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

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TABLE OF CONTENTS

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A B S T R A C T

Background

Millions of workers worldwide are exposed to noise levels that increase their risk of hearing impairment. Little is known 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 Cochrane Central Register of Controlled Trials (CENTRAL); PubMed; EMBASE; CINAHL; Web of Science; BIOSIS Previews; Cambridge Scientific Abstracts; and OSH update to 25 January 2012.

Selection criteria

We included randomised controlled trials (RCT), controlled before-after studies (CBA) and interrupted time-series (ITS) of non-clinical hearing loss prevention interventions under field conditions among workers exposed to noise.

Data collection and analysis

Two authors independently assessed study eligibility and risk of bias and extracted data.

Main results

We included 25 studies. We found no controlled studies on engineering controls for noise exposure but one study evaluated legislation to reduce noise exposure in a 12-year time-series analysis. Eight studies with 3,430 participants evaluated immediate and long-term effects of personal hearing protection devices (HPDs) and sixteen studies with 82,794 participants evaluated short and long-term effects of hearing loss prevention programmes (HLPPs). The overall quality of studies was low to very low.

The one ITS study that evaluated the effect of new legislation in reducing noise exposure found that the median noise level decreased by 27.7 dB(A) (95% confidence interval (CI) -36.1 to -19.3 dB) immediately after the implementation of stricter legislation and that this was associated with a favourable downward trend in time of -2.1 dB per year (95% CI -4.9 to 0.7).

Hearing protection devices attenuated noise with about 20 dB(A) with variation among brands and types but for ear plugs these findings depended almost completely on proper instruction of insertion. Noise attenuation ratings of hearing protection under field conditions were consistently lower than the ratings provided by the manufacturers.

One cluster-RCT compared a three-year information campaign as part of a hearing loss prevention programme for agricultural students to audiometry only with three and 16-year follow-up but there were no significant differences in hearing loss. Another study compared a HLPP, which provided regular personal noise exposure information, to a programme without this information in a CBA design. Exposure information was associated with a favourable but non-significant reduction of the rate of hearing loss of -0.82 dB per year (95% CI -1.86 to 0.22). Another cluster-RCT evaluated the effect of extensive on-site training sessions and the use of personal noise-level indicators versus information only on noise levels but did not find a significant difference after four months follow-up (Mean Difference (MD) -0.30 dB(A) (95%CI -3.95 to 3.35).

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

In four long-term studies, workers in a HLPP still had a 0.5 dB greater hearing loss at 4 kHz than workers that were not exposed to noise (95% CI -0.5 to 1.7) which is about the level of hearing loss caused by exposure to 85 dB(A). In addition, two other studies showed substantial risk of hearing loss in spite of the protection of a HLPP compared to non-exposed workers.

Authors' conclusions

There is low quality evidence that implementation of stricter legislation can reduce noise levels in workplaces. Even though case studies show that substantial reductions in noise levels in the workplace can be achieved, there are no controlled studies of the effectiveness of such measures. The effectiveness of hearing protection devices depends on training and their proper use. 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. Better implementation and reinforcement of HLPPs is needed. Better evaluations of technical interventions and long-term effects are needed.

PLAIN LANGUAGE SUMMARY

Interventions to prevent hearing loss caused by noise at work

Millions of workers are exposed to noise levels that increase the risk of hearing loss and hearing impairment. In many countries there are mandatory hearing loss prevention programmes (HLPPs), which are considered an effective means to prevent noise induced hearing loss. However, the evidence for this assumption is unclear.

We found one study that showed that noise levels decreased after the implementation of stricter legislation in the mining industry. Even though case studies show that substantial reductions in noise levels in workplaces can be achieved, there were no further reports of controlled studies that this can be implemented and maintained at a larger scale.

In six studies with 188 workers, hearing protection reduced noise exposure of workers about 20 dB(A). However, one high quality study showed that if workers lack proper instructions in the use of earplugs, the attenuation offered is much reduced. Two studies with 3,242 workers evaluated the long-term effect of ear muffs versus ear plugs on noise-exposure and found no significant difference.

