Suter 2022). The evidence for reducing risks from various workplace hazards favours controlling the source of exposures (primary prevention). In practice, however, the most common attempt to reduce noise exposure consists of distributing hearing protection devices (HPDs) (Themann 2013a). A 2017 Cochrane review on the effectiveness of interventions to prevent work-related noise-induced hearing loss identified strategies that effectively reduced occupational noise exposure and hearing loss: the implementation of stricter legislation, better use of hearing protection devices as part of hearing loss prevention programmes (HLPPs), and training in the proper use of earplugs. However, the overall quality of evidence was very low to moderate, and there was limited follow-up of participants receiving training for insertion of earplugs (Tikka 2017). The authors concluded that further research is likely to have an important impact and could modify the conclusions reached (Tikka 2017). Our review is an elaboration and update of the fit testing of earplugs with accompanying instructions.

Since it is clear that the fit of HPDs determines to a large extent their noise attenuation, it is necessary to accurately measure the individual noise attenuation (ANSI 2018). That information reveals who needs instructions to improve the fit and, thus, the protection against the adverse effects of noise. Currently, the most accurate technology to measure individual fit and attenuation is the field attenuation estimation system, commonly referred to as HPD fit testing (ANSI 2018; Berger 2022). Since the mid-1970s, laboratory studies have used many forms of hearing protection fit-test technology to investigate the actual acoustic attenuation hearing protectors provide, often to inexperienced users. Technology to measure the noise attenuation obtained by individual workers wearing HPDs has become commercially available in the past decade, and research has also looked into the implementation of this technology (Byrne 2018; Voix 2022). A few countries have published standards recommending (Argentina, Australia, Brazil, Italy, Russia, Uruguay, and Venezuela) or regulating (Canada, Germany, Malaysia, USA) the use of fit testing as part of hearing conservation interventions (Wells 2024).

Description of the condition

Long-term exposure to noise levels greater than 80 A-weighted decibels (dBA) carries an excess risk of hearing loss (ISO 2018; Prince 1997). (The unit 'dBA' reports on the use of a frequency-weighting filter to adjust sound measurement results to better reflect how human ears process sound.) The risk increases with noise level and can ultimately lead to hearing impairment. The impairment is characterised by a limitation in situational awareness, as well as in the capacity to engage in conversation in meetings or social activities. Hearing difficulties can therefore become a significant barrier to establishing or maintaining emotional relationships. Such outcomes have prompted studies which reported the association between hearing loss and depression, cognitive decline, increased hospitalisations and healthcare costs, and mortality (Basner 2014; Themann 2019). Workers with hearing loss have higher rates of absenteeism; may be at increased risk of work-related injuries; and are more likely to be underemployed or unemployed (Dzhambov 2017; Kerr 2017; Themann 2013b). The condition is permanent, and there is no effective treatment for it. However, the risk of noise-induced hearing loss can be greatly minimised if noise is reduced to below 80 dBA (NIOSH 1998).

Despite decades of study, workplace interventions, and regulations, noise-induced hearing loss is consistently amongst the most common self-reported occupational illnesses or injuries (Nelson 2005). Information is also available for self-reported hearing difficulty and tinnitus amongst workers and non-workers (Masterson 2016a), as well as disability-adjusted life years (Masterson 2016b). A 4-kHz audiometric 'notch', a decrease in hearing acuity at the frequency of 4 kHz, is understood to be one of the first signs of noise-induced hearing loss (Nelson 2005). Worldwide, 16% of disabling hearing loss in adults is attributed to occupational noise. Leigh and colleagues calculated a global annual incidence of noise-induced hearing loss of 1,628,000 cases, which means an annual incidence rate of almost two new cases per 1000 older workers (Leigh 1999). The risk for work-related hearing loss is present in more economic sectors than originally anticipated. As discussed by Themann 2019, industry- and occupation-specific estimates indicate risk in unexpected sectors, such as transportation, warehousing, and real estate.

Workers outside manufacturing are rarely offered preventive interventions, such as risk assessment, audiometric testing, or access to hearing protection (Themann 2019). The prevalence of HPD non-use was 53% amongst all workers in the USA who were exposed to hazardous workplace noise (Green 2021).

When properly selected and fitted, hearing protectors can be an effective means to prevent hearing loss (Tikka 2017). However, many workers are not fully protected when they do not wear their hearing protectors correctly or consistently (Groenewold 2014). Gong 2021a found that, of 503 workers who were exposed to noise levels between 80 and 100 dBA, 28% had insufficient protection because their earplugs did not fit well. After receiving proper earplug fitting instructions, noise attenuation was improved by an average of 15 dB (Gong 2021a).

Description of the intervention

Technically, most hearing protectors can attenuate noise exposure enough to prevent hearing disorders (Voix 2022). A Cochrane review on the effectiveness of interventions to prevent work-related hearing loss concluded that the use of HPDs in a well-implemented hearing loss prevention programme was associated with less hearing loss, and that instruction on how to insert plugs into the ears was key to their effectiveness in noise reduction (Tikka 2017).

The noise attenuation provided by HPDs is described by a numerical rating calculated from measurements in a laboratory with human subjects (Berger 2008). Different rating systems are in use around the world. In the USA, the noise reduction rating (NRR) is required to be measured in the laboratory and published on the primary label of every HPD by the U.S. Environmental Protection Agency (EPA 1979). The NRR is then used to assess the adequacy of the attenuation of a hearing protector for a given noise exposure. For example, an HPD with an NRR of 22 dB would reduce an environmental noise level of 100 C-weighted decibels to 80 dBA (a 2-dB C- to A-weighted correction is applied, Berger 2008) in the ear, if it worked as properly as in the laboratory. Consequently, in the industrial setting, HDPs are chosen only based on the published NRR value to ensure that efficient noise reduction is possible. In practice, this theoretical reduction is rarely achieved because of improper application of the devices (Berger 1983; Murphy 2011). Earplugs can be especially difficult to insert due to the small dimensions of the ear canal or lack of skills to do it properly (Berger 2008).

In contrast to the NRR reported by the manufacturer of the HPDs, the personal attenuation rating (PAR) is the attenuation of the given HPD achieved by an individual at the moment of fit testing, in the real world (Voix 2022). Different technologies estimate PAR, and results are presented in similar ways. Current methods used in the field to estimate a personal attenuation rating (PAR) are: real-ear attenuation at threshold (REAT, ISO 2018), microphone in the real-ear (MIRE, ANSI 2018), and the alternating binaural loudness balance under headphones (Voix 2022). The REAT measures the difference in the minimum sound level one can detect when wearing and when not wearing a hearing protector. The MIRE measures the difference between the sound pressure levels in the ear canal with and without an earplug in place (result expressed as insertion loss) and the difference in sound pressure levels outside or underneath the HPD, referred to as noise reduction. For the alternating binaural loudness balance, the individual is asked to indicate with and without earplugs when the loudness between ears is balanced (Rimmer 1997). Each of the different fit-test methods combines the attenuation measurements at different frequencies to determine an overall PAR for the individual being tested. Some fit-test systems may also present visual cues such as pass/fail indicator lights (Voix 2022). The HPD's fit testing per se is aimed at measuring an individual worker's attenuation level with a particular protector. Achieving the desired attenuation requires proper selection and use of HPDs; this knowledge is likely to have motivated the incorporation of instructions/training components to the fit-test intervention (Voix 2022).

HPD fit testing is neither an invasive technology nor a clinical medical treatment, and the test is usually completed quickly (Federman 2021; Murphy 2007). These factors suggest that there would be no adverse effects from it, but it is not always safe to assume this. There might be a minor risk of fatigue or discomfort completing HPD fit tests. Workers may experience discomfort from notifications about insufficient noise attenuation received from the HPDs they wear. The adverse effects of HPD fit testing cannot be prespecified as they are not currently known or suspected to be associated with the intervention. Therefore, potential adverse effects associated with HPD fit testing still need to be examined.

How the intervention might work

Fit-test interventions aim to help an individual worker achieve his/her needed personal attenuation level with a particular protector. Instructions will result in a better fit which can be objectively measured, but workers will also gain a sense of what proper insertion feels like and what that level of attenuation sounds like. It has been suggested that these effects may also prompt greater adherence to hearing protection use, as a consequence of the objective results and an increased sense of self-efficacy (Schulz 2011; Stephenson 2011).

Better noise attenuation whilst wearing hearing protection and better adherence to hearing protection use will eventually lead to less hearing loss amongst workers (Sayler 2018). In a study of 14 metal manufacturing plants, Sayler and colleagues reported that the four plants which spent the most on training and conducted fit testing of hearing protectors for at least five years had the lowest hearing loss amongst workers, measured as percentages of age-corrected standard hearing threshold shifts. These plants also had the lowest 10-year average high-frequency hearing loss rates (Sayler 2018). In a study conducted in the mining industry, an association between PAR values and hearing loss was reported, with greater hearing loss associated with smaller PARs, as measured by fit testing (Ullman 2021).

Why it is important to do this review

The global burden of disease attributed to noise-induced hearing loss, together with the widespread provision of HPDs to reduce this burden, warrant a systematic review of the effects of HPDs on noise levels at the ear. There is uncertainty regarding the effects of this developing fit-testing technology and associated training on the attenuation of noise levels at the ear and workers' adherence to hearing protection use. A review of these initial practices can assess their effectiveness, and has the potential to guide future research and the implementation of new standards.

OBJECTIVES

To assess: (1) the effects of field attenuation estimation systems and associated training on the noise attenuation provided by HPDs compared to no instruction or to less instruction in workers exposed to noise; and (2) whether these interventions promote adherence to HPD use.

METHODS

Criteria for considering studies for this review

Types of studies

Evaluations of hearing loss prevention interventions can be biassed by factors that affect noise exposure (Tikka 2017). Randomisation is the best protection against such bias. Studies in which individual workers are randomised to an intervention and a control group are difficult to perform in the work setting because of the presence of many stakeholders and high levels of social interaction between participants (Tikka 2017). Cluster-randomisation, in which whole companies or departments are randomly assigned to the intervention and control groups, is a way to replace randomisation at the individual level whilst still leading to bias reduction. Therefore, we chose to include RCTs and cluster-RCTs.

Given the difficulty of randomisation in the workplace, we also included controlled before-after (CBA) studies in which the outcome is measured at least once before and once after the intervention in both the intervention and control groups.

With data that are often routinely gathered, interrupted time-series (ITS) studies are also a feasible non-randomised study design. Hearing loss data are often routinely collected. Therefore, we also included ITS studies in which outcomes were measured at least three times before and three times after the intervention in one group of study participants (EPOC 2012; Ramsay 2003).

We also considered including uncontrolled before-and-after (UBA) studies which compare individual results before and after the intervention (Reeves 2021). However, we felt that the lack of a control group in UBA studies makes it difficult to determine if the effects can be attributed to the intervention. Thus, we decided to consider findings from UBA studies in the Discussion section of the review, but we did not use these data in the review's analyses or conclusions.

We excluded studies whose participants were not routinely exposed to occupational noise in the workplace because we considered they could differ from our target population in multiple ways, including demographics, educational level, awareness of risk, knowledge of hearing protection devices, and motivation to protect hearing.

Types of participants

We included studies conducted with adult workers at workplaces with noise levels of more than 80 dBA as a time-weighted average (TWA) over an entire work shift, working day, or part of the work shift. The unit 'dBA' reports on the use of a frequency-weighting filter to adjust sound measurement results to better reflect how human ears process sound. The selected exposure metric identifies populations that are likely to be at risk of hearing loss and likely to be offered the studied intervention in the workplace.

Types of interventions

We included studies that evaluated field attenuation estimation systems with the objective of examining if a needed personal attenuation rating (PAR) was provided by various types of HPDs that workers use. The fit-testing system should also have included instructions for workers on how to properly select and fit HPDs. We considered any type of instruction sufficient for a study to be included in the review.

We included interventions based on any type of technology (REAT, MIRE, and the alternating binaural loudness balance) to perform fit tests with any type of HPDs (earmuffs, canal caps, foam earplugs, premoulded earplugs, push-in earplugs, etc).

