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Interventions to prevent occupational noise-induced hearing loss (Review)

Tikka C, Verbeek JH, Kateman E, Morata TC, Dreschler WA, Ferrite S

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[Intervention Review]

Interventions to prevent occupational noise-induced hearing loss

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ABSTRACT

Background

This is the second update of a Cochrane Review originally published in 2009. Millions of workers worldwide are exposed to noise levels that increase their risk of hearing disorders. There is uncertainty about the effectiveness of hearing loss prevention interventions.

Objectives

To assess the effectiveness of non-pharmaceutical interventions for preventing occupational noise exposure or occupational hearing loss compared to no intervention or alternative interventions.

Search methods

We searched the CENTRAL; PubMed; Embase; CINAHL; Web of Science; BIOSIS Previews; Cambridge Scientific Abstracts; and OSH UPDATE to 3 October 2016.

Selection criteria

We included randomised controlled trials (RCT), controlled before-after studies (CBA) and interrupted time-series (ITS) of non-clinical interventions under field conditions among workers to prevent or reduce noise exposure and hearing loss. We also collected uncontrolled case studies of engineering controls about the effect on noise exposure.

Data collection and analysis

Two authors independently assessed study eligibility and risk of bias and extracted data. We categorised interventions as engineering controls, administrative controls, personal hearing protection devices, and hearing surveillance.

Main results

We included 29 studies. One study evaluated legislation to reduce noise exposure in a 12-year time-series analysis but there were no controlled studies on engineering controls for noise exposure. Eleven studies with 3725 participants evaluated effects of personal hearing protection devices and 17 studies with 84,028 participants evaluated effects of hearing loss prevention programmes (HLPPs).

Effects on noise exposure

Engineering interventions following legislation

One ITS study found that new legislation in the mining industry reduced the median personal noise exposure dose in underground coal mining by 27.7 percentage points (95% confidence interval (CI) −36.1 to −19.3 percentage points) immediately after the implementation of stricter legislation. This roughly translates to a 4.5 dB(A) decrease in noise level. The intervention was associated with a favourable but statistically non-significant downward trend in time of the noise dose of −2.1 percentage points per year (95% CI −4.9 to 0.7, 4 year follow-up, very low-quality evidence).

Engineering intervention case studies

We found 12 studies that described 107 uncontrolled case studies of immediate reductions in noise levels of machinery ranging from 11.1 to 19.7 dB(A) as a result of purchasing new equipment, segregating noise sources or installing panels or curtains around sources. However, the studies lacked long-term follow-up and dose measurements of workers, and we did not use these studies for our conclusions.

Hearing protection devices

In general hearing protection devices reduced noise exposure on average by about 20 dB(A) in one RCT and three CBAs (57 participants, low-quality evidence). Two RCTs showed that, with instructions for insertion, the attenuation of noise by earplugs was 8.59 dB better (95% CI 6.92 dB to 10.25 dB) compared to no instruction (2 RCTs, 140 participants, moderate-quality evidence).

Administrative controls: information and noise exposure feedback

On-site training sessions did not have an effect on personal noise-exposure levels compared to information only in one cluster-RCT after four months' follow-up (mean difference (MD) 0.14 dB; 95% CI −2.66 to 2.38). Another arm of the same study found that personal noise exposure information had no effect on noise levels (MD 0.30 dB(A), 95% CI −2.31 to 2.91) compared to no such information (176 participants, low-quality evidence).

Effects on hearing loss

Hearing protection devices

In two studies the authors compared the effect of different devices on temporary threshold shifts at short-term follow-up but reported insufficient data for analysis. In two CBA studies the authors found no difference in hearing loss from noise exposure above 89 dB(A) between muffs and earplugs at long-term follow-up (OR 0.8, 95% CI 0.63 to 1.03), very low-quality evidence). Authors of another CBA study found that wearing hearing protection more often resulted in less hearing loss at very long-term follow-up (very low-quality evidence).

Combination of interventions: hearing loss prevention programmes

One cluster-RCT found no difference in hearing loss at three- or 16-year follow-up between an intensive HLPP for agricultural students and audiometry only. One CBA study found no reduction of the rate of hearing loss (MD −0.82 dB per year (95% CI −1.86 to 0.22) for a HLPP that provided regular personal noise exposure information compared to a programme without this information.

There was very-low-quality evidence in four very long-term studies, that better use of hearing protection devices as part of a HLPP decreased the risk of hearing loss compared to less well used hearing protection in HLPPs (OR 0.40, 95% CI 0.23 to 0.69). Other aspects of the HLPP such as training and education of workers or engineering controls did not show a similar effect.

In three long-term CBA studies, workers in a HLPP had a statistically non-significant 1.8 dB (95% CI −0.6 to 4.2*)* greater hearing loss at 4 kHz than non-exposed workers and the confidence interval includes the 4.2 dB which is the level of hearing loss resulting from 5 years of exposure to 85 dB(A). In addition, of three other CBA studies that could not be included in the meta-analysis, two showed an increased risk of hearing loss in spite of the protection of a HLPP compared to non-exposed workers and one CBA did not.

Authors' conclusions

There is very low-quality evidence that implementation of stricter legislation can reduce noise levels in workplaces. Controlled studies of other engineering control interventions in the field have not been conducted. There is moderate-quality evidence that training of proper insertion of earplugs significantly reduces noise exposure at short-term follow-up but long-term follow-up is still needed.

There is very low-quality evidence that the better use of hearing protection devices as part of HLPPs reduces the risk of hearing loss, whereas for other programme components of HLPPs we did not find such an effect. The absence of conclusive evidence should not be interpreted as evidence of lack of effectiveness. Rather, it means that further research is very likely to have an important impact.

PLAIN LANGUAGE SUMMARY

Interventions to prevent hearing loss caused by noise at work

What is the aim of this review?

The aim of this Cochrane Review was to find out if hearing loss caused by noise at work can be prevented. Cochrane researchers collected and analysed all relevant studies to answer this question. They found 29 studies that studied the effect of preventive measures.

Key messages

Stricter legislation might reduce noise levels. At the personal level, earmuffs and earplugs can reduce noise exposure to safe levels. However, instruction on how to put plugs into the ears is needed. Without instruction earplugs probably do not protect enough. Providing feedback to workers on noise exposure probably does not decrease noise. Engineering solutions such as better maintenance might lead to similar noise reduction as hearing protection. Better evaluation of these engineering solutions is needed.

The effects of hearing loss prevention programmes (HLPP) are unclear. Better use of hearing protection as part of a programme probably helps but does not fully protect against hearing loss. Improved implementation might provide better protection.

What was studied in the review?

Millions of workers are exposed to noise that can lead to hearing loss. The review authors were interested in the effect of any intervention to reduce noise or hearing loss at workplaces, such as engineering solutions, hearing protection or hearing loss prevention programmes.

What are the results of the review?

Effects on noise exposure

Engineering solutions

We found one study that showed that noise levels decreased by about 5 decibels (dB) after the implementation of stricter legislation in the mining industry. Even though many case studies show that technical improvements can reduce noise levels at workplaces by as much as 20 dB, there were no controlled studies outside the laboratory that would show this with more confidence.

Hearing protection

In eight studies with 358 workers, hearing protection reduced noise exposure of workers by about 20 dB(A). However, for earplugs there was moderate-quality evidence in two randomised studies that if workers lack proper instructions in the use of earplugs, the attenuation offered is reduced by on average 9 dB.

Feedback on noise exposure

Providing feedback on noise exposure did not change noise levels in the construction industry in one study.

Effects on hearing loss

We found 16 studies with 81,220 participants on the long-term effects of hearing protection on hearing loss.

Hearing protection

The use of hearing protection devices in a well-implemented HLPP was associated with less hearing loss. For other elements of programmes such as worker training, audiometry alone, noise monitoring, or providing feedback on personal noise exposure, there was no clear effect. Two studies with 3242 workers found that there was no difference in the long-term effect of earmuffs versus earplugs on hearing loss.

Hearing loss prevention programmes

Four studies provided very low-quality evidence that, compared to non-exposed workers, average HLPPs do not reduce the risk of hearing loss to below a level at least equivalent to that of workers who are exposed to 85 dB(A). Two comparable additional studies showed that the risk of hearing loss is still substantial despite being covered by a HLPP. However, one low-quality study showed that a stricter HLPP can protect workers from hearing loss.

The absence of conclusive evidence should not be interpreted as evidence of lack of effectiveness. Rather, it means that further research is very likely to affect the conclusions we reached. Higher-quality prevention programmes, better quality of studies, especially in the field of engineering controls, and better implementation of legislation are needed to prevent noise-induced hearing loss.

How up to date is this review?

The review authors searched for studies that had been published up to October 2016

SUMMARY OF FINDINGS

Summary of findings for the main comparison. Stricter legislation for noise exposure

Stricter legislation compared with existing legislation for noise exposure

Patient or population: workers with noise exposure

Settings: coal mines

Intervention: stricter legislation

Comparison: existing legislation

Outcomes	Illustrative comparative risks* (95% CI)		No of observations (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Existing legislation	Stricter legislation			
Immediate change in level in year 2000 (noise level at work as PEL dose in dB(A); range 0 to 6400, log scale) 1 year	The mean noise levels during pre-intervention years were 56.9 PEL dose	The mean noise exposure level after introduction was 27.70 PEL dose lower (36.1 lower to 19.3 lower PEL dose)	14 years pre-intervention and 4 years post-intervention (1 ITS)	⊕⊝⊝⊝ **very low[1]**	The reduction of 27.7 PEL dose translates to about 4.5 dB(A)
Change in slope after introduction (noise level at work as PEL dose in dB(A); range 0 to 6400, log scale) 4 years	The mean noise levels during pre-intervention years were 56.9 PEL dose	The mean change in level of noise exposure per year after introduction was 2.10 PEL dose lower (4.90 lower to 0.70 PEL dose higher)	14 years pre-intervention and 4 years post-intervention (1 ITS)	⊕⊝⊝⊝ **very low[1]**	

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the absolute effect of the intervention (and its 95% CI).
CI: Confidence interval; **PEL**: permissible exposure level

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded by one level from low to very low because there is only one study and it has a high risk of bias.

Summary of findings 2. Earplugs with instruction versus without instruction (noise exposure)

Earplugs with instruction compared with no instruction for noise reduction

Patient or population: workers with exposure to noise

Settings: industrial

Intervention: instruction on how to insert earplugs

Comparison: no instruction

Outcomes	Illustrative comparative risks* (95% CI)		No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Without instruction	With instruction			
Mean noise attenuation over 0.5, 1, 2, 3, 4, 6, 8 kHz (dB) Immediate follow-up	The mean noise attenuation ranged across frequencies from 5.5 to 25.9 dB	The mean noise attenuation in the intervention groups was 8.59 dB higher (6.92 dB higher to 10.25 dB higher)	140 participants (2 RCTs)	⊕⊕⊕⊝ **moderate**[1]	

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded from high quality by one level because of imprecision due to small number of participants.

Summary of findings 3. Training plus exposure information compared to training (noise exposure)

Exposure information compared with training as usual for noise exposure

Patient or population: workers exposed to noise

Settings: construction industry

Intervention: provision of noise level indicator

Comparison: safety training as usual

Outcomes	Illustrative comparative risks* (95% CI)		No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Training as usual	Plus noise level indicator			
Change in noise levels at 4 months' follow-up (dB(A))	The mean noise level in the control group ranged from 87.1 to 89 dB(A)	The mean noise level in the intervention groups was 0.3 dB(A) higher (2.31 dB(A) lower to 2.91 dB(A) higher	176 (1 study, RCT)	⊕⊕⊝⊝ **low**[1]	

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded by two levels from high to low because of high risk of bias and imprecision.

Summary of findings 4. Earmuffs versus earplugs (hearing loss)

Earmuffs compared with earplugs for noise-induced hearing loss

Patient or population: workers exposed to 88-94 dB(A)

Settings: shipyard

Intervention: most wearing earmuffs

Comparison: most wearing earplugs

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Earplugs	Earmuffs				
Hearing loss change over 3 years (4 kHz/STS) 2 to 3 years' follow-up	**High risk population**		OR 0.8 (0.63 to 1.03)	3242 (2 CBA studies)	⊕⊝⊝⊝ **very low**[1]	At lower exposures the results were too heterogeneous to be combined
	42 per 1000	**34 per 1000** (26 to 43)				

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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; **OR:** Odds Ratio; **STS**: standard threshold shift

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded from low quality to very low quality because of high risk of bias in both studies.

Summary of findings 5. Hearing loss prevention programme compared to audiometric testing (hearing loss)

Hearing loss prevention programme (HLPP) compared to audiometric testing

Patient or population: agricultural students without hearing loss

Settings: agricultural schools
Intervention: HLPP with information
Comparison: audiometric testing only

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Audiometric testing only	HLPP with information				
Hearing loss STS ≥ 10 dB loss average over 2, 3, 4 kHz in either ear Follow-up: mean three years	**21 per 1000**	**18 per 1000** (6 to 49)	**OR 0.85** (0.29 to 2.44)	687 (1 study, RCT)	⊕⊕⊕⊝ **moderate**[1]	
Hearing loss STS ≥ 10 dB hearing loss average over 2, 3, 4 kHz in either ear Follow-up: mean 16 years	**149 per 1000**	**141 per 1000** (74 to 250)	**OR 0.94** (0.46 to 1.91)	355 (1 study, RCT)	⊕⊕⊕⊝ **moderate**[1]	

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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; **HLPP**; hearing loss prevention programme; **OR:** Odds ratio; **STS**: standard threshold shift

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded one level from high to moderate due to lack of information on randomisation and allocation concealment.

Summary of findings 6. Hearing loss prevention programme (HLPP) with exposure information compared to HLPP without exposure information (hearing loss)

HLPP with exposure information compared with HLPP without exposure information for noise-induced hearing loss

Patient or population: workers exposed to noise

Settings: aluminium smelter

Intervention: exposure information as part of HLPP

Comparison: no such information

Outcomes	Illustrative comparative risks* (95% CI)		No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Without exposure info	With exposure info			
Annual increase in hearing threshold (dB/year at 2,3 and 4 kHz) 4-year follow-up	The mean hearing loss rate in the control group was 1.0 dB per year	The mean hearing loss rate in the intervention groups was 0.82 dB/year lower (1.86 lower to 0.22 higher)	312 (1 CBA study)	⊕⊝⊝⊝ **very low**[1]	Matched for age, gender, baseline hearing loss and baseline hearing

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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; **HLPP**: hearing loss prevention programme

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]We downgraded by one level from low to very low because of high risk of bias.

Summary of findings 7. Well-implemented hearing loss prevention programme (HLPP) compared to less well-implemented HLPP (hearing loss)

Well-implemented hearing loss prevention programme (HLPP) compared to less well-implemented HLPP for hearing loss

Patient or population: workers
Settings: exposure to noise
Intervention: well-implemented HLPP
Comparison: less well-implemented HLPP

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Less well-implemented HLPP	Well-implemented HLPP				
Hearing loss STS > 10 dB change average over 2, 3 and 4 kHz[1] Follow-up: mean 9.3 years	**86 per 1000**	**36 per 1000** (21 to 61)[2]	**OR 0.40** (0.23 to 0.69)[3]	16,301 (3 studies[4])	⊕⊝⊝⊝ **very low**[5]	SMD 0.26 (0.14 to 0.47)

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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; **HLPP**: hearing loss prevention programme; **OR:** Odds ratio; **STS**: standard threshold shift

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]STS used in two studies, change of mean 4 kHz threshold in one study.
[2]Number of events based on median event rate in included studies.
[3]Result from the meta-analysis of three studies.
[4]One extra study provided similar evidence but could not be combined in the meta-analysis.
[5]We downgraded by one level from low to very low because of risk of bias due to lack of adjustment for age and hearing loss.

Summary of findings 8. Hearing loss prevention programme (HLPP) compared to non-exposed workers (hearing loss)

Hearing loss prevention programme (HLPP) compared to non-exposed workers

Patient or population: workers
Settings: exposure to noise
Intervention: HLPP
Comparison: non-exposed workers

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Non-exposed workers	HLPP				
Hearing loss Change in hearing threshold at 4 kHz in dB Follow-up: mean five years	The mean hearing loss in the control groups was **3.6 dB at 4 kHz**[1]	The mean hearing loss in the intervention groups was **1.8 dB higher** (0.6 lower to 4.2 higher)		1846 (3 studies[2])	⊕⊝⊝⊝ **very low**[3,4]	pooled effect size 0.17 (95% CI -0.06 to 0.40) recalculated into dBs

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (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; **HLPP**: hearing loss prevention programme; **SMD**: standardised mean difference

GRADE Working Group grades of evidence

High quality: we are very confident that the true effect lies close to that of the estimate of the effect

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

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

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

[1]Assumed increase of hearing threshold: median of three studies with respectively 3.4, 3.6 and 5.2 dB increase in hearing threshold at 4 kHz after five years' follow-up.
[2]Results from three of five studies included in sensitivity analysis because one study was at serious risk of bias and one other study showed that in spite of hearing protection workers were still more at risk than non-exposed workers.
[3]We downgraded by one level from low to very low because three studies did not adjust for age and hearing loss at baseline.
[4]We would have downgraded by one more level because the confidence interval does not exclude a risk of hearing loss similar to exposure to 85 dB(A) but we had already reached a rating of very low quality evidence.

BACKGROUND

Description of the condition

Noise is a prevalent exposure in many workplaces. Approximately nine million workers in the USA alone are exposed to time-weighted average (TWA) sound levels of 85 dB(A) and above (WHO 2002). The first signs of noise-induced hearing loss (NIHL) can be detected in the typical 4 kHz 'notch' observed on audiograms (Nelson 2005). Worldwide, 16% of disabling hearing loss in adults is attributed to occupational noise. Leigh 1999 calculated a global annual incidence of NIHL of 1,628,000 cases, which means an annual incidence rate of almost two new cases per 1000 older workers. Noise-induced hearing loss is the second most common self-reported occupational illness or injury, despite decades of study, workplace interventions, and regulations (Nelson 2005). Information is also available for self-reported hearing difficulty and tinnitus among workers and non-workers (Masterson 2016a), incidence and prevalence data from audiometric data sets (Masterson 2015), and disability-adjusted life years (Masterson 2016b). Self-reported rates of hearing difficulty and tinnitus were higher among noise-exposed workers when compared to non-workers (Masterson 2016a). The mining sector had the highest prevalence of workers with any hearing impairment (hearing loss that impacts day-to-day activities), and with moderate or worse impairment, followed by the construction and manufacturing sectors (Masterson 2016b); rates were also high among workers in the healthcare and social assistance sector (Masterson 2015). Two-and-a-half healthy life years were lost each year for every 1000 noise-exposed US workers because of hearing impairment. Mining, construction and manufacturing workers lost more healthy years than workers in other industry sectors, respectively 3.5, 3.1 and 2.7 healthy years were lost each year for every 1000 workers due to hearing impairment.

Construction workers are still considered as an underserved population where it comes to hearing loss prevention, with one in twenty construction workers estimated to have occupational hearing loss (Suter 2009; Tak 2009). An analysis of the noise exposure on construction sites shows the difficulties for preventive interventions in this industrial sector. Due to the setting and nature of the job, noise exposure varies over time and there are often combined exposures such as chemicals and vibration. Various trades work in the same environment, which also puts quiet trades at risk. Communication and sound localisation are of vital importance for the workers but personal hearing protection devices can degrade those abilities. The use of personal hearing protection also causes other problems such as hygiene problems or occlusion effects (Suter 2002). Interventions to reduce noise at the source such as efficient design, retrofit, and maintenance of equipment or special marks for extra quiet equipment are presented in the literature but these have not been evaluated nor sufficiently implemented (Seixas 2001; Suter 2002; Trabeau 2008). Overall there is a lack of information about noise exposure and hearing ability of construction workers even though methods are available (Haron 2009; Neitzel 2011; Seixas 2001; Suter 2002). One reason is that it is difficult to keep records and organise follow-up of workers in the construction industry. Mobility among the workers is high, employment periods are often short and seasonal, and self-employed workers might not even be part of a hearing conservation programme (Suter 2002).

Long-term exposure to noise levels beyond 80 dB(A) carries an increased risk of hearing loss, which increases with the noise level and can ultimately lead to hearing impairment (ISO 1990). The risk of hearing impairment also increases substantially with age. There are various definitions of hearing impairment in use. The most commonly used definition for hearing impairment is a weighted average hearing loss at 1 kHz, 2 kHz, 3 kHz and 4 kHz greater than 25 dB (John 2012). Such a hearing loss decreases the capacity to engage in conversation in meetings or social activities thus creating a significant barrier in establishing or maintaining emotional relationships. Measured this way, the probability of hearing impairment occurring in persons not exposed to noise at the ages of 35 and 65 is estimated to be 10% and 55% respectively, because it increases naturally with age. Ten years of noise exposure at the level of 100 dB(A) will raise the probability of hearing impairment for the same individuals to 94.5% and 99.5%. Thus, 10 years of noise exposure entails a relative risk of hearing impairment of 9.9 for a 35 year-old worker and 1.8 for a 65 year-old worker compared to their non-exposed peers (Prince 1997). Concurrent exposure to ototoxic substances (that is, damaging to the cochlea or auditory nerve), such as solvents and heavy metals, may increase the damaging potential of noise (EU 2003; Johnson 2010). The condition is permanent and there is no effective treatment for permanent hearing loss resulting from excessive noise exposure. However, the risk of noise-induced hearing loss can be greatly minimised if noise is reduced to below 80 dB(A) (ISO 1990).

Description of the intervention

The preventive potential of reducing noise exposure has led to mandatory HLPPs in many countries. However, the reportedly continuing high rate of occupational noise-induced hearing loss casts doubt upon the effectiveness of these standards and workers' compliance with them. Moreover, the broad range of interventions included in HLPPs makes it difficult to appraise the most effective strategy for reducing risk.

How the intervention might work

There is a general belief that it is most effective to apply control measures in a hierarchical order. This means first using measures that eliminate the source of the noise and, at the other end of the spectrum, implementing measures that protect the individual worker only. In occupational hygiene terms this is called the hierarchy of controls (Ellenbecker 1996). Despite the general consensus that this should be the leading principle for noise reduction strategies at the workplace, the first attempt to reduce noise often is limited to the provision of hearing protectors. Also clinical interventions such as the use of magnesium or anti-oxidants such as N-acetylcysteine for preventing noise-induced hearing loss have been studied (Le Prell 2012; Lynch 2005). These will not be included in this review.

Why it is important to do this review

A more general and non-systematic review on the effectiveness of hearing conservation programmes concluded in 1995 that there was no convincing evidence that HLPPs are effective (Dobie 1995). A systematic review of studies that have evaluated interventions to reduce occupational exposure to noise or to decrease occupationally-induced hearing loss is therefore warranted. This is the second update of a Cochrane Review originally published in 2009.

OBJECTIVES

To assess the effectiveness of non-pharmaceutical interventions for preventing occupational noise exposure and occupational hearing loss compared to no or alternative interventions.

METHODS

Criteria for considering studies for this review

Types of studies

We included randomised controlled trials (RCT), cluster-randomised trials, controlled before-after studies (CBA) and interrupted time-series (ITS).

Evaluations of hearing loss prevention interventions can be biased by factors that also cause hearing loss other than noise, such as ageing or exposure to ototoxic substances (Kirchner 2012). Randomisation is the best protection against such bias. However, noise reduction is an intervention that is almost never carried out only at the individual level. Noise reduction in enterprises usually entails replacing noisy machinery or shielding off noisy machinery or tools. Cluster-randomisation, in which whole companies or departments are randomly assigned to the intervention and control group, is a way to replace randomisation at the individual level and is a relatively new trial design.

As randomisation is difficult to perform for the interventions of interest in this review, we therefore also included CBA studies. There is no uniform nomenclature for non-randomised studies. In the literature CBA studies are also known as cohort studies, quasi-experimental studies, non-randomised pre-post-intervention or controlled clinical trials. For studies that measured an immediate effect of hearing protection it was difficult to assess what the control group should be. We included only studies that measured an immediate effect of two types of hearing protectors if this was measured in the same study participants. For studies that measured hearing loss in the long-term we excluded those that did not collect data on a proper control group but used only data from available databases.

In addition, hearing loss is often registered in medical databases. These can form a reliable source in which changes can be observed in trends over time as a result of interventions. These type of data are also called ITS. Cochrane Effective Practice and Organisation of Care (EPOC) has defined these as studies in which the outcome has been measured at least three times before and three times after the intervention (EPOC 2012; Ramsay 2003).

We also included uncontrolled before-and-after studies that evaluated the effectiveness of engineering controls in reducing noise levels to compare studies and review results in the discussion part of this review. We only included studies if they compared noise readings in the same location during similar work operations before and after engineering controls were implemented.

For the effect of hearing protection devices on noise attenuation, we only included studies that compared different devices worn by the same workers in real work conditions. This is because hearing attenuation depends both on the skills of the worker to fit a device and the properties of the device itself. A comparison between devices worn by different groups of workers would be a comparison between skills of workers and the attenuation of devices at the same time and the effects would be impossible to disentangle.

For the effect of training workers in the fitting of hearing protection devices on noise attenuation, we included studies with a comparison group including different workers but for the same device.

We excluded laboratory studies because it has been repeatedly reported that the results in the laboratory are often overly positive due to the lack of real-world conditions, such as change of working tasks, differences in training in the fitting of devices, and wearing of glasses.

Types of participants

We included studies with male and female workers at workplaces exposed to noise levels of more than 80 dB(A) as a TWA over a period of an entire work shift or working day or part of the work shift.

Types of interventions

We included studies where the interventions intended to prevent noise-induced hearing loss, or which formed part of a noise-induced hearing loss prevention programme (HLPP). We included interventions consisting of one or more of the following elements.

1. Engineering controls: reducing or eliminating the source of the noise, changing materials, processes or workplace layout (NIOSH 1997)
2. Administrative controls: changing work practices, management policies or worker behaviour (NIOSH 1997)
3. Personal hearing protection devices (NIOSH 1998)
4. Hearing surveillance: monitoring the hearing levels of exposed workers (NIOSH 1998)

We excluded all clinical interventions such as the use of anti-oxidants, magnesium or other compounds.

Types of outcome measures

We included two main outcomes: noise exposure and hearing loss. We included studies that reported the effects of the intervention on either noise exposure or hearing loss. For both outcomes we took the change in the outcome between before and after the implementation of the intervention. We did so because we included mostly non-randomised studies where workers could already have had hearing loss before the intervention.

We included noise exposure as a primary outcome because the relation between exposure to noise at work and hearing loss has been well established (ISO 1990; Prince 1997). It can be safely assumed that interventions that reduce noise exposure will in turn lead to a decrease in participants with hearing loss. Noise exposure is therefore a good predictor of the eventual health outcome, hearing loss. We also made a distinction between short-term and long-term effects. We considered three follow-up times as important: less than one year, one to five years and more than five years. Short-term effects were considered if a change in outcome was possible in less than one year. Long-term effects were considered to occur only after at least one year.

An alternative technique to evaluate immediate or long-term effects on hearing ability is the measurement of otoacoustic emissions (OAEs). OAEs provide a measurement of outer hair cell integrity with two most prominent types of measurement: transient evoked otoacoustic emissions (TEOAEs), and dual-tone evoked distortion product otoacoustic emissions (DPOAEs). Both can be used for example to check the attenuation effect of hearing protection devices in real wearing conditions (Bockstael 2008). Nevertheless there is an ongoing discussion in the literature about the use of TEOAEs and DPOAEs as diagnostic tools in occupational health examinations of noise-exposed workers (EU-OSHA 2009; Helleman 2010). Because of considerable uncertainties regarding the use of OAEs we decided not to use OAE test results as outcome measurements. References of studies qualifying for inclusion but measuring noise-induced hearing loss only as OAEs were listed as references pending classification. In cases where study results were measured additionally as OAEs the studies were included with the outcome measurements mentioned above.

Noise exposure

We included studies that directly measured the change in noise exposure level either as the difference in noise levels (dB) or the difference in exposure doses (%). We also included noise levels measured as noise attenuation effects from hearing protection devices assessed as the difference in hearing threshold with and without the hearing protection device. We included studies regardless of the frequencies measured (Hz). All outcomes can either be measured as long-term or short-term effects, depending on the follow-up time of the study.

We included studies reporting noise exposure measurements for either a specific area or a specific worker. Measurement instruments could be fixed in one location, attached on a person (e.g. on the collar), or installed in the ear behind the hearing protection device (e.g. microphone in real ear (MIRE)). We included outcome measures of the exposure for one point in time and measures over longer time periods (e.g. average exposure over one working day).

We intended to include all noise outcomes that were measured with a measurement instrument that was calibrated before use. Although we intended to include only measurements executed according to a written national or international standard, in which information on measurement method and measurement settings (e.g. time weighting) was given, this turned out to be an excessively strict criterion. We therefore included all reported noise measurements.

Noise level

We included studies that reported sound pressure levels, either as absolute measures or as averages over time in dB.

TWA noise levels are used to convey a worker's daily exposure to noise (normalised to an eight-hour day), taking into account the average levels of noise and time spent in each area. Decisions have to be made on which parameters to use in these calculations. The Equivalent Continuous Sound Level - (L_{eq}) is based on the equal energy hypothesis, which states that equal amounts of sound energy produce equal amounts of damage regardless of their distribution over time. L_{eq} calculations are based on an 85 dB limit and an exchange rate of 3 dB. However, in the USA, noise levels are often reported as TWA, or averaged sound level (Lavg) with an exchange rate of 5 dB and threshold level of 90 dB, as these are the levels set by the Occupational Safety and Health Administration (OSHA). This results in one hour of exposure to 90 dB(A) in US studies being equal to half an hour of exposure to 95 dB(A) whereas in European studies this would equal half an hour of 93 dB(A). As a consequence, the US time-weighted figure would be an underestimate of the same noise levels measured according to the European methodology. Because we had no method to correct for this, we used the outcome measurements as described by the study authors.

Exposure dose

The calculation of a dose is based on the permissible exposure limit. For example a day-long exposure to 90 dB(A) would lead to a dose of 100% for that day. With each 5 dB increase or decrease the dose would be doubled or halved. However different standards recommend different exposure limits (e.g. 90 dB(A), 85 dB(A) or 80 dB(A)) as well as different exchange rates (e.g. 3 dB, 4 dB, 5 dB) and different threshold levels. As a consequence, the same exposure would be expressed as a smaller dose for the higher exposure limits. We again used the outcome measurements as described by the study authors.

Immediate hearing threshold changes

We included measures of differences between hearing thresholds with and without hearing protection. This method is called real ear attenuation at threshold (REAT) and is equivalent to the noise attenuation effect of the hearing protection device.

Hearing loss

Short-term effects

We also included measures of temporary threshold shifts (TTS), a temporary decrease in hearing acuity after some hours of exposure. We included studies that used TTS as an effect measure of the noise attenuation of hearing protection devices.

Long-term effects

We included studies that measured permanent threshold shifts (PTS). Those threshold shifts are non-reversible and only occur after several years. We also included studies that used standard thresholds shifts (STS), which is a measure of a minimum relevant shift of the PTS by, for example, 15 dB.

We intended to include only hearing loss measured with a calibrated audiometer and defined by means of a written protocol, which was the case for most studies. However, in some cases this was found to be an excessively strict criterion so we also included audiometric measurements when there was no written protocol reported.

Search methods for identification of studies

We conducted systematic searches for RCTs, CBA studies, ITS studies and noise reduction case studies. We used no restrictions on language, publication year or publication status. The date of the last search was 26 September 2016 for Pubmed, Embase, Web of Science and OSHupdate. The database Central and CINAHL were last searched on 3 October 2016.

Electronic searches

We searched:

1. the Cochrane Central Register of Controlled Trials (CENTRAL, 2008, Issue 4) in the Cochrane Library (until 3 October 2016) (including Cochrane Ear, Nose and Throat Disorders Group's Trials Register and Cochrane Work's Trials Register);
2. PubMed (until 26 September 2016);
3. Embase (using Embase) (until 26 September 2016);
4. CINAHL (until 3 October 2016);
5. Web of Science (until 26 September 2016);
6. OSHupdate (until 26 September 2016) (including the databases from the US National Institute of Occupational Safety and Health (NIOSHTIC, NIOSHTIC-2), International Occupational Safety and Health Information Centre of The International Labour Organisation (CISDOC), International bibliographic, UK Health and Safety executive (HSELINE), Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Canada (IRRST), Ryerson Technical University Library, Toronto, Canada (RILOSH)

The following databases were included in the original review (2008) but were not included in the update, as we did not locate additional relevant studies:

1. LILACS;
2. KoreaMed;
3. IndMed;
4. PakMediNet;
5. CAB Abstracts;
6. BIOSIS Previews;
7. *mR CT* (Current Controlled Trials); and
8. Google.

We modelled subject strategies for databases on the search strategy designed for CENTRAL. We did not combine subject strategies with a methodological filter because we wanted to identify all occupational health studies, both randomised and non-randomised (Verbeek 2005).

The search strategy for CENTRAL is shown in Appendix 1.

The search strategies for other key databases including PubMed are shown in Appendix 2.

Searching other resources

We scanned reference lists of identified studies for further papers. We also searched PubMed, TRIPdatabase, NHS Evidence - Ear, Nose, Throat and Audiology (formerly NLH ENT & Audiology Specialist Library) and Google to retrieve existing systematic reviews possibly relevant to this systematic review, so that we could scan their reference lists for additional studies.

We contacted Dr E Berger who keeps an up-to-date archive on hearing protector effectiveness and obtained copies from the grey literature studies that he included in his review of real field effectiveness studies of hearing protection. Of the 22 studies in his review we were unable to retrieve two because they were personal communications (Berger 1996).

Data collection and analysis

Selection of studies

To determine which studies to assess further, pairs of the review authors (EK, JV, TM, WD, CM, SF) independently scanned the titles and abstracts of every record retrieved. Full articles were retrieved for further assessment if the information given suggested that the study could meet all of the following criteria:

1. included workers exposed to noise levels greater than 80 dB(A);
2. concerned interventions aimed at reduction of noise exposure to prevent noise-induced hearing loss;
3. used noise exposure or noise-induced hearing loss as an outcome; and
4. used RCT, CBA studies, or ITS as the study design.

Data extraction and management

For each study included, pairs of the review authors (EK, JV, TM, WD, CM, SF) extracted data independently. Where possible, we resolved discrepancies in the results by discussion or we involved a third review author. Studies with unclear information were often over 20 years old and we refrained from trying to contact the authors. We contacted eight authors of recent studies and obtained additional data from three (Davies 2008; Joy 2007; Rabinowitz 2011).