We found 15 studies with 79,986 participants that evaluated the long-term effects of protection against noise exposure in hearing loss prevention programmes. The use of hearing protection devices in well-implemented 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. There was one study that showed a possible preventive effect on hearing loss when using personal noise exposure monitoring and worker feedback compared to not using these devices in a hearing loss prevention programme. There was also very low quality evidence in four studies that, compared to non-exposed workers, average hearing loss prevention programmes 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 hearing loss prevention programme.

Higher quality prevention programmes, better quality of studies especially in the field of engineering controls and better implementation of legislation are needed to better prevent noise-induced hearing loss.

SUMMARY OF FINDINGS FOR THE MAIN COMPARISON [Explanation]

Hearing loss prevention programme compared to audiometric testing (agriculture students, long-term, three-year and 16-year follow-up) - RCT for

Patient or population: patients with hearing loss
Settings: agricultural schools
Intervention: Hearing loss prevention programme 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	**Hearing loss prevention programme 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)	⊕⊕⊕◯ **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)	⊕⊕⊕◯ **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; **OR:** Odds ratio;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

[1] One study only with limited number of participants

BACKGROUND

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 observed 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 noise induced hearing loss 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). Exposure is especially prevalent in mining, manufacturing, and the construction industry (Tak 2009). 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 puts also 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. The mobility among the workers is high, employment periods are often short and seasonal, and a worker might not even be part of a hearing conservation program if he is self-employed (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 will ultimately lead to hearing impairment. 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, 2, 3 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; Morata 1993). 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).

The preventive potential of reducing noise exposure has led to mandatory hearing loss prevention programmes in many countries. However, the reportedly continuing high rate of occupational noise induced hearing loss casts doubt upon the effectiveness of these standards or people's compliance with them. Moreover, the broad range of interventions included in hearing loss prevention programmes makes it difficult to select the most effective strategy for reducing risk. 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 belief that this should be the leading principle for noise reduction strategies in the workplace, in many situations the first attempt to reduce noise will be the provision of hearing protectors. The effectiveness of interventions to promote the use of hearing protectors has been studied in another Cochrane Review (El Dib 2012). 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 (Lynch 2005). They will not be included in 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 hearing loss prevention programmes 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.

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, cluster-randomised trials, controlled before-after studies and interrupted time-series. 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 controlled before-after studies. There is no uniform nomenclature for non-randomised studies. In the literature controlled before-after studies are also known as cohort studies, quasi-experimental studies 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 that 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 interrupted time-series. The Cochrane Effective Practice and Organisation of Care (EPOC) Group 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 collected uncontrolled before-after studies to compare with the results of our review.

For hearing protection devices, we included studies that compared noise attenuation between different devices in the same workers in real life situations. We excluded laboratory studies because it has been repeatedly reported that the results in the laboratory are often falsely or excessively positive due to factors such as training in the fitting of devices, wearing of glasses and other practical conditions . We excluded studies without a no intervention comparison group because the hearing attenuation depends very much on the skills of the worker to fit the device. A comparison between devices would

in these cases be a comparison between skills of workers and not between the attenuation of devices.

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 time-weighted average (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 form part of a noise induced hearing loss prevention programme. 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 noise 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 made a distinction between immediate effects and long-term effects. Immediate effects were considered if a change in outcome was possible after, at most, eight hours. This was the case for noise reduction as a result of noise reduction interventions and for noise attenuation or a decrease in temporary threshold shift (TTS) as a result of hearing protection devices. Hearing loss prevention programmes aim to prevent permanent threshold shifts (PTS) which only occur after several years and which can possibly be prevented by implementing engineering or administrative control measures or by consistently using protective equipment. Permanent threshold shifts were considered long-term effects.