We considered studies eligible regardless of whether the intervention was part of a work-related hearing loss prevention programme. We included interventions provided as part of corporate safety and health programmes, by either in-house personnel or third parties. We also included studies reporting measurements for either a specific facility or a specific type of worker, and regardless of the frequencies measured (Hz).

We compared: (1) fit testing systems that measured noise attenuation at the ear (in dB) with training to fit testing systems without training; and (2) fit testing systems with different levels of training (simple or extensive). We defined extensive training as any training format with an individualised instruction component, and simple training as any training format without an individualised instruction component.

We excluded laboratory studies, as it is difficult to assess if their results can be applied to real-world situations.

We excluded studies on other types of interventions, such as engineering controls to reduce or eliminate the noise source, changing materials, processes or workplace layout (Cohen 1997), and administrative control measures that involve changing work practices.

Types of outcome measures

We included studies measuring workers' personal noise attenuation obtained through their personal hearing protection using either MIRE, REAT, or loudness balance technologies.

Primary outcomes

- Noise attenuation at the ear, measured as an overall PAR. The PAR is calculated as the average noise attenuation, as measured by the fit testing system, for frequencies measured at both ears, weighted according to the A-filter (a type of frequency weighting filter used to adjust sound measurements to better reflect how human ears perceive noise).
- Noise attenuation at the ear, measured as a PAR pass rate. The PAR pass rate indicates the percentage of participants whose HPDs sufficiently attenuated their environmental noise levels.
- Any adverse effects of HPD fit testing.

We included studies evaluating immediate (same day), short-term (up to six months of follow-up), and long-term effects (longer than six months of follow-up).

Secondary outcomes

We planned to include the proportion of workers who wear hearing protectors as a secondary outcome.

Search methods for identification of studies

We conducted systematic searches for RCTs, CBA, ITS, and UBA studies of field attenuation estimation systems. We developed a search strategy based on the concepts of occupational noise exposure, hearing protection, and fit testing. The search strategy is shown in Appendix 1.

We imposed no restrictions on language, publication year, or publication status.

Two authors (TM, WG) searched the reference lists of all the included studies. The databases were last searched on 29 February 2024.

Electronic searches

We searched the following databases:

- Cochrane Central Register of Controlled Trials (CENTRAL) via the Cochrane Library (including Cochrane Ear, Nose and Throat Disorders Group's Trials Register and Cochrane Work's Trials Register), from 1800 to 29 February 2024;
- MEDLINE (Ovid), from 1946 to 29 February 2024;
- Embase (Ovid), from 1988 to 29 February 2024;
- PsycINFO (Ovid), from 1806 to 29 February 2024;
- CINAHL (EBSCOhost) (Cumulative Index to Nursing and Allied Health Literature), from 1981 to 29 February 2024;
- Scopus, from 1788 to 29 February 2024;
- NIOSHTIC-2 (National Institute for Occupational Safety and Health), from 1930 to 29 February 2024;
- ClinicalTrials.gov, from 2000 (inception) to 29 of February 2024;
- World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP), from 2005 (inception) to 29 February 2024.

Searching other resources

An information specialist from the US Centers for Disease Control and Prevention, with experience in systematic reviews, advised on the strategy, search terms used and tailored, and ran all electronic searches.

To identify additional studies (published, unpublished, conference presentations, dissertations, theses, and ongoing trials), we scanned reference lists of identified studies for further papers. Using the same electronic search strategy, we also searched the Trip medical database, National Health Service (NHS) Evidence - Ear, Nose, Throat and Audiology (formerly NLH ENT & Audiology Specialist Library) for systematic reviews, and two authors (TM, WG) scanned their reference lists for additional studies until 29 February 2024. We also searched the Open Researcher and Contributor IDentifier (ORCID), Google Scholar, and ResearchGate pages of principal investigators identified from relevant publications using the same search terms as used for the databases until February 2024. The latest search was on 29 February 2024. We have reached out to Mr Elliott Berger, M.S., who retired from the 3M Personal Safety Division in 2018. He currently serves as the National Hearing Conservation Association historian and maintains a comprehensive list of references on hearing protector effectiveness as of 23 November 2023.

Data collection and analysis

We used Covidence for abstract and full-text screening, and for collecting data on study characteristics and outcomes extracted from the included studies (Covidence).

Selection of studies

We selected eligible studies in two stages.

First, three review authors (TM, WG, AS) independently screened the titles and abstracts of all studies identified by our systematic search. We excluded studies that either did not fulfil the inclusion criteria or that fulfilled the exclusion criteria. Second, we retrieved the full-text study reports or publications for all included references. Two review authors (of TM, WG, AS, CT) independently and in duplicate assessed full texts for eligibility. We resolved disagreements through discussion or by consulting a third review author (JV), if required, to make a final decision.

We recorded reasons for exclusion of studies at the full-text stage. We identified duplicates and collated multiple reports of the same study under one study ID. We recorded the selection process in a PRISMA study flow diagram (Figure 1). When our systematic search identified studies conducted by the authors of this review (AS, WG, TM), these authors did not participate in making decisions on inclusion or risk of bias assessment to avoid conflict of interest.

Figure 1. PRISMA study flow diagram

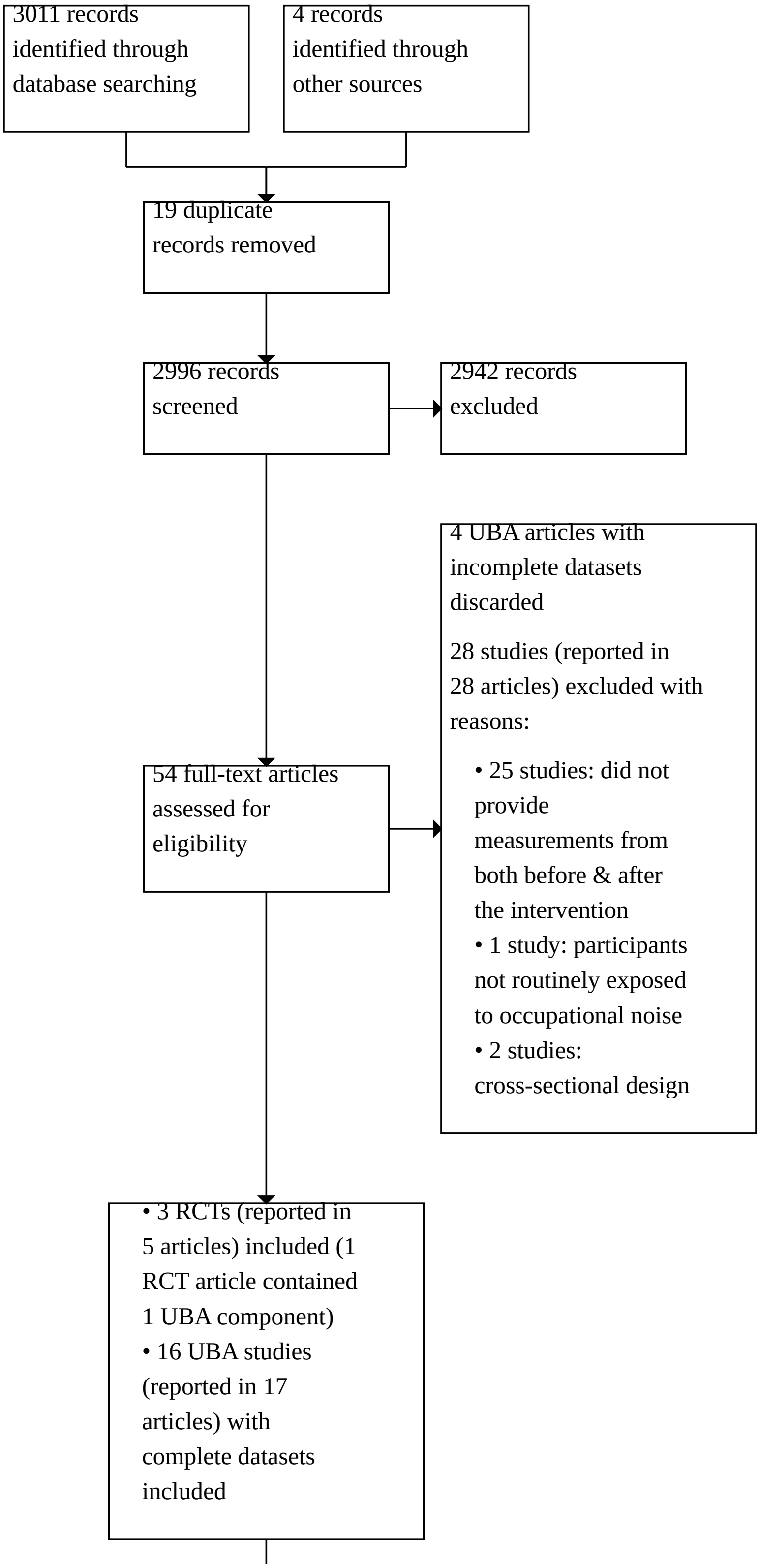
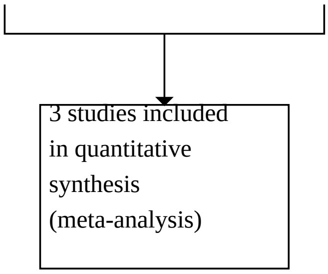


Figure 1. (Continued)



Data extraction and management

Two review authors (WG, TM) extracted study characteristics using the data collection form that was used to produce the Cochrane review 'Interventions to prevent occupational noise-induced hearing loss' (Tikka 2017).

We collected information on methods, study design and setting (including industrial sector, occupation, and country), participant characteristics (including age, gender, type of workplace), study eligibility criteria, details of the interventions given, outcomes assessed, source of study funding, and any conflicts of interest reported by the investigators. For RCTs, we were interested in the effect of the assignment to the intervention.

Two of three review authors (WG, TM, AS) independently extracted outcome data from each of the included studies. We resolved any disagreements by consensus or by involving a third review author (JV). One review author (WG) contacted the study authors where key information was missing, and transferred the data to Review Manager (RevMan 2024). We double-checked that data had been entered correctly by comparing the data presented in the systematic review with the study reports. A second review author (TM) spot-checked study characteristics for accuracy against the trial report.

For studies published in languages other than English, German, Dutch, Chinese, or Portuguese, we planned to arrange for a native speaker or sufficiently qualified person outside the review team to help with data extraction, but there were no such studies.

Assessment of risk of bias in included studies

For randomised studies, we used the updated Cochrane risk of bias tool (RoB 2) (RoB 2 Excel template; Risk of bias tools), following the guidance in the *Cochrane Handbook for Systematic Reviews of interventions* on assessing the risk of bias for a specific outcome (Higgins 2023). Two authors (WG, JV) assessed the risk of bias independently and in duplicate for intention-to-treat effects for the primary 'PAR' and 'PAR pass rate' outcomes, measured using fit-test technology on immediate (same day), short-term (until six-month follow-up), and long-term (longer than six-month follow-up) time points after the start of the intervention (Higgins 2023). We attempted to resolve any disagreements first through discussion; failing that, we deferred to a third review author (CT).

We graded the risk of bias as high, some concerns, or low for each domain and for an overall risk-of-bias judgement for a specific result, using the signalling questions built into the tool. We supported our rating with a study quote where possible and with a justification for our judgement. We summarised the risk of bias judgements for each outcome across all the studies for each of the following risk of bias domains:

- bias arising from the randomisation process;
- bias due to deviations from intended interventions;
- bias due to missing outcome data;
- bias in measurement of the outcome;
- bias in selection of the reported result.

If information on risk of bias related to unpublished data or correspondence with a trial, we planned to note this in the risk of bias table, but there was no need for this step.

We judged each result to have a high risk of bias overall if at least one domain was judged to have a high risk of bias. If no domain was at high risk but one or more domains were judged to have some concerns, the overall result was judged at some risk of bias. We judged the result to have a low risk of bias overall if all key domains were judged to have a low risk of bias.

We planned to use the Risk Of Bias In Non-randomised Studies of Interventions (ROBINS-I) tool to assess the risk of bias in CBA studies (Sterne 2016). We also planned to use the risk of bias criteria developed by the Cochrane Effective Practice and Organisation of Care (EPOC) group to assess the risk of bias in ITS studies (EPOC 2012). However, we did not include any CBA or ITS studies in the review.