We used a standard form to extract the following information: characteristics of the study (design, methods of randomisation); setting; participants; interventions and outcomes (types of outcome measures, timing of outcomes, adverse events).

Assessment of risk of bias in included studies

We conducted the evaluation of the risk of bias of RCTs and cohort studies included in the review by means of the checklist developed by Downs and Black (Downs 1998). We only used the items on internal validity of the checklist and not those on reporting quality or external validity. We slightly adapted the way answers to the items of the checklist were formulated to make it fit the Cochrane 'Risk of bias' tool (Higgins 2011a) as implemented in Review Manager 5 (RevMan 5) (RevMan 2014) and thus used the judgements high, low or unclear risk of bias instead of using scores 1 or 0 as proposed by the checklist authors.

For non-randomised studies, for item allocation concealment, we judged all studies to have an unclear risk of bias because this item is not applicable to non-randomised studies and the effect of unconcealed allocation on the outcome hearing loss and noise is unknown.

We assessed risk of bias due to confounding separately for noise and hearing loss outcomes. We judged studies based on the assessment and adjustment for confounders. If confounders were similar at baseline or confounders were adjusted for adequately in the analysis, we judged studies to be at low risk of bias for confounding. We judged none of the engineering control studies to be at high risk of bias for confounding, as we don't know of factors that have been shown to be significant predictors of noise exposure. For behavioural interventions, we considered age, gender, and hearing loss to be possible confounders of noise exposure outcomes as those participant characteristics could lead to different behaviours (e.g. distance to noisy equipment) and could therefore alter the effect of an intervention. We judged studies adjusting for at least two of those possible confounders to have a low risk of bias and studies not fulfilling that criteria to have an unknown risk of bias. We considered age, hearing levels, recreational noise exposure, ototoxic medication and previous ear infections as possible confounders for studies measuring hearing loss outcomes. We considered age to be the most important confounder and judged studies that did not adjust for age to have a high risk of bias irrespective of adjustment to other factors. We considered age to be similar between intervention and control group as long as the mean age difference was smaller than five years. We judged studies that adjusted for age and at least one additional possible confounder to have a low risk of bias. Studies that did not report sufficient information about baseline differences or necessary statistical adjustments, we judged to have an unknown risk of bias.

Pairs of the review authors independently examined the risk of bias of the studies. We resolved disagreements by discussion. We defined low risk of bias overall as a score of more than 50% on the internal validity scale of the checklist.

For ITS we used the quality criteria as presented by Ramsay 2003.

Measures of treatment effect

The included studies measured noise exposure on a continuous scale in decibels (dB) with A or C weighting. The A weighting takes into account the sensitivity of the human ear to certain frequencies whereas the C weighting is used for peak sound level measurements. The studies calculated the effect of an intervention, either as attenuation of noise level or as change in noise level over time, by subtracting the level after the intervention from the level measured before the intervention. In one study (Joy 2007) the authors used the medians of all noise measurements in a year as the measure of effect in an ITS analysis to show the long-term effect. We used a PEL of 90 dB(A) as 100% and a 5 dB exchange rate to convert the change in the exposure dose into the change in dB(A).

For immediate effects of noise attenuation, authors used the MIRE to measure the difference in noise levels inside and outside hearing protection (Pääkkönen 1998; Pääkkönen 2001). They also used REAT, which measures hearing thresholds with and without protection (Park 1991b protection). The MIRE and REAT methods yield slightly different results at different frequencies. For studies that reported noise attenuation in dB for each frequency measured we calculated the mean noise attenuation over all measured frequencies. We calculated the mean noise attenuation as the average of the reported means with a standard deviation calculated from the variances, as square root of the average variance (Salmani 2014). We applied the same formula for calculating the mean noise exposure from machinery if studies reported mean noise level measurements separately for multiple machines of the same type (Küpper 2013). Two studies included participants with different times of follow-up between control and intervention group. We recalculated the effect as RR per 100 person years to adjust for the differences in the length of follow-up (Muhr 2006; Muhr 2016). We have reported the original study data that we used to recalculate the outcomes in Table 1.

For hearing loss, the included studies measured effects both as permanent loss of hearing acuity (dB units) on a continuous scale expressed as differences in means, and as the rate of workers with a certain amount of hearing loss, which was expressed using odds ratios (OR). Usually these amounts were defined as a STS and measured as a change or shift in hearing loss of at least 10 dB averaged over 2 kHz, 3 kHz and 4 kHz in either ear, which is also the criterion used by OSHA to maintain a safe and healthy work environment (Rabinowitz 2007). In one study this was defined as the better ear (Davies 2008) and in one study as the worst ear (Lee-Feldstein 1993). In one study the STS was considered for all frequencies tested (Nilsson 1980). In another study it was defined as greater than 15 dB at the best ear at any test frequency (Muhr 2006). We considered STS to be the event and were recalculated rates per 100 person-years for all studies that used the STS as an outcome measure.

We used the change in hearing level at 4 kHz as the effect measure because this frequency is generally considered to be the most susceptible to the detrimental effects of noise (May 2000). We took the last minus the first measurement in all cases, thus a positive number indicates an increase in hearing loss.

For TTS, all outcomes were recalculated in order to reflect hearing thresholds before noise exposure minus hearing thresholds after noise exposure. TTS is highly dependent on the amount of time between exposure and measurement. All authors indicated this time interval. We presented the results according to this time interval.

For time-series, were extracted data from the original papers (Joy 2007) or obtained additional data from the authors (Rabinowitz 2011) and re-analysed them according to the recommended methods for analysis of ITS designs for inclusion in systematic reviews (Ramsay 2003). These methods utilise a segmented time-series regression analysis to estimate the effect of an intervention while taking into account secular time trends and any autocorrelation between individual observations. For the included studies, we fitted a first order auto regressive time-series model to the data using a modification of the parameters of Ramsay 2003. Details of the mode specification are as follows:

$$Y = ß0 + ß1time + ß2\,(time-p)\,I(time > p) + ß3\,I(time > p) + E,\ E \sim N(0, s2)$$

For time = 1,...,T, where p is the time of the start of the intervention, I (time ≥ p) is a function that takes the value 1 if time is p or later and zero otherwise, and where the errors E are assumed to follow a first order auto regressive process (AR1). The parameters ß have the following interpretation:

ß1 is the pre-intervention slope;
ß2 is the difference between post and pre-intervention slopes;
ß3 is the change in level at the beginning of the intervention period, meaning that it is the difference between the observed level at the first intervention time point and that predicted by the pre-intervention time trend.

Unit of analysis issues

There were no cluster-randomised trials for which we had to assess a unit of analysis error. However, there were three studies (Adera 2000; Lee-Feldstein 1993; Simpson 1994) that used a cluster of companies as a control group but did not correct for the clustering effect and thus had artificially high precision. We assumed an intra-class correlation coefficient of 0.06, based on analogy of the study on workplace health promotion by Martinson 1999. We adjusted the size of the control groups for the design effect according to the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins

2011b). For studies that used a cluster-randomised design and adjusted statistically for the design effect (Berg 2009), we used the adjusted OR to be entered into RevMan 5 (RevMan 2014). One other study (Seixas 2011) used a combined cluster- and individually-randomised design but did not provide enough information about the clustering to be able to adjust for clustering effects.

One study had multiple intervention arms (Hager 1982). To include it in a meta-analysis, we chose to include the arm with the most active intervention and the control group with the least noise exposure, thus avoiding the inclusion of the same control group twice.

Dealing with missing data

We asked seven study authors to provide missing data and we obtained data from six of them (Davies 2008; Huttunen 2011; Joy 2007; Moshammer 2015; Rabinowitz 2011; Seixas 2011). In two cases we calculated standard deviations (SDs) from P values (Hager 1982) and standard errors (SE) from OR and 95% confidence interval (CI) values (Berg 2009) according to the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011b).

We also contacted the author of one study to categorise the evaluated helicopters to the two different types of intervention compared in the study (with or without advanced technology) and we received the additional information (Küpper 2013).

Assessment of heterogeneity

First we assessed whether studies were sufficiently homogeneous to be included in one comparison, based on the similarity of the timing of the outcome measurement (immediate or long-term) and the type of intervention, what the control condition was (poor-quality HLPP, non-exposed workers) and when the outcome was measured (one year, one to five years, more than five years).

Next, we tested for statistical heterogeneity by means of the I^2 statistic as presented in the meta-analysis graphs generated by the RevMan software (Higgins 2003; RevMan 2014). If this test statistic was greater than 50% we considered there to be substantial heterogeneity between studies (Deeks 2011).

Assessment of reporting biases

Since there were no comparisons for which we could include more than five studies we did not attempt to assess publication bias.

Data synthesis

We included studies that we deemed sufficiently homogeneous with regard to interventions, participants, settings and the outcomes measured in a meta-analysis.

For HLPPs, we deemed both the change in hearing loss at 4 kHz and the STS sufficiently similar to combine them as similar outcomes in the meta-analysis. Because the former is a continuous measure and the latter a dichotomous measure we had to use effect sizes to combine these two. We used the mean change in hearing threshold at 4 kHz to calculate effect size as follows: (effect size = mean change difference/standard deviation). For the rate of occurrence of standard threshold shifts we calculated the ORs, took their natural logarithm and divided them by 1.8 to transform them also into effect sizes (Chinn 2000). We entered these effect sizes and their standard errors into the meta-analysis using the Generic Inverse Variance method as implemented in RevMan 2014.

When the results were statistically heterogeneous according to the I^2 statistic we used a random-effects model for the meta-analysis.

After meta-analysis we recalculated a mean change difference from the pooled effect size using the median standard deviation of the included studies in the formula: (pooled mean change = pooled effect size * median standard deviation).

Some study authors reported the results according to hearing thresholds at the start of the study (Pell 1973). We included these categories as subgroups and combined them in the meta-analysis as subcategories. Other study authors presented the data according to gender (Adera 2000) and we combined these data following the instructions of the *Cochrane Handbook for Systematic Reviews of Interventions* (Deeks 2011). In two studies, we used the same control group as a comparison in multiple subgroups. To avoid using the same control group data more than once, we split the control group into three (Muhr 2006) or two (Seixas 2011) equal subgroups that were subsequently combined in the meta-analysis.

In our protocol we planned to conduct a qualitative synthesis. However the GRADE approach is now the recommended method. We therefore used the GRADE approach to rate the quality of evidence as follows. The quality of the evidence on a specific outcome is based on the study design, risk of bias, consistency, directness (generalisability) and precision (sufficient or precise data) of results and publication bias across all studies that measure that particular outcome. The overall quality is considered to be high when RCTs with low risk of bias, with consistent, precise and directly applicable results and without evidence of reporting bias, measure the results for the outcome, and is reduced by a level for each of the factors not met. For observational studies, the overall quality is considered low at the start of the rating process and this can be further downgraded in the same way as for RCTs but upgraded if the studies have special strengths (large effect size, dose response and findings contrary to confounding). For non-randomised studies, the judgement of the quality of the evidence is more difficult than for RCTs because of the wider variation and the lesser likelihood of being able to combine studies in a meta-analysis. Therefore we presented our GRADE rating in a separate table that includes all comparisons (Table 2).

The interpretation of the quality of evidence is as follows. With high-quality evidence, it is unlikely that further research will change our confidence in the estimate of effect. With moderate-quality evidence, further research is likely to have an impact and may change the estimates. With low-quality evidence, further research is very likely to have an important impact and with very low-quality evidence any estimate of effect is very uncertain.

We entered the results for the most important comparisons into eight 'Summary of findings' tables (Summary of findings for the main comparison). To keep the amount of information manageable we left out the comparison of the effects of various hearing protection devices on noise exposure and temporary hearing loss, the comparison of frequent versus less frequent use, the comparison of follow-up of STS and the comparison of HLPP for long versus normal shifts.

Sensitivity analysis

We conducted a sensitivity analysis, which involved leaving out one study (Pell 1973) that had the highest risk of bias, due to differences in age between the intervention and the control group.

RESULTS

Description of studies

Results of the search

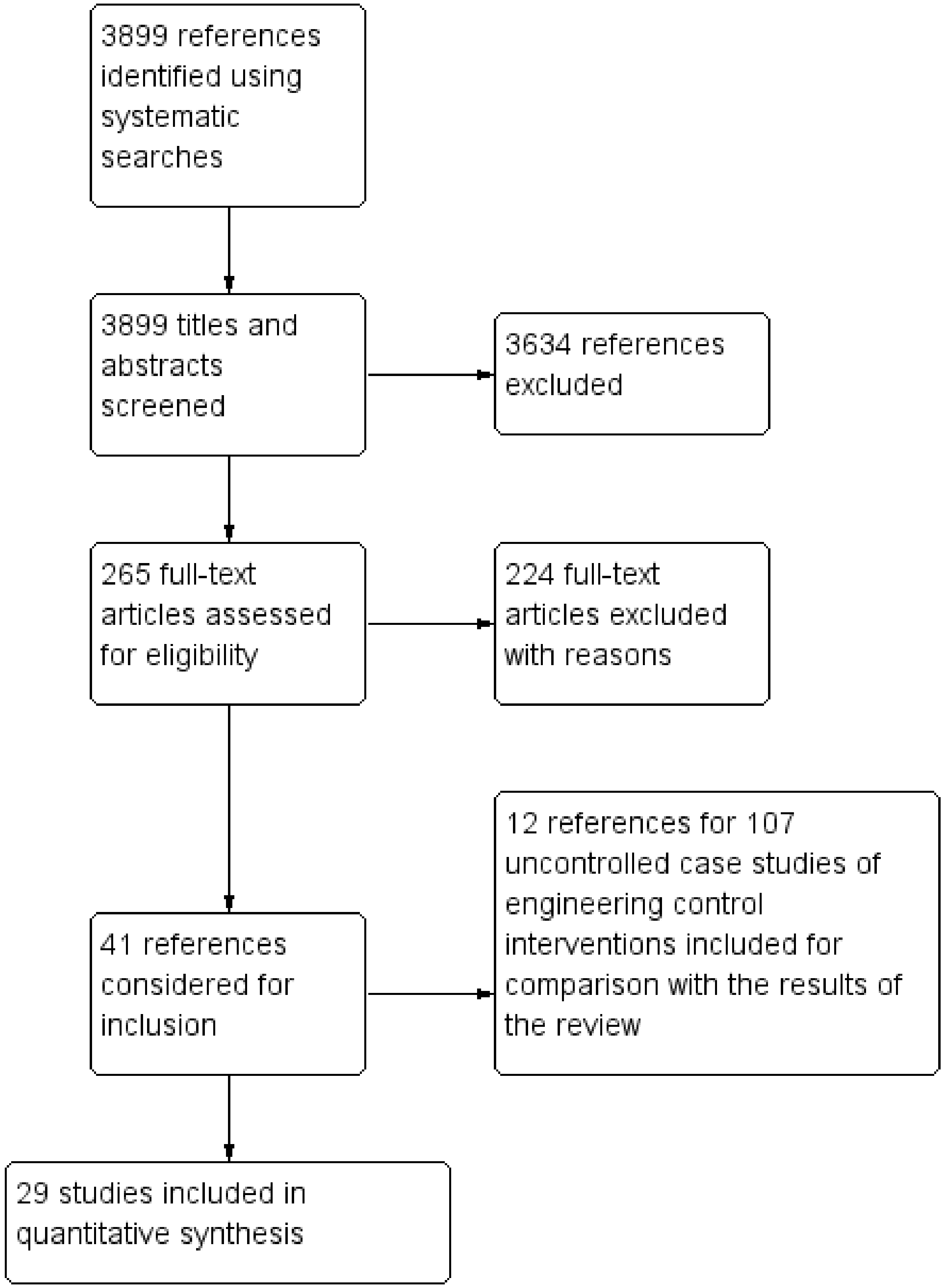
Our search yielded 3899 references in total (1360 in 2009, plus 1129 in 2012, plus 1410 in 2016). The search in 2009 yielded 1198 references from a combined search of MEDLINE and Embase using Ovid, 86 from CINAHL, 76 from CENTRAL and 9 from the Cochrane Work's Trials Register up until 2005. An additional search from 2005 to December 2008 yielded an additional 256 references. The update in January and February 2012 for references from 2009 to 2012 brought 54 new references from PubMed, 299 from Embase, 601 from Web of Science, 168 from NIOSHTIC and 7 references from reference lists of articles. The update in September 2016 was based on two searches, one in 2015 and one in 2016. The combined retrieval for references from 2012 to 2016 yielded 987 references from PubMed and Embase, 385 from Web of Science, and 204 from OSHupdate. We searched CENTRAL and CINAHL for references from 2009 to September 2016 and found 294 references from CENTRAL (excluding reviews) and 263 from CINAHL.

The screening of references for eligibility resulted in 265 studies (104 in 2009, 50 in 2012, 111 in 2016), which we then retrieved in full text.

Following further screening using our eligibility checklist, 29 articles ultimately fulfilled our inclusion criteria. One article described two trials (Park 1991a instructions; Park 1991b protection) and two articles described the same study. This resulted in 29 included studies (21 in 2009, 4 in 2012, and 4 in 2016).

See also Figure 1.

Figure 1. PRISMA Study flow diagram



Included studies

See also the 'Characteristics of included studies' table.

Design

We had considerable difficulty in establishing the types of study design used. In many articles, studies reported technical measurements that would apparently not be prone to bias and would not require a control group or long-term follow-up. Four studies used a randomised design (Berg 2009; Park 1991a instructions; Salmani 2014; Seixas 2011) and one study used a quasi-randomised design with alternation (Royster 1980). Another two studies used an interrupted time-series (ITS) design (Joy 2007; Rabinowitz 2011). All remaining studies used a form of controlled before-after (CBA) design.

To measure the long-term effects of hearing loss prevention, only two studies used a randomised design (Berg 2009; Seixas 2011) and another study used a CBA design but reported data for an ITS analysis, and we used these data for the analysis (Rabinowitz 2011). Seven studies implicitly used an equivalence design in which they tried to prove that the intervention (a hearing loss prevention programme (HLPP)) led to the same amount of hearing loss as in a non-exposed control group (Davies 2008; Gosztonyi 1975; Hager 1982; Lee-Feldstein 1993; Muhr 2006; Muhr 2016; Pell 1973). In another five studies, the authors tried to show that better implementation of a HLPP led to a better outcome. Adera 1993, Adera 2000 and Simpson 1994 compared study companies with companies from a database called ANSI S12.13, which were rated as having a very high-quality HLPP, and Brink 2002 compared workers who wore hearing protection less than 33% of the time to those who wore hearing protection more often. A similar comparison of more versus less use of hearing protection devices was used in Moshammer 2015. Heyer 2011 used a retrospective study design and combined historical data of noise exposure, working tasks and audiometric results of the workforce of three plants. The authors compared the effect on the rate of hearing change during the time individuals were in a well-implemented hearing conservation programme, with the rate observed among individuals who were in less well-implemented programmes, by programme component.

All but three of the long-term equivalence and implementation studies were retrospective by design meaning that the data were already gathered before the study was planned. The first of these three studies reported to be prospective (Pell 1973), whereas the second study (Seixas 2011) collected noise exposure measurement data pre-intervention and at two- and four month follow-up times. The third study (Berg 2009) collected hearing loss data of students enrolled in a HLPP prospectively over a three- and 16-year follow-up and used retrospectively collected data to assess exposure for the 16-year follow-up. Many studies reported only the change, which made it difficult to assess baseline comparability of age and hearing loss.

To measure the immediate effects of hearing protection, studies essentially used before-after measurements in which it was not always clearly stated what the comparison was. In this case, before and after the intervention should be interpreted as 'outside' versus 'inside' the hearing protector (Pääkkönen 1998; Pääkkönen 2001; Park 1991a instructions) or 'before exposure with protection' versus 'after exposure with protection' (Horie 2002; Royster 1980).

For assessing the immediate effect, all studies used a prospective design in which data were gathered after the study had been planned. One study used a Latin square design in which participants were randomised to four different types of hearing protection with and without instructions for use (Park 1991a instructions; Park 1991b protection). Another study randomised participants to the same type of hearing protections either with or without training (Salmani 2014). In five studies the same workers used sequentially different types of hearing protection (Horie 2002; Huttunen 2011; Pääkkönen 1998; Pääkkönen 2001; Royster 1980).

Sample sizes

Although large numbers of workers were examined, this number was reduced substantially in many cases because workers had to be followed over a long period of time in the same noise levels, thus reducing the number of eligible subjects.

The sample size of the first ITS noise exposure study was 142,735 workplaces, measured during 18 years of follow-up, four years post-intervention and 14 years pre-intervention with the intervention implemented in the year 2000 (Joy 2007). The other ITS study included 312 workers followed during nine years from 2000 to 2009 with the year of intervention being 2005 (Rabinowitz 2011).

In the 19 hearing loss evaluation studies, sample sizes ranged from 43 to 22,376 workers, amounting to a total of 84,153 with an average of 4429 participants per study. We adjusted for the cluster effect by reducing the sample size according to the number of clusters and the design effect. After adjustment the sample sizes totaled 55,908 with an average of 2943 participants per study.

Numbers in the eight immediate effect studies ranged from 4 to 150, amounting to a total of 358, with an average of 45 workers per study.

Setting

The legislation evaluation study (Joy 2007) was carried out in coal mines and the administrative control intervention study (Seixas 2011) in construction sites in the USA.

Eight studies evaluated immediate effects (noise attenuation) and three studies evaluated the preventive effect on hearing loss of personal hearing protection devices. One of the immediate studies was carried out in Japan, one in Iran, three in Finland and three in the USA. Four of the immediate effect studies were carried out after 2000, three in the 1990s and one in 1980. All of the hearing loss studies were based on data from the 1980s, two were carried out in Sweden and one in Austria. In one study we found a potential conflict of interest as the company that produced the earplugs that were tested also participated in the study (Royster 1980).

Nine long-term hearing loss evaluation studies were published after 2000, five in the 1990s, one in the 1980s, and two in the 1970s. Since most studies were retrospective, they were based on data gathered in the decade(s) preceding their publication.

Thirteen of the long-term HLPP evaluation studies were carried out in the USA, one in Canada (Davies 2008) and two in Sweden (Muhr 2006; Muhr 2016), which is of importance because of the different weighting used for summarising noise levels over time.

Two older studies were carried out by in-house occupational health professionals (Gosztonyi 1975; Pell 1973) and four by in-house military officials (Adera 1993; Meyer 1993; Muhr 2006; Muhr 2016). They were thus actually financed by the companies that were supposed to benefit from the HLPP. This created, in our view, a potential conflict of interest in the sense that the employers of the authors could potentially benefit from a positive result of their studies.

Participants

The participants in all studies were described as being exposed to noise at work. However, these descriptions were often based on measurement methods that were not clearly described.

Noise-exposed participants worked on construction sites (one study), in mines (one study), in the automobile industry (three studies), in the steel industry (two studies), in an aluminium smelter (one study), in agriculture (one study), in the lumber industry (one study), in an orchestra (one study), at a shipyard (two studies), in the military (four studies), in one unspecified company (three studies) or were gathered from various workplaces (eight studies). One study did not specify the type of industry nor the type of jobs included in the study (Salmani 2014).

In most studies only men were included or there were mostly male workers at the workplaces that were studied.

Interventions

We found one study that evaluated technical noise reduction measures over time based on the change of legislation that forced coal mines to take measures to decrease noise levels (Joy 2007). The new legislation established the primacy of engineering and administrative controls and an Action Level of 85 dB(A), at which enrolment for hearing conservation programmes should be started. The legislation officially came into effect in the year 2000 but many employers had already prepared themselves to address it in 1999. Nevertheless we chose the year 2000 as the intervention year but we also present results for the year 1999. The intervention was supposed to be equally effective for the above ground and underground workplaces. We present the outcomes for both situations.

Another study intended to change workers' behaviour (Seixas 2011). The intervention consisted of two types of information and the distribution of personal noise level indicators. The control group received information at baseline only. It was a one-time information session consisting of two hours of instructions for hearing protection device use and fitting as well as noise control techniques (sound barriers and distance). The three intervention groups each received a different combination of the interventions: both types of information (extensive information), noise level indicator with extensive information, or noise level indicator with one-time information only. The extensive information consisted of a one month long weekly on-site training session focusing on areas of hearing protection device use and noise control. Workers receiving the noise level indicator clipped it to their shoulder or chest. The noise level indicators were implemented for two months and gave a light signal when the noise level exceeded 85 dB(A), 95 dB(A), 105 dB(A) and in addition vibrated at 115 dB(A).

Studies that evaluated hearing protection devices evaluated active noise cancellation devices (Horie 2002; Pääkkönen 2001), special communication earmuffs (Pääkkönen 1998), the effect of fitting instructions (Park 1991a instructions; Salmani 2014), alternative hearing protection (Erlandsson 1980; Huttunen 2011; Nilsson 1980; Park 1991b protection; Royster 1980) or the percentage of working time with hearing protection devices (more versus less use) (Moshammer 2015).

In sixteen studies a hearing surveillance, hearing conservation or HLPP was evaluated as the intervention of interest. We have described the contents of the interventions extensively in Table 3. For example, in one study the intervention consisted of annual audiometry and instruction once but with yearly reminders delivered to the home address and free hearing protection whereas the control group received only audiometry (Berg 2009). In another study the intervention was daily monitoring of at-ear noise exposure with regular feedback from a supervisor in addition to the ongoing mandatory hearing conservation programme (Rabinowitz 2011). In Meyer 1993 the intervention was frequent follow-up for one year after a standard threshold shift (STS) had been found in a person exposed to noise, with the aim of detecting susceptible people with increasing hearing loss. Reynolds 1990a evaluated the effectiveness of a HLPP for workers on 12-hour work shifts.

Outcomes and measures

In one ITS and all but one long-term evaluation study, the authors measured hearing thresholds as an outcome measure for hearing loss. Three studies measured the difference in hearing thresholds with and without hearing protection as the effect measure for noise attenuation. One ITS and three short-term evaluation studies measured sound pressure levels as the outcome measure for noise exposure.

In some studies the authors also reported the percentage of workers whose hearing got worse or the percentage of workers whose hearing got better. Others used the increase in standard deviations of hearing levels to show the effect of the programme or summarised audiometric results in low and high frequencies. However we did not use these percentages of workers nor increases in standard deviation because they did not add anything to the outcomes that we already included.

Authors used varying definitions of hearing loss. In seven studies they used STS, defined as an increase in hearing threshold of at least 10 dB averaged over 2 kHz, 3 kHz or 4 kHz compared to a baseline measurement or the previous measurement (Adera 1993; Adera 2000; Berg 2009; Davies 2008; Lee-Feldstein 1993; Meyer 1993; Simpson 1994). In one study STS was defined as an increase of more than 10 dB in any frequency. In another study STS was defined as an increase of 15 dB in one or both ears at one or more frequencies (0.25 kHz to 8 kHz) between the first and second audiometry (Muhr 2016). In other studies hearing loss was measured as the average over the frequencies 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz and 6 kHz. One study used the frequencies 3 kHz, 4 kHz and 6 kHz (Heyer 2011). Two studies also included the frequency of 8 kHz (Muhr 2006; Park 1991a instructions). One study used the rate of hearing loss in the binaural average hearing level at 2 kHz, 3 kHz, and 4 kHz (Rabinowitz 2011). One study did not clearly define hearing loss but used the baseline hearing minus age-related hearing loss at the last observation as the outcome measurement (Moshammer 2015).

The authors of two studies measured temporary threshold shifts (TTS) as the effect measure of noise attenuation (difference in hearing levels before and after exposure to noise) (Horie 2002; Royster 1980). Four other studies used REAT (the differences in hearing thresholds with and without hearing protection) (Huttunen 2011; Park 1991a instructions; Park 1991b protection; Salmani 2014). Two studies reported the mean (SD) noise attenuation over the frequencies 0.125 kHz to 8 kHz (Huttunen 2011) or over the frequencies 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and

8 kHz (Salmani 2014). In Salmani 2014 the SDs reported were unrealistically small and did not match with the box-plots in the figure. We contacted the study authors but they did not reply. We then extracted the interquartile ranges from the box-plots and multiplied them by 1.35 to obtain a more realistic estimate of the SDs, according to the advice in the *Cochrane Handbook for Systematic Reviews of Interventions* (Deeks 2011). One study reported the noise attenuation per frequency (0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz) and we calculated the mean (SD) noise attenuation over all measured frequencies (Park 1991a instructions).

In one study, authors used personal noise dosimeters with a 3 dB exchange rate, 80 dB(A) threshold level, 85 dB(A) criterion level, and slow response to measure the full-shift Equivalent Continuous Sound Level (L_{eq}) (Seixas 2011). In one study authors used the eight-hour time-weighted average (TWA) as a measure for noise exposure transformed to a permissible exposure level (PEL) dose (Joy 2007). The PEL dose transforms the noise levels to an equivalent of a 90 dB(A) noise exposure by using an exchange rate of 5 dB for doubling the dose. This translates 90 dB(A) into a 100% PEL dose, and for example 85 dB(A) into 50% and 95 dB(A) into 150% PEL dose. Two studies used MIRE (microphone in real ear) to measure the difference in noise levels inside and outside the hearing protectors (Pääkkönen 1998; Pääkkönen 2001).

Case studies

In this 2017 update, we collected 12 additional references that reported effects of engineering control interventions of 107 cases (Azman 2012; Caillet 2012; Cockrell 2015; Golmohammadi 2014; HSE 2013; HSE 2015; Küpper 2013; Maling 2016; Morata 2015; Pan 2016; Thompson 2015; Wilson 2016). Table 4 provides an overview of study characteristics. We have presented the results under the heading Effects of interventions and in additional tables (Table 5; Table 6; Table 7; Table 8; Table 9; Table 10; Table 11).

For most cases the country location of the intervention was not reported (78 of 107 cases). Eighteen cases were implemented and evaluated in the USA, three in Australia, three in Iran and one in France.

Study authors reported funding sources for only seven out of 107 cases. Funds came from ALCOA, Strategic Marine, and SVT Engineering Consultants (no grant numbers reported) (Pan 2016), Hamadan University (Golmohammadi 2014), and Eurocopter Ltd (Caillet 2012). Study authors did not report conflict of interest, except for three cases where they declared no conflict of interest (Golmohammadi 2014). Nevertheless study authors reported for 14 cases that the outcome was evaluated by an acoustical consultant or an employee at the firm where the intervention was evaluated and a conflict of interest was apparent (Caillet 2012; Maling 2016; Wilson 2016).

For most cases (n = 87) the effect of the intervention was measured as change in absolute noise levels. For other cases the personal noise exposure for workers was measured, either as TWA (12) or as PEL exposure dose (OSHA 2, MSHA PEL 10, NIOSH 2, other 1).

Study authors reported information on the collection of the noise data only for 16 of the cases and on the measurement device settings only for eight of the cases. Study authors reported that noise data for those eight cases was collected A-weighted with a slow response with four of those cases using a 5 dB exchange rate.

Most cases evaluated design changes (n = 41), followed by installing damping material and silencers (n = 20), purchasing new equipment (n = 14), the use of enclosures (n = 12), acoustic panels and curtains (n = 10), and maintenance only (n = 4).

None of the study authors reported the time of the intervention. Only for a few case studies authors reported the time of follow up (7 of 107 cases). Five cases had an immediate follow-up (Azman 2012; Caillet 2012; Pan 2016) and two cases a short-term follow-up, with one study collecting data for one year (Küpper 2013) and another study reporting that the device was used to drill a total of 253 holes (Azman 2012).

Interventions were mostly evaluated in the manufacturing industry, followed by mining, steel, drilling, helicopter, textile, and paper-shredding industry. Types of jobs, when reported, included operating machines and driving vehicles.

Excluded studies

See also the 'Characteristics of excluded studies' table.

We excluded one study (Pääkkönen 2005) because most of the data had already been reported in another article (Pääkkönen 1998) and the remainder did not meet the inclusion criteria. Most studies were excluded because they were either not empirical studies or because the authors did not use a control group. We excluded one controlled study on noise reduction in an MRI scanner because only the patients were exposed to the noise and not the healthcare workers (Mechfske 2002). In another study the participants were excluded if they were routinely exposed to occupational noise (Byrne 2011). Other identified studies of noise reduction in occupational settings were either case studies (Jelinic 2005; Knothe 1999; Pingle 2006; Scannell 1998; Stone 1971) or had a cross-sectional design without pre-intervention measurements (Chou 2009), consisted of descriptions of a noise abatement strategy but without a control group (as for example Groothoff 1999), or recommended noise reductions without evaluating them (such as Bowes 1990; Golmohammadi 2010; Kardous 2003). For long-term hearing evaluation we excluded studies that used data from existing databases as control group material (Brühl 1994).

We excluded hearing protection studies that evaluated immediate effects on volunteers or that were not field studies such as Franks 2000; Merry 1992; Toivonen 2002; Williams 2004. We also excluded studies that evaluated the immediate effects of hearing protection but did not use the same workers for the evaluation (Giardino 1996; Neitzel 2005; Reynolds 1990b).

Risk of bias in included studies

The overview of risk of bias, based on the Downs and Black checklist (Downs 1998), is shown in Figure 2 and Figure 3.

Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies. Please note that the blank space corresponds to the studies that have an ITS study design.