An alternative technique to evaluate immediate or long-term effects 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 until today 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 the considerable uncertainties regarding the use of OAEs we decided to exclude OAEs 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 below.

Immediate effects

The relation between exposure to noise at work and noise-induced 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 hearing loss. Noise exposure levels are therefore a good estimate of the eventual health outcome. Occupational noise exposure measurements should be made with a sound level meter as area measurements, or with a noise dosimeter as personal measurements. A noise dosimeter integrates the noise measurements over time whereas the observer has to do this himself with area measurements. Although 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, this turned out to be an excessively strict criterion. We therefore included all reported noise measurements. The integration of noise measurements over time 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. However, in the US, the integration of noise levels over time is different from that in Europe with an 'exchange rate' of 5 and 3 dB respectively. This means that in American studies one hour of exposure to 90 dB(A) equals 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 American time-weighted figure would be an underestimate of the same noise levels measured according to the European methodology. We used the outcome measurements as described by the authors.

There is also an immediate temporary effect of noise exposure which manifests itself as a decrease in hearing acuity after some hours of exposure; the so-called temporary threshold shift (TTS). The TTS is indicative of noise exposure. For immediate effects of hearing protection we also included studies that used the TTS as the outcome measure.

In addition, noise attenuation of hearing protection can be measured as the difference in noise levels inside and outside hearing protection, which is referred to as microphone-in-real-ear (MIRE). An alternative to MIRE is the measurement of hearing levels with and without hearing protection. The difference between these two values is equivalent to the level of noise attenuation. This method is called real ear attenuation at threshold (REAT).

Long-term effects

It is possible to measure permanent hearing loss over several years in a stable working population. Interventions such as the provision and use of protective equipment, or environmental changes such as changes in equipment and machinery, can decrease noise exposure over time. Therefore we also included noise-induced hearing loss as an outcome measure. 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.

Timing of outcome assessment

For long-term follow-up we considered three follow-up times as important: less than one year, one to five years and more than five years. These follow-up times were considered to have similar outcomes.

Search methods for identification of studies

We conducted systematic searches for randomised controlled trials, controlled before-after studies and interrupted time-series studies. We used no restrictions on language, publication year or publication status. The date of the last search was 25 January 2012.

Electronic searches

We searched:
- the Cochrane Ear, Nose and Throat Disorders Group Trials Register;
- the Cochrane Central Register of Controlled Trials (CENTRAL, *The Cochrane Library* Issue 4, 2008);
- PubMed;
- EMBASE;
- CINAHL;
- LILACS;
- KoreaMed;
- IndMed;
- PakMediNet;
- CAB Abstracts;
- Web of Science;
- National Institute of Occupational Safety and Health database (NIOSHTIC);
- International Labour Organisation database (CISDOC);
- BIOSIS Previews;
- *m*RCT (Current Controlled Trials); and
- 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. PubMed, TRIPdatabase, NHS Evidence - Ear, Nose, Throat and Audiology (formerly NLH ENT & Audiology Specialist Library) and Google were also searched 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 authors (EK, JV, TM, WD, CM) 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 randomised controlled trial, controlled before-after studies, or interrupted time-series as the study design.

Data extraction and management

For each study included, pairs of the review authors (EK, JV, TM, WD, CM) extracted data independently. Where possible, we resolved discrepancies in the results by discussion or we involved a third 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 randomised controlled trials 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 risk of bias tool as implemented in RevMan 2011 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 the item allocation concealment we judged all studies to have an unclear risk of bias because this item is not applicable to non-randomised studies. Pairs of the review authors independently examined the risk of bias of the studies. We resolved disagreements by discussion. We defined high quality as a score of more than 50% on the internal validity scale of the checklist.

For interrupted time-series we used the quality criteria as presented by Ramsay 2003.

Measures of treatment effect

Noise exposure was measured 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 effect of an intervention, whether as attenuation of noise level or as change in noise level over time, was calculated 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.