We did not plan to assess the risk of bias of the included uncontrolled before-and-after studies as we included these in the Discussion section only to compare them with RCTs, given the limitations of their study design and the high risk of bias.

Assessment of bias in conducting the systematic review

We conducted the review according to a published protocol (Morata 2021), and have reported differences between the protocol and review in the appropriate section (see Differences between protocol and review). We included tables that profile the evidence in more detail, reporting study characteristics and the consensus decisions for the signalling questions of risk of bias.

Measures of treatment effect

We entered the outcome data for each study into the data tables in RevMan 2024 to calculate the treatment effects. We used risk ratios (RRs) for dichotomous outcomes (PAR pass rate), and mean differences (MDs) for continuous outcomes (PAR). We would have used standardised mean differences if MDs had been reported on different scales.

If only effect estimates and their 95% confidence intervals (CIs) or standard errors were reported in studies, we would have entered these data into Review Manager using the generic inverse-variance method (RevMan 2024). We ensured that higher scores for continuous outcomes have the same meaning for a given outcome, and we explained the direction to the reader and reported where the directions were reversed, if that was necessary. If the results could not have been entered in either way, we planned to describe them in the 'Characteristics of included studies' table or enter the data into 'Additional tables', but there was no need to take these steps.

We would have recalculated an SMD into an MD from the pooled effect size using the median standard deviation of the included studies in the formula: (pooled MD = pooled SMD × median standard deviation).

For ITS studies, we would have extracted data from the original papers and re-analysed them according to the recommended methods for analysis of ITS designs for inclusion in systematic reviews (Ramsay 2003). We would have used the standardised change in level and change in slope as effect measures. However, no ITS studies were included in the review. For CBAs, we would have reported odds ratios (ORs) and MDs or SMDs, using baseline data for comparison.

We provided 95% confidence intervals for all effect sizes.

Unit of analysis issues

For studies that employed a cluster-randomised design and reported sufficient data to be included in the meta-analysis but did not make an allowance for the design effect, we would have calculated the design effect based on a fairly large assumed intracluster correlation coefficient of 0.10. We base this assumption of 0.10 as being a realistic estimate by analogy to studies about implementation research (Campbell 2001). We would have followed the methods described in the *Cochrane Handbook for Systematic Reviews of Interventions* for the calculations (Deeks 2021). However, in this version of the review, there were no such studies.

If cross-over trials reported continuous outcomes for which the authors did not report a paired analysis, we would have performed a paired analysis based on a reported or imputed correlation between the outcomes of the intervention and the control condition (Higgins 2021). For dichotomous outcomes, we would have adjusted the CIs for the paired analysis according to Elbourne 2002. However, there were no such studies in this version of the review.

Where multiple trial arms were reported in a single trial, we included only the relevant arms. If two or three comparisons were combined in the same meta-analysis with the same control group, we would have halved or divided the control group into two or three to avoid double-counting (Analysis 2.1; Analysis 2.2).

Dealing with missing data

If data were missing that we considered important for assessing the results or the risk of bias, we contacted the investigators or study sponsors to verify the key study characteristics and to obtain missing numerical outcome data where possible. We did so for two of the included studies in this version of the review (Federman 2021; Murphy 2007). In cases where this was not possible, we would have calculated the missing data from available information, such as missing standard deviations (SDs) from P values, as described in the *Cochrane Handbook* (Higgins 2023), but there were no studies where this step was needed.

Assessment of heterogeneity

We assessed the homogeneity of the results of the included studies based on similarity of the study design, population, intervention, comparator, outcome, and follow-up time.

- We considered each study design, as stated in the Types of studies section, as different and did not combine their results.
- We considered all workers exposed to noise above 80 dBA as similar enough to combine studies.
- We considered all fit-test systems described in the Types of interventions section as similar enough to be combined. For control interventions, we considered the results separately for studies with no instruction, simple instruction, and extensive instruction.
- We considered the follow-up times of immediate, short term, and long term as different and did not combine study results across these categories.

We would have tested for statistical heterogeneity by means of the I^2 statistic, as presented in the meta-analysis graphs generated by Review Manager (Deeks 2021; RevMan 2024), but we did not do any meta-analysis. If this test statistic was greater than 50%, we would have considered there to be substantial heterogeneity between studies (Deeks 2021).

Assessment of reporting biases

We planned to assess publication bias through funnel plots (and the tests used for examining funnel plot asymmetry) but there were too few studies to do so.

Data synthesis

We would have pooled data from studies deemed sufficiently homogeneous regarding interventions, participants, and settings, but none of the comparisons had multiple studies. If more than one study provided useable data in any single comparison, we would have performed a meta-analysis. We would have used a random-effects model because we believe that the type of intervention and study designs included always lead to heterogeneity.

The primary analysis included all eligible studies. We would have performed sensitivity analyses to show how conclusions might be affected if studies at high risk of bias were excluded, but there were too few studies to conduct this analysis.

Subgroup analysis and investigation of heterogeneity

We planned to carry out the following subgroup analyses: by age, gender, earplug type, and HPD use experience. We planned to use the following outcomes in the subgroup analyses: PAR and PAR pass rate. We planned to use the Chi^2 test to test for subgroup interactions in Review Manager (RevMan 2024). However, we did not carry out subgroup analyses because none of the comparisons included multiple studies.

Sensitivity analysis

We would have performed sensitivity analysis defined a priori to assess the robustness of our conclusions. This would have involved studies with low risk of bias versus studies with high risk of bias. However, none of the comparisons included multiple studies.

Summary of findings and assessment of the certainty of the evidence

We created summary of findings tables for the following comparisons:

- effects of fit testing HPDs with instructions versus fit testing HPDs without instructions;
- effects of fit testing HPDs with extensive instructions versus fit testing HPDs with simple instructions.

We reported all outcomes for these comparisons. We used the five GRADE considerations (risk of bias, inconsistency, imprecision, indirectness, and publication bias) to assess the certainty of a body of evidence as it related to the studies that contributed data for the prespecified outcomes. We used the overall RoB 2 judgements to feed into the GRADE assessment. Two review authors (WG, TM) independently performed the GRADE assessments and compared results. We used the methods and recommendations described in Chapter 12 of the *Cochrane Handbook for Systematic Reviews of Interventions* (McKenzie 2021), employing GRADEpro GDT software (GRADEpro GDT). We justified all decisions to downgrade or upgrade the certainty of the evidence using footnotes and comments in each table.

We based our conclusions on studies with the lowest risk of bias designs, such as RCTs. If there was no difference in risk of bias across designs, we would have used all the available studies for our conclusions, but there were no non-randomised studies that fulfilled our inclusion criteria.

RESULTS

Description of studies

Results of the search

Our searches, which were run up to 29 February 2024, yielded 3015 references in total (see Figure 1). We assessed 54 articles in full text.

- Three RCTs fulfilled our inclusion criteria (Federman 2021; Murphy 2007; Salmani 2014). These studies were reported in five articles and included a total of 756 participants. One study reported results in three articles (Murphy 2007).
- We identified 17 UBA studies with complete datasets (Assunção 2019; Casali 1991; Chiu 2020; Copelli 2021; Federman 2016; Gong 2019; Gong 2021a; Hayes 2022; Kim 2019; Liu 2018; Liu 2020; Martin 2019; Murphy 2016; Park 1991; Takada 2020; Tsukada 2008; Zhong 2023). The results from one UBA study were reported in two articles (Casali 1991; Park 1991). One RCT article reported a UBA component on PAR for the same participants before and after training (Federman 2021). The 17 UBA studies included a total of 2932 participants. We reviewed these studies to support the discussion, but not the conclusions, of this review.
- Of the remaining 32 articles, we discarded four articles reporting on UBA trials because their datasets were incomplete (Cassano 2015; Johnson 2011; Kunz 2014; Smith 2014). We listed the remaining 28 studies (28 articles) as 'excluded studies' with reasons.

We did not identify any cluster-RCTs, CBA or ITS studies in our search results. All included articles were published in English. We did not list any studies as 'awaiting classification'. To the best of our knowledge, there are no relevant ongoing studies.

We did not find any studies that examined whether fit testing and training contributed to hearing protector use, nor any studies that examined whether age, gender, or HPD experience influenced attenuation.

Included studies

Design

Three studies used a randomised design (RCT) in which participants were randomised to different types of instructions (Federman 2021; Murphy 2007; Salmani 2014).

Sample size

Of 807 participants who were recruited in the three RCTs, a total of 756 were eligible to participate. Federman 2021 included 321 participants and Salmani 2014 included 150. Murphy 2007 included 285 workers, of which 209, 197, and 103 participants participated in the one, four, and 12 months of follow-up, respectively.

Setting

Murphy 2007 was carried out in American manufacturing companies, and Federman 2021 in the US Marine Corps. Salmani 2014 was conducted in Iran, but did not specify the type of industry nor the type of jobs included in the study. Two RCTs reported immediate effects of the intervention (Federman 2021; Salmani 2014), and one RCT reported short-term and long-term effects (Murphy 2007).

Participants

All participants were described as being exposed to noise at work.

The participants in Federman 2021 were Marine Corps training recruits. Recruits were exposed during training to rifle noise with an average peak sound pressure level of approximately 165 dB (measured at 15 cm from the shooter's ear) (Federman 2021). The United Auto Workers in Murphy 2007 were exposed to noise levels above 85 dBA. As noted above, Salmani 2014 did not describe the type of industry nor the type of job studied.

Of the three RCTs, only Salmani 2014 reported participants' socio-demographic information. Participants were between 19 and 39 years old and mostly male.

Interventions

Fit testing HPDs included five independent elements: fit-test technology, type of HPDs, instruction intensity, the time of follow-up, and HPDs' noise reduction rating (NRR) label. For the three included RCTs, we found the following combinations of intervention elements.

Fit-test technology

All studies used the REAT method to measure the effect on personal attenuation ratings (PAR).

Type of hearing protection devices (HPDs)

All studies used earplugs. Studies evaluated the effect of fit testing of foam earplugs (Federman 2021), premoulded earplugs (Salmani 2014), and foam and premoulded earplugs (Murphy 2007).

Instruction intensity

One study compared simple instructions to no instructions (Murphy 2007). One study compared extensive instructions to no instructions (Salmani 2014). One study compared extensive to simple instructions (Federman 2021).

Simple instructions were: receiving a written brochure accompanied by minimal instructions (Murphy 2007), or receiving a small group video instruction (Federman 2021). In the self-training session, participants practised automatic threshold testing for familiarisation with the testing procedure.

Extensive instructions were: receiving individualised training instructions (Federman 2021), receiving small group video training followed by individualised training (Federman 2021), or 15 minutes of training in the correct methods of wearing the earplugs and self-fit under the supervision of a trainer (Salmani 2014).

Follow-up

Two studies measured the outcome immediately after the intervention (Federman 2021; Salmani 2014). One study measured the effect at short-term (1- and 4-month follow-up) and long-term follow-up (12 months) (Murphy 2007).

Noise reduction rating (NRR)

Studies used HPDs with various NRRs. Values ranged from 22 dB to 37 dB (Table 1).

Outcomes and measures

Primary outcomes

- PAR (dB)
  - All included studies measured and reported PAR (dB).
  - Murphy 2007 reported the mean PAR levels achieved from each tested earplug. We contacted the author who provided us with the individual PAR values of the participants. We then calculated the mean and SDs of PARs from all tested earplugs for each group at different visits (see Table 2).
  - In Salmani 2014, the SDs reported were unrealistically small, and did not match with the box plot in the published figure. The study authors did not reply when we asked for clarification. Therefore, we extracted the interquartile ranges from the box plot and divided them by 1.35 to obtain a more realistic estimate of the SDs (Table 2), according to guidance in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2023). We summed the square SD at each frequency by adding them all up, divided the sum by the number of SDs, and then calculated the square root of the result, resulting in an overall SD over all frequencies.
- PAR pass rate (%)
  - Only one RCT carried out by the US Marine Corps reported PAR pass rates determined by the target 25 dBA pass criterion (Federman 2021). This means that the PAR had to be at least 25 dBA to attain sufficient attenuation for the environmental noise levels to which the workers were exposed.
- Adverse effects
  - We did not locate any studies which evaluated or mentioned potential adverse effects of the studied interventions.