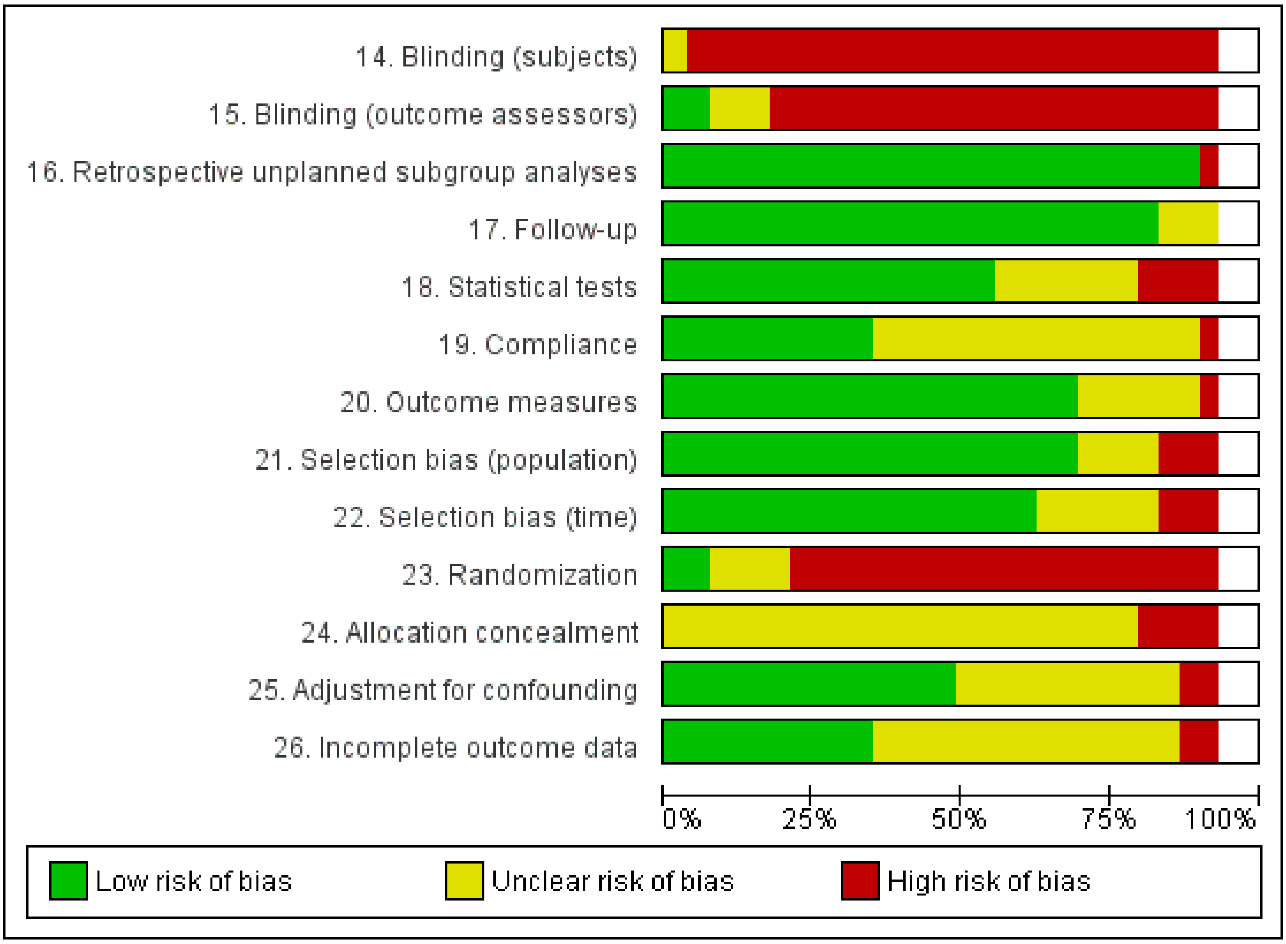


Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Please note that the blank spaces correspond to the studies that have an ITS study design.

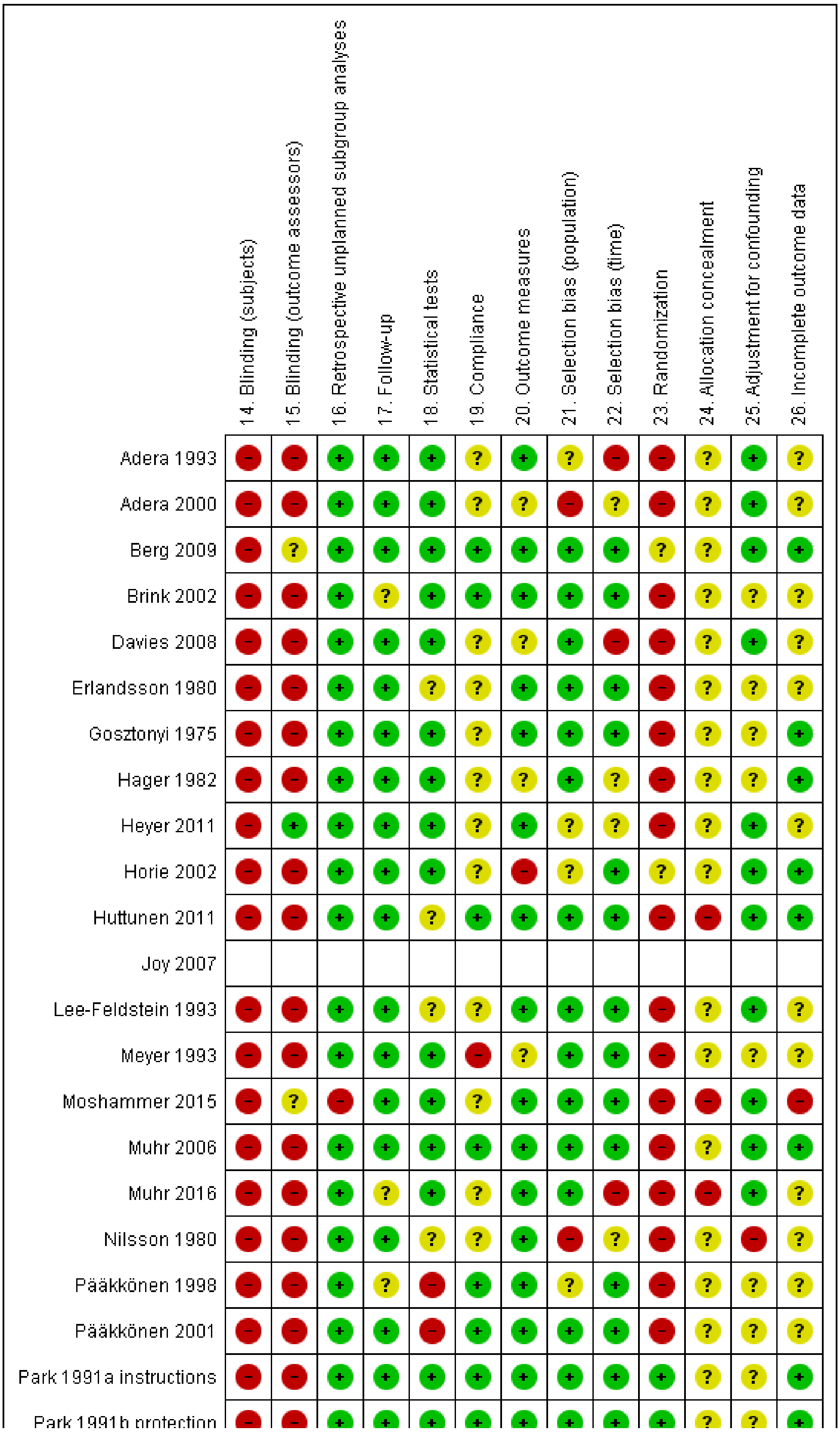
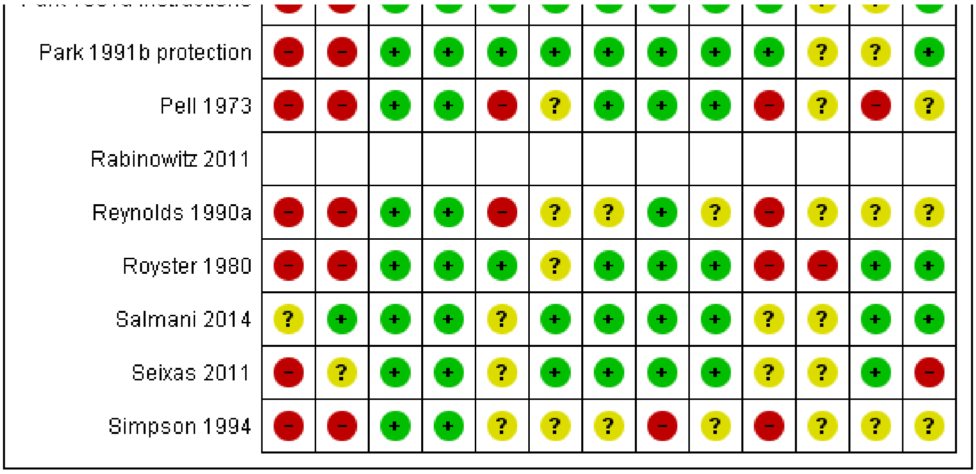


Figure 3. (Continued)



Allocation

Four studies randomised participants to intervention and control groups (Berg 2009; Park 1991a instructions; Salmani 2014; Seixas 2011). Of these only one study properly described the randomisation process (Park 1991a instructions). Salmani 2014 indicated using random number tables but not how these were used and the authors did not provide an explanation. None of the included studies reported allocation concealment.

Confounding and selection bias

For studies measuring hearing loss, the age and hearing loss of the intervention and control group participants should be comparable at baseline. Comparability of both age and hearing loss at baseline could be ascertained in six studies (Davies 2008; Heyer 2011; Lee-Feldstein 1993; Moshammer 2015; Muhr 2006; Muhr 2016), age only in two studies (Berg 2009; Gosztonyi 1975) and hearing loss only in one study (Pell 1973), and neither age nor hearing loss in one study (Hager 1982). In Pell 1973 there was a difference of 10 years between the protected and the non-exposed group, artificially increasing the risk in the non-exposed group. In Hager 1982 there was a 7.8 dB difference in hearing level at entry to the study between the protected and non-exposed group, thus artificially increasing the risk in the protected group. In Lee-Feldstein 1993 and Pell 1973 the non-exposed group still had considerable exposure and could thus have confounded an effect of the intervention programme. One study recruited participants from different time periods for control and intervention groups (Muhr 2016). Thus, according to our judgment, only three long-term evaluation studies had a low risk of confounding and selection bias.

Blinding

Only two studies reported blinded outcome assessment leading to our assessment of a low risk of bias (Heyer 2011; Salmani 2014).

Incomplete outcome data

Most study authors did not report the loss of follow-up or had a loss of more than 20%. Only nine studies had a low risk of bias in this domain (Berg 2009; Gosztonyi 1975; Hager 1982; Huttunen 2011; Muhr 2006; Park 1991a instructions; Park 1991b protection; Royster 1980; Salmani 2014).

Selective reporting

We did not formally test for reporting bias. However as many studies were funded or carried out by professionals that were part of the company where the intervention took place it can be assumed that they had an interest in reporting favourable results. We considered it conceivable that the results of the studies were biased towards a positive outcome. Horie 2002 and Royster 1980 did not provide SDs and were thus at risk for outcome reporting bias.

Other potential sources of bias

One of the two ITS studies met three of the seven risk of bias criteria, which means that there was considerable risk of bias in the study (Joy 2007). The most serious risk of bias was that the intervention and the outcome measurements were not independent. The number of inspections on which the noise measurement data are based increased after the intervention and might also have included workplaces with lower noise levels that were not previously included (Table 12). The other ITS study met five of the seven criteria and thus we judged it to have a low risk of bias overall (Rabinowitz 2011).

Overall risk of bias per study

Most studies scored poorly on all aspects of the checklist. Six studies (four well-designed CBA studies and two well-designed RCTs) achieved more than 50% of the maximum score of 13 on the internal validity scale of the checklist and we considered them to be at low risk of bias overall (Berg 2009; Horie 2002; Huttunen 2011; Muhr 2006; Park 1991a instructions; Salmani 2014).

Effects of interventions

See: **Summary of findings for the main comparison** Stricter legislation for noise exposure; **Summary of findings 2** Earplugs with instruction versus without instruction (noise exposure); **Summary of findings 3** Training plus exposure information compared to training (noise exposure); **Summary of findings 4** Earmuffs versus earplugs (hearing loss); **Summary of findings 5** Hearing loss prevention programme compared to audiometric testing (hearing loss); **Summary of findings 6** Hearing loss prevention programme (HLPP) with exposure information compared to HLPP without exposure information (hearing loss); **Summary of findings 7** Well-implemented hearing loss prevention programme (HLPP) compared to less well-implemented HLPP (hearing loss); **Summary of findings 8** Hearing loss prevention programme (HLPP) compared to non-exposed workers (hearing loss)

1 Effect on noise exposure

1.1 Immediate and short-term follow-up (noise reduction)

1.1.1 Engineering controls following legislation

Legislation in the mining industry (ITS)

We found one study that indirectly measured the effect of legislation on the decrease of noise levels. We assumed that the effect was mediated by better engineering controls. The content of legislation was directed at better compliance with the law with primacy for engineering and administrative controls.

Outcome: noise exposure (dB)

In the Joy 2007 study, in which legislation was introduced to reduce noise levels in the mining industry, the immediate effect of introducing changes in surface mining locations in the year 2000 was a 27.7 percentage points reduction in the median noise dose level (95% confidence interval (CI) −36.10 to −19.30 percentage points) compared to that predicted by extrapolation of the pre-intervention slope (Analysis 1.1). The noise dose was measured as a permissible exposure level (PEL) dose percentage. Given a predicted post-intervention level of 58.7 PEL dose and a measured level of 31 PEL dose, this means a change from 86.1 dB(A) to 81.6 dB(A) or a 4.5 dB(A) decrease.

For the underground mining noise levels the immediate effect was −16.8 noise dose percentage points (95% CI −23.5 to −10.1 percentage points). Given a predicted post-intervention level of 79.8 PEL dose and a measured level of 63 PEL dose, this means a change from 88.3 dB(A) to 86.7 dB(A).

Taking 1999 as the year in which the change of legislation was implemented, the immediate effect is smaller but the change of slope larger and significant. We rated the overall quality of evidence as very low (see Summary of findings for the main comparison).

1.1.2 Personal hearing protection devices

a) Hearing protection devices with instructions versus without instructions

Earmuffs with instruction versus without instruction (RCT, immediate)

Outcome: noise attenuation (REAT, dB(A) at one frequency)

The use of earmuffs with instructions compared to no instructions increased noise attenuation, measured as REAT, at 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz but the effect was non-significant (Park 1991a instructions, Analysis 2.1; Analysis 2.2; Analysis 2.3; Analysis 2.4; Analysis 2.5; Analysis 2.6; Analysis 2.7). Noise attenuation at 4 kHz increased slightly but non-significantly after instruction with 0.83 dB (95% CI −3.28 dB to 4.95 dB) for two different types of earmuffs (Analysis 2.5). We rated the quality of evidence as moderate.

Earplugs with instruction versus without instruction (RCT, immediate)

Outcome: noise attenuation (REAT, dB(A) at one frequency)

The use of earplugs with instructions compared to no instructions significantly increased noise attenuation at 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz, measured as REAT (Park 1991a instructions; Analysis 3.1; Analysis 3.2; Analysis 3.3; Analysis 3.4; Analysis 3.5; Analysis 3.6; Analysis 3.7). Noise attenuation at 4 kHz significantly increased with 7.97 dB (95% CI 3.60 dB to 12.34 dB) for two different types of earplugs (Analysis 3.5). We rated the quality of evidence as moderate.

Outcome: noise attenuation (REAT, mean dB(A) over frequencies 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 7 kHz, and 8 kHz)

The use of earplugs with instructions compared to no instructions significantly increased the mean noise attenuation over 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 7 kHz, and 8 kHz by 8.59 dB (95% CI 6.92 to 10.25; I^2 = 0%) (Park 1991a instructions; Salmani 2014; Analysis 3.8).

Earplugs with instructions versus earplugs without instructions but a higher noise reduction rate

Outcome: noise attenuation (REAT, mean dB(A) over frequencies 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 7 kHz, and 8 kHz)

The use of earplugs with instructions compared to earplugs with a higher noise reduction rate but without instructions significantly increased the mean noise attenuation over 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 7 kHz, and 8 kHz by 2.62 dB (95% CI 1.75 to 3.49) (Salmani 2014; Analysis 4.1).

b) Hearing protection versus alternative hearing protection

Hearing protection with noise cancelling devices versus hearing protection without noise cancelling devices (CBA, immediate)

Outcome: noise attenuation (MIRE, dB(A))

The installation of active noise cancellation in the same hearing protector increased the total noise reduction (measured with MIRE) from 17 dB(A) to 25 dB(A) in one helmet and from 20 dB(A) to 24 dB(A) in another helmet (Pääkkönen 2001, Analysis 5.1).

Earplugs with higher noise reduction rates versus earplugs with lower noise reduction rates (CBA, immediate)

Outcome: mean noise attenuation (REAT, dB over frequencies 0.125 kHz to 8 kHz)

Earplugs with a higher noise reduction rate compared to earplugs with a lower noise reduction rate increased noise attenuation by 3.1 dB(A) (95% CI 1.12 to 5.08) (Huttunen 2011; Analysis 6.1).

Noise attenuation of various hearing protection devices (RCT, CBA)

Outcome: noise attenuation (dB)

In the RCT and with fitting instructions, the EAR plug had a 17 dB higher noise attenuation than the Bilsom muff at 0.5 kHz and 16 dB at 1 kHz, and outperformed the other plug and muff at all other frequencies (Park 1991b protection).

For peak noise, the noise attenuation ranged between 22 dB (SD 14) and 27 dB (SD 16) for six different types of hearing protectors but none of the differences were significant (Pääkkönen 1998, Analysis 7.1).

1.1.3 Hearing loss prevention programmes (HLPP)

Hearing loss prevention training with noise level indicators versus training only (RCT, four-month follow-up)

Outcome: noise level (L_{eq} dB(A))

In Seixas 2011, we compared the change in noise level of two intervention groups to one control group. The comparison was basic information plus extensive information in so called tool-box sessions plus personal noise-level indicators or basic information plus personal noise level indicators versus basic information only. We entered the two interventions as subgroups in one comparison. Noise level indicators with or without information did not show a significant effect in lowering the sound pressure level compared to the group receiving information only. At two months, the noise level decreased 0.32 dB more in the control group (95% CI −2.44, 3.08) but at four months' follow-up the noise levels in the intervention group decreased 0.14 dB more than in the control group (95% CI −2.66 to 2.38) but neither were statistically significant (Analysis 8.1; Analysis 8.2).

Extensive information versus information only (RCT, four-month follow-up)

Outcome: noise level (L_{eq} dB(A))

In the same study (Seixas 2011), noise levels of workers who received additional extensive information in four tool-box sessions were compared to those of workers who received one baseline information session only but there were no significant differences. The noise level decreased 1.7 dB more in the information-only control group at two months (95% CI −1.24 to 4.64) but 0.3 dB less at four months (95% CI −2.31 to 2.91) compared to the intervention group (Analysis 9.1; Analysis 9.2).

1.2 Long-term follow-up (noise reduction)

1.2.1 Engineering controls, legislation

Legislation in the mining industry (ITS)

The same study that measured immediate effects of legislation change also measured the impact of the intervention on the trend over time.

Outcome: noise exposure (dB)

In the Joy 2007 study, in which legislation was introduced to reduce noise levels in the mining industry, the long-term effect in the change of trend in time as measured by the change in slope before and after the intervention was −2.1 PEL dose percentage points per year but this was not statistically significant (95% CI −4.9 to 0.7 points) (Analysis 1.2). For the underground mining noise levels the long-term effect was −3.8 PEL dose points per year (95% CI −6.2 to −1.4 dB). Taking 1999 as the year in which the change of legislation was implemented, the immediate effect is smaller but the change of slope larger and significant. We rated the overall quality of evidence as very low (see Summary of findings for the main comparison).

2 Effect on hearing loss

2.1 Short-term follow-up (temporary hearing loss)

2.1.1 Personal hearing protection devices

a) Hearing protection versus alternative hearing protection

Hearing protection with noise cancelling devices versus hearing protection without noise cancelling devices (CBA)

Outcome: TTS (dB at single frequencies 1 kHz, 2 kHz, 4 kHz, 6 kHz and 8 kHz)

Protectors with noise cancellation compared to protectors without noise cancellation resulted in less temporary hearing loss at the frequencies 1 kHz, 2 kHz, 4 kHz, 6 kHz and 8 kHz (Horie 2002, Analysis 5.2; Analysis 5.3; Analysis 5.4; Analysis 5.5; Analysis 5.6). The average temporary hearing loss at 4 kHz was 11.2 dB for conventional protectors without cancellation devices and 5.8 dB for different protectors with noise cancellation (Analysis 5.4). The study did not provide SDs and the statistical significance is unclear.

Earplug versus alternative earplug (RCT, CBA)

Outcome: TTS (dB at single frequencies 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz and 6 kHz)

In one study, the EAR plug users had less TTS than those wearing another plug (V-51-R) which, according to the study authors, was significant but we could not check it due to missing standard deviations (Royster 1980, Analysis 10.1; Analysis 10.2; Analysis 10.3; Analysis 10.4; Analysis 10.5; Analysis 10.6).

All hearing protectors performed worse than the official attenuation ratings provided by the manufacturers.

2.2 Long-term follow-up (permanent hearing loss)

2.2.1 Personal hearing protection devices

a) Hearing protection versus alternative hearing protection

Earmuffs versus earplugs (CBA, three-year follow-up)

Outcome: standard threshold shift (STS)

Studies divided workers into high and low noise exposure groups. We did not combine study results in a meta-analysis because of considerable inconsistency in the results due to one study. Most studies show no difference in preventing permanent hearing loss between earmuffs and earplugs (Erlandsson 1980; Nilsson 1980; Analysis 11.1). We rated the overall quality of evidence as very low.

b) More versus less hearing protection device use

Outcome: hearing loss (dB) (CBA, more than two-year follow-up)

In one study the authors reported that an increase in the use of hearing protection devices at work in noisy areas from 80% to 90% of the time showed a decrease in hearing loss of 3 dB to 5 dB (Moshammer 2015). The study authors also reported a regression coefficient of −5.342 (95% CI −9.116 to −1.568) from a different and unpublished analysis, which they calculated to be a 0.2 dB to 1.6 dB reduction in hearing loss (additional email conversation). We were not able to recalculate the reported results ourselves from the available data. The difference between the two analyses is unclear.

2.2.2 Hearing Loss Prevention Programmes (HLPPs)

a) Components of HLPPs

HLPP versus audiometric testing only (RCT, more than five-year follow-up)

Outcome: standard threshold shift (STS)

Berg 2009 calculated the likelihood of developing a STS. The three-year and 16-year follow-up showed no difference between intervention and control group with an odds ratio (OR) of 0.85 (95% CI 0.29 to 2.44) after three years' follow-up and 0.94 (95% CI 0.46 to 1.91) after 16 years' follow-up (Analysis 12.1, Summary of findings 5).

HLPP with daily noise exposure monitoring and feedback versus audiometric testing only (ITS, five-year follow-up)

Outcome: change in mean hearing threshold (dB) at 2 kHz, 3 kHz, and 4 kHz

In Rabinowitz 2011 there was no effect of the programme immediately after introduction (Analysis 13.1). The trend over time showed a significant yearly decrease of the rate of hearing loss, measured as the mean hearing threshold at 2 kHz, 3 kHz, and 4 kHz controlled for differences in age, gender, and baseline hearing, of −1.57 dB (95% CI −2.37 to −0.77) in the intervention group (Analysis 13.2). Similar but smaller improvements over time also occurred in the control group (−0.23 dB per year with 95% CI −0.39 to −0.07). The trend of the difference between the intervention and control group remained significant with −1.35 dB per year for the intervention group (95% CI −2.09 to −0.61).

The study authors could also control for the initial rate of hearing loss as a potential confounder. The results were similar to the previous comparison but the trend over time for the intervention group minus the control group was no longer significant (−0.82 with 95% CI −1.86 to 0.22) (Analysis 13.2).

The study authors also analysed the data as the mean yearly change in rate of hearing loss before and after the introduction of the intervention but their results were similar to our findings.

Follow-up examinations after STS versus no follow-up in one year (CBA, one-year follow-up)

Outcome: standard threshold shift (STS)

In one study the OR for sustaining a STS was 0.87 (95% CI 0.56 to 1.36) after having a year of follow-up examinations versus no examinations (Meyer 1993) (Analysis 14.1).

b) HLPPs compared to other HLPPs

Well-implemented HLPP versus less well-implemented HLPP (CBA, one-year follow-up)

Outcome: standard threshold shift (STS)

In Simpson 1994, employees in companies with a well-implemented HLPP ran a lower risk of STS than those in companies with less well-implemented programmes, with a relative risk of 0.36, which was not significant (95% CI 0.09 to 1.42) (Analysis 15.1).

Well-implemented HLPP versus less well-implemented HLPP (CBA, more than five-year follow-up)

Outcome: standard threshold shift (STS at 4 kHz)

In a meta-analysis of three studies we estimated the effect as the OR of sustaining a STS during the follow-up period in workers in companies with a well-implemented HLPP versus those in companies with less well-implemented programmes (Adera 1993; Adera 2000; Brink 2002). The OR for the risk of sustaining a STS was 0.40 (95% CI 0.23 to 0.69) (Analysis 16.1) for workers covered by well-implemented programmes. The results were statistically heterogeneous, with an I^2 of 66%. We rated the overall quality of evidence as very low (Summary of findings 7).

Outcome: changes in binaural hearing thresholds at 3 kHz, 4 kHz, and 6 kHz

In Heyer 2011, only one out of three quality aspects of the HLPP was associated with hearing loss. We could not include the data in a meta-analysis because they were reported as the results of a regression analysis. Years with more than 50% use of hearing protection devices (better quality) caused less hearing loss than years in a HLPP with less than 50% compliance of using hearing protection devices, for men with a beta of −0.31 dB(A) (95% CI −0.37 to −0.24)) and for women −0.14 dB(A) (95% CI −0.27 to −0.01). The other quality aspect, noise monitoring (men: beta −0.13 dB(A) (95% CI −0.20 to −0.07); women: beta −0.15 dB(A) 95% CI −0.44 to 0.14) showed varying results but was, according to the study authors likely to be confounded by plant. The quality aspects of audiometric testing (men: beta 0.13 dB(A) (95% CI 0.06 to 0.19); women: beta 0.33 dB(A) 95% CI 0.19 to 0.47) and worker training (men: beta −0.04 dB(A) (95% CI −0.10 to 0.02); women: beta −0.05 dB(A) 95% CI −0.18 to 0.07), did not show a significant association with hearing loss.

c) HLPPs compared to less or no exposure

HLPP for 12-hour shifts versus eight-hour shifts (CBA, one-year follow-up)

Outcome: change in hearing level (dB) at 4 kHz

In one study the mean difference in change in hearing level over one year at 4 kHz for the same HLPP between the 12-hour shift and 8-hour shift was −0.68 dB (95% CI -1.85 to 0.49) (Reynolds 1990a) (Analysis 17.1).

HLPP versus non-exposed workers (CBA, one-year follow-up)

Outcome: standard threshold shifts (STS), per 100 person-years

In Muhr 2006 the rate ratio per 100 person-years of sustaining a STS in the total cohort of recruits was 3.38 (95% CI 1.23 to 9.32) compared to recruits waiting for their training and not exposed. Meta-analysis results for the subgroups have to be interpreted with caution as the control group in the analysis was split into three parts and the total number of events was small (n = 4) (Analysis 18.1). Results show that the risk of sustaining a STS compared to non-exposed recruits increased for exposed recruits with the level of exposure from low to high. Separate calculations of the rate ratio for low, medium, and high exposed recruits versus all controls show a rate ratio of 1.55 (95% CI 0.49 to 4.87), 2.12 (95% CI 0.69 to 6.5), and 7.04 (95% CI 2.5 to 19.8) (Table 1).

In Muhr 2016 the rate ratio per 100 person-years of sustaining a STS in a cohort of high exposed recruits (artillery and armoured vehicle crew members) compared to recruits waiting for their training did not show a difference between the exposed enrolled in the HLPP and the unexposed (RR 1.00, 95% CI 0.48 to 2.11) (Analysis 19.1).

HLPP or hearing protection versus non-exposed workers (CBA, more than five-year follow-up)

Outcome: change in hearing levels (dB) at 4 kHz

In the meta-analysis of four studies the summary effect size estimate was 0.05 (95% CI −0.05 to 0.16) (Analysis 20.1). When calculated back to a difference in mean changes in hearing level at 4 kHz the result was 0.53 dB (95% CI −0.53 to 1.68) (Gosztonyi 1975; Hager 1982; Lee-Feldstein 1993; Pell 1973). The results were statistically homogeneous.

We performed a sensitivity analysis by leaving out the Pell 1973 study because of the 10-year age difference between the intervention and the non-exposed group, which could explain a difference of 7 dB hearing thresholds (calculated based on ISO 1990). This yielded an effect size of 0.17 (95% CI −0.06 to 0.40) (Analysis 21.1). When calculated back to a difference in mean changes in hearing level at 4 kHz, this resulted in 1.8 dB (95% CI −0.6 to 4.2).

These results indicate that the workers in a HLPP have equivalent hearing thresholds to the non-exposed workers. However, the 95% CI includes the possibility of a hearing loss as great as 4.2 dB. This threshold is equivalent to thresholds resulting from five years of exposure to 85 dB(A). Consequently these results do not rule out the risk of hearing loss in protected workers.

Outcome: time to a standard threshold shift (STS)

Davies 2008 measured the time to a STS and compared the hazard ratio (HR) to a non-exposed group with a result of 2.1 (95% CI 1.26 to 3.49) for workers with exposure of 80 to 85 dB-years. The HR gradually increased to 6.6 (95% CI 5.56 to 7.84) for workers with an exposure of more than 100 dB-years. Combined in the meta-analysis, this yielded a HR of 3.78 (95% CI 2.69 to 5.31) (Analysis 20.2).

We rated the overall quality of evidence as very low (Summary of findings 8).

3. Effects from uncontrolled before after case studies of engineering control interventions

New equipment

A reduction in noise levels with new equipment was reported for fourteen cases.

Outcome: personal noise exposure (L_{eq} eight hours dB(A))

One study reported a decrease in personal daily noise exposure at work based on a case of renovating helicopters. The use of helicopters for rescue operations with advanced technology decreases daily personal noise exposure by 10.51 dB(A) (95% CI 15.45 to 5.57 dB(A), L_{eq} 8 hours) compared to helicopters without this technology (Küpper 2013; Table 1; Table 5).

Outcome: noise level (dB(A))

Study authors reported for the other thirteen cases a mean noise reduction with new equipment of 19.7 dB(A) (HSE 2013; Maling 2016; Morata 2015; Table 5).

Acoustic panels and curtains

Outcome: noise level (dB(A))

In nine cases of application of panels and curtains, study authors reported a mean reduction in noise levels of 11.1 dB (Golmohammadi 2014; HSE 2013; Morata 2015; Table 6).

Damping material and silencers

Outcome: personal noise exposure (eight-hour TWA dB)

In two cases, damping material and application of silencers reduced the personal noise exposure of workers by 5.5 dB (Thompson 2015; Wilson 2016; Table 7).

Outcome: Mine Safety and Health Administration (MSHA) PEL dose (%)

In three cases the effect was measured as exposure dose (MSHA PEL) and the intervention reduced the dose on average by 60 percentage points.

Outcome: noise level (dB(A))

In another 15 cases, damping material and silencers reduced noise on average by 7 dB (Caillet 2012, HSE 2013; Maling 2016; Morata 2015; Wilson 2016; Table 7).

Design changes

Outcome: personal noise exposure (eight-hour TWA dB)

Design changes led to a mean decrease in the TWA noise exposure for workers of 3.4 dB in nine cases (Azman 2012; Cockrell 2015; Maling 2016; Thompson 2015; Table 8).

Outcome: Occupational Safety and Health Administration (OSHA) PEL dose (%)

Design changes reduced the noise OSHA PEL dose by 39.5 percentage points in two cases (Cockrell 2015; Table 5).

Outcome: MSHA PEL dose (%)

The design changes decreased MSHA PEL noise dose by 90.1 percentage points in seven cases (Azman 2012; Morata 2015; Thompson 2015; Table 8).

Outcome: noise level (dB(A))

In another 31 cases, authors reported a mean decrease in noise levels of 9.6 dB(A) (HSE 2013; HSE 2015; Maling 2016; Morata 2015; Pan 2016; Thompson 2015; Wilson 2016).

Enclosure

Outcome: noise level (dB(A))

Studies reported a mean noise level reduction of 11.8 dB in 12 cases (HSE 2013; HSE 2015; Maling 2016; Morata 2015; Table 9).

Maintenance

Outcome: noise level (dB(A))

A mean noise level reduction of 3 dB was reported in four cases studies (HSE 2013; Table 10).

Segregation

Outcome: noise level (dB(A))

Studies reported a mean noise level reduction of 17.1 dB in five cases (HSE 2013; Table 11).

DISCUSSION

Summary of main results

Effects on noise exposure

We found 12 studies describing 107 cases of engineering interventions to reduce noise exposures but we could not draw conclusions about the long-term effects due to the lack of controls and long-term follow-up. There was very low-quality evidence from one study showing that legislation can probably induce technical improvements in the working environment that lead to a relevant reduction in noise exposure levels.

For hearing protection we found an average noise reduction of approximately 20 dB with variation among brands. Noise attenuations achieved under field conditions, however, are lower than indicated ratings provided by the manufacturers. Noise cancellation devices provide some additional noise attenuation in the low frequencies. For peak noise, there were no significant differences in the noise attenuation of several types of hearing protection. There was moderate-quality evidence that instructions for inserting earplugs into the ear canal have a considerable effect on the noise attenuation of the devices with a 8.6 dB (95% CI 6.9 to 10.3) higher protection averaged across frequencies.

Providing feedback on daily noise exposure or providing on-site training sessions on noise reduction behaviour did not lead to lower noise-exposure levels in one cluster RCT.

Effects on hearing loss

The long-term evaluation of the effect of earmuffs versus earplugs on hearing loss showed that, in high noise levels, earmuffs might perform better than earplugs but in low noise levels the effects were better for plugs (very low-quality evidence).

One cluster-RCT did not find an effect of an extensive HLPP in agricultural students at three- or 16-year follow-up (moderate-quality evidence).

Very low-quality evidence of long-term evaluation studies of components of HLPPs showed that the use of hearing protection devices in a well-implemented HLPP was associated with less hearing loss. This could not be shown for other elements such as worker training, audiometry alone or noise monitoring by very low- and moderate-quality evidence. More individual information on daily noise exposure as part of a HLPP showed favourable but non-significant effects on hearing loss in one study.