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 levels with and without protection (Park 1991b protection). The MIRE and REAT methods yield slightly different results at different frequencies.

For hearing loss, effects were measured 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. Usually these amounts were defined as a Standard Threshold Shift (STS) and measured as a change or shift in hearing loss of at least 10 dB averaged over 2, 3 and 4 kHz in either ear, which is also the criterion used by OSHA, the US government agency in the Department of Labor, 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). STS was considered to be the event, and rates were recalculated 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 temporary threshold shifts 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, data from the original papers (Joy 2007) were extracted or additional data were obtained from the authors (Rabinowitz 2011) and re-analysed according to the recommended methods for analysis of interrupted time-series (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, a first order auto regressive time-series model was fitted 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 which 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 that 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 2011). For studies that used a cluster-randomised design and adjusted statistically for the design effect (Berg 2009),

we used the adjusted odds ratio to be entered into Revman. 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 or the control group with the least noise exposure, thus avoiding the inclusion of the same control group twice.

Dealing with missing data

We asked six authors to provide missing data and we obtained data from four of them (Davies 2008; Joy 2007; 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 values (Berg 2009) according to the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011).

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 hearing loss prevention programme, 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 (RevMan 2011). If this test statistic was greater than 50% we considered there to be substantial heterogeneity between studies.

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 were deemed sufficiently homogeneous with regard to interventions, participants, settings and the outcomes measured in a meta-analysis.

For hearing loss prevention programmes, we deemed both the change in hearing loss at 4 kHz and the standard threshold shift 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 odds ratios, 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 2011.

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 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 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* (Higgins 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 quality and this can be upgraded if the studies have special strengths or downgraded if the studies have important limitations.

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

Sensitivity analysis

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

R E S U L T S

Description of studies

See: Characteristics of included studies; Characteristics of excluded studies.

Results of the search

Our search yielded 2491 references (1360 in 2009 plus 1129 in 2012), of which 1198 came from a combined search of MEDLINE and EMBASE using Ovid, 86 from CINAHL, 76 from CENTRAL and nine from the COHF database 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 screening of references for eligibility resulted in 104 studies in 2009 plus 50 new references in 2012, which we then retrieved in full text.

Following further screening using our eligibility checklist, 25 articles ultimately fulfilled our inclusion criteria. One article described two trials and two articles described the same study. This resulted in 25 included studies of which four were added during the update in 2012. Checking the references of these four articles did not identify any new studies.

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. Three studies used a randomised design (Park 1991a instructions; Berg 2009; 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 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 controlled before after design but reported data for an interrupted time-series analysis and we used these data for the analysis (Rabinowitz 2011). Six studies implicitly used an equivalence design in which they tried to prove that the intervention (a hearing loss prevention programme) 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; Pell 1973). In another five studies, the authors tried to show that better implementation of a hearing loss prevention programme 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 hearing loss prevention programme, and Brink 2002 compared workers who wore hearing protection less than 33% of the time to those that wore hearing protection more often. 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). In four studies the same workers used sequentially different types of hearing protection (Horie 2002; 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 17 long-term evaluation studies, sample sizes ranged from 43 to 22,376 workers, amounting to a total of 82,794 with an average of 4,870 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 54,549 with an average of 3,209 participants per study. Numbers in the six immediate effect studies ranged from 4 to 70, amounting to a total of 188, with an average of 31 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 US.

Six studies evaluated immediate effects and two studies evaluated long-term effects of personal HPD. One of the immediate studies was carried out in Japan, two in Finland and three in the US. Both of the long-term studies were carried out in the 1980s in Sweden. Two of the immediate effect studies had been carried out after 2000, three in the 1990s and one in 1980. 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).

Seven long-term 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 are based on data gathered in the decade(s) preceding their publication.

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

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

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 the automobile industry (one study), in the steel industry (one study), in an aluminium smelter (one study), in agriculture (one study), at a shipyard (two studies), in the chemical industry (two studies), in the military (five studies), in one unspecified company (three studies) or were gathered from various workplaces (six studies).