Secondary outcome

- Proportion of workers who wear hearing protectors
  - We did not find any studies that examined whether fit testing and training had an effect on the proportion of workers who wear hearing protectors.

Excluded studies

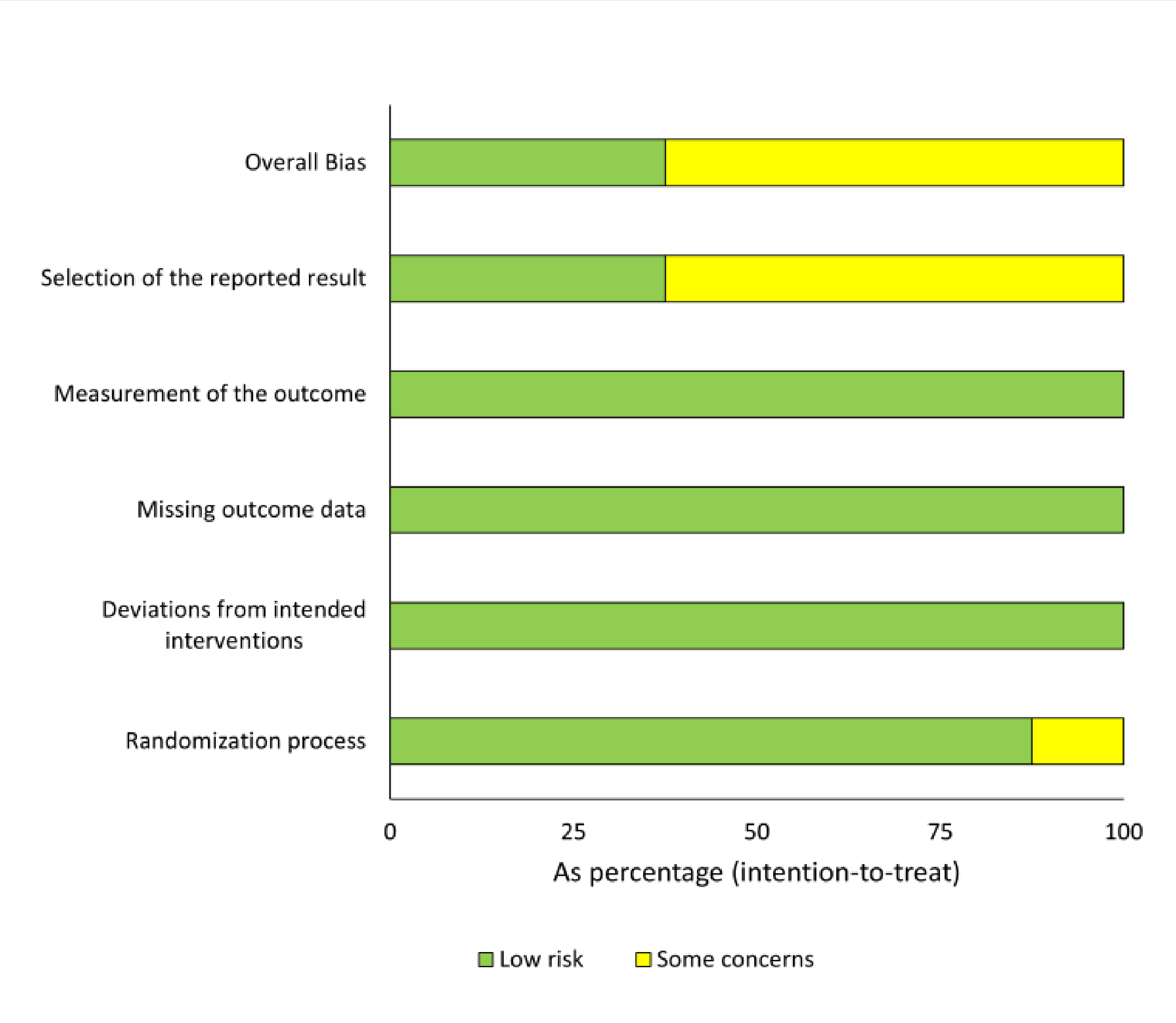
We excluded 28 studies because they did not meet all the inclusion criteria (Biabani 2017a; Biabani 2017b; Byrne 2011; Cassano 2013; Davis 2011; De Vito 2017a; De Vito 2017b; Edwards 1978; Edwards 1979; Gaudreau 2008; Giardino 1996; Gibbs 2017; Gong 2020; Green 1989; Kabe 2012; Lee 2020; Lempert 2010; Mlynski 2014; Murphy 2013; Neitzel 2006; Pfeiffer 1992; Rocha 2016; Samelli 2015; Samelli 2018; Smoorenburg 1982; Ullman 2021; Upegui-Rincon 2019; Wu 2016). Most of them compared the PARs or noise attenuation, as reported by the participants, with the HPD manufacturers' noise reduction ratings.

We excluded one study because the participants were not routinely exposed to occupational noise in the workplace (Murphy 2013). We excluded two cross-sectional studies which were carried out at a public university. The experimental group was composed of 40 workers while the control group consisted of students and workers (Samelli 2015; Samelli 2018). We excluded the remaining 25 studies because they did not provide measurements from workers for PAR and PAR pass rate both before the intervention and after the intervention.

Risk of bias in included studies

The results of the risk of bias assessment per domain are presented in Figure 2 and Appendix 2.

Figure 2. Risk of bias graph: review authors' judgements about each risk of bias domain presented as percentages across all outcomes from the included RCT studies



Randomisation process

All included RCTs reported that the participants were randomised into intervention and control groups. One study used a random number table (Salmani 2014); however, the study authors did not explain how this was used. Murphy 2007 reported using a random card draw. When contacted, the authors explained that after volunteers signed an informed consent agreement, they drew a card from a deck which was shuffled by the researchers. Federman 2021, the Marine Corps study, did not report which randomised method was used. When contacted, the study authors explained that they screened 821 participants in order to identify people who failed to achieve the minimum target PAR of 25 dB (Federman 2021). Participants who failed were randomly assigned to three test groups based on the penultimate digit in the participants' social security number (Social Security Bulletin 1982).

None of the included studies reported allocation concealment. However, the authors of two studies confirmed that the allocation sequence was concealed until the participants were enroled and assigned to intervention groups (Federman 2021; Murphy 2007).

Only one study reported no or little difference in age or gender between the intervention and control groups (Salmani 2014). We identified no or little difference in the baseline PAR levels between the intervention and control groups in all three included RCTs.

Deviations from intended interventions

Given the nature of field study with different instruction methods or different types of tested HPDs, it is not possible to blind participants or people delivering the intervention. One study did not report if participants in the intervention group read or followed the written instructions they received (Murphy 2007), which led to some concerns about participants adhering to the intervention. However, it was unlikely that the deviation from the intended interventions arose because of the trial context.

Missing outcome data

All studies reported that the outcomes were available for all participants (Salmani 2014), or nearly all (Federman 2021; Murphy 2007), which led to a low risk of bias in this domain.

Measurement of the outcome

Two studies reported how the blinding of outcome assessors was done (Federman 2021; Salmani 2014). Furthermore, all studies applied the same measurement technology to all randomised participants and followed the same measurement procedure. Since this was an objective measurement and did not include a subjective element, we judged all studies to have a low risk of bias.

Selection of the reported results

The HPD fit-test studies evaluated the effectiveness of HPDs in reducing workers' exposure to noise. Protocols for Federman 2021 and Salmani 2014 were not published, which led to some concerns over the reported results possibly deviating from the protocol.

Overall bias

We judged that the results for the comparison of fit testing plus simple instructions versus fit testing without instructions at different follow-up times had low risk of bias overall. The two other comparisons (extensive instruction versus none; extensive versus simple instruction) were judged as having some concerns about risk of bias overall.

Effects of interventions

See: **Summary of findings 1** Effects of instructions versus no instructions for fit testing HPDs; **Summary of findings 2** Effects of extensive instructions versus simple instructions for fit testing HPDs

Comparison 1. Fit testing HPDs with instructions versus no instructions

See Summary of findings 1.

Primary outcomes

Personal attenuation rating (PAR) (dB)

Simple instructions versus no instructions (earplugs, short-term follow-up)

- **HPDs:** multiple types of earplugs (26 to 33 dB NRR)
- **Participants:** n = 285
- **Results:** fit testing earplugs with simple instructions probably has little or no effect on PAR in the short term compared to no instructions. PAR values were 1.62 dB higher after one month (95% CI -0.93 to 4.17; Z = 0.21, P = 0.21; 1 study, 209 participants) and 0.40 dB higher after four months (95% CI -2.28 to 3.08; Z = 0.29, P = 0.77; 1 study, 197 participants) for workers receiving simple instructions compared to workers receiving no instructions (moderate-certainty evidence; Analysis 1.1). We downgraded the certainty of evidence by one level because of imprecise results from a small sample size (fewer than 400 participants) (Murphy 2007).

Simple instructions versus no instructions (earplugs, long-term follow-up)

- **HPDs:** multiple types of earplugs (26 to 33 dB NRR)
- **Participants:** n = 103
- **Results:** fit testing earplugs with simple instructions probably has little or no effect on PAR values in the long term compared to no instructions. After 12 months, PAR values for workers receiving simple instructions for fit testing earplugs were 0.15 dB higher compared to those receiving no instructions for fit testing earplugs (95% CI -3.44 to 3.74; Z = 0.08, P = 0.93; 1 study, 103 participants; moderate-certainty evidence; Analysis 1.1). We downgraded the evidence by one level to moderate certainty because of imprecise results from a small sample size (fewer than 400 participants) (Murphy 2007).

Extensive instructions versus no instructions (earplugs, immediate follow-up)

- **HPDs:** premoulded earplugs (25 dB NRR)
- **Participants:** n = 100
- **Results:** fit testing premoulded earplug with extensive instructions for better fitting (Table 1) compared to no instructions may increase the mean PAR by 8.34 dB (95% CI 7.32 to 9.36; Z = 15.99, P < 0.001; 1 study, 100 participants; low-certainty evidence; Analysis 1.1). We rated the certainty of evidence as low because of lack of information about randomisation and imprecise results from a small sample size (fewer than 400 participants) (Salmani 2014).

Personal attenuation rating (PAR) pass rate (%)

We did not locate any studies which evaluated this outcome.

Adverse effects

We did not locate any studies which evaluated or mentioned potential adverse effects of the studied interventions.

Secondary outcome: proportion of workers who wear hearing protectors

We did not find any studies that examined whether fit testing and training affected the proportion of workers who wear hearing protectors.

Comparison 2. Fit testing HPDs with extensive instructions versus fit testing with simple instructions

See Summary of findings 2.

Primary outcomes

Personal attenuation rating (PAR) (dB)

Extensive instructions versus simple instructions (earplugs, immediate follow-up)

- **HPDs:** foam earplugs (33 dB NRR)
- **Participants:** n = 321
- **Results:** one study with two experimental arms evaluated the immediate effect of extensive instructions, and found an increase in the mean PAR of 8.62 dB compared to simple instructions (95% CI 6.31 to 10.93; Z = 7.31, P < 0.001; 321 participants; moderate-certainty evidence; Analysis 2.1). We downgraded the evidence by one level due to imprecision from having fewer than 400 participants (Federman 2021).

Personal attenuation rating (PAR) pass rate (%)

Extensive instructions versus simple instructions (earplugs, immediate follow-up)

- **HPDs:** foam earplugs (33 dB NRR)
- **Participants:** n = 321
- **Results:** one study with two experimental arms found that the PAR pass rate probably increases for fit testing foam earplugs with extensive instructions compared to simple instructions (risk ratio (RR) 1.75, 95% CI 1.44 to 2.11; Z = 5.72, P < 0.001; 321 participants; moderate-certainty evidence; Analysis 2.2). We downgraded the evidence by one level due to imprecision from having fewer than 400 participants.

Adverse effects

We did not locate any studies which evaluated or mentioned potential adverse effects of the studied interventions.