There was also very low-quality evidence that, compared to non-exposed workers in long-term follow-up, average HLPPs do not reduce the risk of hearing loss to below a level at least equivalent to that of workers who are exposed to 85 dB(A). We were able to combine some studies in a meta-analysis and found a hearing loss at 4 kHz of 0.5 dB with an upper confidence limit of 1.7 dB for studies with a five-year follow-up. After sensitivity analysis hearing loss was 1.8 dB with an upper limit of 4.2 dB. To be able to asses whether HLPPs are as good as not being exposed to noise we had to make an assumption about the minimal clinically relevant hearing loss. For this we took the hearing loss that is caused by exposure to 85 dB(A) as the minimum amount of damage that should be avoided by protection. Based on ISO 1990 we calculated that the amount of hearing loss after five years of exposure to 85 dB(A) for the median, 10th and 90th percentile would be 4.2 dB, 2.1 dB and 6.1 dB, respectively. Based on Hozo 2005, this is equivalent to a mean of 4.2 dB hearing loss and represents clinically relevant hearing loss. The 95% CI of our meta-analysis should therefore include zero but not 4.2 to be sure that the hearing losses from the protected and the non-exposed group are equivalent (Piaggio 2006). After sensitivity analysis, the 95% CI includes 4.2 dB hearing loss, which means that even though there is no significant difference between the protected and the non-exposed workers, we still cannot be sure that the protected workers are not at risk of a clinically relevant hearing loss. In addition, two other studies that could not be combined in the meta-analysis still found considerable risks of hearing loss in spite of participants being covered by a HLPP. Another more recent study found no difference between exposed and unexposed workers and concluded that the HLPP was sufficiently improved over time.

Overall completeness and applicability of evidence

It is striking that only one controlled study evaluated measures to reduce noise exposure at the macro-level. We could not find any controlled studies in which technical measures to reduce noise levels were evaluated at the company level. In a previous version of this review we had already noted that case reports of engineering interventions showed considerable reductions in noise level; for example, 7 dB(A) to 9 dB(A) in Jelinic 2005, 30 dB(A) in Knothe 1999, 3 dB(A) to 22 dB(A) in Pingle 2006, 10 dB(A) to 20 dB(A) in Scannell 1998, 13 dB in Stone 1971, 4 dB(A) to 15 dB(A) in Kavraz 2009, 3 dB(A) in Smith 2006 and Smith 2009. We then concluded that our criterion for controlled studies was too strict in the light of the reductions in sound level that are possible by technical interventions alone. Glasziou 2007 argues that in such cases no control group is necessary. On the other hand, the measurement of noise levels in real working life is not simple and can be biased by many factors such as the worker, the task and the environment, where it is impossible to control all operational and environmental variables. Therefore, in our 2017 update of this review, we systematically searched for uncontrolled studies and extracted data from those that we located. All 107 engineering control intervention cases showed reductions in noise levels or personal noise exposure. Engineering solutions such as new equipment, segregation of noisy equipment, installation of enclosures, and panels or curtains can substantially reduce noise levels, with mean reductions of 19.7 dB, 17.1 dB, 11.8 dB and 11.1 dB respectively. These effects are similar to those of hearing protection devices. This means that engineering interventions can potentially make the use of hearing protection devices in workplaces unnecessary, along with the other components of hearing conservation programmes. As engineering interventions do not depend on training, personal preferences or ear canal anatomy, this is a significant advantage.

However, in most case studies, authors measured environmental noise levels in the immediate surroundings of machinery without reporting a measurement protocol. It is therefore unclear if the measured reductions also represent reductions in personal level noise exposure. Even studies that measured the personal noise exposure of workers as TWA or exposure dose did not report measurement protocols including items such as the place of measurement, the exchange rate and permissible exposure levels used to calculate the outcome. Also here we are uncertain what the exact reductions in personal level noise exposure dose are.

Moreover, a long-term follow-up was missing from all but one of the case studies that had a one-year follow-up. We believe that for many of the engineering interventions such as panelling or maintenance, the effects could wear off over time and it is necessary to show that these are lasting solutions. We also believe that publication bias as well as conflict of interest issues can have distorted the results. To us, it seems probable that a case study with negative results, not showing a reduction in noise levels, would not so easily make it into a publication as a study with positive results. In many cases, the evaluators had a direct interest in showing that the situation improved and we believe that this creates a conflict of interest. Because there are still so many potential biases in the uncontrolled studies that at least partly would be remediated by a control group and long-term follow-up we did not include the case-studies in our conclusions.

However, the case studies do show that engineering controls are feasible across a range of noise problems and can have a considerable immediate effect on noise exposure. Better reporting of the noise measurements and longer-term follow-up would be needed to make them more reliable evidence.

No studies evaluated the effectiveness of the practice of recommendations from occupational health services, national agencies or occupational health professionals to reduce noise levels. A possible but speculative reason for the low number of studies could be the tight regulation regarding noise at work, which makes it difficult to challenge current practice in experiments.

For immediate effects of hearing protection, we restricted our inclusion criteria to field studies among workers and excluded studies that made use of volunteers (Franks 2000; Merry 1992; Williams 2004) or were carried out in a laboratory environment (Toivonen 2002). All of these excluded studies showed a benefit of extra instruction compared to less or no instruction. The increase in attenuation was similar to that found in our review (Park 1991a instructions; Salmani 2014). We only included studies that compared different devices worn by the same workers because the evaluation depends to such a great extent on the wearer. That criterion excluded a great number of studies that evaluated different devices worn by different workers. However this provides us with more reliable results of the effect.

Authors of studies that intended to evaluate a HLPP did not clearly define the programmes. It is unclear if the results are applicable in other settings and if measures to reduce noise levels were taken or if workers got training and education in addition to being provided with hearing protection devices. Only two studies that evaluated a HLPP (or components thereof) used a randomised design. Even though randomised studies are more robust to bias, they did not show beneficial effects of HLPPs. One study was conducted in the construction industry, the other RCT (Berg 2009) managed to follow the participants for many years. It shows that, even though it has often been argued that it is difficult to randomise workers, this is feasible even in difficult sectors such as the construction industry (Seixas 2011).

There were two studies that offered a novel component of a HLPP: monitoring personal noise exposure in a way that the individual worker was made aware of his exposure levels (Rabinowitz 2011; Seixas 2011). Possibly due to small sample sizes neither of them found a significant outcome but given the problems in construction industry with varying noise sources that at least partly can be controlled by the worker, this could be a promising intervention to be tested further in this branch of industry.

Quality of the evidence

The risk of bias was high (especially for the long-term evaluation studies) because it is difficult to control for the confounding effect of aging and prior hearing loss and most studies were set up retrospectively. Consquently there is a need for better quality studies, which is possible, as demonstrated by the one RCT with long-term follow-up that we found. Also the ITS design has potential for evaluating HLPPs because much data is collected routinely. We believe that these studies would provide better-quality evidence than comparing HLPPs to non-exposed workers or using a retrospective design.

For the immediate effect evaluation, only two studies used a randomised design, even though it is not too demanding to randomise hearing protection in studies of its immediate effects. Since individual factors, such as the skills necessary to use hearing protection, have an important effect on the outcome, it is important that there are no baseline differences. Randomisation is the only way to ensure this equivalence. Some study authors consider effectiveness to be such a technical matter that they do not even describe the participants in their study.

There was also a lack of information on the implementation level of the prevention measures. This is especially important in the studies that compared well-implemented HLPPs with those of poorer quality. It is possible to compare different HLPPs or single programme components, or different levels of implementation in a cluster-randomised design. This would eventually yield much higher-quality information on the effectiveness of hearing loss prevention. Given the enormous numbers of hearing-impaired workers, this effort seems justified.

Potential biases in the review process

Even though we made significant efforts to search databases that would contain grey literature, such as NIOSHTIC, we did not have the opportunity to go through all conference proceedings. It is therefore possible that we missed retrospective cohort studies or controlled noise-reduction studies.

Publication bias could play a role in the results of the evaluation studies of HLPPs, with four of the studies being funded or carried out by people employed by the company responsible for the intervention, who could possibly have an interest in publishing studies demonstrating a preventative effect of HLPPs (Muhr 2006; Muhr 2016).

Agreements and disagreements with other studies or reviews

Berger 1996 reviewed 22 studies that evaluated the field performance of many different types of hearing protection devices (also partly reported in Berger 1998). The main purpose of the included studies was to evaluate the noise attenuation of hearing protection when worn by different workers in field conditions. All these studies concluded that there was great variation among workers leading to large standard deviations in the average attenuation values. This was mainly due to the problem of a lack of fitting instructions and training in fitting the devices (Royster 1996). The inclusion criteria of these studies were therefore essentially different from ours because different workers wore different devices, whereas we only included studies that compared devices among the same subjects. However, the conclusions from all these studies are in agreement: under field conditions the noise attenuation of hearing protection devices is much less than is possible to achieve in the lab and what is indicated by the manufacturer. The inherent lack of precision of the methods used since the late 1970s for determining noise attenuation (used in the labelling of these products) is widely recognised. To address this issue, de-rating procedures for the reported attenuation values in the labels have been proposed (Franks 2000), and standards have been developed with new strategies for a more accurate determination of the noise attenuation provided in the field (ANSI/ASA 2007; ANSI/ASA 2008; ISO 1999b; ISO 2006). The latest standards incorporate the variance of both the fit of the protector across a population of test subjects and the variance of the protector's performance in a wide range of noise spectra. In the USA, new regulation has been proposed that provides guidance for passive hearing protection devices, active noise reduction devices and also for impulse noise reduction devices such as sound restoration or nonlinear acoustic protectors (Murphy 2008).

One other review concluded that the available evidence from long-term evaluation studies does not support the effectiveness of HLPPs (Dobie 1995). The author acknowledges that he did not perform a systematic search. He included and commented upon the same two evaluation studies that compared hearing protection users versus non-users and those that compared protected workers to non-exposed workers as we included in this review. He included three long-term evaluation studies, of which two were also included in this review. His conclusions are similar to ours in that the evidence for the effectiveness of HLPPs is not very convincing.

Borchgrevink 2003 reviewed only occupational noise-induced hearing loss data and because hearing loss still occurred he concluded that HLPPs were ineffective. Daniell 2006 evaluated the quality of HLPPs in companies and concluded that they were commonly incomplete and that consideration of noise control was low in all industries. This concurs with the conclusions of our review. Another narrative review was directed at one sector only (mining) (McBride 2004), but drew similar conclusions.

AUTHORS' CONCLUSIONS

Implications for practice

There is one study that shows that legislation can reduce noise-exposure levels at the branch level. Technical measures can yield similar reductions in noise levels to hearing protection devices but there are, however, no controlled long-term evaluation studies on implemented technical measures to reduce noise levels in companies, nor on advice to take such measures. Technical measures, therefore, should be the first choice in the management of noise problems at work, especially if the noise reductions lead to a reduction in personal noise doses received by workers. Better implementation and reinforcement of the law could be effective in better implementing technical measures for reducing noise levels.

Hearing protection from various manufacturers showed an immediate effect of noise attenuation of around 20 dB at frequencies 0.5 kHz to 8 kHz under field conditions. This is significantly lower than the attenuation advertised by manufacturers. There was moderate-quality evidence that personal instructions for the insertion of earplugs are needed to guarantee sufficient noise reduction. If properly inserted, earplugs can provide protection equivalent to earmuffs. There is a great variation in noise attenuation between various hearing protection devices. Active noise cancellation devices and devices with a higher noise-reduction rate can lead to a moderate additional reduction of noise levels. For noise cancellation devices this has been shown to take place in the lower frequency range.

There was very low-quality evidence that the use of hearing protection devices in well-implemented hearing loss prevention programmes (HLPP) was associated with less hearing loss but this could not be shown for other elements, such as worker training or audiometry alone or noise monitoring. More individual information on noise exposure as part of a HLPP showed a favourable but non-significant effect. There was also very low-quality evidence that, compared to non-exposed workers, average HLPPs do not reduce the risk of hearing loss to below a level at least equivalent to that of workers who are exposed to 85 dB(A). It might be that a better-implemented HLPP could prevent hearing loss in workers at a level comparable to not being exposed at all.

Implications for research

Research on the long-term effects of engineering interventions to reduce noise is needed. Even field case studies with valid measurements of personal noise doses of workers with long-term follow-up would provide better evidence than what is currently available. The effects of recommendations of measures should preferably be evaluated using a cluster-randomised design in which companies or departments are randomised to either the intervention or the control group.

Future evaluation studies of the immediate effects of hearing protection should use randomisation and take into account the effects of instruction and field conditions. Also studies that evaluate the effects of engineering control interventions should make use of control conditions or use an interrupted time-series approach with at least three measurements before and three after the intervention. Noise measurements can be improved by taking into account the known variability in noise levels (ISO 9612:2009) and by adapting the number of measurements accordingly. Studies need to better report the measurement criteria used, especially when calculating time-weighted averages or exposure doses.

HLPPs should also be evaluated in a cluster-randomised design, in which programmes with specific components can be compared to programmes without these components. A follow-up time of five years has been shown to be feasible and should be sufficient to show effects on hearing given the observation that hearing threshold changes at 4 kHz can already occur in the first year of exposure and can be more than 25 dB after two to five years (Sulkowski 2007). A detailed process evaluation could reveal how well the measures were implemented. Studies evaluating HLPPs with innovative content are especially needed in branches of industry where noise exposure is prevalent and difficult to eliminate such as the construction industry or military.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

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

Adera 1993

Methods	CBA study
Participants	Various occupations n = 692 USA Military
Interventions	Intervention: HLPP in company with apparently good programme (1972-1981); n = 93 Comparison: HLPP in study company (1980-1989) with poor programme; n = 599
Outcomes	STS/100 person-years ≥ 10 dB in either ear as the mean change at 2, 3 and 4 kHz 9-year follow-up
Notes	Long term Comparability - intervention/control: age: adjusted hearing level: ?

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same time period
18. Statistical tests	Low risk	RR (95%CI)
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported (STS)
21. Selection bias (population)	Unclear risk	not reported
22. Selection bias (time)	High risk	recruited over different time periods
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable

Adera 1993 *(Continued)*

25. Adjustment for confounding	Low risk	adjusted for age and gender
26. Incomplete outcome data	Unclear risk	not reported

Adera 2000

Methods	CBA study
Participants	Various occupations n = 19,640 USA 1 company
Interventions	Intervention: well-implemented HLPP in 5 companies; n = 4317, after adjustment for design n = 22 Comparison: HLPP in 1 company with poor quality HLPP; n = 15,323
Outcomes	STS/100 person-years ≥ 10 dB in either ear as the mean change at 2, 3 and 4 kHz 5-year follow-up
Notes	Long-term Comparability - intervention/control: age: adjusted hearing: adjusted

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same time period
18. Statistical tests	Low risk	HR model, 95%CI
19. Compliance	Unclear risk	not reported
20. Outcome measures	Unclear risk	STS, audiometry quality not reported
21. Selection bias (population)	High risk	different companies
22. Selection bias (time)	Unclear risk	not reported
23. Randomization	High risk	not randomised

Adera 2000 *(Continued)*

24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Low risk	adjusted for age, race, hearing loss
26. Incomplete outcome data	Unclear risk	not reported

Berg 2009

Methods	Cluster-randomised controlled study
Participants	Agricultural students involved in farm work n = 753 USA 34 schools
Interventions	Intervention: hearing test yearly, instruction once, 11 mailings at home, free hearing protection plus replacements, use of sound meter Control: yearly hearing tests plus questionnaires
Outcomes	STS with ≥ 10 dB loss at 2, 3, 4 kHz in either ear Median and mean thresholds at 0.5, 1, 2, 3, 4, 5, 6 kHz High-frequency average (3, 4, 6 kHz) and low-frequency average (0.5, 1, 2 kHz) thresholds Bulge depth 3-year and 16-year follow-up
Notes	Long-term Comparability - intervention/control: mean age: intervention 14.5 years, control 14.6 years hearing: max. threshold (R or L) at 0.5 kHz intervention md 10 dB/control md 5 dB, at 1, 2, 3, 4 kHz intervention/control md 5 dB, at 6 kHz intervention md 15 dB/control md 10 dB

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	Unclear risk	not reported
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analysis
17. Follow-up	Low risk	RCT

Berg 2009 *(Continued)*

18. Statistical tests	Low risk	multilevel analysis
19. Compliance	Low risk	increase in hearing protector use
20. Outcome measures	Low risk	hearing thresholds, STS
21. Selection bias (population)	Low risk	RCT
22. Selection bias (time)	Low risk	RCT
23. Randomization	Unclear risk	randomisation stated but no method reported
24. Allocation concealment	Unclear risk	no information provided
25. Adjustment for confounding	Low risk	adjustment for baseline differences
26. Incomplete outcome data	Low risk	< 20%

Brink 2002

Methods	CBA study
Participants	Automobile workers n = 264 USA 1 automobile company
Interventions	Intervention: wearing hearing protection > 33% of the time; n = 132 Control: wearing hearing protection < 33% of the time; n = 132
Outcomes	Hearing thresholds at 0.5, 1, 2, 3, 4 kHz 14-year follow-up
Notes	Long-term Comparability - intervention/control: age: ? hearing: ?

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses

Brink 2002 *(Continued)*

17. Follow-up	Unclear risk	not reported
18. Statistical tests	Low risk	ANOVA
19. Compliance	Low risk	HPD use measured
20. Outcome measures	Low risk	audiometry quality reported (STS)
21. Selection bias (population)	Low risk	same population
22. Selection bias (time)	Low risk	same time
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Unclear risk	no difference in age
26. Incomplete outcome data	Unclear risk	not reported

Davies 2008

Methods	CBA study
Participants	Workers in lumber mills during 1979-1996 who had at least 2 hearing tests n = 22,376 Canada, British Columbia
Interventions	Intervention: hearing conservation programme; n = 16,347 Control: those exposed to < 80 dB-years plus those at their first hearing test following baseline; n = 6002 estimated from the number of person-years of 41,357 with 6.8-year follow-up
Outcomes	STS: ≥ 10 dB at 2, 3 or 4 kHz in the better ear
Notes	Long-term Comparability - intervention/control: proportional hazards model to adjust for age and hearing ability at baseline

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analyses

Davies 2008 *(Continued)*

17. Follow-up	Low risk	same time period for cases and controls (dB-years)
18. Statistical tests	Low risk	multivariable (Cox) regression analyses, HR (95% CI)
19. Compliance	Unclear risk	no information provided
20. Outcome measures	Unclear risk	audiometry quality not reported (hearing thresholds, STS)
21. Selection bias (population)	Low risk	same industry
22. Selection bias (time)	High risk	different time period
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Low risk	adjusted for age and hearing loss
26. Incomplete outcome data	Unclear risk	not reported

Erlandsson 1980

Methods	CBA study	
Participants	Shipyard workers n = 40 Assembly department n = 26 < 89 dB(A) exposure n = 26 Boiler department n = 24 > 89 dB(A) exposure n = 24 Sweden One shipyard	
Interventions	Intervention: those wearing earmuffs; n = 20 Control: those wearing earplugs; n = 30	
Outcomes	Average change in hearing thresholds over 3 years at 2, 3, 4, 6, 8 kHz 3-year follow-up	
Notes	Long-term Comparability - intervention/control: age: matched hearing: ?	
Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded

Erlandsson 1980 *(Continued)*

16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same time period
18. Statistical tests	Unclear risk	statistical methods not reported
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometric quality reported (hearing thresholds)
21. Selection bias (population)	Low risk	same population
22. Selection bias (time)	Low risk	same time
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Unclear risk	only adjusted for age
26. Incomplete outcome data	Unclear risk	not reported

Gosztonyi 1975

Methods	CBA study
Participants	Various occupations in 1 company n = 142 USA
Interventions	Intervention: HLPP; n = 71 Control: non-exposed workers; n = 71
Outcomes	Average change in hearing thresholds over 3 years at 0.5, 1, 2, 3, 4, 6 kHz 5-year follow-up
Notes	Long-term Comparability - intervention/control: age: intervention - md 42.8 years; control - md 43.2 years hearing: ?

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded

Gosztonyi 1975 *(Continued)*

15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	similar time (either 4 or 5 years)
18. Statistical tests	Low risk	only analyses of variance
19. Compliance	Unclear risk	mandatory programme, no measurement
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same factory
22. Selection bias (time)	Low risk	same time period
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Unclear risk	only adjusted for age
26. Incomplete outcome data	Low risk	no loss

Hager 1982

Methods	CBA study
Participants	Various workers n = 43 USA 1 company
Interventions	Intervention: hearing protection as part of HLPP in company; n = 27 Control: non-exposed colleagues; n = 16
Outcomes	Hearing thresholds at entrance minus HT at follow-up at 0.5, 1, 2, 3, 4, 6 kHz Follow-up average 5 and 10 years
Notes	Long-term Comparability - intervention/control: age: ? hearing: intervention 8.1 dB 4 kHz; control 0.3 dB 4 kHz

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**

Hager 1982 *(Continued)*

14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same time (5years)
18. Statistical tests	Low risk	t-test
19. Compliance	Unclear risk	not reported
20. Outcome measures	Unclear risk	audiometry quality not reported
21. Selection bias (population)	Low risk	same factory
22. Selection bias (time)	Unclear risk	control subjects not grouped according to period of time
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Unclear risk	age corrected control group
26. Incomplete outcome data	Low risk	not reported

Heyer 2011

Methods	CBA study (retrospective)
Participants	Workers of 2 automotive plants, 1 food-processing plant n = 6483 USA
Interventions	HLPP quality data available 1. training and education 2. noise monitoring 3. engineering and administrative controls 4. audiometric testing and surveillance 5. medical referral 6. HPD use 7. administrative and record keeping procedures Intervention: years in better-implemented programme based on (based on more HPD use, better training, better noise monitoring, better audiometry)

Heyer 2011 *(Continued)*

	Control: years in less well-implemented programme based on same criteria
Outcomes	Rate of hearing loss increase over 3, 4, 6 kHz both ears between the first and subsequent audiograms
Notes	Long-term Comparability - intervention/control: age and hearing: adjusted noise exposure: adjusted, based on retrospective noise level assessment

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	Low risk	blinded, those evaluating quality of interventions were not aware of audiometric data
16. Retrospective unplanned subgroup analyses	Low risk	no data dredging
17. Follow-up	Low risk	adjustment for exposure and exposure to intervention
18. Statistical tests	Low risk	GEE analysis
19. Compliance	Unclear risk	measurements very crude
20. Outcome measures	Low risk	audiometry programme
21. Selection bias (population)	Unclear risk	comparison was between rate of change in hearing according to stratified years of employment within estimated component of the programme of a certain quality level for each of the five defined components
22. Selection bias (time)	Unclear risk	plants were followed for different time periods
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Low risk	initial hearing loss and age
26. Incomplete outcome data	Unclear risk	not reported

Horie 2002

Methods	CBA study
Participants	Steel industry quality check workers n = 12 Japan

Horie 2002 *(Continued)*

	1 company
Interventions	Intervention: hearing protection with active noise cancellation: proactive PA-3100; n = 12 Control: hearing protection without active noise cancellation; n = 12
Outcomes	TTS after 4 hours of exposure at 1, 2, 4, 6, 8 kHz (HT after - HT before) (immediate)
Notes	Immediate

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same time
18. Statistical tests	Low risk	MANOVA
19. Compliance	Unclear risk	not reported
20. Outcome measures	High risk	audiometry quality reported but no SDs provided
21. Selection bias (population)	Unclear risk	same company
22. Selection bias (time)	Low risk	same time
23. Randomization	Unclear risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Low risk	same workers
26. Incomplete outcome data	Low risk	no loss

Huttunen 2011

Methods	CBA immediate follow-up (REAT) Finland Music industry (orchestra)

Huttunen 2011 *(Continued)*

Participants	Age, gender, hearing ability not reported n = 10
Interventions	Intervention: custom-moulded musician's ear-plug ER-15 by Etymotic Research Inc., Elk Grove Village, IL, USA Control group: custom-moulded musician's ear-plug ER-9 by Etymotic Research Inc., Elk Grove Village, IL, USA
Outcomes	Noise attenuation: REAT
Notes	

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analysis
17. Follow-up	Low risk	same time period
18. Statistical tests	Unclear risk	not reported
19. Compliance	Low risk	immediate follow-up
20. Outcome measures	Low risk	REAT audiometry
21. Selection bias (population)	Low risk	participants as their own controls (REAT)
22. Selection bias (time)	Low risk	same time
23. Randomization	High risk	no randomisation
24. Allocation concealment	High risk	no randomisation
25. Adjustment for confounding	Low risk	participants as their own controls
26. Incomplete outcome data	Low risk	no loss

Joy 2007

Methods	ITS
Participants	Coal mines

Joy 2007 *(Continued)*

	Workplace measurements n = 142,735 USA Whole mining branch
Interventions	Introduction of new legislation in 1999 becoming effective in 2000: primacy of engineering and administrative controls, establishment of an Action Level of 85 dB(A), hearing conservation programme enrolment starting from 85 dB(A), introduction of statutory hearing loss of 25 dB average over 2, 3 and 4 kHz in either ear
Outcomes	Median of measurements of compliance with PEL, which includes all sound pressure levels from 90 dB(A) to 140 dB(A) with a doubling rate of 5 dB as an 8-hour TWA
Notes	Outcomes for general noise levels and underground noise levels respectively: 1987: 61 and 65.8 dB, 1988: 55 and 65 dB, 1989: 62 and 63 dB, 1990: 63 and 65.4 dB, 1991: 59 and 69.4 dB, 1992: 54.2 and 73.4 dB, 1993: 63 and 74.9 dB, 1994: 67 and 76 dB, 1995: 58.9 and 68 dB, 1996: 60 and 69.3 dB, 1997: 56.5 and 73 dB, 1998: 48.8 and 74 dB, 1999: 57.1 and 78.2 dB, 2000: 31 and 63 dB, 2001: 23 and 54 dB, 2002: 22 and 50 dB, 2003: 20 and 52 dB, 2004: 20 and 50 dB

Lee-Feldstein 1993

Methods	CBA study
Participants	Automobile workers n = 11,435 USA 1 company
Interventions	Intervention: HLPP; n = 11,104, after cluster adjustment n = 97 Control: non-exposed colleagues; n = 331
Outcomes	Rate of STS, average change in mean hearing threshold at 2, 3 and 4 kHz in the worst ear follow-up average 5 years
Notes	Long-term Comparability - intervention/control: age: adjusted hearing: adjusted

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	similar
18. Statistical tests	Unclear risk	not reported

Lee-Feldstein 1993 *(Continued)*

19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same factory
22. Selection bias (time)	Low risk	same period
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Low risk	adjusted for age and hearing loss
26. Incomplete outcome data	Unclear risk	not reported

Meyer 1993

Methods	CBA study
Participants	Various occupations n = 1377 USA Military
Interventions	Intervention: detailed follow-up examination after STS; n = 496 Control: no detailed follow-up; n = 821
Outcomes	Rate of new STS; before 1990 defined as a change of 20 dB or more at 1, 2, 3 or 4 kHz, after 1990 an average change of 10 dB or more at 2, 3 and 4 kHz in either ear 1-year follow-up
Notes	Long-term Comparability - intervention/control: age: ? hearing: ?

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses

Meyer 1993 *(Continued)*

17. Follow-up	Low risk	same follow-up
18. Statistical tests	Low risk	RR (95% CI)
19. Compliance	High risk	only few got detailed follow-up
20. Outcome measures	Unclear risk	no audiometry quality reported
21. Selection bias (population)	Low risk	all subjects from the army
22. Selection bias (time)	Low risk	all subjects selected between 1989-1991
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Unclear risk	not reported

Moshammer 2015

Methods	CBA (arc sin transformed linear regression analysis of HPD use on NIHL) Austria Type of industry: steel factory
Participants	Fitters and welders at a steel factory Age mean 16.4 years, range 14-19 years Gender, hearing ability not reported Average noise exposure: 90.8 dB(A) (range 85.4-107.4 dB(A) over 13.3 years (range 2-23 years) n = 125
Interventions	Use of hearing protection, self-reported percentage of use, geometric mean of responses on questionnaire at 3 annual health examinations when hearing level was measured
Outcomes	Noise-induced hearing loss at 4 kHz, measured as hearing level at baseline adjusted for age minus hearing level at end of follow-up adjusted for age (information from the study authors); also the average hearing loss at 2, 3 and 4 kHz was measured
Notes	The study was set up to predict hearing loss based on TTS at start of the study. Participants were selected from a cohort of workers that started as apprentices at the firm between 1982 and 1989, who had at least 2 years of noise exposure and who worked at places that were noisy

Risk of bias

Bias	Authors' judgement	Support for judgement

Moshammer 2015 *(Continued)*

14. Blinding (subjects)	High risk	No blinding; participants chose themselves about wearing or not wearing HPD
15. Blinding (outcome assessors)	Unclear risk	Not clear if audiometrists were aware of HPD use
16. Retrospective unplanned subgroup analyses	High risk	different data analysis and results because of comments on journal article
17. Follow-up	Low risk	regression analysis includes adjustment for different time of follow-up (noise years)
18. Statistical tests	Low risk	multivariate analysis
19. Compliance	Unclear risk	self-reports of use of hearing protectors in noisy areas, unclear how valid
20. Outcome measures	Low risk	NIHL was calculated from thresholds measured with audiogram minus age related HL
21. Selection bias (population)	Low risk	same workplaces, type of work (closed cohort in 1 steel plant)
22. Selection bias (time)	Low risk	workers in I and C started between 1982-1989
23. Randomization	High risk	no randomisation, participants chose themselves how often they used HPDs in noisy areas
24. Allocation concealment	High risk	no randomisation
25. Adjustment for confounding	Low risk	adjusted confounders
26. Incomplete outcome data	High risk	> 60% lost to follow-up

Muhr 2006

Methods	CBA study
Participants	Army conscripts n = 885 conscripted between 1 June 1999 and 1 June 2000 with hearing loss < 20 dB average over 2 and 3 kHz and < 32.5 dB over 4 and 6 kHz or < 25 dB over 2 and 3 kHz and < 20 dB over 4 and 6 kHz Exposure to impulse noise from shooting Sweden Military
Interventions	Intervention: regular hearing protection; n = 747 Control: non-exposed waiting for training period; n = 138
Outcomes	STS ≥ 15 dB at the best ear at any of 0.25, 0.5, 1, 2, 3, 4, 6 or 8 kHz between baseline and follow-up hearing test with average follow-up of 7.5-11 months
Notes	—

Muhr 2006 *(Continued)*

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	similar time for controls and study subjects
18. Statistical tests	Low risk	RR (95% CI)
19. Compliance	Low risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	all subjects recruits of the army
22. Selection bias (time)	Low risk	all from 1999-2000
23. Randomization	High risk	no randomisation
24. Allocation concealment	Unclear risk	no randomisation, not applicable
25. Adjustment for confounding	Low risk	age, all male
26. Incomplete outcome data	Low risk	< 20%

Muhr 2016

Methods	CBA study
Participants	Army conscripts (n= 1234) Control group: before military service in 2002-2004 (n = 839), Intervention group: in military service 2004-2005 (n = 395), 40 servicemen from the armoured regiment included in the control-group are also included in the intervention group. Mean age: intervention, 19 years, control, 18 years at enrolment Gender: male Hearing ability: most participants had maximum hearing thresholds of 25 dB for frequencies 0.5 to 8 kHz in both ears at enrolment to study (I 88.4%, C 85.5%)

Muhr 2016 *(Continued)*

	Exposure: intervention group exposed to impulse noise from shooting Sweden Military
Interventions	Intervention: HLPP including HPDs and administrative controls (n = 395) Control: non-exposed to military noise, waiting for training period (n = 839)
Outcomes	STS ≥ 15 dB at 1 or both ears at any of 0.25, 0.5, 1, 2, 3, 4, 6 or 8 kHz between baseline and follow-up, hearing test with average follow-up of 8 months (intervention group) and 13 months (control group)
Notes	

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analysis, data dredging unlikely
17. Follow-up	Unclear risk	approximate difference of 5 months in follow-up between intervention and control, 1.5 times longer for control
18. Statistical tests	Low risk	RR (95%CI)
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	all subjects recruits to the army
22. Selection bias (time)	High risk	different time periods, 2004/2005 vs 2002-2004
23. Randomization	High risk	no randomisation
24. Allocation concealment	High risk	no randomisation
25. Adjustment for confounding	Low risk	Control and intervention groups of similar age and hearing, baseline for other confounders not reported
26. Incomplete outcome data	Unclear risk	loss of follow-up not reported

Nilsson 1980

Methods	CBA study

Nilsson 1980 *(Continued)*

Participants	Ship builders; n = 231 Highly exposed group with > 94 dB(A); n = 1838 Low exposed group with < 88 dB(A); n = 1354 Sweden 1 shipyard
Interventions	Intervention: workers wearing earmuffs; n = 1883 Control: workers wearing earplugs; n = 1309
Outcomes	STS > 10 dB any frequency in either ear per 100 person-years; frequencies tested: 0.25, 0.5, 1, 2, 3, 4, 6, 8 kHz
Notes	Long-term Comparability - intervention/control: age: ? hearing: both groups < 35 dB all frequencies

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analyses
17. Follow-up	Low risk	all about 3.3 years' follow-up
18. Statistical tests	Unclear risk	one sided Chi^2 test
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	High risk	same factory but different departments with different noise exposure
22. Selection bias (time)	Unclear risk	same time
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	High risk	5 years' difference in average age
26. Incomplete outcome data	Unclear risk	not reported

Park 1991a instructions

Methods	RCT
Participants	Various workers n = 40 USA Several companies
Interventions	Intervention: fitting instructions for earplugs and earmuffs in step-by-step procedure; n = 20 Control: instructions on paper as provided by the manufacturer n = 20
Outcomes	Hearing thresholds with and without protection at 0.5, 1, 2, 3, 4, 6, 8 kHz
Notes	Immediate

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	all 3 weeks
18. Statistical tests	Low risk	ANOVA
19. Compliance	Low risk	wearing of HPD checked
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same population
22. Selection bias (time)	Low risk	same time
23. Randomization	Low risk	subjects were randomly assigned
24. Allocation concealment	Unclear risk	not reported, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Low risk	no loss

Park 1991b protection

Methods	RCT

Park 1991b protection *(Continued)*

Participants	Various workers n = 40 USA Several companies
Interventions	Intervention: 4 different types of hearing protectors: EAR foam plug, Bilsom UF1 earmuff, Ultrafit plug, Wilson Sound Ban Muff; n = 20 Control: earmuffs versus earplugs; n = 20
Outcomes	Hearing thresholds with and without protection at 0.5, 1, 2, 3, 4, 6, 8 kHz
Notes	Immediate

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	all three weeks
18. Statistical tests	Low risk	ANOVA
19. Compliance	Low risk	wearing of HPD checked
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same population
22. Selection bias (time)	Low risk	same time
23. Randomization	Low risk	subjects were randomly assigned
24. Allocation concealment	Unclear risk	not reported
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Low risk	no loss