In most studies only men were included or there were only 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 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 HPD 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 onsite training session focusing on areas of HPD use and noise control. Workers receiving the noise level indicator clipped them to their shoulder or chest. The noise level indicators were implemented for two month and gave a light signal when the noise level exceeded 85, 95, 105dB(A) and in addition vibrated at 115dB(A).

The studies that measured the immediate effects of hearing protection evaluated active noise cancellation devices (Horie 2002; Pääkkönen 2001), special communication earmuffs (Pääkkönen 1998), the effect of fitting instructions (Park 1991a instructions) or alternative hearing protection (Park 1991b protection; Royster 1980). In two studies the long-term effects of using earmuffs were compared to using earplugs (Erlandsson 1980; Nilsson 1980).

In fifteen studies a hearing surveillance, hearing conservation or hearing loss prevention programme was evaluated as the intervention of interest. We described the contents of the interventions extensively in Table 1. For example in one study the intervention consisted of annual audiometry and instruction once but with yearly reminders delivered at the home address and free hearing protection whereas the control group only received 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 during one year after a standard thresh-

old shift had been found in a person exposed to noise, with the aim of detecting susceptible persons with increasing hearing loss. Whereas Reynolds 1990a evaluated the effectiveness of a hearing loss prevention programme for workers on 12-hour work shifts.

Outcomes

In all but one long-term evaluations, the authors measured some kind of hearing threshold increase. However, the authors used varying definitions of hearing loss. In seven studies they used a standard threshold shift (STS), defined as an increase in hearing threshold of at least 10 dB averaged over 2, 3 or 4 kHz compared to a baseline measurement or the previous measurement (Adera 1993; Adera 2000; Lee-Feldstein 1993; Meyer 1993; Simpson 1994; Davies 2008; Berg 2009). In one study STS was defined as an increase of more than 10 dB in any frequency. In other studies hearing loss was measured as the average over the frequencies 0.5, 1, 2, 3, 4 and 6 kHz. One study used the frequencies 3, 4 and 6 kHz (Heyer 2011). Two studies also included the frequency of 8 kHz (Muhr 2006; Park 1991a instructions). 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 summarized 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 were already used. are similar to the other outcomes. In Seixas 2011 the authors used personal noise dosimeters to measure the sound pressure level as full-shift L_{eq} with 3dB exchange rate, 80 dB(A) threshold, 85dB(A) criterion level, and slow response.

In the immediate effect evaluations, two studies used the TTS as the effect measure (Horie 2002; Royster 1980). Two studies used MIRE as the difference in noise levels inside and outside the hearing protectors (Pääkkönen 1998; Pääkkönen 2001). Another study used REAT (the difference in hearing level inside and outside the hearing protector) as the effect measure for noise attenuation (Park 1991a instructions; Park 1991b protection).

In the ITS studies, one study measured the noise exposure as eight-hour TWA exposure (Joy 2007) and the second study used the rate of hearing loss in the binaural average hearing level at 2, 3, and 4 kHz (Rabinowitz 2011).

Excluded studies

See also the 'Characteristics of excluded studies' table.

One study (Pääkkönen 2005) was excluded because most of the data were already 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. One controlled study on noise reduction in an MRI scanner was excluded 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 were not field studies such as Franks 2000; Merry 1992; Toivonen 2002; Williams 2004. Studies that evaluated the immediate effects of hearing protection but did not use the same workers for the evaluation were also excluded (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, is shown in Figure 1 and Figure 2. Most studies scored poorly on all aspects of the checklist.