Secondary outcome: proportion of workers who wear hearing protectors

We did not find any studies that examined whether fit testing and training affected the proportion of workers who wear hearing protectors.

DISCUSSION

Summary of main results

Effects of instructions versus no instructions for fit testing HPDs

Fit testing with simple instructions probably has no or little effect on PAR at short-term follow-up (1 month: MD 1.62 dB, 95% CI -0.93 to 4.17; 4 months: MD 0.40 dB, 95% CI -2.28 to 3.08; 1 study; moderate-certainty evidence; Summary of findings 1) or at long-term follow-up (MD 0.15 dB, 95% CI -3.44 to 3.74; 1 study, moderate-certainty evidence; Summary of findings 1). It is possible that this finding resulted from there being little room for improvement in PAR amongst the study participants. They already had very high PAR results (of 24 dB) at baseline.

We found that fit testing with extensive instructions compared to no instructions may immediately increase the mean PAR from premoulded earplugs in workers by 8.34 dB (95% CI 7.32 to 9.36; low-certainty evidence; Summary of findings 1). This is significant because every 3 dB decrease in noise exposure level halves the energy entering the ear.

RCTs on the short- and long-term effects of fit testing of HPDs with extensive instructions versus fit testing of HPDs without instructions are missing. No studies reported adverse effects of the interventions.

Effects of extensive instructions versus simple instructions for fit testing HPDs

Fit testing of foam earplugs with extensive instructions probably increases PAR (MD 8.62 dB, 95% CI 6.31 to 10.93; moderate-certainty evidence; Summary of findings 2) and probably improves PAR pass rates (RR 1.75, 95% CI 1.44 to 2.11) at immediate follow-up compared to simple instructions (moderate-certainty evidence; Summary of findings 2).

RCTs on the short-term and long-term effects of fit testing HPDs with extensive instructions versus fit testing HPDs with simple instructions are missing. No studies reported adverse effects of the interventions.

Overall completeness and applicability of evidence

We did not find RCT studies that evaluated the effects of fit testing ear plugs with extensive instructions on short- or long-term follow-up. Two UBA studies suggested an effect could be maintained for up to a year, even when instructions are not repeated during that time period (Kim 2019; Liu 2018). However, from other UBA studies, it seems that the interventions achieve lower PAR values at longer follow-up times. UBA studies indicated that repeated fit testing of HPDs with extensive instructions over time may maintain the achieved attenuation from use of HPDs. RCTs would be needed to evaluate the effects of periodic testing and training. It might be that refreshing only the training component is sufficient to maintain or improve the PAR. Three UBA studies reported that when the same participants received extensive instructions periodically (either weekly, biannually, or annually), mean PAR improved incrementally by an average of 2.4 dB (95% CI 1.04 to 3.75) per training period (Assunção 2019; Kim 2019; Martin 2019).

Studies did not report environmental noise levels very well. The measurement of noise levels in the work environment can be challenging and biassed by many factors, such as the worker, the task, and operational and environmental variables. We believe studies should strive to better measure and describe noise exposure, as it will determine the needed attenuation of HPDs.

The issues of previous training experience or experience of using earplugs were not reported very well in studies. Across studies, we noted very different initial attenuation values at the initial testing (Federman 2021; Murphy 2007; Salmani 2014), which may be due to different experience in use or training. Future studies should report this. Studies also did not report age and gender very well. In general, elderly people and women are reported to be less risk-taking and better at following guidance (Rolison 2014). Future studies should better report on participants' gender and age.

None of the included studies measured or reported any adverse effects. Even though it is difficult to conceive adverse effects from this intervention, user satisfaction can indicate if there are any problems. We recommend that this should be measured in future studies.

Certainty of the evidence

Given the difficulty of conducting randomised studies in workplaces, we were happy to see three properly conducted RCTs in this field. It shows that it is possible to conduct high-quality research in this field.

Since individual factors, such as the workers' attitude towards HPD use (Smith 2014), personal preference, and comfort (Samelli 2018), can have an important effect on the outcome, it is important to minimise the possibility of baseline differences between groups. Randomisation is the only way to ensure this equivalence. Authors we contacted indicated that a main obstacle to implementing randomisation was obtaining agreement from companies to have workers fit tested without giving the results to a subgroup of those workers. This confirms both that substantial effort is needed to implement a randomised design and that it is still possible to do so.

Publication of an a priori study protocol differed between studies. One RCT had a published study protocol (Murphy 2007). Federman 2021 did not report a study protocol, but when contacted, the authors indicated that they did have a protocol which was submitted to obtain funding, and that there were no differences in study design between the protocol and the study. Salmani 2014 did not report sufficient detail on the randomisation process and apparently lacked a study protocol. We recommend publishing study protocols for future studies.

Potential biases in the review process

Even though we made significant efforts to search databases that would contain grey literature (such as NIOSHTIC-2), and to contact the Open Researcher and Contributor IDentifier (ORCID), Google Scholar, and ResearchGate pages of principal investigators identified from relevant publications, we did not have access to a few conference proceedings. Therefore, it is possible that we missed some studies on HPD fit testing. Some eligible study authors did not provide information we requested, which could have led to selection bias.

Agreements and disagreements with other studies or reviews

Comparison with UBA studies

We located 17 UBA studies which measured PAR, PAR pass rates, or both, before and after the intervention for workers exposed to noise in different industries or military settings (Table 3).

There were 2923, 440, and 159 workers who attended the initial test, short-term follow-up fit tests, and long-term follow-up tests, respectively. Fifteen of 17 evaluated immediate effects (Assunção 2019; Chiu 2020; Copelli 2021; Federman 2016; Federman 2021; Gong 2019; Gong 2021a; Hayes 2022; Kim 2019; Liu 2018; Liu 2020; Murphy 2016;Takada 2020; Tsukada 2008 Zhong 2023). Seven studies evaluated the short-term effects (Assunção 2019; Gong 2021a; Liu 2018; Martin 2019; Park 1991; Takada 2020; Tsukada 2008). Four studies evaluated long-term effects (Kim 2019; Liu 2018; Liu 2020; Murphy 2016). We could deduce three interesting PICOs (population, interventions, comparators and outcomes) from the UBA studies that both compared well to the RCTs and provided information that was not available from the RCTs.

The first comparison was the evaluation of the change in PAR after fit testing with extensive instructions, when previously no instructions had been given. In the immediate follow-up, in all studies, this statistically significantly increased the mean PAR from foam earplugs, with MDs ranging from 2.2 to 17.9 dB (Copelli 2021; Federman 2021; Gong 2019; Gong 2021a; Kim 2019), and also increased the PAR pass rates, with RRs ranging from 1.07 to 2.56 (Chiu 2020; Federman 2016; Gong 2019). The same results were found for premoulded earplugs, with MDs ranging from 12 to 15 dB (Gong 2021a; Liu 2020; Zhong 2023). Liu 2018 also observed an improvement in mean PAR values from earmuffs of 5 dB (95% CI 3.96 to 6.01 dB). This compares well to the difference in PAR values in the RCT included in this review (Salmani 2014), which found an MD of 8.34 dB (95% CI 7.32 to 9.36) from the comparison between extensive and no instructions.

The second interesting comparison was the evaluation of the change in PAR immediately after workers received extensive instructions, when previously they had received only simple instructions. This improved the mean PAR for foam earplugs, with MDs ranging from 2.5 to 3.6 dB, and for premoulded earplugs, with MDs ranging from 2 to 3 dB (Assunção 2019; Takada 2020; Tsukada 2008). Another study reported a change in PAR after fit testing with extensive instructions amongst workers who previously had only received simple instructions after short-term follow-up (Park 1991). The mean change in PARs was 12 dB, 7.7 dB, 1.6 dB, and 3.5 dB for foam earplugs, premoulded earplugs, earmuffs, and canal caps, respectively. This compares well to the difference in PAR values in the RCT included in this review (Federman 2021), with MD 8.62 dB (95% CI 6.31 to 10.93) from the comparison between extensive and simple instructions.

The third interesting comparison that was not available in the RCTs included in this review was the change in PAR after workers received periodic, extensive instructions, where previously they had had one initial session of fit testing with extensive training. Three UBA studies reported a change in mean PAR from foam and premoulded earplugs of 2.4 dB (95% CI 1.04 to 3.75; I^2 = 66%) after weekly-, biannually-, or annually-repeated fit testing with extensive instructions (Assunção 2019; Kim 2019; Martin 2019). This stresses the need for repetition of the instruction because the effect may wear off. That the effect wears off over time is demonstrated by six UBA studies that reported that mean PAR values generally decreased after the initial fit test with extensive instruction when the instructions were not repeated (Gong 2019; Kim 2019; Liu 2018; Liu 2020; Murphy 2016; Tsukada 2008).

Comparison with other reviews

A 2017 Cochrane review on the effectiveness of interventions to prevent work-related hearing loss evaluated the noise attenuation effects of HPDs (Tikka 2017). Two RCTs were included and reported that fit testing improved the noise attenuation from HPDs. However, one of the studies was interpreted incorrectly and did not randomise workers to fit testing with instructions (Park 1991). We could only use this study as a UBA study after receiving further information from the authors.

A narrative HPD review summarised at least 23 available studies providing measurements of real-world HPD attenuation (Berger 1996). More recently, Berger and Voix updated the analysis by removing results considered to be no longer relevant and by adding two more recent studies (Berger 2022). The two reviews compared the difference between the noise attenuation received in real workplaces and the NRR values on the labels of the HPDs. They found that 84% of workers received only approximately a 7-dB to 15-dB attenuation from their HPDs, much less than the labelled NRR values, ranging from mid-20 dB to low 30 dB. The objectives and inclusion criteria of these reviews were different from ours because we evaluated the effects of fit testing with training.

AUTHORS' CONCLUSIONS

Implications for practice

We found that hearing protection device (HPD) fit testing associated with simple instructions probably does not improve the personal attenuation rating (PAR) for foam and premoulded earplugs in the short and long terms, compared to no instructions. Therefore, in the workplace, simply providing HPDs with no or with simple instructions probably does not ensure that noise-exposed workers achieve the needed levels of protection from the HPDs they wear.

Fit testing earplugs accompanied by extensive instructions probably improves the PAR values from foam and premoulded earplugs by 8.6 decibels (dB) (95% confidence interval 6.3 to 10.9 dB) compared to no instructions at immediate follow-up. This is a relevant increase in protection: every 3 dB decrease in noise exposure level halves the energy entering the ear. Workers who are using foam and premoulded earplugs whose fit is insufficient probably need extensive instructions on how to wear their earplugs correctly to achieve sufficient noise reduction from the earplugs they wear.

There were no studies that evaluated workers' adherence to wearing HPDs, and there was no evidence on how often the test and training would need to be repeated to maintain the results.

Implications for research

To increase the certainty of the evidence, more randomised controlled trials (RCTs) of fit testing HPDs with instructions on how to improve their fit are needed. Preferably, first the fit test should be performed, and then workers who have insufficient attenuation should be randomised to receive simple instruction, extensive instruction, or no instruction. This will avoid a ceiling effect from workers who already have sufficient attenuation, as noted in one of the included RCTs (Murphy 2007). In addition, RCTs that evaluate if and how often fit tests should be repeated are needed. It is conceivable – and supported by uncontrolled studies – that the effect of instructions wears off and should be repeated. This review shows that RCTs are possible and feasible. Given that RCTs have a lower risk of bias than other study designs, updates of the current review should only include RCTs.

Better characterisation of noise exposure conditions of the participants would allow the extrapolation of findings across studies. Noise levels and work tasks can vary widely, which suggests different needs in terms of noise attenuation. Earplugs can become "loose" with time and require periodic re-inserting (Nélisse 2012), but, so far, few field studies have examined possible fluctuations in PAR values over work shifts (Gong 2023; Nadon 2021; Wu 2016). In theory, current technologies could address this issue by providing continuous monitoring of an individual's actual noise exposure with HPD. In practice, however, this approach has had limited implementation so far (Voix 2022).