Pell 1973

Methods	CBA study Prospective

Pell 1973 *(Continued)*

Participants	Various workers n = 1572 n = 628 < 20 dB hearing loss at entrance n = 559 15-35 dB hearing loss at entrance n = 385 > 40 dB hearing loss at entrance USA 1 company
Interventions	Intervention: HLPP mainly hearing protection; n = 399 Control: non-exposed colleagues; n = 1173
Outcomes	Average change in hearing thresholds last-entrance measurement at 0.5, 1, 2, 3, 4, 6 kHz 5-year follow-up
Notes	Long-term Comparability - intervention/control: average age: intervention - 34 years; control - 43 years hearing: stratified according to HL at start

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no unplanned analyses
17. Follow-up	Low risk	5-year follow-up
18. Statistical tests	High risk	ANOVA
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same factory
22. Selection bias (time)	Low risk	same time
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	High risk	difference in mean age was 10 years
26. Incomplete outcome data	Unclear risk	not reported

Pääkkönen 1998

Methods	CBA study
Participants	Shots with 762 Rk 62 rifle n = 5 shots Finland Military
Interventions	Intervention: Hearing Protector Earmuffs: Peltor H61, Peltor H7, Peltor H6, Bilsom Marksman, Silenta Hunter at 156 Lcpeak dB(C); n = 5
Outcomes	Difference in noise level outside versus inside the protectors
Notes	Immediate

Risk of bias

Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analysis
17. Follow-up	Unclear risk	immediate outcome measurement (inside/outside HPD)
18. Statistical tests	High risk	no test used
19. Compliance	Low risk	closely observed use of HPD
20. Outcome measures	Low risk	calibrated measurements
21. Selection bias (population)	Unclear risk	all subjects were military staff
22. Selection bias (time)	Low risk	same day in 1995
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Unclear risk	not reported

Pääkkönen 2001

Methods	CBA study
Participants	Air combat plane n = 2 Finland Military
Interventions	Intervention: noise cancellation on in helmet: Alpha 200 series, Gentex/Bose Control: noise cancellation off Exposure time 8 minutes L_{eq} 104-106 dB(A)
Outcomes	Difference in noise level outside versus inside the helmets
Notes	Immediate

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analysis
17. Follow-up	Low risk	immediate outcome (inside outside measurement)
18. Statistical tests	High risk	no statistical tests used
19. Compliance	Low risk	took proper adjustment of helmet into account
20. Outcome measures	Low risk	A-weighted equivalent sound pressure levels
21. Selection bias (population)	Low risk	same military staff
22. Selection bias (time)	Low risk	probably same time period (compare Pääkönen 1998) but not clearly reported
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Unclear risk	not reported

Rabinowitz 2011

Methods	CBA study/ITS (authors provided additional data for ITS analysis)
Participants	Various workers of an aluminium smelter n = 312
Interventions	Intervention: daily monitoring of at-ear noise exposure and regular feedback from supervisors Control: ongoing hearing conservation programme (regulation-mandated hearing tests, noise measurements, training)
Outcomes	Median TWA ambient noise exposures Median and range of noise exposures inside hearing protection (intervention group) High frequency hearing threshold levels (2, 3, 4 kHz) Annual rate of hearing loss (dB/year)
Notes	Long-term Comparability - intervention/control (matched on age, gender and hearing): age: similar age (within 5 years); intervention mean 48.7 years, control mean 48,6 years hearing: controls matched (control group 1) and highly matched (control group 2): Control group 1: baseline hearing = similar high frequency hearing threshold levels (binaural average of 2, 3 and 4 kHz) (within 5 dB) (intervention, n = I 78; control n = 234) Control group 2: baseline hearing and initial rate of hearing loss during pre-intervention period (intervention, n = 46; control, n = 138) For risk of bias see Table 12

Reynolds 1990a

Methods	CBA study
Participants	Various workers n = 852 USA 1 company in the chemical industry
Interventions	Intervention: HLPP at 12-h shifts; n = 272, adjusted for design effect n = 218 Control: HLPP at 8-h shifts; n = 580
Outcomes	Average change in hearing thresholds at 0.5, 1, 2, 3, 4, 6 kHz 1-year follow-up
Notes	Long-term Comparability - intervention/control: age: ? hearing: similar loss

Risk of bias

Bias	Authors' judgement	Support for judgement

Reynolds 1990a *(Continued)*

14. Blinding (subjects)	High risk	not blinded
15. Blinding (outcome assessors)	High risk	not blinded
16. Retrospective unplanned subgroup analyses	Low risk	no additional analysis
17. Follow-up	Low risk	same time length (annual hearing test differences)
18. Statistical tests	High risk	ANOVA, no RR, no CI
19. Compliance	Unclear risk	not reported
20. Outcome measures	Unclear risk	audiometry quality not reported
21. Selection bias (population)	Low risk	same company
22. Selection bias (time)	Unclear risk	each employee's last audiometry test in the same year
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Unclear risk	not reported

Royster 1980

Methods	CBA study
Participants	Various occupations n = 70 USA
Interventions	Intervention: V-51R plug Control: EAR plug
Outcomes	Temporary threshold shift at 0.5, 1, 2, 3, 4, 6 kHz. In 3 subgroups after leaving noise after 8, 14, 6, 20 and 27.2 minutes
Notes	Immediate

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding

Royster 1980 *(Continued)*

15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	immediate outcomes
18. Statistical tests	Low risk	t-test
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported
21. Selection bias (population)	Low risk	same company
22. Selection bias (time)	Low risk	prospective study
23. Randomization	High risk	alternation
24. Allocation concealment	High risk	not properly randomised
25. Adjustment for confounding	Low risk	similar in age, race, sex
26. Incomplete outcome data	Low risk	2/72 lost to follow-up

Salmani 2014

Methods	RCT
Participants	Occupations not reported n = 150 Age: mean ± SD 28.3 ± 5.4 (range: 19–39) years Gender: 42% male Iran
Interventions	Intervention: earplugs with training in correct methods of wearing and inserting plugs Control group1: earplugs without training Control group 2: earplug with higher noise attenuation without training
Outcomes	Noise attenuation (REAT)
Notes	
Risk of bias	

Salmani 2014 *(Continued)*

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	Unclear risk	participants knew if they were in the control or intervention group (type of earplug and training)
15. Blinding (outcome assessors)	Low risk	blinding of audiometrist
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analysis
17. Follow-up	Low risk	immediate follow-up
18. Statistical tests	Unclear risk	not reported
19. Compliance	Low risk	immediate follow-up
20. Outcome measures	Low risk	ANSI
21. Selection bias (population)	Low risk	randomised to intervention or control
22. Selection bias (time)	Low risk	recruited over similar time period (over 1 year)
23. Randomization	Unclear risk	random digit table, procedure not described
24. Allocation concealment	Unclear risk	unconcealed
25. Adjustment for confounding	Low risk	outcome was measured as difference in hearing threshold between with and without earplugs, no baseline differences in age and sex
26. Incomplete outcome data	Low risk	no loss

Seixas 2011

Methods	Both cluster and individually randomised RCT, first 4 work sites got baseline training, then these were cluster-randomised to tool-box or no tool-box training and then individuals were randomised to noise level indicators or no indicators
Participants	Construction workers; various trades n = 176 USA
Interventions	Many comparisons possible, we choose to compare two interventions considered to be most relevant for practice Intervention 1: baseline training plus noise 'tool box' on-site training (n = 44) Intervention 2: baseline training plus noise 'tool box' on-site training plus personal noise level indicator (n = 41)

Seixas 2011 *(Continued)*

	Control: baseline training (n = 46)	
Outcomes	Noise level measured as L_{eq} at 2 and 4 months' follow-up	
Notes		
Risk of bias		
Bias	**Authors' judgement**	**Support for judgement**
14. Blinding (subjects)	High risk	different interventions at the same site visible
15. Blinding (outcome assessors)	Unclear risk	not reported
16. Retrospective unplanned subgroup analyses	Low risk	no subgroup analyses
17. Follow-up	Low risk	similar follow-up
18. Statistical tests	Unclear risk	differences in outcome not tested
19. Compliance	Low risk	NLI checked every week, participating in training course or excluded
20. Outcome measures	Low risk	L_{eq} according to NIOSH criteria
21. Selection bias (population)	Low risk	different intervention groups
22. Selection bias (time)	Low risk	same time
23. Randomization	Unclear risk	methods not reported
24. Allocation concealment	Unclear risk	not reported
25. Adjustment for confounding	Low risk	intention to treat
26. Incomplete outcome data	High risk	reported, no differences between groups, but loss to follow-up ranged from 20%-33%

Simpson 1994

Methods	CBA study
Participants	Various occupations in 21 companies n = 13283 USA
Interventions	Intervention: well-implemented HLPP Control: poor quality HLPP
Outcomes	Rate of STS defined as on average ≥ 10 dB at 2, 3 and 4 kHz in either ear

Simpson 1994 *(Continued)*

	Follow-up average 1 year
Notes	Long-term Comparability - intervention/control: age: ? hearing: ?

Risk of bias

Bias	Authors' judgement	Support for judgement
14. Blinding (subjects)	High risk	no blinding
15. Blinding (outcome assessors)	High risk	no blinding
16. Retrospective unplanned subgroup analyses	Low risk	no additional analyses
17. Follow-up	Low risk	same period (second audiogram fell within time window of 6-18 months)
18. Statistical tests	Unclear risk	no tests mentioned
19. Compliance	Unclear risk	not reported
20. Outcome measures	Unclear risk	audiometry quality not reported
21. Selection bias (population)	High risk	different companies
22. Selection bias (time)	Unclear risk	not reported
23. Randomization	High risk	not randomised
24. Allocation concealment	Unclear risk	not randomised, not applicable
25. Adjustment for confounding	Unclear risk	not reported
26. Incomplete outcome data	Unclear risk	not reported

ANOVA = analysis of variance
ANSI = American National Standards Institute
CBA = controlled before and after (study)
CI = confidence interval
? = no information available
HL = hearing loss
HLPP = hearing loss protection programme
HPD = hearing protection device
HR = hazard ratio
HT = hearing threshold
ITS = interrupted time series
L = left
L_{eq} = equivalent continuous sound level

MANOVA = multivariate analysis of variance
md = median
NIHL = noise-induced hearing loss
NLI = Noise level indicator
PEL = permissible exposure level
R = right
REAT = real ear attenuation at threshold
RR = risk ratio
STS = standard threshold shift
TTS = temporary threshold shift
TWA = time-weighted average

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

Study	Reason for exclusion
Aybek 2010	Study design: one measurement per intervention, no before measurement, groups not comparable
Bealko 2009	Study design: cross-sectional design
Bockstael 2008	Participants: HPD not tested on same participants
Bowes 1990	Intervention and study design: only noise measurements and recommendations, no evaluation of measures taken
Brueck 2009	Study design, intervention, outcome measurement: no work place intervention, laboratory tests and observations
Brühl 1994	Study design: control group taken from database
Byrne 2011	Participants: subjects were excluded if they were routinely exposed to occupational noise
Casali 2009	Outcome: operational performance, no noise or hearing tests
Chou 2009	Study design: cross-sectional study, no pre-intervention measurements
Franks 2000	Participants: not a field study with workers
Giardino 1996	Study design: not the same workers using different hearing protection
Golmohammadi 2010	Study design: effect of intervention not evaluated
Griest 2008	Participants and outcome: school-age children, behaviour change, attitudes and knowledge
Groothoff 1999	Study design: several case studies on noise reduction but no control group
Jelinic 2005	Study design: case study only
Kardous 2003	Study design: case study on noise reduction
Karlsmose 2001	Participants: no noise-exposed workers included
Kavraz 2009	Study design and exposure: quasi-experimental, attenuation not measured for the workers over a typical work day/situation (noise duration?, TWA?, high frequencies?, shift dose?)
Knothe 1999	Study design: case study on noise reduction

Study	Reason for exclusion
Kotarbinska 2009	Study design: immediate effect of HPD, but no control group and no comparison of 2 types of HPD on the same workers
Lempert 1983	Study design: no control group, only one measurement before intervention
Lutz 2015	study design: before – after comparison of HPDs on different persons
Mechfske 2002	Participants: noise reduction for patients not for healthcare personnel
Merry 1992	Participants: not a field study with workers
Monazzam 2011	Study design: no measurement after the intervention
Mrena 2008	Study design: two cross-sectional studies
Murphy 2011	Study design: laboratory results
Nair 2009	Study design: no before measurement
Neitzel 2005	Study design: not the same workers using different hearing protection
Neitzel 2008	Study design and outcome measurement: one measurement before and after intervention, no control group, self reported HPD use
Niskanen 2001	Study design: no control group, not an ITS
Oestenstad 2008	Study design and exposure: retrospective study, control group built from database/recalculation of exposure data
Pearlman 2009	Study design: experimental study in a laboratory
Pingle 2006	Study design: case study only
Pääkkönen 2005	Similar results as in Pääkkönen 1998 Study design: not the same workers using different hearing protection
Randolph 2008	Study design, participants: no control group/ITS, no real workers/workplaces
Reeves 2009	Study design: examples of before-after measurements but not as time series or with some sort of control
Reynolds 1990b	Study design: not the same workers using hearing protection
Sataloff 2010	Study design and participants: cross-sectional study, no occupational noise exposure
Scannell 1998	Study design: case study on technical noise reducing measures
Schaefer 1992	Study design: case study on technical noise reducing measures
Smith 2006	Study design: no ITS, no control group
Smith 2009	Study design: no CBA measurements, no ITS
Smith 2011	Study design: only one measurement before and one after intervention, no ITS, no control group

Study	Reason for exclusion
Stone 1971	Study design: case study on technical noise reducing measures
Toivonen 2002	Participants: not a field study with workers
Tsukada 2008	Study design: no control group, no ITS
Walter 2009	Study design: no control group, no ITS
Waugh 1990	Outcome: no audiometric measurements, noise measurements before but not after the intervention
Williams 2004	Participants: not a field study with workers
Wu 2009	Study design: no data of controls before intervention

CBA = controlled before and after
HPD = hearing protection device
ITS = interrupted time series
TWA = time-weighted average

DATA AND ANALYSES

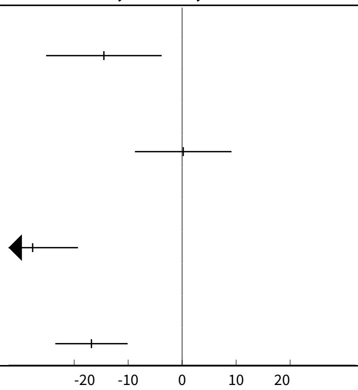
Comparison 1. Legislation to decrease noise exposure (long-term) - ITS

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Immediate change in level	1		immediate change in level (Random, 95% CI)	Totals not selected
1.1 Surface noise Intervention (Int) Year 1999	1		immediate change in level (Random, 95% CI)	0.0 [0.0, 0.0]
1.2 Underground noise Int Year 1999	1		immediate change in level (Random, 95% CI)	0.0 [0.0, 0.0]
1.3 Surface noise Int Year 2000	1		immediate change in level (Random, 95% CI)	0.0 [0.0, 0.0]
1.4 Underground noise Int Year 2000	1		immediate change in level (Random, 95% CI)	0.0 [0.0, 0.0]
2 Change in slope	1		change in slope (Random, 95% CI)	Totals not selected
2.1 Surface noise Int Year 1999	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]
2.2 Underground noise Int Year 1999	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]
2.3 Surface noise Int Year 2000	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.4 Underground noise Int Year 2000	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]

Analysis 1.1. Comparison 1 Legislation to decrease noise exposure (long-term) - ITS, Outcome 1 Immediate change in level.

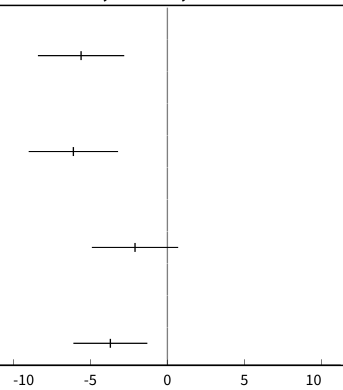
Study or subgroup	Experimental N	Control N	immediate change in level (SE)	immediate change in level IV, Random, 95% CI
1.1.1 Surface noise Intervention (Int) Year 1999				
Joy 2007	0	0	-14.5 (5.459)	-14.5[-25.2,-3.8]
1.1.2 Underground noise Int Year 1999				
Joy 2007	0	0	0.2 (4.566)	0.2[-8.75,9.15]
1.1.3 Surface noise Int Year 2000				
Joy 2007	0	0	-27.7 (4.286)	-27.7[-36.1,-19.3]
1.1.4 Underground noise Int Year 2000				
Joy 2007	0	0	-16.8 (3.418)	-16.8[-23.5,-10.1]



Favours experimental | Favours control

Analysis 1.2. Comparison 1 Legislation to decrease noise exposure (long-term) - ITS, Outcome 2 Change in slope.

Study or subgroup	Experimental N	Control N	change in slope (SE)	change in slope IV, Random, 95% CI
1.2.1 Surface noise Int Year 1999				
Joy 2007	0	0	-5.6 (1.429)	-5.6[-8.4,-2.8]
1.2.2 Underground noise Int Year 1999				
Joy 2007	0	0	-6.1 (1.48)	-6.1[-9,-3.2]
1.2.3 Surface noise Int Year 2000				
Joy 2007	0	0	-2.1 (1.429)	-2.1[-4.9,0.7]
1.2.4 Underground noise Int Year 2000				
Joy 2007	0	0	-3.7 (1.225)	-3.7[-6.1,-1.3]



Favours experimental | Favours control

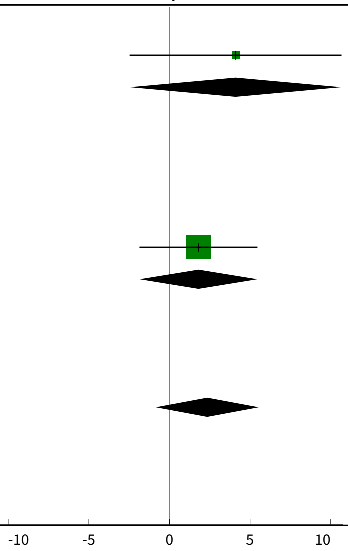
Comparison 2. HPD (muffs) with instructions vs without instructions (immediate) - RCT

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation at 0.5 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	2.34 [-0.85, 5.54]
1.1 Wilson Sound Ban cap	1	20	Mean Difference (IV, Random, 95% CI)	4.1 [-2.47, 10.67]
1.2 Bilsom UF-1 muff	1	20	Mean Difference (IV, Random, 95% CI)	1.80 [-1.86, 5.46]
2 Noise attenuation at 1 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	0.89 [-3.02, 4.80]
2.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	3.80 [-3.70, 11.30]
2.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	-0.20 [-4.78, 4.38]
3 Noise attenuation at 2 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	2.57 [-0.23, 5.38]
3.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.70 [-1.89, 7.29]
3.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	2.5 [-1.05, 6.05]
4 Noise attenuation at 3 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	2.23 [0.09, 4.36]
4.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	1.60 [-3.01, 6.21]
4.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	2.40 [-0.01, 4.81]
5 Noise attenuation at 4 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	0.83 [-3.28, 4.95]
5.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	0.90 [-6.18, 7.98]
5.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.80 [-4.26, 5.86]
6 Noise attenuation at 6 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	0.64 [-3.76, 5.04]
6.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.30 [-7.31, 11.91]
6.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.20 [-4.75, 5.15]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
7 Noise attenuation at 8 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	1.14 [-3.59, 5.87]
7.1 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.0 [-8.13, 12.13]
7.2 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.90 [-4.45, 6.25]

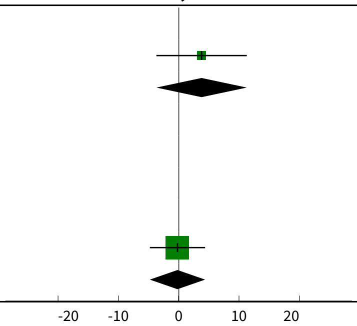
Analysis 2.1. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 1 Noise attenuation at 0.5 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.1.1 Wilson Sound Ban cap							
Park 1991b protection	10	16.5 (6.2)	10	12.4 (8.6)		23.67%	4.1[-2.47,10.67]
Subtotal ***	**10**		**10**			**23.67%**	**4.1[-2.47,10.67]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.22(P=0.22)							
2.1.2 Bilsom UF-1 muff							
Park 1991b protection	10	20.8 (2.6)	10	19 (5.3)		76.33%	1.8[-1.86,5.46]
Subtotal ***	**10**		**10**			**76.33%**	**1.8[-1.86,5.46]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.96(P=0.33)							
Total ***	**20**		**20**			**100%**	**2.34[-0.85,5.54]**
Heterogeneity: Tau²=0; Chi²=0.36, df=1(P=0.55); I²=0%							
Test for overall effect: Z=1.44(P=0.15)							
Test for subgroup differences: Chi²=0.36, df=1 (P=0.55), I²=0%							

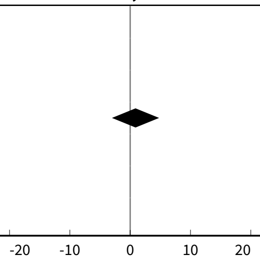


Analysis 2.2. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 2 Noise attenuation at 1 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.2.1 Wilson Sound Ban Cap							
Park 1991b protection	10	16 (6.5)	10	12.2 (10.2)		27.2%	3.8[-3.7,11.3]
Subtotal ***	**10**		**10**			**27.2%**	**3.8[-3.7,11.3]**
Heterogeneity: Tau²=0; Chi²=0, df=0(P<0.0001); I²=100%							
Test for overall effect: Z=0.99(P=0.32)							
2.2.2 Bilsom UF-1 Muff							
Park 1991b protection	10	27.3 (3.7)	10	27.5 (6.4)		72.8%	-0.2[-4.78,4.38]
Subtotal ***	**10**		**10**			**72.8%**	**-0.2[-4.78,4.38]**

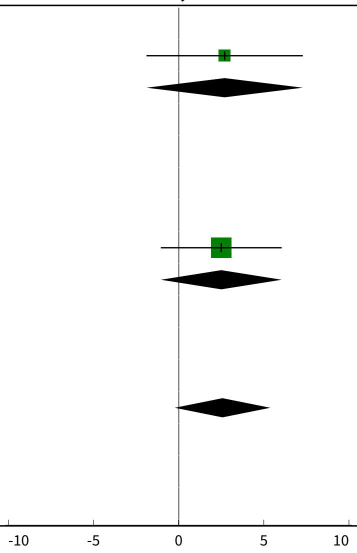


Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Heterogeneity: Not applicable							
Test for overall effect: Z=0.09(P=0.93)							
Total * **	**20**		**20**			**100%**	**0.89[-3.02,4.8]**
Heterogeneity: Tau²=0; Chi²=0.8, df=1(P=0.37); I²=0%							
Test for overall effect: Z=0.45(P=0.66)							
Test for subgroup differences: Chi²=0.8, df=1 (P=0.37), I²=0%							



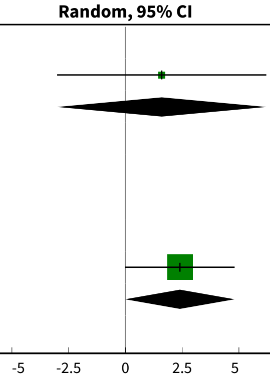
Analysis 2.3. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 3 Noise attenuation at 2 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.3.1 Wilson Sound Ban Cap							
Park 1991b protection	10	30.3 (3.9)	10	27.6 (6.3)		37.41%	2.7[-1.89,7.29]
Subtotal * **	**10**		**10**			**37.41%**	**2.7[-1.89,7.29]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.15(P=0.25)							
2.3.2 Bilsom UF-1 Muff							
Park 1991b protection	10	29.4 (4)	10	26.9 (4.1)		62.59%	2.5[-1.05,6.05]
Subtotal * **	**10**		**10**			**62.59%**	**2.5[-1.05,6.05]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.38(P=0.17)							
Total * **	**20**		**20**			**100%**	**2.57[-0.23,5.38]**
Heterogeneity: Tau²=0; Chi²=0, df=1(P=0.95); I²=0%							
Test for overall effect: Z=1.8(P=0.07)							
Test for subgroup differences: Chi²=0, df=1 (P=0.95), I²=0%							

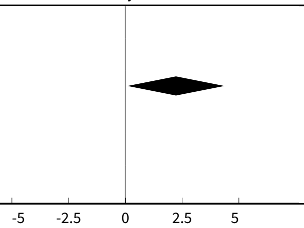


Analysis 2.4. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 4 Noise attenuation at 3 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.4.1 Wilson Sound Ban Cap							
Park 1991b protection	10	34.3 (5.5)	10	32.7 (5)		21.5%	1.6[-3.01,6.21]
Subtotal * **	**10**		**10**			**21.5%**	**1.6[-3.01,6.21]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.68(P=0.5)							
2.4.2 Bilsom UF-1 Muff							
Park 1991b protection	10	36.5 (2.7)	10	34.1 (2.8)		78.5%	2.4[-0.01,4.81]
Subtotal * **	**10**		**10**			**78.5%**	**2.4[-0.01,4.81]**
Heterogeneity: Not applicable							

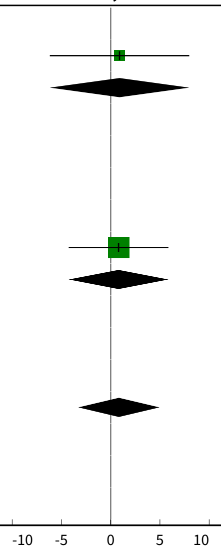


Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Test for overall effect: Z=1.95(P=0.05)							
Total ***	**20**		**20**			**100%**	**2.23[0.09,4.36]**
Heterogeneity: Tau²=0; Chi²=0.09, df=1(P=0.76); I²=0%							
Test for overall effect: Z=2.04(P=0.04)							
Test for subgroup differences: Chi²=0.09, df=1 (P=0.76), I²=0%							
				Favours control	-5 -2.5 0 2.5 5	Favours intervention	



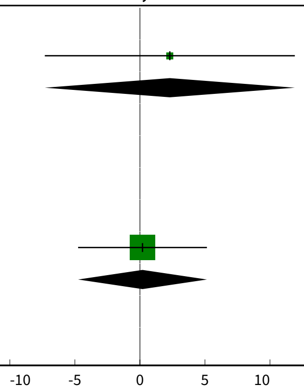
Analysis 2.5. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 5 Noise attenuation at 4 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.5.1 Wilson Sound Ban Cap							
Park 1991b protection	10	32.7 (8.7)	10	31.8 (7.4)		33.84%	0.9[-6.18,7.98]
Subtotal ***	**10**		**10**			**33.84%**	**0.9[-6.18,7.98]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.25(P=0.8)							
2.5.2 Bilsom UF-1 Muff							
Park 1991b protection	10	38.2 (5.2)	10	37.4 (6.3)		66.16%	0.8[-4.26,5.86]
Subtotal ***	**10**		**10**			**66.16%**	**0.8[-4.26,5.86]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.31(P=0.76)							
Total ***	**20**		**20**			**100%**	**0.83[-3.28,4.95]**
Heterogeneity: Tau²=0; Chi²=0, df=1(P=0.98); I²=0%							
Test for overall effect: Z=0.4(P=0.69)							
Test for subgroup differences: Chi²=0, df=1 (P=0.98), I²=0%							
				Favours control	-10 -5 0 5 10	Favours intervention	

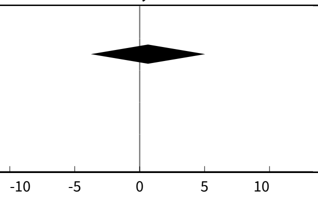


Analysis 2.6. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 6 Noise attenuation at 6 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.6.1 Wilson Sound Ban Cap							
Park 1991b protection	10	34 (9.7)	10	31.7 (12.1)		20.98%	2.3[-7.31,11.91]
Subtotal ***	**10**		**10**			**20.98%**	**2.3[-7.31,11.91]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.47(P=0.64)							
2.6.2 Bilsom UF-1 Muff							
Park 1991b protection	10	37.2 (5.6)	10	37 (5.7)		79.02%	0.2[-4.75,5.15]
Subtotal ***	**10**		**10**			**79.02%**	**0.2[-4.75,5.15]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.08(P=0.94)							
				Favours control	-10 -5 0 5 10	Favours intervention	

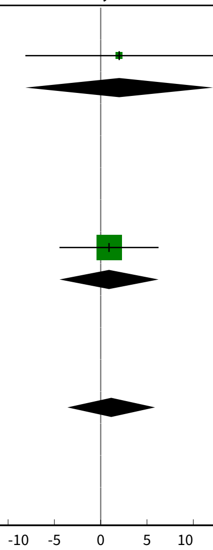


Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Total ***	**20**		**20**			**100%**	**0.64[-3.76,5.04]**
Heterogeneity: Tau²=0; Chi²=0.14, df=1(P=0.7); I²=0%							
Test for overall effect: Z=0.29(P=0.78)							
Test for subgroup differences: Chi²=0.14, df=1 (P=0.7), I²=0%							



Analysis 2.7. Comparison 2 HPD (muffs) with instructions vs without instructions (immediate) - RCT, Outcome 7 Noise attenuation at 8 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
2.7.1 Wilson Sound Ban Cap							
Park 1991b protection	10	32.9 (10.3)	10	30.9 (12.7)		21.79%	2[-8.13,12.13]
Subtotal ***	**10**		**10**			**21.79%**	**2[-8.13,12.13]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.39(P=0.7)							
2.7.2 Bilsom UF-1 Muff							
Park 1991b protection	10	36 (5.9)	10	35.1 (6.3)		78.21%	0.9[-4.45,6.25]
Subtotal ***	**10**		**10**			**78.21%**	**0.9[-4.45,6.25]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.33(P=0.74)							
Total ***	**20**		**20**			**100%**	**1.14[-3.59,5.87]**
Heterogeneity: Tau²=0; Chi²=0.04, df=1(P=0.85); I²=0%							
Test for overall effect: Z=0.47(P=0.64)							
Test for subgroup differences: Chi²=0.04, df=1 (P=0.85), I²=0%							



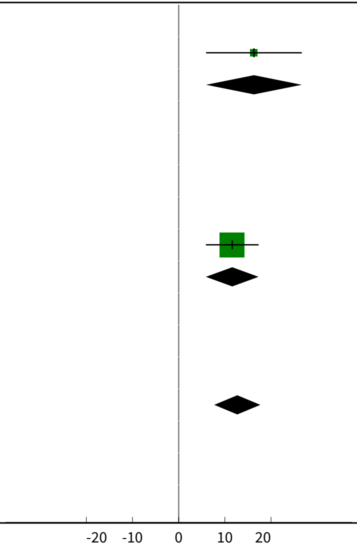
Comparison 3. HPD (plugs) with instructions vs without instructions (immediate) - RCT

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation at 0.5 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	12.69 [7.69, 17.69]
1.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	16.30 [5.93, 26.67]
1.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	11.6 [5.89, 17.31]
2 Noise attenuation at 1 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	13.31 [8.13, 18.50]
2.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	15.40 [5.62, 25.18]
2.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	12.5 [6.39, 18.61]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3 Noise attenuation at 2 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	9.62 [4.52, 14.72]
3.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	7.90 [-1.21, 17.01]
3.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	10.40 [4.25, 16.55]
4 Noise attenuation at 3 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	6.71 [2.66, 10.76]
4.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	6.20 [-1.54, 13.94]
4.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	6.90 [2.15, 11.65]
5 Noise attenuation at 4 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	7.97 [3.60, 12.34]
5.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	6.00 [-1.23, 13.23]
5.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	9.10 [3.62, 14.58]
6 Noise attenuation at 6 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	12.13 [6.21, 18.05]
6.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	9.2 [-1.87, 20.27]
6.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	13.3 [6.30, 20.30]
7 Noise attenuation at 8 kHz (REAT)	1	40	Mean Difference (IV, Random, 95% CI)	11.07 [4.51, 17.64]
7.1 EAR foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	7.60 [-0.97, 16.17]
7.2 UltraFit plugs	1	20	Mean Difference (IV, Random, 95% CI)	14.3 [6.11, 22.49]
8 Mean noise attenuation over 0.5, 1, 2, 3, 4, 6, 8 kHz (REAT)	2	140	Mean Difference (IV, Fixed, 95% CI)	8.59 [6.92, 10.25]
8.1 Moldex Comets, EN352, USA	1	100	Mean Difference (IV, Fixed, 95% CI)	8.34 [6.58, 10.10]
8.2 EAR foam plugs	1	20	Mean Difference (IV, Fixed, 95% CI)	9.8 [0.60, 19.00]
8.3 UltraFit plugs	1	20	Mean Difference (IV, Fixed, 95% CI)	11.16 [4.87, 17.45]

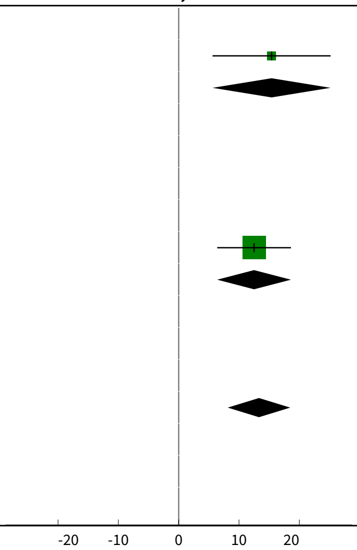
Analysis 3.1. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 1 Noise attenuation at 0.5 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.1.1 EAR foam plugs							
Park 1991b protection	10	33.2 (7.2)	10	16.9 (15.1)		23.26%	16.3[5.93,26.67]
Subtotal ***	**10**		**10**			**23.26%**	**16.3[5.93,26.67]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.08(P=0)							
3.1.2 UltraFit plugs							
Park 1991b protection	10	19 (6.1)	10	7.4 (6.9)		76.74%	11.6[5.89,17.31]
Subtotal ***	**10**		**10**			**76.74%**	**11.6[5.89,17.31]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.98(P<0.0001)							
Total ***	**20**		**20**			**100%**	**12.69[7.69,17.69]**
Heterogeneity: Tau²=0; Chi²=0.61, df=1(P=0.44); I²=0%							
Test for overall effect: Z=4.98(P<0.0001)							
Test for subgroup differences: Chi²=0.61, df=1 (P=0.44), I²=0%							