To effectively facilitate the implementation of HPD fit-testing interventions, studies analysing the cost-effectiveness of HPD fit testing associated with training, as well as evaluating the HPD fit-testing integration into hearing loss prevention programmes are especially needed. Studies on the effects of fit-test interventions should not necessarily be restricted to hearing outcomes. One study reported that using three HPD fit-test frequencies (500, 1000, and 2000 Hz) was sufficient for accurately estimating workers' PAR (Federman 2016), and some studies reported that different PARs were estimated using different test methods (Kabe 2012; Neitzel 2006; Samelli 2015). Therefore, studies examining the specifics and suitability of test protocols are also needed.

Research is needed to address the quality concerns identified in the present review (randomisation, detailed description of the study population, of their exposures, testing procedures, and publication of a protocol before data collection). High-quality studies would offer greater certainty on implementation strategies that could lead to the protection of workers from noise exposure.

Currently, adverse effects are generally not recorded in the literature. This may be because investigators lack a mechanism to identify them. Future studies should report any adverse effects if they happen.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

Federman 2021

Study characteristics	
Methods	RCT
Participants	Training recruits N = 321 Marine Corps USA
Interventions	A total of 821 randomly selected recruits were screened for the fit of their hearing protection devices. They completed a baseline earplug fit test and a live, large group instruction. Of these 821, 344 recruits did not achieve the target 25 dB PAR pass rate and were randomly assigned to one of three HPD fit-training (current, experiential, integrated) formats. Three were somehow not randomised, and after randomisation, 20 participants were excluded: 11 used a different earplug, 7 could not achieve a PAR of 25 dB even after fit by an expert; and 2 did not complete the training. These losses to follow-up seemed similar across trial arms but there were no clear figures in the report. Intervention group 1: experiential training; n = 105 analysed Intervention group 2: integrated training (small group video training followed experiential training); n = 105 analysed Control group: current training (small group video training); n = 111 analysed We compared the outcomes measured between intervention group 1 and control group, and between intervention group 2 and control group, for the effect of extensive instructions versus simple instructions. For both intervention groups, we also compared the within-group before and after training outcomes as a UBA study in the discussion section. The results were used to compare with the findings from RCTs for the effects of extensive instruction verses no instructions.
Outcomes	PAR (dB) and PAR pass rate (%)
Notes	Immediate follow-up

Murphy 2007

Study characteristics	
Methods	RCT
Participants	Automotive workers N = 285 An automobile stamping factory

Murphy 2007 *(Continued)*

	USA
Interventions	Baseline test: total N = 285 Intervention group: multi-earplug (foam and premoulded) users with written instructions; n = 153 Control group: multi-earplug (foam and premoulded) users without written instructions; n = 132 Follow-up test: • 1-month: intervention group n = 100, control group n = 109 • 4-month: intervention group n = 103, control group n = 94 • 12-month: intervention group n = 49, control group n = 54
Outcomes	PAR (dB)
Notes	Short-term and long-term follow-up

Salmani 2014

Study characteristics	
Methods	RCT
Participants	Occupations not reported N = 150 Age: 28.3 ± 5.4 (range: 19 to 39) years Gender: 42% male Iran
Interventions	Intervention: earplugs with training in correct methods of wearing and inserting plugs; n = 50 Control group 1: earplugs without training; n = 50 Control group 2: earplug with higher noise attenuation without training; n = 50 We compared the outcomes measured between intervention group and control group 1 for the effect of extensive instructions versus no instructions.
Outcomes	PAR (dB)
Notes	Immediate follow-up

dB: decibel; **HPD:** hearing protection device; **PAR:** personal attenuation rating; **RCT:** randomised controlled trial; **UBA:** uncontrolled before-and-after study

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Biabani 2017a	Study design: no measurements both before the intervention and after the intervention
Biabani 2017b	Study design: no measurements both before the intervention and after the intervention
Byrne 2011	Study design: no measurements both before the intervention and after the intervention
Cassano 2013	Study design: no measurements both before the intervention and after the intervention

Study	Reason for exclusion
Davis 2011	Study design: no measurements both before the intervention and after the interventionthey
De Vito 2017a	Study design: no measurements both before the intervention and after the intervention
De Vito 2017b	Study design: no measurements both before the intervention and after the intervention
Edwards 1978	Study design: no measurements both before the intervention and after the intervention
Edwards 1979	Study design: no measurements both before the intervention and after the intervention
Gaudreau 2008	Study design: no measurements both before the intervention and after the intervention
Giardino 1996	Study design: no measurements both before the intervention and after the intervention
Gibbs 2017	Study design: no measurements both before the intervention and after the intervention
Gong 2020	Study design: no measurements both before the intervention and after the intervention
Green 1989	Study design: no measurements both before the intervention and after the intervention
Kabe 2012	Study design: no measurements both before the intervention and after the intervention
Lee 2020	Study design: no measurements both before the intervention and after the intervention
Lempert 2010	Study design: no measurements both before the intervention and after the intervention
Mlynski 2014	Study design: no measurements both before the intervention and after the intervention
Murphy 2013	Population and study design: one case was not for noised-exposed workers; another case was no intervention at the workplaces
Neitzel 2006	Study design: no measurements both before the intervention and after the intervention
Pfeiffer 1992	Study design: no measurements both before the intervention and after the intervention
Rocha 2016	Study design: no measurements both before the intervention and after the intervention
Samelli 2015	Study design: cross-sectional study
Samelli 2018	Study design: cross-sectional study
Smoorenburg 1982	Study design: no measurements both before the intervention and after the intervention
Ullman 2021	Study design: no measurements both before the intervention and after the intervention
Upegui-Rincon 2019	Study design: no measurements both before the intervention and after the intervention
Wu 2016	Study design: no measurements both before the intervention and after the intervention

RISK OF BIAS

Legend: Low risk of bias | High risk of bias | Some concerns

Risk of bias for analysis 1.1 Personal attenuation rating (PAR; dB) (immediate, short-term, long-term)

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Subgroup 1.1.1 Simple instructions versus no instructions, earplugs, short-term follow-up (1 and 4 months)						
Murphy 2007	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Murphy 2007	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Subgroup 1.1.2 Simple instructions versus no instructions, earplugs, long-term follow-up						
Murphy 2007	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias
Subgroup 1.1.3 Extensive instructions versus no instructions, earplugs, immediate follow-up						
Salmani 2014	Some concerns	Low risk of bias	Low risk of bias	Low risk of bias	Some concerns	Some concerns

Risk of bias for analysis 2.2 Earplugs, PAR pass rate (%) (immediate)

	Bias					
Study	**Randomisation process**	**Deviations from intended interventions**	**Missing outcome data**	**Measurement of the outcome**	**Selection of the reported results**	**Overall**
Federman 2021	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Some concerns	Some concerns
Federman 2021	Low risk of bias	Low risk of bias	Low risk of bias	Low risk of bias	Some concerns	Some concerns

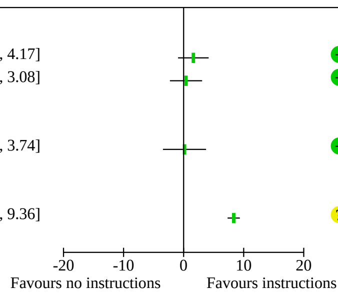
DATA AND ANALYSES

Comparison 1. Fit testing of HPDs with instructions versus fit testing of HPDs without instructions for improving noise attenuation (immediate, short-term, long-term)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.1 Personal attenuation rating (PAR; dB) (immediate, short-term, long-term)	2		Mean Difference (IV, Random, 95% CI)	Totals not selected
1.1.1 Simple instructions versus no instructions, earplugs, short-term follow-up (1 and 4 months)	1		Mean Difference (IV, Random, 95% CI)	Totals not selected
1.1.2 Simple instructions versus no instructions, earplugs, long-term follow-up	1		Mean Difference (IV, Random, 95% CI)	Totals not selected
1.1.3 Extensive instructions versus no instructions, earplugs, immediate follow-up	1		Mean Difference (IV, Random, 95% CI)	Totals not selected

Analysis 1.1. Comparison 1: Fit testing of HPDs with instructions versus fit testing of HPDs without instructions for improving noise attenuation (immediate, short-term, long-term), Outcome 1: Personal attenuation rating (PAR; dB) (immediate, short-term, long-term)

Study or Subgroup	Instructions Mean [dB]	Instructions SD [dB]	Instructions Total	No instructions Mean [dB]	No instructions SD [dB]	No instructions Total	Mean Difference IV, Random, 95% CI [dB]	Risk of Bias A	B	C	D	E	F
1.1.1 Simple instructions versus no instructions, earplugs, short-term follow-up (1 and 4 months)													
Murphy 2007 (1)	25.92	9	100	24.3	9.8	109	1.62 [-0.93 , 4.17]	+	+	+	+	+	+
Murphy 2007 (2)	24.39	9.7	103	23.99	9.5	94	0.40 [-2.28 , 3.08]	+	+	+	+	+	+
1.1.2 Simple instructions versus no instructions, earplugs, long-term follow-up													
Murphy 2007 (3)	26.19	8.7	49	26.04	9.9	54	0.15 [-3.44 , 3.74]	+	+	+	+	+	+
1.1.3 Extensive instructions versus no instructions, earplugs, immediate follow-up													
Salmani 2014 (4)	13.88	2.8	50	5.54	2.4	50	8.34 [7.32 , 9.36]	?	+	+	+	?	?



Footnotes
(1) Murphy 2007: simple instructions = providing written brochure on how to wear earplugs correctly plus time-limited counselling as needed, 1-month follow-up.
(2) Murphy 2007: simple instructions = providing written brochure on how to wear earplugs correctly plus time-limited counselling as needed, 4-month follow-up.
(3) Murphy 2007: simple instructions = providing written brochure on how to wear earplugs correctly plus time-limited counselling as needed, 12-month follow-up.
(4) Salmani 2014: extensive instructions = 15-minute training in correct methods of wearing the earplugs and self-fit under supervision of a trainer.

Risk of bias legend
(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

Comparison 2. Fit testing of HPDs with extensive instructions versus fit testing of HPDs with simple instructions for improving noise attenuation (immediate)

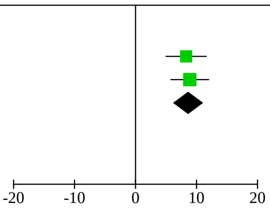
Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.1 Personal attenuation rating (PAR; dB) (immediate)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.1.1 Earplugs	1	321	Mean Difference (IV, Random, 95% CI)	8.62 [6.31, 10.93]
2.2 Earplugs, PAR pass rate (%) (immediate)	1	321	Risk Ratio (M-H, Random, 95% CI)	1.75 [1.44, 2.11]

Analysis 2.1. Comparison 2: Fit testing of HPDs with extensive instructions versus fit testing of HPDs with simple instructions for improving noise attenuation (immediate), Outcome 1: Personal attenuation rating (PAR; dB) (immediate)

Study or Subgroup	Extensive instructions Mean	SD	Total	Simple instructions Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Risk of Bias A B C D E F
2.1.1 Earplugs									
Federman 2021 (1)	33.5	9.6	105	25.2	10.8	56	46.9%	8.30 [4.93 , 11.67]	+ + + + ? ?
Federman 2021 (2)	34.1	7.2	105	25.2	10.8	55	53.1%	8.90 [5.73 , 12.07]	+ + + + ? ?
Subtotal (95% CI)			**210**			**111**	**100.0%**	**8.62 [6.31 , 10.93]**	

Heterogeneity: Tau² = 0.00; Chi² = 0.06, df = 1 (P = 0.80); I² = 0%
Test for overall effect: Z = 7.31 (P < 0.00001)



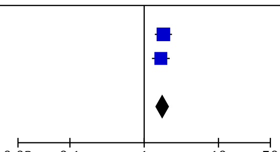
Footnotes
(1) Federman 2021: extensive = small group (≤ 6 person) instructional video, ~30 sec of one-on-one training + expert help with earplug fitting; simple = small group (≤ 6 person) video.
(2) Federman 2021: extensive = about 30 sec of one-on-one training + expert help with earplug fitting; simple = small group (≤ 6 person) instructional video.

Risk of bias legend
(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

Analysis 2.2. Comparison 2: Fit testing of HPDs with extensive instructions versus fit testing of HPDs with simple instructions for improving noise attenuation (immediate), Outcome 2: Earplugs, PAR pass rate (%) (immediate)

Study or Subgroup	Extensive instructions Events	Total	Simple instructions Events	Total	Weight	Risk Ratio M-H, Random, 95% CI	Risk of Bias A B C D E F
Federman 2021 (1)	97	105	28	55	51.8%	1.81 [1.39 , 2.37]	+ + + + ? ?
Federman 2021 (2)	88	105	28	56	48.2%	1.68 [1.27 , 2.21]	+ + + + ? ?
Total (95% CI)		**210**		**111**	**100.0%**	**1.75 [1.44 , 2.11]**	
Total events:	185		56				

Heterogeneity: Tau² = 0.00; Chi² = 0.17, df = 1 (P = 0.68); I² = 0%
Test for overall effect: Z = 5.72 (P < 0.00001)
Test for subgroup differences: Not applicable



Footnotes
(1) Federman 2021: extensive = ~30 seconds of one-on-one training + expert help with earplug fitting; simple = small group (≤ 6 person) instructional video.
(2) Federman 2021: extensive = small group (≤ 6 person) instructional video, ~30 sec of one-on-one training + expert help with earplug fitting; simple = small group (≤ 6 person) video.

Risk of bias legend
(A) Bias arising from the randomization process
(B) Bias due to deviations from intended interventions
(C) Bias due to missing outcome data
(D) Bias in measurement of the outcome
(E) Bias in selection of the reported result
(F) Overall bias

ADDITIONAL TABLES

Table 1. RCT intervention descriptions

Study	Fit-test technology	HPD	NRR (dB)	Instruction (Intervention group)	Instruction (Control group)	Effect	Outcome
Federman 2021	REAT	Foam earplug	33	**Extensive instructions:** Group 1: One-on-one instructions; Group 2: integrated short video and one-on-one instructions	**Simple instructions:** Short video instruction	Immediate	PAR, PAR pass rate
Murphy 2007	REAT	Multi-earplugs	26 - 33	**Simple instructions:** Counselling group (minimal instructions)	**No instructions**	Short term, long term	PAR
Salmani 2014	REAT	Two types of premoulded earplugs	25 - 30	**Extensive instructions:** 15-minute instruction on correct methods of wearing earplugs and wearing earplugs under supervision of a trainer (NRR = 25 dB)	**No instructions:** Wearing earplugs without any training, group 1: NRR = 25 dB; Group 2: NRR = 30 dB.	Immediate	PAR

HPD: hearing protection device; **NRR:** noise reduction rating; **PAR:** personal attenuation rating; **REAT:** real-ear attenuation at threshold

Table 2. Recalculation of study data for review results and meta-analysis

Murphy 2007[#]

Test	**Group**	**n**	**Recalculation PAR (dB)**	
			Mean	**SD**
Initial test	Group B	153	27.57	10.5
	Group C	132	26.63	8.9
1-month follow-up test	Group B	100	25.92	9.0
	Group C	109	24.30	9.8
4-month follow-up test	Group B	103	24.39	9.7
	Group C	94	23.99	9.5
12-month follow-up test	Group B	49	26.19	8.7
	Group C	54	26.04	9.9

Salmani 2014

Study data	**Published PAR (dB)**		**Recalculation PAR (dB)**	
Group	**Mean**	**SD**	**Mean**	SD
Group 1	5.5	1.5	5.5	2.4
Group 2	13.9	2	13.9	2.8
Group 3	11.3	2.45	11.3	3.2

[#]Description of the recalculation methods can be found at Included studies (Results > Description of included studies > Outcome measures > Primary Outcomes).
PAR: personal attenuation rating; **SD:** standard deviation

Table 3. Uncontrolled before-and-after studies

HPD	**Intervention**	**Before situation (control)**	**Follow-up**	**Study**	**MD PAR value / RR PAR pass rate**
1. Change in PAR after fit testing of various HPDs with extensive instructions at immediate, short- or long-term follow-up. Before: no instructions.					
Foam earplugs	Extensive instructions: individualised training	No instructions	Immediate	Copelli 2021;Federman 2021; Gong 2019; Gong 2021a; Kim 2019	PAR MD 11.5 dB higher, P < 0.00001

Table 3. Uncontrolled before-and-after studies *(Continued)*

			Immediate	Chiu 2020; Federman 2016; Gong 2019	PAR pass rate RR 1.59, P = 0.08
			6-month	Gong 2019	PAR MD 10 dB higher, P < 0.00001 PAR pass rate RR 2.08, P < 0.00001
			12-month	Kim 2019	PAR MD 2.8 dB higher, P = 0.002
Premoulded earplugs	Extensive instructions: individualised training	No instructions	Immediate	Gong 2021a; Liu 2020; Zhong 2023	PAR MD 12.7 dB higher, P < 0.00001
			6-month	Liu 2020	PAR MD 8 dB higher, P < 0.00001
			12-month	Liu 2020	PAR MD 6 dB higher, P < 0.00001
Multi-earplugs	Extensive instructions: individualised training	No instructions	Immediate	Hayes 2022;	PAR MD 15.3 dB higher, P < 0.00001
				Gong 2021a; Hayes 2022; Murphy 2016	PAR pass rate RR 1.49, P < 0.0001
Earmuffs	Extensive instructions: individualised training	No instructions	Immediate	Liu 2018	PAR MD 5 dB higher, P < 0.00001 PAR pass rate RR 1.13, P = 0.001
			6-month	Liu 2018	PAR MD 2 dB higher, P = 0.008
			12-month	Liu 2018	PAR MD 3 dB higher, P = 0.006
2 Change in PAR after fit testing of HPDs with extensive instructions at immediate follow-up. Before: simple instructions.					
Foam earplugs	Extensive instructions: manufacturers' package instructions, expert demonstration, and self-training	Simple instructions: manufacturers' package instructions	Immediate	Assunção 2019; Takada 2020	PAR MD 3.23 dB higher, P < 0.0001
					PAR pass rate RR 1.39, p < 0.0001
		Simple instructions: manufacturers' package instructions	3-week	Park 1991	MD 12 dB higher, P= 0.01
			6-month	Assunção 2019	PAR MD 1 dB higher, P = 0.55
					PAR pass rate RR 0.94, P = 0.80
Premoulded earplugs	Extensive instructions: manufacturers' package instructions, expert demonstration, and self-training (premoulded earplugs)	Simple instructions: Manufactures' package instructions	Immediate	Assunção 2019; Takada 2020	PAR MD 2.59 dB higher, P <0.0001
					PAR pass rate RR 1.29, P = 0.0001
			3-week	Park 1991	PAR MD 7.7 dB higher, P = 0.02
			6-month	Assunção 2019	PAR MD 0.3 dB higher, P = 0.86
					PAR pass rate RR 0.80, P = 0.30
Unknown type of earplugs	Extensive instructions: individualised training	Simple instructions: group training	Immediate	Tsukada 2008	PAR MD 4.4 dB higher, P = 0.007
					PAR pass rate RR 1.58, p = 0.003

Table 3. Uncontrolled before-and-after studies *(Continued)*

			2-month	Tsukada 2008	PAR pass rate MD 2.81 dB higher, P = 0.03
					PAR pass rate RR 1.35, P = 0.06
Earmuffs	Manufactures' package instructions, expert demonstration, and self-training	Manufactures' package instructions and self-training (ear muffs)	3-week	Park 1991	MD 1.60 dB higher, P = 0.39
Canal caps	Manufactures' package instructions, expert demonstration, and self-training	Manufactures' package instructions and self-training (ear muffs)	3-week	Park 1991	MD 3.5 dB higher, P = 0.29
3 Change in PAR after fit testing of HPDs with periodically repeated extensive instructions. Before: initial one-time extensive instructions					
Foam earplugs	Periodical extensive instructions	Initial extensive instructions	Weekly	Martin 2019	PAR MD 1.79 dB higher, P < 0.0001
			6-month	Assunção 2019	PAR pass rate RR 1.05, P = 0.77
			12-month	Kim 2019	PAR MD 7.39 dB higher, P = 0.001
Premoulded earplugs	Periodical extensive instructions	Initial extensive instructions	Weekly	Martin 2019	PAR MD 1.21 dB higher, P = 0.005
			6-month	Assunção 2019	RR 0.92, P = 0.52
4 Change in PAR after fit testing of HPDs without instructions at short- or long-term follow-up. Before: fit-testing of HPDs with extensive instructions					
Foam earplugs	Follow-up without instructions	Initial extensive instructions	6-month	Gong 2019	PAR MD 4 dB lower, P < 0.00001
			12-month	Kim 2019	PAR MD 1.57 dB lower, P = 0.12
Premoulded earplugs	Follow-up without instructions	Initial extensive instructions	6-month	Liu 2020	PAR MD 4 dB lower, P < 0.00001
			12-month	Liu 2020	PAR MD 7 dB lower, P < 0.00001
Unknown type earplugs	Follow-up without instructions	Initial extensive instructions	2-month	Tsukada 2008	PAR pass rate RR 0.86, P = 0.21
Multi-earplugs	Follow-up without instructions	Initial extensive instructions	12-month	Murphy 2016	PAR pass rate RR 0.53, P = 0.0005
Earmuffs	Follow-up without instructions	Initial extensive instructions	6-month	Liu 2018	PAR MD 2 dB lower, P = 0.001
			12-month	Liu 2018	PAR MD 2 dB lower, P = 0.03

HPD: hearIng protection device; **MD:** mean difference; **PAR:** personal attenuation rating; **RR:** risk ratio

APPENDICES

Appendix 1. Search strategy

Database	Strategy	Records Inception – 10/07/2021	Records 10/07/2021 – 08/77/2022	Records 08/77/2022 – 07/13/2023	Records 07/13/2023–02/29/2024	Records in total
MEDLINE **(Ovid)** **1946-**	1. Noise, Occupational/ OR ((noise OR hearing OR sound exposure*) AND (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)).ti,ab,kf. 2. exp Ear Protective Devices/ OR (((noise* OR hearing OR sound) ADJ5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR protective equipment OR protective device* OR protector* OR control* OR (loss ADJ3 prevent*) OR (hearing ADJ3 conserv*) OR (hearing ADJ3 protect*) OR ear muff* OR earmuff* OR ear plug* OR earplug* OR ear defender*).ti,ab,kf. 3. (field attenuation* OR personal attenuation* OR sound attenuation OR attenuation rating* OR attenuation estimate* OR attenuation threshold OR PARs OR PAR OR noise dosimetry OR real ear* OR REAT OR FAES OR fit test* OR (field ADJ3 test*) OR field microphone* OR (field ADJ3 attenuation) OR fit check* OR fitcheck OR validation system* OR E-A-Rfit OR estimation system* OR evaluation OR assessment* OR protection level* OR training).ti,ab,kf. 4. 1 and 2 and 3	884	43	74	18	1019
Embase **(Ovid)** **1974-**	1. Industrial noise/ OR ((noise OR hearing OR sound exposure*) AND (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)).ti,ab,kw. 2. exp Ear Protective Device/ OR (((noise* OR hearing OR sound) ADJ5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR protective equipment OR protective device* OR protector* OR control* OR (loss ADJ3 prevent*) OR (hearing ADJ3 conserv*) OR (hearing ADJ3 protect*) OR ear muff* OR earmuff* OR ear plug* OR earplug* OR ear defender*).ti,ab,kw. 3. (field attenuation* OR personal attenuation* OR sound attenuation OR attenuation rating* OR attenuation estimate* OR	720-duplicates = 367 Unique items 49-duplicates = 24 Unique items	49-duplicates = 24 Unique items	40-duplicates = 34 Unique items	13-duplicates = 0 Unique items	425