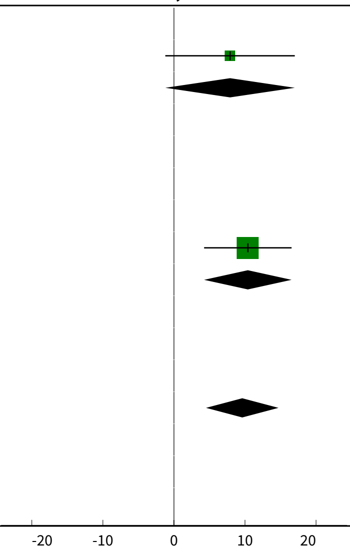
Analysis 3.2. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 2 Noise attenuation at 1 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.2.1 EAR foam plugs							
Park 1991b protection	10	32.3 (6)	10	16.9 (14.6)		28.07%	15.4[5.62,25.18]
Subtotal ***	**10**		**10**			**28.07%**	**15.4[5.62,25.18]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.09(P=0)							
3.2.2 UltraFit plugs							
Park 1991b protection	10	22.2 (5)	10	9.7 (8.5)		71.93%	12.5[6.39,18.61]
Subtotal ***	**10**		**10**			**71.93%**	**12.5[6.39,18.61]**
Heterogeneity: Not applicable							
Test for overall effect: Z=4.01(P<0.0001)							
Total ***	**20**		**20**			**100%**	**13.31[8.13,18.5]**
Heterogeneity: Tau²=0; Chi²=0.24, df=1(P=0.62); I²=0%							
Test for overall effect: Z=5.03(P<0.0001)							
Test for subgroup differences: Chi²=0.24, df=1 (P=0.62), I²=0%							



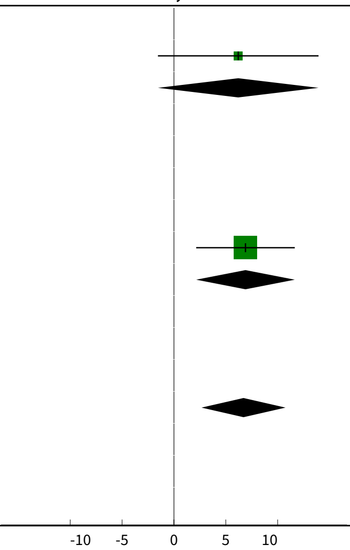
Analysis 3.3. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 3 Noise attenuation at 2 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.3.1 EAR foam plugs							
Park 1991b protection	10	34.9 (3.8)	10	27 (14.2)		31.33%	7.9[-1.21,17.01]
Subtotal ***	**10**		**10**			**31.33%**	**7.9[-1.21,17.01]**
Heterogeneity: Tau²=0; Chi²=0, df=0(P<0.0001); I²=100%							
Test for overall effect: Z=1.7(P=0.09)							
3.3.2 UltraFit plugs							
Park 1991b protection	10	27.3 (5.6)	10	16.9 (8.2)		68.67%	10.4[4.25,16.55]
Subtotal ***	**10**		**10**			**68.67%**	**10.4[4.25,16.55]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.31(P=0)							
Total ***	**20**		**20**			**100%**	**9.62[4.52,14.72]**
Heterogeneity: Tau²=0; Chi²=0.2, df=1(P=0.66); I²=0%							
Test for overall effect: Z=3.7(P=0)							
Test for subgroup differences: Chi²=0.2, df=1 (P=0.66), I²=0%							



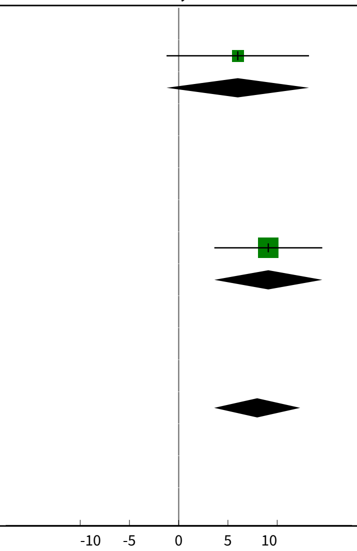
Analysis 3.4. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 4 Noise attenuation at 3 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.4.1 EAR foam plugs							
Park 1991b protection	10	38.5 (3.1)	10	32.3 (12.1)		27.38%	6.2[-1.54,13.94]
Subtotal ***	**10**		**10**			**27.38%**	**6.2[-1.54,13.94]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.57(P=0.12)							
3.4.2 UltraFit plugs							
Park 1991b protection	10	28.9 (4.9)	10	22 (5.9)		72.62%	6.9[2.15,11.65]
Subtotal ***	**10**		**10**			**72.62%**	**6.9[2.15,11.65]**
Heterogeneity: Not applicable							
Test for overall effect: Z=2.85(P=0)							
Total ***	**20**		**20**			**100%**	**6.71[2.66,10.76]**
Heterogeneity: Tau²=0; Chi²=0.02, df=1(P=0.88); I²=0%							
Test for overall effect: Z=3.25(P=0)							
Test for subgroup differences: Chi²=0.02, df=1 (P=0.88), I²=0%							



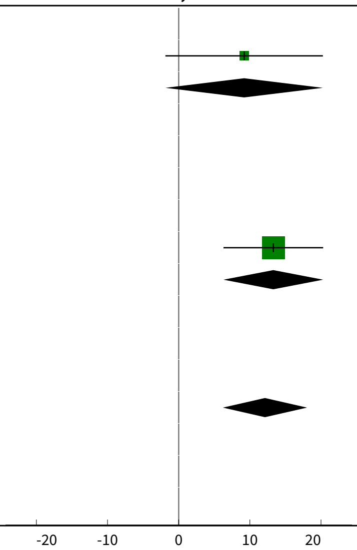
Analysis 3.5. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 5 Noise attenuation at 4 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.5.1 EAR foam plugs							
Park 1991b protection	10	36.3 (3.6)	10	30.3 (11.1)		36.47%	6[-1.23,13.23]
Subtotal ***	**10**		**10**			**36.47%**	**6[-1.23,13.23]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.63(P=0.1)							
3.5.2 UltraFit plugs							
Park 1991b protection	10	28.1 (5.4)	10	19 (7)		63.53%	9.1[3.62,14.58]
Subtotal ***	**10**		**10**			**63.53%**	**9.1[3.62,14.58]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.25(P=0)							
Total ***	**20**		**20**			**100%**	**7.97[3.6,12.34]**
Heterogeneity: Tau²=0; Chi²=0.45, df=1(P=0.5); I²=0%							
Test for overall effect: Z=3.58(P=0)							
Test for subgroup differences: Chi²=0.45, df=1 (P=0.5), I²=0%							



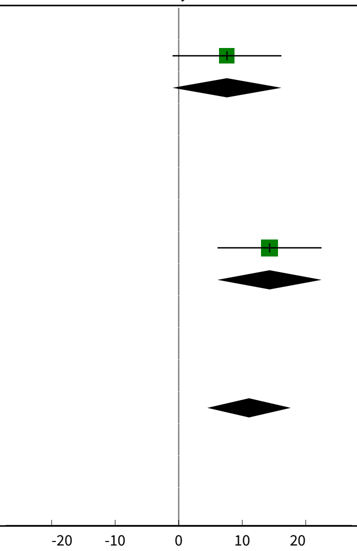
Analysis 3.6. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 6 Noise attenuation at 6 kHz (REAT).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
3.6.1 EAR foam plugs							
Park 1991b protection	10	38.5 (9.2)	10	29.3 (15.3)		28.6%	9.2[-1.87,20.27]
Subtotal ***	**10**		**10**			**28.6%**	**9.2[-1.87,20.27]**
Heterogeneity: Not applicable							
Test for overall effect: Z=1.63(P=0.1)							
3.6.2 UltraFit plugs							
Park 1991b protection	10	30.2 (6.7)	10	16.9 (9.1)		71.4%	13.3[6.3,20.3]
Subtotal ***	**10**		**10**			**71.4%**	**13.3[6.3,20.3]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.72(P=0)							
Total ***	**20**		**20**			**100%**	**12.13[6.21,18.05]**
Heterogeneity: Tau²=0; Chi²=0.38, df=1(P=0.54); I²=0%							
Test for overall effect: Z=4.02(P<0.0001)							
Test for subgroup differences: Chi²=0.38, df=1 (P=0.54), I²=0%							



Analysis 3.7. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 7 Noise attenuation at 8 kHz (REAT).

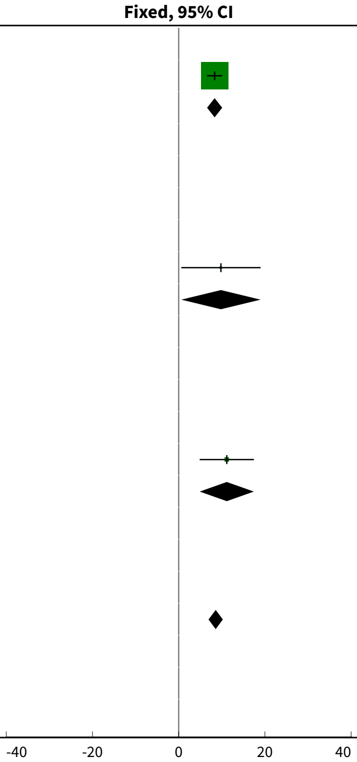
Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Weight	Mean Difference Random, 95% CI
3.7.1 EAR foam plugs						
Park 1991b protection	10	36.3 (6.1)	10	28.7 (12.4)	48.15%	7.6[-0.97,16.17]
Subtotal ***	**10**		**10**		**48.15%**	**7.6[-0.97,16.17]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.74(P=0.08)						
3.7.2 UltraFit plugs						
Park 1991b protection	10	32.1 (7.6)	10	17.8 (10.8)	51.85%	14.3[6.11,22.49]
Subtotal ***	**10**		**10**		**51.85%**	**14.3[6.11,22.49]**
Heterogeneity: Not applicable						
Test for overall effect: Z=3.42(P=0)						
Total ***	**20**		**20**		**100%**	**11.07[4.51,17.64]**
Heterogeneity: Tau²=4.18; Chi²=1.23, df=1(P=0.27); I²=18.61%						
Test for overall effect: Z=3.31(P=0)						
Test for subgroup differences: Chi²=1.23, df=1 (P=0.27), I²=18.61%						



Favours no training | Favours training

Analysis 3.8. Comparison 3 HPD (plugs) with instructions vs without instructions (immediate) - RCT, Outcome 8 Mean noise attenuation over 0.5, 1, 2, 3, 4, 6, 8 kHz (REAT).

Study or subgroup	earplug with training N	earplug with training Mean(SD)	earplug without training N	earplug without training Mean(SD)	Weight	Mean Difference Fixed, 95% CI
3.8.1 Moldex Comets, EN352, USA						
Salmani 2014	50	13.9 (5)	50	5.5 (3.9)	89.73%	8.34[6.58,10.1]
Subtotal ***	**50**		**50**		**89.73%**	**8.34[6.58,10.1]**
Heterogeneity: Not applicable						
Test for overall effect: Z=9.31(P<0.0001)						
3.8.2 EAR foam plugs						
Park 1991b protection	10	35.7 (5.9)	10	25.9 (13.6)	3.27%	9.8[0.6,19]
Subtotal ***	**10**		**10**		**3.27%**	**9.8[0.6,19]**
Heterogeneity: Not applicable						
Test for overall effect: Z=2.09(P=0.04)						
3.8.3 UltraFit plugs						
Park 1991b protection	10	26.8 (6)	10	15.7 (8.2)	7%	11.16[4.87,17.45]
Subtotal ***	**10**		**10**		**7%**	**11.16[4.87,17.45]**
Heterogeneity: Tau²=0; Chi²=0, df=0(P<0.0001); I²=100%						
Test for overall effect: Z=3.48(P=0)						
Total ***	**70**		**70**		**100%**	**8.59[6.92,10.25]**
Heterogeneity: Tau²=0; Chi²=0.79, df=2(P=0.67); I²=0%						
Test for overall effect: Z=10.12(P<0.0001)						
Test for subgroup differences: Chi²=0.79, df=1 (P=0.67), I²=0%						



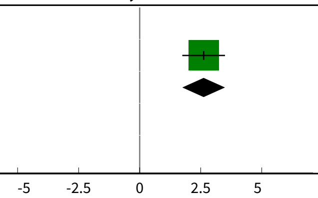
Favours no training | Favours training

Comparison 4. HPD (plugs) lower noise reduction rate (NRR) with instructions vs higher NRR without instructions (immediate) - RCT

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Mean attenuation at 0.5, 1, 2, 3, 4, 6, 8 kHz	1		Mean Difference (IV, Fixed, 95% CI)	Subtotals only
1.1 NRR 20 vs NRR 30	1	100	Mean Difference (IV, Fixed, 95% CI)	2.62 [1.75, 3.49]

Analysis 4.1. Comparison 4 HPD (plugs) lower noise reduction rate (NRR) with instructions vs higher NRR without instructions (immediate) - RCT, Outcome 1 Mean attenuation at 0.5, 1, 2, 3, 4, 6, 8 kHz.

Study or subgroup	earplug with training N	earplug with training Mean(SD)	earplug without training N	earplug without training Mean(SD)	Mean Difference Fixed, 95% CI	Weight	Mean Difference Fixed, 95% CI
4.1.1 NRR 20 vs NRR 30							
Salmani 2014	50	13.9 (2)	50	11.3 (2.5)		100%	2.62[1.75,3.49]
Subtotal ***	**50**		**50**			**100%**	**2.62[1.75,3.49]**
Heterogeneity: Not applicable							
Test for overall effect: Z=5.87(P<0.0001)							



Favours no training | Favours training

Comparison 5. HPD with ANC vs without ANC (immediate)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation (dB)	1	4	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.1 Alpha-200 series with Active Noise Cancelling	1	2	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 Gentex/Bose Active Noise Cancelling	1	2	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2 TTS at 1 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
3 TTS at 2 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
4 TTS at 4 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
5 TTS at 6 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
6 TTS at 8 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only

Analysis 5.1. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 1 Noise attenuation (dB).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Fixed, 95% CI	Weight	Mean Difference Fixed, 95% CI
5.1.1 Alpha-200 series with Active Noise Cancelling							
Pääkkönen 2001	1	25 (0)	1	17 (0)			Not estimable
Subtotal ***	**1**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
5.1.2 Gentex/Bose Active Noise Cancelling							
Pääkkönen 2001	1	24 (0)	1	20 (0)			Not estimable
Subtotal ***	**1**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Total ***	**2**		**2**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Test for subgroup differences: Not applicable							
				Favours Control	-10 -5 0 5 10	Favours Intervention	

Analysis 5.2. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 2 TTS at 1 kHz (before exposure - after exposure).

Study or subgroup	Noise cancellation N	Noise cancellation Mean(SD)	Earplug/phone N	Earplug/phone Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Horie 2002	12	-2.5 (0)	12	-4.2 (0)			Not estimable
				Favours Control	-20 -10 0 10 20	Favours Intervention	

Analysis 5.3. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 3 TTS at 2 kHz (before exposure - after exposure).

Study or subgroup	Noise cancellation N	Noise cancellation Mean(SD)	Earplug/phone N	Earplug/phone Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Horie 2002	12	-3 (0)	12	-7.1 (0)			Not estimable
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Analysis 5.4. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 4 TTS at 4 kHz (before exposure - after exposure).

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI		Random, 95% CI
Horie 2002	12	-5.8 (0)	12	-11.2 (0)			Not estimable
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Analysis 5.5. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 5 TTS at 6 kHz (before exposure - after exposure).

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI		Random, 95% CI
Horie 2002	12	-3.7 (0)	12	-8.1 (0)			Not estimable
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Analysis 5.6. Comparison 5 HPD with ANC vs without ANC (immediate), Outcome 6 TTS at 8 kHz (before exposure - after exposure).

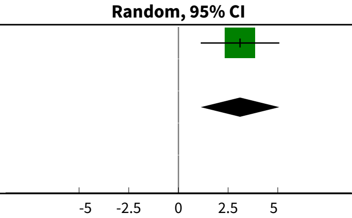
Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI		Random, 95% CI
Horie 2002	12	-4.6 (0)	12	-5.4 (0)			Not estimable
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Comparison 6. Custom-moulded musician HPD (plugs) with higher versus HPD (plugs) with lower noise attenuation

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation dB(A)	1	20	Mean Difference (IV, Random, 95% CI)	3.10 [1.12, 5.08]

Analysis 6.1. Comparison 6 Custom-moulded musician HPD (plugs) with higher versus HPD (plugs) with lower noise attenuation, Outcome 1 Noise attenuation dB(A).

Study or subgroup	ER-15		ER-9		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI		Random, 95% CI
Huttunen 2011	10	13.9 (1.7)	10	10.8 (2.7)		100%	3.1[1.12,5.08]
Total ***	**10**		**10**			**100%**	**3.1[1.12,5.08]**
Heterogeneity: Not applicable							
Test for overall effect: Z=3.07(P=0)							
				Favours ER-9	-5 -2.5 0 2.5 5	Favours ER-15	



Comparison 7. HPD (various) noise attenuation (immediate)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation (dB)	1	36	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.1 Peltor H61 Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 Peltor H7 Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.3 Peltor H6 Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.4 Bilsom Marksman Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.5 Silenta Hunter Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.6 EAR Ultra 9000 Plug	1	6	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]

Analysis 7.1. Comparison 7 HPD (various) noise attenuation (immediate), Outcome 1 Noise attenuation (dB).

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference Fixed, 95% CI	Weight	Mean Difference Fixed, 95% CI
7.1.1 Peltor H61 Muff Elec							
Pääkkönen 1998	5	24 (13)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
7.1.2 Peltor H7 Muff Elec							
Pääkkönen 1998	5	26 (16)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
7.1.3 Peltor H6 Muff Elec							
Pääkkönen 1998	5	25 (13)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
7.1.4 Bilsom Marksman Muff Elec							
Pääkkönen 1998	5	26 (17)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
7.1.5 Silenta Hunter Muff Elec							
Pääkkönen 1998	5	27 (16)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**

Favours intervention -0.01 -0.005 0 0.005 0.01 Favours control

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI		Fixed, 95% CI
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
7.1.6 EAR Ultra 9000 Plug							
Pääkkönen 1998	5	22 (14)	1	0 (0)			Not estimable
Subtotal ***	**5**		**1**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Total ***	**30**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Test for subgroup differences: Not applicable							

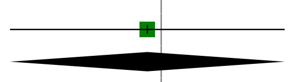
Favours intervention -0.01 -0.005 0 0.005 0.01 Favours control

Comparison 8. HLPP with noise level indicator vs no noise level indicator

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Change in noise levels at 2 months' follow-up	1	132	Mean Difference (IV, Random, 95% CI)	0.32 [-2.44, 3.08]
1.1 Extensive information plus NLI vs information only	1	64	Mean Difference (IV, Random, 95% CI)	-0.40 [-4.37, 3.57]
1.2 Information plus NLI vs Information only	1	68	Mean Difference (IV, Random, 95% CI)	1.0 [-2.84, 4.84]
2 Change in noise levels at 4 months' follow-up	1	132	Mean Difference (IV, Fixed, 95% CI)	-0.14 [-2.66, 2.38]
2.1 Extensive information plus NLI vs information only	1	64	Mean Difference (IV, Fixed, 95% CI)	-0.30 [-3.95, 3.35]
2.2 Information plus NLI vs information only	1	68	Mean Difference (IV, Fixed, 95% CI)	0.0 [-3.48, 3.48]

Analysis 8.1. Comparison 8 HLPP with noise level indicator vs no noise level indicator, Outcome 1 Change in noise levels at 2 months' follow-up.

Study or subgroup	Noise Level Indicator		No noise level indicator		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI		Random, 95% CI
8.1.1 Extensive information plus NLI vs information only							
Seixas 2011	41	-2.2 (6.8)	23	-1.8 (8.3)		48.34%	-0.4[-4.37,3.57]
Subtotal ***	**41**		**23**			**48.34%**	**-0.4[-4.37,3.57]**
Heterogeneity: Not applicable							



Favours experimental -5 -2.5 0 2.5 5 Favours control

Study or subgroup	Noise Level Indicator N	Noise Level Indicator Mean(SD)	No noise level indicator N	No noise level indicator Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Test for overall effect: Z=0.2(P=0.84)							
8.1.2 Information plus NLI vs Information only							
Seixas 2011	45	-0.8 (6.2)	23	-1.8 (8.3)		51.66%	1[-2.84,4.84]
Subtotal ***	**45**		**23**			**51.66%**	**1[-2.84,4.84]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.51(P=0.61)							
Total ***	**86**		**46**			**100%**	**0.32[-2.44,3.08]**
Heterogeneity: Tau²=0; Chi²=0.25, df=1(P=0.62); I²=0%							
Test for overall effect: Z=0.23(P=0.82)							
Test for subgroup differences: Chi²=0.25, df=1 (P=0.62), I²=0%							

Favours experimental -5 -2.5 0 2.5 5 Favours control

Analysis 8.2. Comparison 8 HLPP with noise level indicator vs no noise level indicator, Outcome 2 Change in noise levels at 4 months' follow-up.

Study or subgroup	Noise Level Indicator N	Noise Level Indicator Mean(SD)	No noise level indicator N	No noise level indicator Mean(SD)	Mean Difference Fixed, 95% CI	Weight	Mean Difference Fixed, 95% CI
8.2.1 Extensive information plus NLI vs information only							
Seixas 2011	41	-2.2 (7.3)	23	-1.9 (7.1)		47.63%	-0.3[-3.95,3.35]
Subtotal ***	**41**		**23**			**47.63%**	**-0.3[-3.95,3.35]**
Heterogeneity: Not applicable							
Test for overall effect: Z=0.16(P=0.87)							
8.2.2 Information plus NLI vs information only							
Seixas 2011	45	-1.9 (6.7)	23	-1.9 (7.1)		52.37%	0[-3.48,3.48]
Subtotal ***	**45**		**23**			**52.37%**	**0[-3.48,3.48]**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Total ***	**86**		**46**			**100%**	**-0.14[-2.66,2.38]**
Heterogeneity: Tau²=0; Chi²=0.01, df=1(P=0.91); I²=0%							
Test for overall effect: Z=0.11(P=0.91)							
Test for subgroup differences: Chi²=0.01, df=1 (P=0.91), I²=0%							

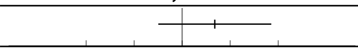
Favours experimental -5 -2.5 0 2.5 5 Favours control

Comparison 9. HLPP with extensive information vs information only

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Change in noise levels at 2 months' follow-up	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
2 Change in noise levels at 4 months' follow-up	1		Mean Difference (IV, Random, 95% CI)	Totals not selected

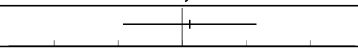
Analysis 9.1. Comparison 9 HLPP with extensive information vs information only, Outcome 1 Change in noise levels at 2 months' follow-up.

Study or subgroup	Experimental		Control		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Fixed, 95% CI	Fixed, 95% CI
Seixas 2011	44	-0.1 (5.8)	46	-1.8 (8.3)		1.7[-1.24,4.64]



Analysis 9.2. Comparison 9 HLPP with extensive information vs information only, Outcome 2 Change in noise levels at 4 months' follow-up.

Study or subgroup	Extensive Information		Information		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	Random, 95% CI	Random, 95% CI
Seixas 2011	44	-1.6 (5.5)	46	-1.9 (7.1)		0.3[-2.31,2.91]



Comparison 10. V-51-R plug versus EAR plug (immediate)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 TTS at 0.5 kHz (Hearing loss before exposure - after exposure)	1	70	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
1.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
1.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
1.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
1.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
2 TTS at 1 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
2.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
2.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
2.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
2.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
3 TTS at 2 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
3.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
3.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
3.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
3.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
4 TTS at 3 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
4.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
4.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
4.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
4.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
5 TTS at 4 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
5.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
5.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
5.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
5.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
6 TTS at 6 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
6.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
6.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
6.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]
6.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	0.0 [0.0, 0.0]

Analysis 10.1. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 1 TTS at 0.5 kHz (Hearing loss before exposure - after exposure).

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.1.1 After 8 minutes out of noise							
Royster 1980	9	-0.8 (0)	9	-1.3 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.1.2 After 14.6 minutes out of noise							
Royster 1980	8	-0.6 (0)	10	-1 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.1.3 After 20 minutes out of noise							
Royster 1980	7	-1.4 (0)	10	-0.7 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.1.4 After 27.2 minutes out of noise							
Royster 1980	11	-0.5 (0)	6	-1.6 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Total ***	**35**		**35**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
Test for subgroup differences: Not applicable							

Favours Control -100 -50 0 50 100 Favours Intervention

Analysis 10.2. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 2 TTS at 1 kHz (before exposure - after exposure).

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.2.1 After 8 minutes out of noise							
Royster 1980	9	-2.8 (0)	9	-2.3 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.2.2 After 14.6 minutes out of noise							
Royster 1980	8	-0.2 (0)	10	-0.1 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.2.3 After 20 minutes out of noise							
Royster 1980	7	-0.4 (0)	10	-0.3 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.2.4 After 27.2 minutes out of noise							
Royster 1980	11	-0.5 (0)	6	0.4 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Analysis 10.3. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 3 TTS at 2 kHz (before exposure - after exposure).

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.3.1 After 8 minutes out of noise							
Royster 1980	9	-3.9 (0)	9	-0.5 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.3.2 After 14.6 minutes out of noise							
Royster 1980	8	-0.1 (0)	10	-0.8 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.3.3 After 20 minutes out of noise							
Royster 1980	7	-0.4 (0)	10	0.2 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.3.4 After 27.2 minutes out of noise							
Royster 1980	11	0.9 (0)	6	2.8 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
		Favours Control			-100 -50 0 50 100	Favours Intervention	

Analysis 10.4. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 4 TTS at 3 kHz (before exposure - after exposure).

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.4.1 After 8 minutes out of noise							
Royster 1980	9	-3.2 (0)	9	0.2 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.4.2 After 14.6 minutes out of noise							
Royster 1980	8	0.1 (0)	10	0.1 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.4.3 After 20 minutes out of noise							
Royster 1980	7	1.6 (0)	10	0.3 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.4.4 After 27.2 minutes out of noise							
Royster 1980	11	1.7 (0)	6	3 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
		Favours Control			-100 -50 0 50 100	Favours Intervention	

Analysis 10.5. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 5 TTS at 4 kHz (before exposure - after exposure).

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.5.1 After 8 minutes out of noise							
Royster 1980	9	-2.4 (0)	9	-0.2 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
		Favours Control			-100 -50 0 50 100	Favours Intervention	

Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
Test for overall effect: Not applicable							
10.5.2 After 14.6 minutes out of noise							
Royster 1980	8	1.6 (0)	10	1.2 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.5.3 After 20 minutes out of noise							
Royster 1980	7	-0.6 (0)	10	1.5 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.5.4 After 27.2 minutes out of noise							
Royster 1980	11	1.9 (0)	6	3.4 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Analysis 10.6. Comparison 10 V-51-R plug versus EAR plug (immediate), Outcome 6 TTS at 6 kHz (before exposure - after exposure).

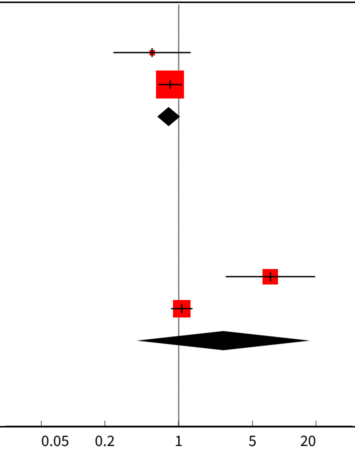
Study or subgroup	V-51-R plug N	V-51-R plug Mean(SD)	EAR plug N	EAR plug Mean(SD)	Mean Difference Random, 95% CI	Weight	Mean Difference Random, 95% CI
10.6.1 After 8 minutes out of noise							
Royster 1980	9	-4.1 (0)	9	0.1 (0)			Not estimable
Subtotal ***	**9**		**9**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.6.2 After 14.6 minutes out of noise							
Royster 1980	8	0.9 (0)	10	0.2 (0)			Not estimable
Subtotal ***	**8**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.6.3 After 20 minutes out of noise							
Royster 1980	7	1.6 (0)	10	0.3 (0)			Not estimable
Subtotal ***	**7**		**10**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
10.6.4 After 27.2 minutes out of noise							
Royster 1980	11	2 (0)	6	1.3 (0)			Not estimable
Subtotal ***	**11**		**6**				**Not estimable**
Heterogeneity: Not applicable							
Test for overall effect: Not applicable							
				Favours Control	-100 -50 0 50 100	Favours Intervention	

Comparison 11. Earmuffs vs earplugs (long-term)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change over 3 years (4 kHz / STS)	2		OR (Random, 95% CI)	Subtotals only
1.1 High noise exposure > 89 dB(A)	2		OR (Random, 95% CI)	0.80 [0.63, 1.03]
1.2 Low noise exposure < 89 dB(A)	2		OR (Random, 95% CI)	2.65 [0.40, 17.52]

Analysis 11.1. Comparison 11 Earmuffs vs earplugs (long-term), Outcome 1 Hearing loss change over 3 years (4 kHz / STS).

Study or subgroup	Muffs N	Plugs N	log[OR] (SE)	Odds Ratio IV, Random, 95% CI	Weight	Odds Ratio IV, Random, 95% CI
11.1.1 High noise exposure > 89 dB(A)						
Erlandsson 1980	0	0	-0.6 (0.431)		8.57%	0.56[0.24,1.3]
Nilsson 1980	0	0	-0.2 (0.132)		91.43%	0.83[0.64,1.08]
Subtotal (95% CI)					**100%**	**0.8[0.63,1.03]**
Heterogeneity: Tau²=0; Chi²=0.76, df=1(P=0.38); I²=0%						
Test for overall effect: Z=1.74(P=0.08)						
11.1.2 Low noise exposure < 89 dB(A)						
Erlandsson 1980	0	0	2 (0.497)		46.88%	7.39[2.79,19.59]
Nilsson 1980	0	0	0.1 (0.119)		53.12%	1.07[0.85,1.35]
Subtotal (95% CI)					**100%**	**2.65[0.4,17.52]**
Heterogeneity: Tau²=1.74; Chi²=14.27, df=1(P=0); I²=92.99%						
Test for overall effect: Z=1.01(P=0.31)						



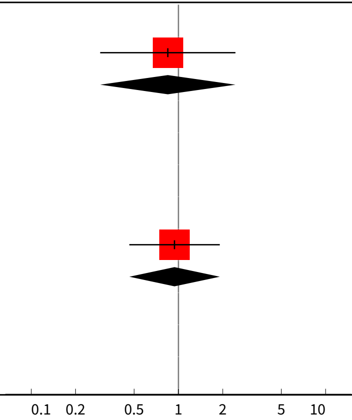
Favours Muffs | Favours Plugs

Comparison 12. HLPP vs audiometric testing (agriculture students, long-term, 3-year and 16-year follow-up) - RCT

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 STS	1		Odds Ratio (Fixed, 95% CI)	Subtotals only
1.1 3-year follow-up	1		Odds Ratio (Fixed, 95% CI)	0.85 [0.29, 2.44]
1.2 16-year follow-up	1		Odds Ratio (Fixed, 95% CI)	0.94 [0.46, 1.91]

Analysis 12.1. Comparison 12 HLPP vs audiometric testing (agriculture students, long-term, 3-year and 16-year follow-up) - RCT, Outcome 1 STS.

Study or subgroup	Favours HLPP N	Control N	log[Odds Ratio] (SE)	Odds Ratio IV, Fixed, 95% CI	Weight	Odds Ratio IV, Fixed, 95% CI
12.1.1 3-year follow-up						
Berg 2009	346	341	-0.2 (0.54)		100%	0.85[0.29,2.44]
Subtotal (95% CI)					**100%**	**0.85[0.29,2.44]**
Heterogeneity: Tau²=0; Chi²=0, df=0(P<0.0001); I²=100%						
Test for overall effect: Z=0.31(P=0.76)						
12.1.2 16-year follow-up						
Berg 2009	0	0	-0.1 (0.36)		100%	0.94[0.46,1.91]
Subtotal (95% CI)					**100%**	**0.94[0.46,1.91]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.17(P=0.86)						
Test for subgroup differences: Chi²=0.03, df=1 (P=0.87), I²=0%						



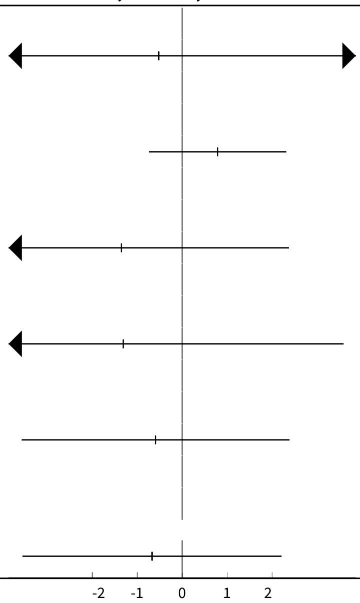
Comparison 13. HLPP with daily noise-exposure monitoring with feedback vs annual audiometry (long-term) - ITS

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 HL (dB/year at 2, 3 and 4 kHz) Δ level	1		rate of hearing loss (Random, 95% CI)	Totals not selected
1.1 intervention - controlled for age, gender, baseline hearing	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
1.2 control - controlled for age, gender, baseline hearing	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
1.3 intervention minus control - controlled for age, gender, baseline hearing	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
1.4 intervention - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
1.5 control - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
1.6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Random, 95% CI)	0.0 [0.0, 0.0]
2 HL (dB/year at 2, 3 and 4 kHz) slope	1		rate of hearing loss (Fixed, 95% CI)	Totals not selected
2.1 intervention - controlled for age, gender, baseline hearing	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]
2.2 control - controlled for age, gender, baseline hearing	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.3 intervention minus control - controlled for age, gender, baseline hearing	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]
2.4 intervention - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]
2.5 control - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]
2.6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL	1		rate of hearing loss (Fixed, 95% CI)	0.0 [0.0, 0.0]

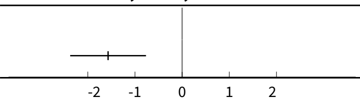
Analysis 13.1. Comparison 13 HLPP with daily noise-exposure monitoring with feedback vs annual audiometry (long-term) - ITS, Outcome 1 HL (dB/year at 2, 3 and 4 kHz) Δ level.