(Continued)

	attenuation threshold OR PARs OR PAR OR noise dosimetry OR real ear* OR REAT OR FAES OR fit test* OR (field ADJ3 test*) OR field microphone* OR (field ADJ3 attenuation) OR fit check* OR fitcheck OR validation system* OR E-A-Rfit OR estimation system* OR evaluation OR assessment* OR protection level* OR training).ti,ab,kw. 4. 1 and 2 and 3 5. limit 4 to dc="20230713-20240229" 6. limit 5 to "pubmed/medline" 7. 5 NOT 6					
PsycINFO **(Ovid)** **1806-**	1. exp "Noise Levels (Work Areas)"/ OR ((noise OR hearing OR sound exposure*) AND (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)).ti,ab,hw. 2. (((noise* OR hearing OR sound) ADJ5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR protective equipment OR protective device* OR protector* OR control* OR (loss ADJ3 prevent*) OR (hearing ADJ3 conserv*) OR (hearing ADJ3 protect*) OR ear muff* OR earmuff* OR ear plug* OR earplug* OR ear defender*).ti,ab,hw. 3. (field attenuation* OR personal attenuation* OR sound attenuation OR attenuation rating* OR attenuation estimate* OR attenuation threshold OR PARs OR PAR OR noise dosimetry OR real ear* OR REAT OR FAES OR fit test* OR (field ADJ3 test*) OR field microphone* OR (field ADJ3 attenuation) OR fit check* OR fitcheck OR validation system* OR E-A-Rfit OR estimation system* OR evaluation OR assessment* OR protection level* OR training).ti,ab,hw. 4. 1 and 2 and 3	152-duplicates = 61 Unique items	12-duplicates = 6 Unique items	9-duplicates = 8 Unique items	7-duplicates = 7 Unique items	82
Cochrane Library	1. [mh "Noise, Occupational"] OR ((noise OR hearing OR (sound NEXT exposure*)) AND (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)):ti,ab 2. [mh "Ear Protective Device"] OR (((noise* OR hearing OR sound) NEAR/5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR "protective equipment" OR "protective device" OR "protective devices" OR protector* OR control* OR (loss NEAR/3 prevent*) OR (hearing NEAR/3 conserv*) OR (hearing NEAR/3 protect*) OR "ear muff" OR "ear muffs" OR	125-duplicates = 78 Unique items	10-duplicates = 7 Unique items	24-duplicates = 22 Unique items	7-duplicates = 7 Unique items	114

(Continued)

	earmuff* OR "ear plug" OR "ear plugs" OR earplug* OR "ear defender" OR "ear defenders"):ti,ab 3. ((field NEXT attenuation*) OR (personal NEXT attenuation*) OR "sound attenuation" OR (attenuation NEXT rating*) OR (attenuation NEXT estimate*) OR "attenuation threshold" OR PARs OR PAR OR "noise dosimetry" OR (real NEXT ear*) OR REAT OR FAES OR (fit NEXT test*) OR (field NEAR/3 test*) OR (field NEXT microphone*) OR (field NEAR/3 attenuation) OR (fit NEXT check*) OR fitcheck OR (validation NEXT system*) OR E-A-Rfit OR (estimation NEXT system*) OR evaluation OR assessment* OR (protection NEXT level*) OR training):ti,ab 4. #1 AND #2 AND #3 August 2022 – February 2024					
CINAHL **(Ebsco)**	S1. ((noise OR hearing OR "sound exposure*") AND (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)) S2. (MH "Ear Protective Device") OR (((noise* OR hearing OR sound) N5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR "protective equipment" OR "protective device*" OR protector* OR control* OR (loss N3 prevent*) OR (hearing N3 conserv*) OR (hearing N3 protect*) OR "ear muff*" OR earmuff* OR "ear plug*" OR earplug* OR "ear defender*") S3. ("field attenuation*" OR "personal attenuation*" OR "attenuation rating*" OR "attenuation estimate*" OR "attenuation threshold" OR "sound attenuation" OR PARs OR PAR OR "noise dosimetry" OR "real ear*" OR REAT OR FAES OR "fit test*" OR (field N3 test*) OR "field microphone*" OR (field N3 attenuation) OR "fit check*" OR fitcheck OR "validation system*" OR E-A-Rfit OR "estimation system*" OR evaluation OR assessment* OR "protection level*" OR training) S4 S1 AND S2 AND S3 Exclude Medline records August 2022 – February 2024	378-duplicates = 278 Unique items	40-duplicates = 27 Unique items	41-duplicates = 32 Unique items	36-duplicates = 29 Unique items	366
Scopus	TITLE-ABS((noise OR hearing OR "sound exposure*") W/10 (occupation* OR work-related OR worker* OR job* OR industry OR industrial OR employment)) AND TI-	1398-duplicates = 537 Unique	59-duplicates = 26 Unique	72-duplicates = 32 Unique	38-duplicates = 29 Unique	624

(Continued)

	TLE-ABS(((noise* OR hearing OR sound) W/5 (attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish*)) OR "protective equipment" OR "protective device*" OR protector* OR control* OR (loss W/3 prevent*) OR (hearing W/3 conserv*) OR (hearing W/3 protect*) OR "ear muff*" OR earmuff* OR "ear plug*" OR earplug* OR "ear defender*") AND TITLE-ABS("field attenuation*" OR "personal attenuation*" OR "attenuation rating*" OR "attenuation estimate*" OR "attenuation threshold" OR "sound attenuation" OR PARs OR PAR OR "noise dosimetry" OR "real ear*" OR REAT OR FAES OR "fit test*" OR (field W/3 test*) OR "field microphone*" OR (field W/3 attenuation) OR "fit check*" OR fitcheck OR "validation system*" OR E-A-Rfit OR "estimation system*" OR evaluation OR assessment* OR "protection level*" OR training) August 2022 – February 2024	items	items	items	items	
NIOSHTIC-2	Noise OR hearing OR sound exposure AND attenuation OR dampen* OR suppress* OR cancel* OR reduc* OR diminish* OR protect* OR control* OR prevent* OR conserv* OR ear muff OR earmuff OR ear plug OR earplug OR ear defender AND 'field attenuation' OR 'personal attenuation' OR 'attenuation rating' OR 'attenuation estimate' OR 'attenuation threshold' OR PARs OR PAR OR 'noise dosimetry' OR 'real ear' OR 'real ears' OR REAT OR FAES OR 'fit test' OR 'fit tests' OR 'field test' OR 'field tests' OR 'field microphone' OR 'field microphones' OR 'fit check' OR 'fit checks' OR fitcheck OR 'validation system' OR 'validation systems' OR E-A-Rfit OR 'estimation system' OR 'estimation systems' August 2022 – February 2024	444-duplicates = 367 Unique items	51-duplicates = 4 Unique items	3-duplicates = 0 Unique items	8-duplicates = 7 Unique items	378
ClinicalTrials.gov	"Noise exposure" OR "hearing loss" OR "sound exposure" OR "ear plugs" OR earplugs OR earmuffs OR "ear muffs" AND (("hearing protection" OR fitcheck OR "fit check" OR attenuation OR "fit test" OR "fit testing" OR "fit tests" OR "validation system" OR "validation systems")			3	0	3

(Continued)

	OR ("noise dosimetry" OR "real ear" OR "real ears" OR "field test" OR "field testing" OR "field tested" OR "field tests" OR "field microphone" OR "field microphones" OR E-A-Rfit OR "estimation system" OR "estimation systems")) August 2022 – February 2024			
WHO ICTRP	(Condition: "Noise exposure" OR "hearing loss" OR "sound exposure" OR Title: "ear plugs" OR earplugs OR earmuffs OR "ear muffs") AND (Intervention: ("hearing protection" OR fitcheck OR "fit check" OR attenuation OR "fit test" OR "fit testing" OR "fit tests" OR "validation system" OR "validation systems" OR "noise dosimetry" OR "real ear" OR "real ears" OR "field test" OR "field testing" OR "field tested" OR "field tests" OR "field microphone" OR "field microphones" OR E-A-Rfit OR "estimation system" OR "estimation systems")) Results : August 2022 – February 2024	0	0	0

[Notes: Duplicates were identified using the EndNote automated 'find duplicates' function with preference set to match on title, author, and year, and removed from EndNote library. There will likely be additional duplicates that EndNote was unable to detect.]

Appendix 2. Risk of bias assessment

The risk of bias Excel sheet can be found here: https://docs.google.com/spreadsheets/d/11Q1ss-4ZUOvu7tKbV_BN13IM13378-zn/edit?usp=sharing&ouid=108595225591542539022&rtpof=true&sd=true

HISTORY

Protocol first published: Issue 10, 2021

CONTRIBUTIONS OF AUTHORS

Conceived the protocol: TM, CT, WG, AS

Commented on drafts of protocol and review: all authors

Co-ordinated the protocol and review: TM, JV

Designed the search strategies: all authors

Conducted eligibility screening, quality assessment of studies, data extraction: WG, TM, CT, AS

Data analysis: WG, JV, TM, CT

Wrote the protocol and review: TM, WG, CT

Provided general advice on the protocol and the development of the review: JV

Secured funding for the protocol: TM

Performed previous work that was the foundation of the current study: WG, AS, CT

DECLARATIONS OF INTEREST

Three review authors (TM, WG, and AS) are authors on papers related to the topic of this review and are specified below. Two different review authors who were not authors of the included papers conducted data extraction and quality assessment for this review, ensuring a neutral assessment of the studies.

The author team has no affiliations with or involvement in any organisation or entity with a direct financial interest in the subject matter of the review (e.g. employment, consultancy, stock ownership, honoraria, or expert testimony). No financial or non-financial conflicts of interests have influenced the submitted work. All authors checked and approved the final version.

Thais Morata (TM): is a senior research audiologist at the National Institute for Occupational Safety and Health (NIOSH) and has engaged in research activities related to the topic of this review as a hearing expert. She was a co-author on Gong 2021b, which was mentioned but not included in this review. She was not involved in the data analysis decisions for that article. TM is a member of the Cochrane Work Editorial Board but was not involved in the editorial process. The views expressed are her own and do not necessarily represent the official position of NIOSH, Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH, or the CDC.

Wei Gong (WG): was awarded the independent contract #75D30120P07102 with Synergy America for completion of this review from January 2020 to January 2022. Synergy America received funds from NIOSH for this contract, which she held. She became a research fellow at NIOSH in the final phases of completing this review (26 September 2022). She was a co-author on Gong 2023, which was mentioned but not included in this review. She has published four uncontrolled before-and-after studies in audiology and industrial medicine journals. WG was involved in data collection, analysis, and preparing the reports for these papers before she worked as a contractor at NIOSH. Three of these studies were included in this review (Gong 2019; Gong 2021a; Liu 2020). The studies were supported by the Jiangsu Provincial Outstanding Medical Academic Leader and Innovation Team (CXTDA2017029), the Natural Science Foundation of the Jiangsu Province (Grant No. BK20151594) and Personal Safety Division of 3M China Ltd. In this review, WG had no involvement in the assessment or data extraction for the studies she co-authored.

Christina Tikka (CT): none known.

Alessandra Samelli (AS): has published four book chapters in Portuguese which detail the use of fit testing within hearing conservation programs. All chapters were part of technical-scientific books, which serve as a basis for the guidance of audiologists and were produced by scientific societies. AS has also been involved with seven studies on topics concerning the use of fit testing as a way to verify the attenuation of different hearing protectors or comparing different forms of training for proper placement of hearing protectors, related to this review in audiology or public health journals. She was involved in data collection, analysis, and preparation of the reports. No external financial support was obtained for those studies. Two of these studies were included in this review (Assunção 2019; Takada 2020). For this review, AS had no involvement in the assessment or data extraction for the studies she co-authored.

Jos Verbeek (JV): Advisor and Member of the Editorial Board of Cochrane Work. JV has excluded himself entirely from the editorial process of this review. In the past five years, he has worked as a consultant methodologist for the World Health Organization (WHO) on a project to synthesise evidence on the adverse health effects of radiofrequency waves.

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DIFFERENCES BETWEEN PROTOCOL AND REVIEW

We made minor changes to the review's title, objectives, background, and methods sections to improve readability and clarity, as recommended by the editorial team and Cochrane Methods. These adjustments did not deviate from our original intentions.

In the protocol, we did not include adverse effects as an outcome. However, in the review, we included adverse effects as a primary outcome. Since we are not aware of any specific reported adverse effects of the intervention of interest, we planned to include any adverse effects that were mentioned by the trial authors. However, no studies reported adverse effects.