Study or subgroup	Favours monitoring N	annual audiometry N	rate of hearing loss (SE)	rate of hearing loss IV, Random, 95% CI	rate of hearing loss IV, Random, 95% CI
13.1.1 intervention - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	-0.5 (2.58)		-0.52[-5.58,4.54]
13.1.2 control - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	0.8 (0.78)		0.79[-0.74,2.32]
13.1.3 intervention minus control - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	-1.3 (1.9)		-1.35[-5.07,2.37]
13.1.4 intervention - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-1.3 (2.5)		-1.31[-6.21,3.59]
13.1.5 control - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-0.6 (1.52)		-0.59[-3.57,2.39]
13.1.6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-0.7 (1.47)		-0.67[-3.55,2.21]
			Favours after Interv.	-2 -1 0 1 2	Favours before Interv.

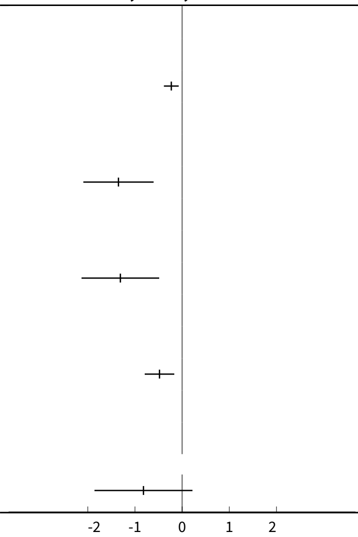


Analysis 13.2. Comparison 13 HLPP with daily noise-exposure monitoring with feedback vs annual audiometry (long-term) - ITS, Outcome 2 HL (dB/year at 2, 3 and 4 kHz) slope.

Study or subgroup	Favours experimental N	annual audiometry N	rate of hearing loss (SE)	rate of hearing loss IV, Fixed, 95% CI	rate of hearing loss IV, Fixed, 95% CI
13.2.1 intervention - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	-1.6 (0.41)		-1.57[-2.37,-0.77]
			Favours after Intervent.	-2 -1 0 1 2	Favours before Intervent.



Study or subgroup	Favours experimental N	annual audiometry N	rate of hearing loss (SE)	rate of hearing loss IV, Fixed, 95% CI	rate of hearing loss IV, Fixed, 95% CI
13.2.2 control - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	-0.2 (0.08)		-0.23[-0.39,-0.07]
13.2.3 intervention minus control - controlled for age, gender, baseline hearing					
Rabinowitz 2011	0	0	-1.3 (0.38)		-1.35[-2.09,-0.61]
13.2.4 intervention - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-1.3 (0.42)		-1.31[-2.13,-0.49]
13.2.5 control - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-0.5 (0.16)		-0.48[-0.79,-0.17]
13.2.6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL					
Rabinowitz 2011	0	0	-0.8 (0.53)		-0.82[-1.86,0.22]



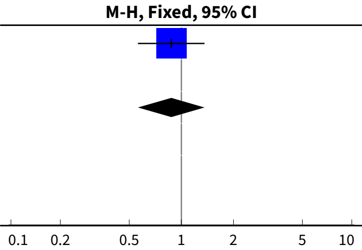
Favours after Intervent. | Favours before Intervent.

Comparison 14. Follow-up exam after initial STS vs no exam (long-term)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change (STS)	1	1317	Odds Ratio (M-H, Fixed, 95% CI)	0.87 [0.56, 1.36]

Analysis 14.1. Comparison 14 Follow-up exam after initial STS vs no exam (long-term), Outcome 1 Hearing loss change (STS).

Study or subgroup	Detailed Follow-up n/N	No follow-up n/N	Odds Ratio M-H, Fixed, 95% CI	Weight	Odds Ratio M-H, Fixed, 95% CI
Meyer 1993	32/496	60/821		100%	0.87[0.56,1.36]
Total (95% CI)	**496**	**821**		**100%**	**0.87[0.56,1.36]**
Total events: 32 (Detailed Follow-up), 60 (No follow-up)					
Heterogeneity: Tau²=0; Chi²=0, df=0(P<0.0001); I²=100%					
Test for overall effect: Z=0.59(P=0.55)					



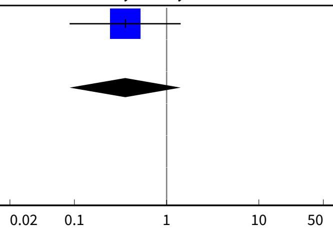
Favours intervention | Favours control

Comparison 15. Well-implemented HLPP vs less well-implemented (long-term, 1-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 STS	1	341	Risk Ratio (M-H, Fixed, 95% CI)	0.36 [0.09, 1.42]

Analysis 15.1. Comparison 15 Well-implemented HLPP vs less well-implemented (long-term, 1-year follow-up), Outcome 1 STS.

Study or subgroup	Well implemented n/N	Not well implemented n/N	Risk Ratio M-H, Fixed, 95% CI	Weight	Risk Ratio M-H, Fixed, 95% CI
Simpson 1994	2/45	37/296		100%	0.36[0.09,1.42]
Total (95% CI)	**45**	**296**		**100%**	**0.36[0.09,1.42]**
Total events: 2 (Well implemented), 37 (Not well implemented)					
Heterogeneity: Not applicable					
Test for overall effect: Z=1.46(P=0.14)					



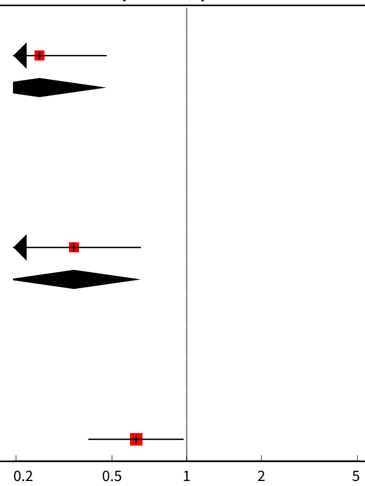
Well implemented | Less quality

Comparison 16. Well-implemented HLPP vs less well-implemented (long-term > 5-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change STS/at 4 kHz	3	16301	OR (Random, 95% CI)	0.40 [0.23, 0.69]
1.1 Adera 2000	1	15345	OR (Random, 95% CI)	0.26 [0.14, 0.47]
1.2 Adera 1993	1	692	OR (Random, 95% CI)	0.35 [0.19, 0.65]
1.3 Brink 2000	1	264	OR (Random, 95% CI)	0.62 [0.40, 0.97]

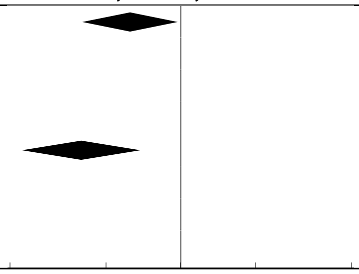
Analysis 16.1. Comparison 16 Well-implemented HLPP vs less well-implemented (long-term > 5-year follow-up), Outcome 1 Hearing loss change STS/at 4 kHz.

Study or subgroup	Excellent/Good HLPP N	Less quality HLPP N	log[OR] (SE)	Odds Ratio IV, Random, 95% CI	Weight	Odds Ratio IV, Random, 95% CI
16.1.1 Adera 2000						
Adera 2000	22	15323	-1.4 (0.317)		30.88%	0.26[0.14,0.47]
Subtotal (95% CI)					**30.88%**	**0.26[0.14,0.47]**
Heterogeneity: Not applicable						
Test for overall effect: Z=4.31(P<0.0001)						
16.1.2 Adera 1993						
Adera 1993	93	599	-1 (0.317)		30.88%	0.35[0.19,0.65]
Subtotal (95% CI)					**30.88%**	**0.35[0.19,0.65]**
Heterogeneity: Not applicable						
Test for overall effect: Z=3.3(P=0)						
16.1.3 Brink 2000						
Brink 2002	132	132	-0.5 (0.226)		38.23%	0.62[0.4,0.97]



Favours high quality | Favours less quality

Study or subgroup	Excellent/Good HLPP N	Less quality HLPP N	log[OR] (SE)	Odds Ratio IV, Random, 95% CI	Weight	Odds Ratio IV, Random, 95% CI
Subtotal (95% CI)					**38.23%**	**0.62[0.4,0.97]**
Heterogeneity: Not applicable						
Test for overall effect: Z=2.08(P=0.04)						
Total (95% CI)					**100%**	**0.4[0.23,0.69]**
Heterogeneity: Tau²=0.16; Chi²=5.84, df=2(P=0.05); I²=65.77%						
Test for overall effect: Z=3.29(P=0)						
Test for subgroup differences: Chi²=5.84, df=1 (P=0.05), I²=65.77%						

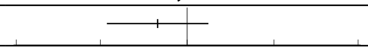


Comparison 17. HLPP 12-hour shift vs HLPP 8-hour shift (long-term 1-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change over 1 year at 4 kHz	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected

Analysis 17.1. Comparison 17 HLPP 12-hour shift vs HLPP 8-hour shift (long-term 1-year follow-up), Outcome 1 Hearing loss change over 1 year at 4 kHz.

Study or subgroup	12 hour shift N	12 hour shift Mean(SD)	8 hour shift N	8 hour shift Mean(SD)	Mean Difference Fixed, 95% CI	Mean Difference Fixed, 95% CI
Reynolds 1990a	272	0.4 (8.6)	580	1.1 (6.9)		-0.68[-1.85,0.49]

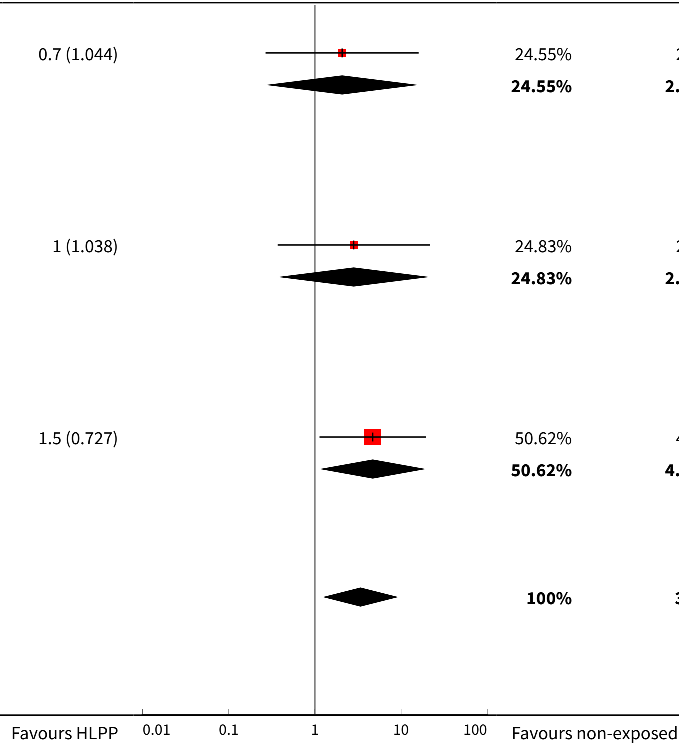


Comparison 18. HLPP vs non-exposed workers (long-term 1-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 hearing loss STS	1		Risk Ratio (Random, 95% CI)	3.38 [1.23, 9.32]
1.1 low-exposed engineers	1		Risk Ratio (Random, 95% CI)	2.07 [0.27, 15.99]
1.2 medium-exposed infantry	1		Risk Ratio (Random, 95% CI)	2.82 [0.37, 21.57]
1.3 high-exposed artillery	1		Risk Ratio (Random, 95% CI)	4.69 [1.13, 19.51]

Analysis 18.1. Comparison 18 HLPP vs non-exposed workers (long-term 1-year follow-up), Outcome 1 hearing loss STS.

Study or subgroup	HLPP N	Non-exposed N	log[Risk Ratio] (SE)	Risk Ratio IV, Random, 95% CI	Weight	Risk Ratio IV, Random, 95% CI
18.1.1 low-exposed engineers						
Muhr 2006	0	0	0.7 (1.044)		24.55%	2.07[0.27,15.99]
Subtotal (95% CI)					**24.55%**	**2.07[0.27,15.99]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.7(P=0.49)						
18.1.2 medium-exposed infantry						
Muhr 2006	0	0	1 (1.038)		24.83%	2.82[0.37,21.57]
Subtotal (95% CI)					**24.83%**	**2.82[0.37,21.57]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1(P=0.32)						
18.1.3 high-exposed artillery						
Muhr 2006	0	0	1.5 (0.727)		50.62%	4.69[1.13,19.51]
Subtotal (95% CI)					**50.62%**	**4.69[1.13,19.51]**
Heterogeneity: Not applicable						
Test for overall effect: Z=2.13(P=0.03)						
Total (95% CI)					**100%**	**3.38[1.23,9.32]**
Heterogeneity: $Tau^2=0$; $Chi^2=0.46$, df=2(P=0.8); $I^2=0\%$						
Test for overall effect: Z=2.36(P=0.02)						
Test for subgroup differences: $Chi^2=0.46$, df=1 (P=0.8), $I^2=0\%$						

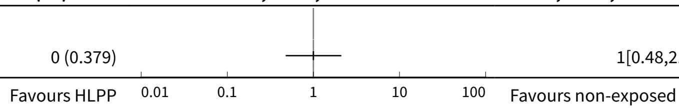


Comparison 19. Improved HLPP vs non-exposed workers (long-term 1-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 hearing loss STS	1		Risk Ratio (Fixed, 95% CI)	Totals not selected
1.1 high-exposed artillery	1		Risk Ratio (Fixed, 95% CI)	0.0 [0.0, 0.0]

Analysis 19.1. Comparison 19 Improved HLPP vs non-exposed workers (long-term 1-year follow-up), Outcome 1 hearing loss STS.

Study or subgroup	HLPP N	Non-exposed N	log[Risk Ratio] (SE)	Risk Ratio IV, Fixed, 95% CI	Risk Ratio IV, Fixed, 95% CI
19.1.1 high-exposed artillery					
Muhr 2016	0	0	0 (0.379)		1[0.48,2.11]

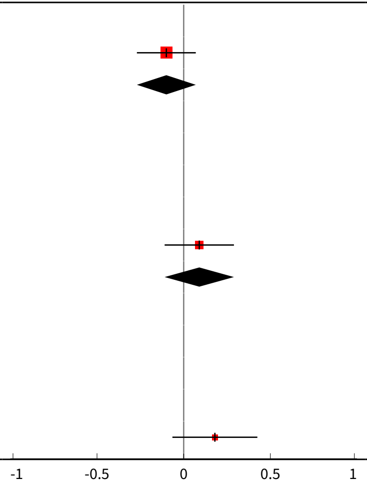


Comparison 20. HLPP vs non-exposed workers (long-term > 5-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change at 4 kHz/STS (5-year follow-up)	4	2231	effect size (Fixed, 95% CI)	0.05 [-0.05, 0.16]
1.1 Pell hearing loss 10 dB	1	628	effect size (Fixed, 95% CI)	-0.1 [-0.27, 0.07]
1.2 Pell hearing loss 15 to 35 dB	1	559	effect size (Fixed, 95% CI)	0.09 [-0.11, 0.29]
1.3 Pell hearing loss 40 dB	1	385	effect size (Fixed, 95% CI)	0.18 [-0.06, 0.42]
1.4 Lee-Feldstein	1	474	effect size (Fixed, 95% CI)	0.29 [-0.07, 0.66]
1.5 Hager	1	43	effect size (Fixed, 95% CI)	-0.1 [-0.72, 0.52]
1.6 Gosztonyi	1	142	effect size (Fixed, 95% CI)	0.15 [-0.18, 0.48]
2 Hazard of STS	1		Hazard Ratio (Random, 95% CI)	3.78 [2.69, 5.31]
2.1 80 to 85 dB-years	1		Hazard Ratio (Random, 95% CI)	2.10 [1.26, 3.49]
2.2 85 to 90 dB-years	1		Hazard Ratio (Random, 95% CI)	3.00 [2.27, 3.96]
2.3 90 to 95 dB-years	1		Hazard Ratio (Random, 95% CI)	3.30 [2.76, 3.94]
2.4 95 to 100 dB-years	1		Hazard Ratio (Random, 95% CI)	4.60 [3.86, 5.48]
2.5 More than 100 dB-years	1		Hazard Ratio (Random, 95% CI)	6.60 [5.56, 7.84]

Analysis 20.1. Comparison 20 HLPP vs non-exposed workers (long-term > 5-year follow-up), Outcome 1 Hearing loss change at 4 kHz/STS (5-year follow-up).

Study or subgroup	Favours protection N	Favours non-exposed N	effect size (SE)	effect size IV, Fixed, 95% CI	Weight	effect size IV, Fixed, 95% CI
20.1.1 Pell hearing loss 10 dB						
Pell 1973	193	435	-0.1 (0.087)		36.21%	-0.1[-0.27,0.07]
Subtotal (95% CI)					**36.21%**	**-0.1[-0.27,0.07]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.15(P=0.25)						
20.1.2 Pell hearing loss 15 to 35 dB						
Pell 1973	125	434	0.1 (0.102)		26.16%	0.09[-0.11,0.29]
Subtotal (95% CI)					**26.16%**	**0.09[-0.11,0.29]**
Heterogeneity: Tau^2=0; Chi^2=0, df=0(P<0.0001); I^2=100%						
Test for overall effect: Z=0.88(P=0.38)						
20.1.3 Pell hearing loss 40 dB						
Pell 1973	81	304	0.2 (0.125)		17.42%	0.18[-0.06,0.42]



Study or subgroup	Favours protection N	Favours non-exposed N	effect size (SE)	effect size IV, Fixed, 95% CI	Weight	effect size IV, Fixed, 95% CI
Subtotal (95% CI)					**17.42%**	**0.18[-0.06,0.42]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.44(P=0.15)						
20.1.4 Lee-Feldstein						
Lee-Feldstein 1993	111	363	0.3 (0.186)		7.88%	0.29[-0.07,0.66]
Subtotal (95% CI)					**7.88%**	**0.29[-0.07,0.66]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.57(P=0.12)						
20.1.5 Hager						
Hager 1982	27	16	-0.1 (0.316)		2.72%	-0.1[-0.72,0.52]
Subtotal (95% CI)					**2.72%**	**-0.1[-0.72,0.52]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.32(P=0.75)						
20.1.6 Gosztonyi						
Gosztonyi 1975	71	71	0.2 (0.168)		9.6%	0.15[-0.18,0.48]
Subtotal (95% CI)					**9.6%**	**0.15[-0.18,0.48]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.89(P=0.37)						
Total (95% CI)					**100%**	**0.05[-0.05,0.16]**
Heterogeneity: Tau²=0; Chi²=6.49, df=5(P=0.26); I²=22.94%						
Test for overall effect: Z=1.02(P=0.31)						
Test for subgroup differences: Chi²=6.49, df=1 (P=0.26), I²=22.94%						

Favours Protection -1 -0.5 0 0.5 1 Favours Non-exposed

Analysis 20.2. Comparison 20 HLPP vs non-exposed workers (long-term > 5-year follow-up), Outcome 2 Hazard of STS.

Study or subgroup	Favours protection N	Favours non-exposed N	log[Hazard Ratio] (SE)	Hazard Ratio IV, Random, 95% CI	Weight	Hazard Ratio IV, Random, 95% CI
20.2.1 80 to 85 dB-years						
Davies 2008	0	0	0.7 (0.26)		15.16%	2.1[1.26,3.49]
Subtotal (95% CI)					**15.16%**	**2.1[1.26,3.49]**
Heterogeneity: Not applicable						
Test for overall effect: Z=2.86(P=0)						
20.2.2 85 to 90 dB-years						
Davies 2008	0	0	1.1 (0.141)		19.93%	3[2.27,3.96]
Subtotal (95% CI)					**19.93%**	**3[2.27,3.96]**
Heterogeneity: Not applicable						
Test for overall effect: Z=7.78(P<0.0001)						
20.2.3 90 to 95 dB-years						

Favours experimental 0.1 0.2 0.5 1 2 5 10 Favours control

Study or subgroup	Favours protection N	Favours non-exposed N	log[Hazard Ratio] (SE)	Hazard Ratio IV, Random, 95% CI	Weight	Hazard Ratio IV, Random, 95% CI
Davies 2008	0	0	1.2 (0.091)		21.59%	3.3[2.76,3.94]
Subtotal (95% CI)					**21.59%**	**3.3[2.76,3.94]**
Heterogeneity: Not applicable						
Test for overall effect: Z=13.12(P<0.0001)						
20.2.4 95 to 100 dB-years						
Davies 2008	0	0	1.5 (0.09)		21.63%	4.6[3.86,5.48]
Subtotal (95% CI)					**21.63%**	**4.6[3.86,5.48]**
Heterogeneity: Not applicable						
Test for overall effect: Z=17.02(P<0.0001)						
20.2.5 More than 100 dB-years						
Davies 2008	0	0	1.9 (0.088)		21.68%	6.6[5.56,7.84]
Subtotal (95% CI)					**21.68%**	**6.6[5.56,7.84]**
Heterogeneity: Not applicable						
Test for overall effect: Z=21.5(P<0.0001)						
Total (95% CI)					**100%**	**3.78[2.69,5.31]**
Heterogeneity: Tau²=0.13; Chi²=46.94, df=4(P<0.0001); I²=91.48%						
Test for overall effect: Z=7.65(P<0.0001)						
Test for subgroup differences: Chi²=46.94, df=1 (P<0.0001), I²=91.48%						
			Favours experimental	0.1 0.2 0.5 1 2 5 10	Favours control	

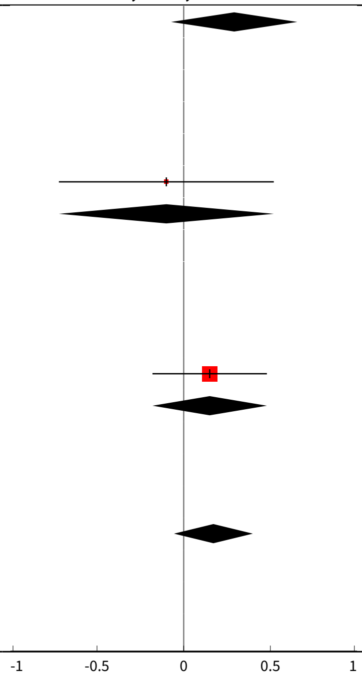
Comparison 21. HLPP vs non-exposed sensitivity analysis (long-term, 5-year follow-up)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change at 4kHz / STS	3		effect size (Fixed, 95% CI)	0.17 [-0.06, 0.40]
1.1 Lee-Feldstein	1		effect size (Fixed, 95% CI)	0.29 [-0.07, 0.66]
1.2 Hager	1		effect size (Fixed, 95% CI)	-0.1 [-0.72, 0.52]
1.3 Gosztonyi	1		effect size (Fixed, 95% CI)	0.15 [-0.18, 0.48]

Analysis 21.1. Comparison 21 HLPP vs non-exposed sensitivity analysis (long-term, 5-year follow-up), Outcome 1 Hearing loss change at 4kHz / STS.

Study or subgroup	Favours protection N	Favours non-exposed N	effect size (SE)	effect size IV, Fixed, 95% CI	Weight	effect size IV, Fixed, 95% CI
21.1.1 Lee-Feldstein						
Lee-Feldstein 1993	111	363	0.3 (0.186)		39.03%	0.29[-0.07,0.66]
			Favours Protection	-1 -0.5 0 0.5 1	Favours Non-exposed	

Study or subgroup	Favours protection	Favours non-exposed	effect size	effect size	Weight	effect size
	N	N	(SE)	IV, Fixed, 95% CI		IV, Fixed, 95% CI
Subtotal (95% CI)					**39.03%**	**0.29[-0.07,0.66]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.57(P=0.12)						
21.1.2 Hager						
Hager 1982	27	16	-0.1 (0.316)		13.47%	-0.1[-0.72,0.52]
Subtotal (95% CI)					**13.47%**	**-0.1[-0.72,0.52]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.32(P=0.75)						
21.1.3 Gosztonyi						
Gosztonyi 1975	71	71	0.2 (0.168)		47.51%	0.15[-0.18,0.48]
Subtotal (95% CI)					**47.51%**	**0.15[-0.18,0.48]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.89(P=0.37)						
Total (95% CI)					**100%**	**0.17[-0.06,0.4]**
Heterogeneity: Tau²=0; Chi²=1.17, df=2(P=0.56); I²=0%						
Test for overall effect: Z=1.48(P=0.14)						
Test for subgroup differences: Chi²=1.17, df=1 (P=0.56), I²=0%						



Favours Protection — Favours Non-exposed

ADDITIONAL TABLES

Table 1. Recalculation of study data for review results and meta-analysis

Küpper 2013 (Outcome: Leq 8 h (dB)[a]) - noise exposure of rescue helicopter personnel - case study								
Study data						**Recalculation - group mean, SD**		
Helicopter type	Helicopter name	mean	SD	dB min	dB max	variance	mean	SD
with advanced technology	EC 135[b]	85.80	4.00	73.00	97.00	16.00	87.9	4.16
	BK 117[b]	87.20	4.60	74.00	101.00	21.16		
	Bell 206 B Jetranger[c]	88.80	4.00	76.00	100.00	16.00		
	Bell 206 Longranger II[c]	89.80	4.00	77.00	101.00	16.00		
without advanced technology	UH 1D[b]	86.80	4.00	74.00	98.00	16.00	98.41	4.49
	BO 105[c]	91.80	4.00	79.00	103.00	16.00		
	Sea King[c]	92.60	7.50	78.00	114.00	56.25		
	Ecureuil AS350B[b]	92.80	4.00	80.00	104.00	16.00		
	Alouette IIIb[b]	98.40	4.80	85.00	113.00	23.04		
	Sikorsky H-23/UH12[c]	99.70	3.90	87.00	111.00	15.21		
	Alouette II[b]	100.10	4.40	87.00	113.00	19.36		
	Sikorsky H-34[c]	101.8	4.00	89.00	113.00	16.00		
	Mi-4[c]	109.10	3.50	97.00	117.00	12.25		
	Sikorsky H-37 Mojave[c]	111	3.40	99.00	119.00	11.56		
Muhr 2016 (Outcome: STS) - hearing loss Swedish military - CBA								

Table 1. Recalculation of study data for review results and meta-analysis *(Continued)*

Study data				Recalculation			
group	follow up mean (month)	# Events	N	follow up (month/year)	**per 100 person-years**		
					event rate	lnRR	SE
HLPP	8	9	395	0.67	3.4	0.002	0.379
non-exposed	13	31	839	1.08	3.4		

Muhr 2006 (Outcome: STS) - hearing loss Swedish military - CBA

Study data				Recalculation						
group	follow up mean (month)	# Events	N	group	follow up (year)	# Events	N	**per 100 person-years**		
								event rate	lnRR	SE
HLPP (low-exposed)	9.25	11	291	HLPP (low-exposed)	0.77	11	291	4.9	0.73	1.04
HLPP (medium-exposed)		13	252	non-exposed (split 1)	0.92	1	46	2.37		
HLPP (high-exposed)		35	204	HLPP (medium-exposed)	0.77	13	252	6.69	1.04	1.04
non-exposed	11	4	138	non-exposed (split 2)	0.92	1	46	2.37		
				HLPP (high-exposed)	0.77	35	204	22.26	1.55	0.73
				non-exposed (split 3)	0.92	2	46	4.74		
				non-exposed (all)	0.92	4	138	3.16		
				low-exposed vs non-exposed (all)					0.439	0.584

Table 1. Recalculation of study data for review results and meta-analysis *(Continued)*

	medium-exposed vs non-exposed (all)	0.750	0.572
	high-exposed vs non-exposed (all)	1.951	0.528

[a]Based on task analysis and helicopter noise data, task analysis is based on measurements of type and duration of tasks per rescue operation of four bases over 1 year (total, 2726 rescue operations).
[b]Study authors obtained helicopter noise data from own measurements (n = 3 per helicopter).
[c]Study authors obtained helicopter noise data from other studies.

Table 2. Assessment of quality of evidence (GRADE)

Comparison	N Studies	1. RoB?	2. Inconsistent?	3. Indirect?	4. Imprecise?	5. Pub bias?	6. Large ES?	7. DR?	8. Opp Conf	Quality[a]
Outcome noise										
Legislation vs no legislation	1 ITS	yes	1 study	no	no	1 study	yes	no	no	very low (1)
One HPD vs another HPD	1 RCT 4 CBA	2 yes	no	no	no	not shown	no	no	no	low (1)
HPD+Instruction vs HPD-instruction	2 RCT	2 no	no	no	yes	not shown	na	na	na	moderate (4)
Information vs no information	1 RCT (2 arms)	1 yes	1 study	no	yes	1 study	na	na	na	low (1, 4)
Outcome hearing loss										
One HPD vs another HPD (TTS)	2 CBA									no data
Muffs vs plugs	2 CBA	2 yes	no	no	yes	not shown	no	no	no	very low (1,4)
Frequent HPD vs less frequent use	1 CBA	1 yes	1 study	no	yes	1 study	no	no	no	very low (1)
HLPP vs audiometry	1 RCT	1 yes	1 study	no	no	1 study	na	na	na	moderate (1)
HLPP+exposure information vs HLPP-information	1 CBA	1 yes	1 study	no	yes	1 study	no	no	no	very low (1,4)

Table 2. Assessment of quality of evidence (GRADE) *(Continued)*

Frequent HPD in HLPP vs less	5 CBA	5 yes	no	no	yes	not shown	no	no	no	very low (1,4)
HLPP vs no exposure	7 CBA	7 yes	no	no	yes	not shown	no	no	no	very low (1,4)
Follow-up vs no follow-up	1 CBA	1 yes	1 study	no	yes	1 study	no	no	no	very low (1,4)
HLPP+long shifts vs HLPP normal	1 CBA	1 yes	1 study	no	yes	1 study	no	no	no	very low (1,4)

1-5 Reasons for downgrading: 1. Risk of bias/Limitations in study design 2. Inconsistency between studies. 3. Indirectness of PICO 4. Imprecision of the results 5. Publication bias.
6-8 Reasons for upgrading: 6. Large effect size. 7. Dose-repsonse relationship 8. Confounding opposes the direction of the effect;
na= not applicable; 1 study = only one study available and impossible to assess consistency or publication bias
[a]Final grading of quality of evidence, between brackets domain that led to down/upgrading the quality.

Table 3. Contents of hearing loss prevention programmes

Study	Described as HLPP	HPD provided	Noise measurements	Technical measures	Administrative measures	Audiometry
Adera 1993	?	Enforced mandatory wearing of hearing protection	Personal dosimeter twice a year	?	?	Audiometric booth ANSI-OSHA
Adera 2000	HLPP	? based on Aldera 1993 we assumed that excellent implementation meant better use of hearing protection	?	?	?	Audiogram taken
Berg 2009	HCP	Beside educational intervention, hearing protection devices were provided free to students and replaced regularly	Students were given opportunity to use sound level meter unaffiliated	Not part of the programme	Not part of the programme	Yearly audiometric testing, calibrated per ANSI standard with Hughson-Westlake modification of the ascending threshold technique
Brink 2002	HCP	?	Area-wide sound level surveys	?	?	Annual audiometric evaluation calibrated Bekesy audiometer ANSI
Davies 2008	HCP	Hearing protection was one element	Noise monitoring was one element	Engineering controls were one element	Administrative controls were one element	Audiometric evaluation by certified audiometric technicians
Erlandsson 1980	?	?	Personal noise dosimeters	?	?	Calibrated ISO r389
Gosztonyi 1975	HCP	Earmuffs mandatory in noise areas	Calibrated personal dosimeters sound level meter in all shop areas	?	?	Soundproof booth ANSI s3.1-1960
Hager 1982	Walsh-Healy standard; OSHA	Yes, mandatory use of approved protection	?	Gradual continuous engineering control wherever, whenever economically feasible	?	Audiometric surveys
Heyer 2011	HCP	? Percent use of hearing protection used as a quality indicator	Used as a quality indicator of the programmes: high quality if any monitoring and worker input	Stated as part of the programme but not possible to evalu-	Training and education stated as part of the programme but not possible to evaluate with study data	Audiometric testing, quality varies, evaluated as days between two tests, audiometry method not reported

Table 3. Contents of hearing loss prevention programmes *(Continued)*

			reported by focus group	ate with the study data		
Lee-Feldstein 1993	?	?	Annual sound surveys	?	?	Automatic audiometer according to ANSI s3.6-1996
Meyer 1993	HCP	Must be provided with effective HP devices	Identify hazardous noise	?	Detailed follow-up 3 and 6 months after a STS	?
Muhr 2006	HCP	Earmuffs and or earplugs with level-dependent function limited to 82 dB(A) with SNR 27 dB	Standardised noise measurements	Risk areas around weapon use	?	Screening audiometry
Muhr 2016	HCP, stated to be stricter than to the one evaluated in Muhr 2006	Mandatory use of HPDs, earmuffs and or earplugs with or without level-dependent function (enable speech communication), (stated to be stricter recommendations and better devices)	?	safety distances (stated to be stricter)	Mandatory training in HPD use and education in NIHL and noise induced tinnitus, stricter audiometry inclusion criteria for acceptance to military service (≤ 25 dB average HL for the frequencies 0.5 to 8 kHz in both ears, 30 dB HL at one or more frequencies, and 35–40 dB HL at one single frequency) (to exclude mild hearing loss cases presumed to be more vulnerable to HL)	Screening audiometry at begin and end of military service
Nilsson 1980	Routine HCP	?	Individual noise dosimetry over long periods	?	?	Calibrated ISO 389 isolated booth
Pell 1973	?	Mandatory hearing protection	Routine noise level surveys	Noise abatement	?	Automatic Bekesy-type ANSI calibrated
Reynolds 1990a	HCP	3 specific types of earplugs	Sound survey, noise dosimeters	?	?	Audiometric database
Simpson 1994	Demonstrate excellent HCP practices	?	?	?	?	?

ANSI = American National Standards Institute
HCP = hearing conservation programme
HL = hearing loss
HLPP = hearing loss prevention programme
HPD = hearing protection device
ISO = International Organization for Standardization
OSHA =Occupational Safety and Health Administration
SNR = Single Number Rating
? = not reported

Table 4. List of included case studies

Reference ID	Case studies included in review					
	Number of cases	**Type of industry**	**Country**	**Intervention[a]**	**Measure[b]**	**Additional information (number of cases)**
Azman 2012	1	mining (1)	USA	retro-fit	noise level, noise dose	description of noise measurement (1), follow-up (1)
Caillet 2012	1	offshore helicopter (1)	France	all retro-fit	noise level	description of noise measurement (1), funding (1), conflict of interest (1)
Cockrell 2015	2	manufacturing (2)	USA	all retro-fit	noise level, dose	description of noise measurement (2)
Golmohammadi 2014	3	steel industry (3)	Iran	all retro-fit	noise level, dose	description of noise measurement (3), funding (3), conflict of interest (3)
HSE 2013a	57	manufacturing (57)	not reported	new 6 retro-fit 51	noise level	-
HSE 2015	2	manufacturing (2)	not reported	all retro-fit	noise level	-
Küpper 2013	1	alpine rescue operation (helicopter) (1)	Austria, Switzerland	new	noise level	description of noise measurement, follow-up, statistical tests used
Maling 2016	8	textile (1), paper shredding (1), manufacturing (6)	USA	new 4, retro-fit 2, both 2	noise level	-
Morata 2015	18	manufacturing (15), drilling industry (2), mining (1)	not reported	new 5, retro-fit 11, both 2	noise level, dose	description of noise measurement (3)
Pan 2016	3	mining (3)	Australia	all retro-fit	dose	description of noise measurement (2), funding (3), follow-up (immediate) (3)
Thompson 2015	5	mining(5)	USA	all retro-fit	noise level, dose	description of noise measurement (1), adverse effects: engine over-

Table 4. List of included case studies *(Continued)*

						heating (1), time of intervention: 2014/2015 (1)
Wilson 2016	6	manufacturing (6)	not reported	all retro-fit	noise level	-
Total	**107**	**manufacturing (88), mining (10), steel (3), drilling (2), helicopter (2), textile (1), paper shredding (1)**	**Australia (3), Iran (3), France (1), USA (16), Austria and Switzerland (1), nr (26)**	**retro-fit (86), new (16), both (4)**	**noise level, dose**	**description of noise measurement (14), funding (7), follow-up (5), conflict of interest (4), adverse effects (1), time of intervention (1), statistical tests used (1)**

[a]Types of intervention: installation of completely new equipment (new), intervention to improve existing equipment (e.g. new parts, additional damping material layers) (retro-fit), or a combination of new and retro-fit interventions (both).

[b]Noise level (including time-weighted averages or sound pressure levels), dose (including calculations according to OSHA, NIOSH, or MSHA PEL specifications).

Table 5. Results case studies - new equipment

New equipment

Noise source	Intervention	follow-up	Initial noise level	Noise level after	8 h TWA before	8 h TWA after	Reference ID
Helicopter	Modern helicopter with advanced technology (compared to older helicopters without advanced technology)	short term (1 year)			mean 98.41 (SD 4.49) (n = 10)	mean 87.9 (SD 4.16) (n = 4)	Küpper 2013
Pumps	New high-pressure coolant pumps have been installed at various metal cutting operations. These new pumps produce more pressure and more volume directly at the cutting tools.	not reported	110 dB	87 dB			Maling 2016
Drill	New injector drill with a sound enclosure for a deep drilling operation	not reported	110 dB	95 dB			
Roof fans	Old roof fans were replaced with new high-efficiency fans	not reported		lowered the noise below the fan			
Air gun	Air gun substitution	not reported	94 dB	85 dB			Morata 2015
Fork lifts	Use of tugs instead of fork lifts	not reported	92 dB	72 dB			
Alarm system	Change from audible alarm to visual warning and pressure sensor	not reported	95 dB	0 dB			
Air wand	Replacement of 45 air wands	not reported	112.8 dB	90.1 dB			
Bottling line - rinser-filler-capper machine	Purchase of a new bottling line	not reported	89 dB	below 80 dB			HSE 2013
Bottle-blowers	New bottle-blowers and segregation	not reported	86-87 dB	below 83 dB			
Glass bottles on transport conveyer	Purchasing new design of bottle transport conveyor	not reported	101 dB	83 dB			
Packing machinery - Compressors and com-	Purchasing policy and fitted silencers	not reported	above 90 dB	below 85 dB			

Table 5. Results case studies - new equipment *(Continued)*

Noise source	Intervention	Follow-up	Initial noise level	Noise level after	Dose before	Dose after	Reference ID
pressed-air exhausts							
Bakery machinery	Not purchasing equipment that produced noise level above 85 dB, company's health and safety adviser would visit the makers of new machinery during its manufacture and conduct a noise assessment to make sure the machinery did not exceed 85 dB	not reported	94 dB	85 dB			
Bottle-laner - bottles banging together on laner conveyor	New machine with guide-rails	not reported	93-96 dB	87 dB			

	Number of cases: 14	mean before	mean after	mean reduction
	Noise level dB	97.4 dB	77.7 dB	19.7
	TWA dB	98.41 (SD 4.49)	87.9 (SD 4.16)	10.51 (95% CI 15.45 to 5.57)

TWA = time weighted average

Table 6. Results case studies - acoustic panels and curtains

Acoustic panels and curtains

Noise source	Intervention	Follow-up	Initial noise level	Noise level after	Dose before	Dose after	Reference ID
Production noise	Door	not reported	85 dB	79 dB			Morata 2015
Blast furnace	Control rooms were redesigned in order to improve acoustical condition: installation of a UPVC window with vacuumed double-layered glass 80 x 80 cm and double wall for entrance by 90° rotate plus a 2.0 × 1.2 m steel door without glass	not reported	80 dB	52.6 dB			Golmohammadi 2014
Blast furnace	In rest room wall facing to the furnace was made from the armed concrete with a thick-	not reported	86.1 dB	58.4 dB			

Table 6. Results case studies - acoustic panels and curtains *(Continued)*

	ness of 20 cm, length of 9 m, and height of 3 m and was located in the entrance by 90° rotate						
Blast furnace	Control room and rest room redesigned to improve acoustical condition	not reported			236% (unspecified)	130% (unspecified)	
Product impact on multi-head weigher	Fitted flexible PVC curtains	not reported	92 dB	88 dB			HSE 2013
Packaging lines	Fitted acoustic baffles to ceiling	not reported	Above 90 dB	below 90 dB			
Noise from hearing protection zones affecting quieter areas	Erected acoustic panels and automatic doors between hearing protection zones and quieter areas	not reported	Above 90 dB	below 85 dB			
Filler pump	Improved efficiency of pump and added acoustic hood	not reported	96 dB	86 dB			
Compressed air in bottle transportation	Acoustic side panels fitted	not reported	85–86 dB	73 dB			
Product impact on hoppers	Flexible PVC curtains fitted	not reported	Above 90 dB	83 dB			
	Number of cases: 10		**mean before**	**mean after**	**mean reduction**		
	noise level dB		88.3	77.2	11.1		
	Dose % (unspecified)		236	130	106		

Table 7. Results case studies - damping material and silencers

Damping material and silencers									
Noise source	**Intervention**	**Follow-up**	**Initial-noise level**	**Noise level after**	**8 h TWA before**	**8 h TWA after**	**Dose before**	**Dose after**	**Reference ID**

Table 7. Results case studies - damping material and silencers *(Continued)*

Confetti machine	Damped machine surfaces: Replaced vacuums with small cyclones that were quieter and had fewer clogs, Installed conveyors to carry the paper into the disintegrators	not reported	95 dB	85 dB						Maling 2016
Production noise	Installation of sound absorbing panels, shields, covers, insulation, sheeting, installation of mufflers for fans and solenoids, reduction of compressed-air pressure and volume in vents, use of vibrating personal alarms instead of audible alarms	not reported		2 to 11 dB noise reduction						
Helicopter	Cover of structural leaks with lightweight materials (e.g. new door seals) and damping of the structure (patches of constrained visco-elastic materials that are bonded to the structure), optimised sound-proofing panels (sandwich panels with “soft core”) and windows (thickened laminated windows with damping layer and double glazing), and Main Gear Box suspension devices (laminated ball joints at MGB support strut foot)	not reported		7 dB noise reduction						Caillet 2012
Pump	Suppressor on palletizer hydraulic pump to minimize hydraulic banging, pump whine contained in sound-insulated box	not reported	88 dB	83 dB						Morata 2015
Air-rotary drill rig	Installation of hydraulic noise suppressors and a lead-fiberglass blanket covering Ihe gap between the inside door and the cab frame	not reported	98 dB	95 dB				MSHA PEL 280%; NIOSH 3222%	MSHA PEL 210%: NIOSH 2585%	
Air-rotary drill rig	Installation of hydraulic noise suppressors	not reported	98 dB	97 dB				MSHA PEL 280%; NIOSH 3222%	MSHA PEL 249%; NIOSH 2951%	
Pumps	Installing mufflers on pumps	not reported	98.1 dB	81.3 dB						
Haul trucks in underground	Improving the engine compartment noise barrier: the usual barrier material has	not reported						MSHA PEL 495%	MSHA PEL 416%	Thompson 2015

Table 7. Results case studies - damping material and silencers *(Continued)*

metal/non-metal mines	been replaced with a barrier material part number Duracote 5356, manufactured by Durasonic						
Chiller	Reduce noise from a chiller with a combination of acoustic absorbent and retro-fit constrained layer damping	not reported		8 dB noise reduction			Wilson 2016
High-speed strip-fed press	Normally the press legs are welded boxes, the press frame was isolated from the fabricated legs by inserting 6 mm composite pads between frame and legs	not reported			101 dB	92 dB	
Product impact on hoppers and chutes	Coated internally with food-grade, sound-deadening material	not reported	96–98 dB	Noise reduced by 2-8 dB			HSE 2013
Gas cylinder impact on metal table	Rubber matting on table	not reported	110 dB peaks	removal of peak noises			
Product impact on ducting	Lagged ductwork with noise-absorbent padding	not reported	92 dB	84 dB			
Product impact on vibrating components	Coated externally with sound-deadening material	not reported	92 dB	84 dB			
Bread-basket stacking machine	Fitted hydraulic dampers	not reported	92 dB	83 dB			
Hand-crimping metal foil packages	Mounted on layers of rubber	not reported	86–89 dB	85–86 dB			
Keg impact on concrete floor	Fitted rubber matting on to floor	not reported	High noise levels	Noise levels reduced			

Table 7. Results case studies - damping material and silencers *(Continued)*

Gas cylinder impact on metal 'A' frame trolleys	Fitted rubber matting on to trolleys	not reported	110 dB peaks	Peak noise levels reduced
Road tanker degassing	Fitted silencers	not reported	92 dB	83 dB
Evaporative condensers and refrigeration plant	Fitted silencers	not reported	94 dB	83–87 dB

Number of cases: 20	**mean before**	**mean after**	**mean reduction**
noise level dB	93.6	86.5	7
TWA dB	101	92	9
Dose % (MSHA PEL) [dosimeter settings: 90 dB Lt, 90 dB Lc, 5-dB exchange rate]	351.7	291.7	60
Dose % (NIOSH) [dosimeter settings: 80 dB Lt, 85 dB Lc, 3-dB exchange rate]	3222	2768	454

MSHA = Mine safety and health administration
NIOSH = National Institute for Occupational Safety and Health
PEL = permissible exposure limit

Table 8. Results case studies - design changes

Design changes

Noise source	**Intervention**	**Follow-up**	**Initial noise level**	**Noise level after**	**8 h TWA before**	**8 h TWA after**	**Dose before**	**Dose after**	**Reference ID**
Roof bolting machine at underground coal mines	New drill bit isolator	immediate				reduced by 3.2 dB	MSHA PEL per hole 0.85%	MSHA PEL per hole 0.57%	Azman 2012

Table 8. Results case studies - design changes *(Continued)*

		short term (after 253 holes and 628 m)				reduced by 2.2 dB	MSHA PEL per hole 0.9%	MSHA PEL per hole 0.66%	
4-roll calender in a tire manufacturing facility "calender operator"	Replacing the piercer brackets, optimising alignment and improving preventative maintenance (increased and more frequent lubrication of the piercer and other areas of the equipment with high friction or pressure)	not reported			87.7 dB	86.3 dB	OSHA dose 72.8%	OSHA dose 59.6%	Cockrell 2015
4-roll calender in a tire manufacturing facility "wind up operator"	Replacing the piercer brackets, optimising alignment and improving preventative maintenance (increased and more frequent lubrication of the piercer and other areas of the equipment with high friction or pressure)	not reported			93.1 dB	89 dB	OSHA dose 153%	OSHA dose 87.3%	
Heavy metal arms which drove the reciprocating blade on the machines	Alternative linkage using flexible nylon straps	not reported	95 dB	75 dB					HSE 2015
Tobacco filter making machine	Machine design improvements on a tobacco filter making machine and room improvements	not reported		9 dB reduction					Maling 2016
Weaving machines	Use of different spindle	not reported	100 dB	90 dB					
Locomotive for mining	Active noise control	immediate							Pan 2016
Mining truck	Active noise control	immediate							
Mining truck	active noise control and damping material	immediate							
Filler	Filler outfeed: line shaft removed, individual drives installed	not reported	107 dB	81 dB					Morata 2015

Table 8. Results case studies - design changes *(Continued)*

Con-air dryer	Machine set on vibration mounts, quieter blower	not reported	94 dB	85 dB					
Transfer cart	not reported	not reported	94 dB	79 dB					
Trimmer	rReplacing nozzles from trimmer with in feed decline drive belt	not reported	98 to 113 dB	86 to 104 dB					
Continuous mining machine	Exchange of a single sprocket chain for a dual sprocket chain on a continuous mining machine (CMM, Joy Mining Machine 14CM-15)	not reported			93.4 to 93.3 dB	92 dB	MSHA PEL 159 %	MSHA PEL 132.5%	
Moen case former	Exchange of pneumatic cylinder for servo-mandrel	not reported	97 dB	87 dB					
Cart	Exchange of cart wheels	not reported	88 dB	72 dB					
Standard longwall cutting drums (mining)	Modified set of longwall cutting drums instead of a set of standard (baseline) drums	not reported	98 dB	92 dB	95.7 dB	93.1 dB	MSHA PEL 220.5%	MSHA PEL 158.6%	Thompson 2015
Haul trucks in underground metal/non-metal mines	Improving the engine compartment noise barrier and changing the fan type, size, and rotation speed (larger fan of different design and different fan pulley to reduce the fan rotation speed to 90%)	not reported			102 dB	93 dB	MSHA PEL 495%	MSHA PEL 158%	
Load-haul-dumps (LHDs) in underground metal/non-metal mines	Improving the engine compartment noise barrier and changing the fan type, size, and rotation speed (larger fan of a different design and a different fan hub to reduce the fan rotation speed to roughly 87% and new noise barrier material (Duracote Durasonic 5356))	not reported			98 dB	96 dB	MSHA PEL 289%	MSHA PEL 231%	
Load-haul-dumps (LHDs) in underground metal/non-metal mines	Improving the engine compartment noise barrier and changing the fan type, size, and rotation speed (a larger fan of a different design was in-	not reported			98 dB	93 dB	MSHA PEL 289%	MSHA PEL 142%	

Table 8. Results case studies - design changes *(Continued)*

	stalled as well as a different fan hub to reduce the fan rotation speed to roughly 95%)				
Standard camshaft washer drying nozzles (pneumatic)	Pneumatic nozzles replaced with suitable entraining units	not reported		12 dB reduction	Wilson 2016
Drier fan	Retro-fitting aerodynamic and acoustic elements inside fan casings and the associated ductwork	not reported		9 dB reduction	
Aluminium can extract and chopper fans	Fitting aerodynamic inserts inside the fan casing	not reported		22 dB reduction	
Separator (large thin sheet distribution dome)	alteration to a vibratory separator: forming this component in stainless sound deadened steel	not reported	105 dB	89 dB	
Metal trays	Replacing metal trays with plastic trays	not reported	89 dB	84-85 dB	HSE 2013
Metal wheels on baking racks	Replacing baking rack wheels with resin wheels	not reported	above 100 dB	86-92 dB	
Loosening product from baking tins with air knives	Air knives modified to operate with a diffuse air jet	not reported	above 90 dB	below 85 dB	
Bottles and cans banging together on conveyors	Fitted a pressureless combiner conveyor system	not reported	above 90 dB	below 90 dB	
Baking tins banging together on chain or slat conveyors	Installing 'tin-friendly' conveyors	not reported	above 90 dB	below 85 dB	
Manual changeover of baking tins on conveyor	Installed robots to handle pans	not reported	94-96 dB	below 90 dB	

Table 8. Results case studies - design changes *(Continued)*

Water pumps on filling machines	Replaced with air pumps and fitted silencers	not reported	90 dB	84 dB
Filling sachets and cups	New design of horizontal powder-feeder and enclosed machine	not reported	83-84 dB	80 dB
Bottle manufacture, filling and packing lines	Acoustic panels fitted to walls, high ceiling installed	not reported	Above 90 dB	83 dB
Contact between metal trays and metal tracking	Replaced with plastic tracking	not reported	94 dB	87 dB
Product impact on metal chutes	Replaced with plastic chutes	not reported	96-98 dB	90 dB
Electrically powered sausage-spooling machines	Replaced with compressed-air spooler	not reported	86-90 dB	below 80 dB
Tray-indexing arm	Plastic caps on fingers of indexing arm	not reported	94 dB	87-89 dB
Vibratory conveyor	Ensured conveyor only used at least noisy speed	not reported	above 90 dB	below 85
Glass bottles on conveyor	New design of conveyor with different chain speeds	not reported	101 dB	84 dB
Lidding and de-lidding tins	Installed robots to lid and de-lid baking tins	not reported	90-93 dB	88 dB

Number of cases: 41	**mean before**	**mean after**	**mean reduction**
Noise level dB	94.5 dB	85.3 dB	9.6 dB
TWA dB	95.4	91.8	3.4 dB
Dose % (OSHA)	112.9	73.5	39.5
Dose % (MSHA PEL)	207.8	117.6	90.1

MSHA = Mine Safety and Health Administration
OSHA = Occupational Safety and Health Administration
PEL = permissible exposure limit

Table 9. Results case studies - enclosure

Enclosure					
Noise source	**Intervention**	**Follow-up**	**Initial noise level**	**Noise level after**	**Reference ID**
Conveyor	An enclosure was put over the conveyor at a cost of GBP 2000 and the conveyor speed was changed to reduce jar clashing	not reported	96 dB	86 dB	HSE 2015
Grinder	Enclosure over the grinder	not reported	93 dB	85 dB	Morata 2015
Not reported	Use of an enclosure with acoustical foam to deburring area	not reported	104 dB	82 dB	
Feeder	Enclosing the bowl feeder	not reported	116 dB	86 dB	Maling 2016
Compressed-air knives	Enclosed machine	not reported	91–92 dB	Below 85 dB	HSE 2013
Glass-bottle conveyor	Enclosed the conveyor noise levels	not reported	Above 90 dB	reduced by 2-8 dB	
Blower machine	Enclosed machine using sound-absorbent panels	not reported	above 90	Below 90 dB	
Bottle-blowing machines	Machine enclosed and segregated	not reported	94 dB	89 dB	
Hammer mill	Enclosed in an acoustic booth	not reported	102 dB	87 dB	
Rinser-filler-capper machine	Enclosed machine	not reported	85 dB	73 dB	
Glass jars clashing together on conveyor	Fitted enclosure and changed conveyor speed	not reported	96 dB	86 dB	
Bottles banging together on filler infeed conveyor	Fitted covers over conveyor	not reported	96-100 dB	92 dB	
	Number of cases: 12		**mean before**	**mean after**	**mean reduction**
	Noise level (dB)		96.3 dB	85.5 dB	11.8 dB

Table 10. Results case studies - maintenance

Maintenance					
Noise source	**Intervention**	**Follow-up**	**Initial noise level**	**Noise level after**	**Reference ID**

Table 10. Results case studies - maintenance *(Continued)*

Dough mixer	Maintenance modifications to a mixing machine	not reported	94 dB	91 dB	HSE 2013
Compressed air in soft drinks factory machines	Regular maintenance of machines to reduce noise from air leaks	not reported	High noise levels	Noise levels reduced by 3 to 4 dB	
Gearboxes on mixing machine	Lubricating gearboxes	not reported	80–85 dB	Noise levels reduced by 1.5 dB	
Compressed-air exhausts on vacuum-wrapping machines	Fitting and maintaining silencers on wrapping machines	not reported	88–90 dB	Below 85 dB	
	Number of cases: 4		**mean before**	**mean after**	**mean reduction**
	Noise level dB		88.5 dB	85.7 dB	3 dB

Table 11. Results case studies - segregation

Segregation					
Noise source	**Intervention**	**Follow-up**	**Initial noise level**	**Noise level after**	**Reference ID**
Main production area of bakery	Re-routing pedestrian traffic, signage and training	not reported	94 dB	below 85 dB	HSE 2013
Bowl chopper and mincers	Moved from main production area to an isolated area	not reported	88–94 dB	below 85 dB	
Basket-washing machine in main bakery	Moved to a separate building	not reported	88 dB	Noise source removed	
High-pressure air-compressor	Located in a separate room	not reported	110–112 dB	60–70 dB outside room	
Vibrating cap-hoppers	Located in separate enclosure	not reported	Above 90 dB	Noise source removed	
Air-compressor	Located in separate, unmanned room	not reported	94–95 dB	80 dB	
Pet food processing area	Solid block wall with acoustic panelling between processing and packaging area	not reported	95 dB	Below 85 dB	
	Number of cases: 7		**mean before**	**mean after**	**mean reduction**
	Noise level dB		97.1 dB	80.0 dB	17.1 dB

Table 12. Risk of bias of interrupted time-series

Study	Independence other changes	Sufficient data points	Formal test for trend	Intervention does not affect data	Blinded assessment of outcome	Complete data set	Reliable outcome measure
Joy 2007	Not done	Done	Done	Not done	Not done	Not clear	Done
Rabinowitz 2011	Not done	Done	Done	Done	Not Done	Done	Done

APPENDICES

Appendix 1. Search strategy for CENTRAL

#1 MeSH descriptor Noise, Occupational explode all trees with qualifier: PC
#2 noise AND (reduction OR abatement OR diminishment OR elimination OR "engineering controls" OR "administrative controls")
#3 "hearing loss prevention" OR "hearing conservation" OR "hearing surveillance"
#4 "ear protective device" OR "ear protective devices" OR "hearing protective device" OR "hearing protective devices" OR "hearing protector" OR "hearing protectors" OR "hearing protection" OR "ear muffs" OR "ear plugs" OR "ear defenders"
#5 ("noise reduction" AND "protective equipment")
#6 MeSH descriptor Noise, Occupational explode all trees
#7 "protective equipment"
#8 (#6 AND #7)
#9 (#1 OR #2 OR #3 OR #4 OR #5 OR #8)

2016

#10 (#9) limited to publication year from 2008

Appendix 2. Search strategies for other databases

PubMed	Embase	CINAHL
2009	**2009**	**2009**
#1 noise [tiab] AND (reduction [tiab] OR abatement [tiab] OR diminishment [tiab] OR elimination [tiab] OR "engineering controls" [tiab] OR "administrative controls"[tiab]) #2 "hearing loss prevention" [tiab] OR "hearing conservation" [tiab] OR "hearing surveillance" [tiab] #3 "ear protective device" [tiab] OR "ear protective devices" [tiab] OR "hearing protective device" [tiab] OR "hearing protective devices" [tiab] OR "hearing protector" [tiab] OR "hearing protectors" [tiab] OR "hearing protection" [tiab] OR "ear muffs" [tiab] OR "ear plugs" [tiab] OR "ear defenders" [tiab] #4 ("noise reduction" [tiab] AND "protective equipment" [tiab]) #5 "Noise, Occupational/prevention and control"[Mesh] #6 "Noise, Occupational"[Mesh] #7 "protective equipment" [tiab] #8 #6 AND #7 #9 #1 OR #2 OR #3 OR #4 OR #5 OR #8 #10 (effect*[tiab] OR control*[tiab] OR evaluation*[tiab] OR program*[tiab]) AND (work*[tiab] OR worker*[tiab] OR workplace*[tiab] OR occupation*[tiab] OR prevention*[tiab] OR protect*[tiab]) #11 #9 AND #10	1 industrial noise/ 2 (protective adj equipment).tw. 3 1 and 2 4 (noise and (reduction or abatement or diminishment or elimination or (engineering adj controls) or (administrative adj controls))).tw. 5 ((hearing adj loss adj prevention) or (hearing adj conservation) or (hearing adj surveillance)).tw. 6 ((ear adj protective adj device) or (ear adj protective adj devices) or (hearing adj protective adj device) or (hearing adj protective adj devices) or (hearing adj protecto) or (hearing adj protectors) or (hearing adj protection) or (ear adj muffs) or (ear adj plugs) or (ear adj defenders)).tw. 7 ((noise adj reduction) and (protective adj equipment)).tw 8 6 or 4 or 3 or 7 or 5 9 ((effect* or control* or evaluation* or program*) and (work or worker* or workplace* or working or occupation* or prevention* or protect*)).tw. 10 8 and 9 11 10 **2012** #1 'industrial noise':de AND [2008-2012]/py #2 protective NEAR/3 equipment AND [2008-2012]/py #3 #1 AND #2 AND [2008-2012]/py #4 noise AND (reduction OR abatement OR diminishment OR elimination OR 'engineering controls' OR 'administrative controls') AND [2008-2012]/py #5 noise:ab,ti AND (reduction:ab,ti OR abatement:ab,ti OR diminishment:ab,ti OR elimination:ab,ti OR 'engineering controls':ab,ti OR 'administrative controls':ab,ti) AND [2008-2012]/py	#1 (noise AND (reduction OR abatement OR diminishment OR elimination OR "engineering controls" OR "administrative controls")) OR "hearing loss prevention" OR "hearing conservation" OR "hearing surveillance" #2 "ear protective device" OR "ear protective devices" OR "hearing protective device" OR "hearing protective devices" OR "hearing protector" OR "hearing protectors" OR "hearing protection" OR "ear muffs" OR "ear plugs" OR "ear defenders" #3 (noise(mh) AND "protective equipment") OR ("noise reduction" AND "protective equipment") #4 (effect* OR control* OR evaluation* OR program*) AND (work* OR worker* OR workplace* OR working OR occupation* OR prevention* OR protect*) #5 (#1 OR #2 OR #3) #6 (#4 AND #5)

(Continued)

2012 #12 2008:2012[dp] #13 #11 AND #12 **2015** #12 "2012"[Date - Publication] : "3000"[Date - Publication] #13 #11 AND #12 **2016** #12 "2015/08/21"[Date - Publication] : "3000"[Date - Publication] #13 #11 AND #12	#6 'hearing loss' NEAR/5 preventionAND [2008-2012]/py #7 hearing NEAR/5 conservation AND [2008-2012]/py #8 'hearing surveillance' AND [2008-2012]/py #9 #6 OR #7 OR #8 AND [2008-2012]/py #10 ear NEAR/5 protective AND device* AND [2008-2012]/py #11 hearing NEAR/3 protect* AND [2008-2012]/py #12 ear NEAR/1 muff* AND [2008-2012]/py #13 ear NEAR/1 plug* AND [2008-2012]/py #14 ear NEAR/1 defender* AND [2008-2012]/py #15 #10 OR #11 OR #12 OR #13 OR #14 AND [2008-2012]/py #16 noise NEAR/1 reduct* AND protect* NEAR/1 equipm* AND [2008-2012]/py #17 #3 OR #4 OR #9 OR #15 OR #16 AND [2008-2012]/py #18 effect* OR control* OR evaluation* OR program* AND (work OR worker* OR workplace* OR working OR occupation* OR prevention* OR protect*) AND [2008-2012]/py #19 #17 AND #18 AND [2008-2012]/py #20 #19 AND [embase]/lim AND [2008-2012]/py #21 #20 NOT [medline]/lim AND [2008-2012]/py **2015** same search as in 2012 except change of time span [2008-2012]/py to [2012-2015]/py **2016** same search as in 2012 except change of time span [2012-2015]/py to [2015-2016]/py	**2015** same strategy, #7 (#6) results limited to date of publication Jan 2012 - October 2016

BIOSIS/CAB Abstracts	**Web of Science**	**NIOSHTIC/OSH UPDATE**
2009 1 (noise and (reduction or abatement or diminishment or elimination or (engineering adj controls) or (administrative adj controls))).tw. 2 ((hearing adj loss adj prevention) or (hearing adj conservation) or (hearing adj surveillance)).tw. 3 ((ear adj protective adj device) or (ear adj protective adj devices) or (hearing adj protective adj device) or (hearing adj protective adj devices) or (hearing adj protec-	**2009** #1 TS=(noise AND (reduction OR abatement OR diminishment OR elimination OR "engineering controls" OR "administrative controls")) #2 TS=("hearing loss prevention" OR "hearing conservation" OR "hearing surveillance") #3 TS=("ear protective device" OR "ear protective devices" OR "hearing protective device" OR "hearing protective devices" OR "hearing protector" OR "hearing protectors" OR "hearing protection" OR "ear muffs" OR "ear plugs" OR "ear defenders") #4 #3 OR #2 OR #1 #5 TS=((effect* OR control* OR evaluation* OR program*) AND (work* OR worker* OR workplace* OR working OR occupation* OR prevention* OR protect*))	**2009 NIOSHTIC** (noise AND (induced OR hearing)) **2012 OSH UPDATE** time span 01-2008 to 01-2012 Searched in bibliographic databases: International bibliographic, CISDOC, HSELINE, IRRST, NIOSHTIC, NIOSHTIC-2, RILOSH

(Continued)

to) or (hearing adj protectors) or (hearing adj protection) or (ear adj muffs) or (ear adj plugs) or (ear adj defenders)).tw. 4 ((noise adj reduction) and (protective adj equipment)).tw 5 ((effect* or control* or evaluation* or program*) and (work or worker* or workplace* or working or occupation* or prevention* or protect*)).tw. 6 4 or 1 or 3 or 2 7 6 and 5	#6 #5 AND #4 **2012** same as search in 2009, added time span 2008-2012 **2016** same as search in 2009, added time span 2012-2016 #7 (#6) refined by: WEB OF SCIENCE CATEGORIES: (PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR ACOUSTICS OR ENGINEERING MECHANICAL OR METALLURGY METALLURGICAL ENGINEERING OR ENGINEERING ENVIRONMENTAL OR MECHANICS OR ENGINEERING MANUFACTURING OR CONSTRUCTION BUILDING TECHNOLOGY OR ENGINEERING MULTIDISCIPLINARY OR TRANSPORTATION OR GEOSCIENCES MULTIDISCIPLINARY OR MEDICINE GENERAL INTERNAL OR OPERATIONS RESEARCH MANAGEMENT SCIENCE OR BEHAVIORAL SCIENCES OR ENGINEERING INDUSTRIAL OR ENGINEERING AEROSPACE OR MEDICINE RESEARCH EXPERIMENTAL OR AGRICULTURE MULTIDISCIPLINARY)	#1 DC{OUBIB OR OUCISD OR OUHSEL OR OUISST OR OUNIOC OR OUNIOS OR OURILO} #2 GW{noise} #3 GW{induced OR hearing} #4 #2 AND #3 #5 #1 AND #4 #6 PY{2008 OR 2009 OR 2010 OR 2011 OR 2012} #7 #5 AND #6 **2015 OSHupdate** strategy same as in 2012, change of time span: # 6 PY{2012 OR 2013 OR 2014 OR 2015} **2016 OSHupdate** all databases, strategy same as 2012, change of time span: #6 PY{2015 OR 2016}

WHAT'S NEW

Date	Event	Description
9 January 2019	Amended	Missing reference added from study that has been screened and excluded in the 2017 update, Date of assessed as up-to-date changed from June to April 2017 (within 6 month of date of search)

HISTORY

Protocol first published: Issue 1, 2007
Review first published: Issue 3, 2009

Date	Event	Description
26 June 2017	New search has been performed	New citations, conclusions not changed:

Date	Event	Description
		Search updated. Four new studies included. Overview of uncontrolled engineering control studies added. Methods section improved.
8 May 2012	New citation required and conclusions have changed	New search and study selection conducted. Four new studies included. Methods improved. Conclusions changed.

CONTRIBUTIONS OF AUTHORS

All: Comment on drafts of protocol and review.

Christina Tikka: Searching, eligibility screening, quality assessment, data extraction, data analysis, update of the text. Christina Tikka is the guarantor of this review.

Jos Verbeek: Protocol development, searching, eligibility screening, quality assessment, data extraction, data analysis, writing and update of the text.

Erik Kateman: Protocol development, searching for trials, eligibility screening, quality assessment of studies, data extraction, review development.

Thais Morata: Searching for studies, eligibility screening, data extraction, and update of the text.

Wouter Dreschler: Eligibility screening and data extraction.

Silvia Ferrite: Eligibility screening and data extraction.

DECLARATIONS OF INTEREST

Christina Tikka: None known.

Jos Verbeek: None known.

Erik Kateman: None known.

Thais Morata: None known.

Wouter Dreschler: None known.

Silvia Ferrite: None known.

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Internal sources

- No sources of support supplied

External sources

- Dutch Ministry of Social Affairs and Employment as part of the KIS programme, Netherlands.

  Erik Kateman received a grant of EUR 5000 for the original (2009) version of this review.
- Cochrane Work formerly known as Cochrane Occupational Safety and Health Review Group, Finland.

  Provided support in kind.
- Stichting Arbouw, Netherlands.

  Provided EUR 5000 for Cochrane Work for the 2012 update of the review.
- Cochrane Editorial Unit, UK.

  Provided GBP 5000 to Christina Tikka for the 2017 update.

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

For noise measurements, we intended to include only measurements executed according to a written national or international standard in which information on measurement method, time weighting etc. was given. However, this transpired to be an excessively strict criterion. We therefore included all reported noise measurements, with the permission of the editorial base.

For hearing loss measurements, we intended to include only hearing loss measured with a calibrated audiometer and defined by means of a written protocol, which was the case for most studies. However, in some cases this was found to be an excessively strict criterion so we also included audiometric measurements when there was no written protocol reported, with the consent of the editorial base.

We intended to use a qualitative analysis if the data could not be combined in a quantitative way. Instead of the proposed synthesis we used the GRADE approach to rate the quality of the evidence.

NOTES

Disclaimer: The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

INDEX TERMS

Medical Subject Headings (MeSH)

*Ear Protective Devices; Audiometry; Coal Mining [legislation & jurisprudence]; Controlled Before-After Studies; Engineering [methods]; Health Education [standards]; Hearing Loss, Noise-Induced [diagnosis] [*prevention & control]; Noise, Occupational [adverse effects] [legislation & jurisprudence] [*prevention & control]; Occupational Diseases [diagnosis] [etiology] [*prevention & control]; Program Evaluation; Randomized Controlled Trials as Topic

MeSH check words

Humans