Figure 1. 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.
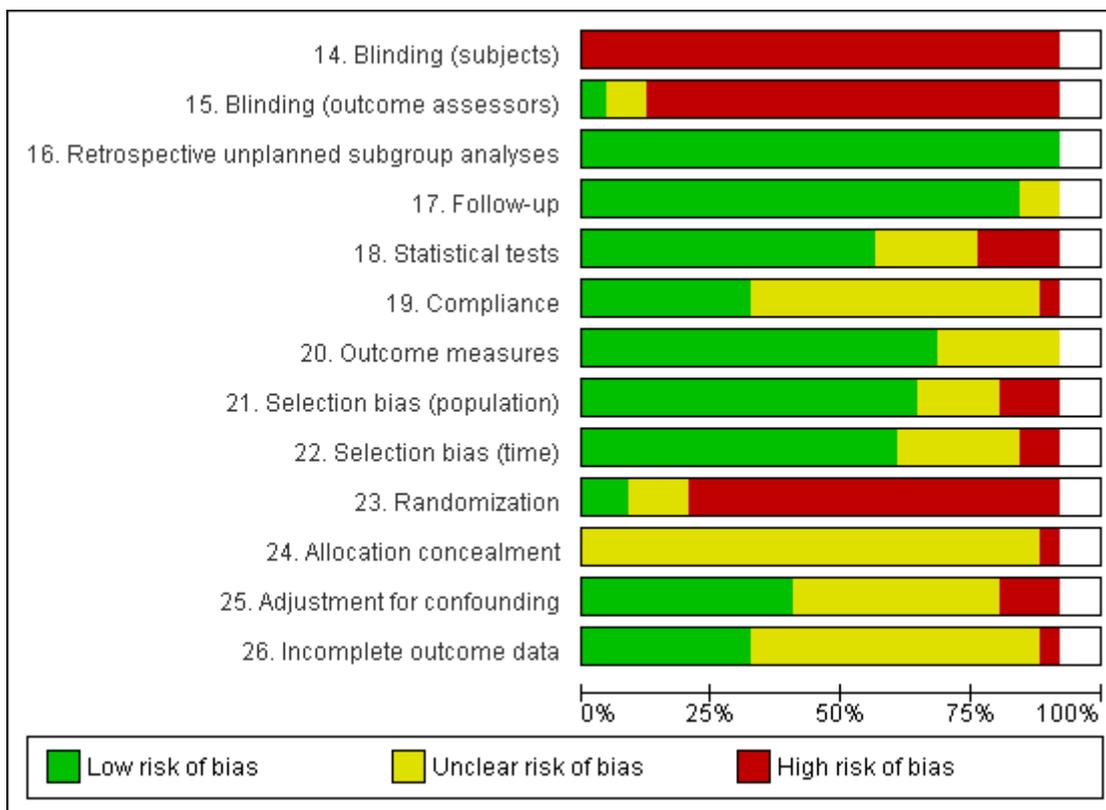
Figure 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study. Please note that the blank spaces correspond to the studies that have an ITS study design.

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 2). 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).

Four studies (three well-designed, controlled, before-after studies and a well-designed randomised controlled trial) achieved more than 50% of the maximum score of 13 on the internal validity scale of the checklist and were considered high quality (Horie 2002; Park 1991a instructions; Muhr 2006; Berg 2009). None of the studies used blinded outcome assessment.

For long-term evaluation, particularly in studies that used non-exposed workers as the control group, 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 four studies (Davies 2008; Lee-Feldstein 1993; Muhr 2006; Heyer 2011), age only in two studies (Gosztonyi 1975; Berg 2009), 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 ten 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 Pell 1973 and Lee-Feldstein 1993 the non-exposed group still had considerable exposure and could thus have confounded an effect of the intervention programme. Thus, according to our judgment, only three long-term evaluation studies had a low risk of bias.

Reporting bias

We did not formally test for reporting bias. However as many authors had an interest in reporting favourable results we considered it conceivable that the results of the studies are biased towards a positive outcome.

Effects of interventions

See: **Summary of findings for the main comparison** Hearing loss prevention programme compared to audiometric testing (agriculture students, long-term, 3-years and 16-years follow-up) - RCT for; **Summary of findings 2** Well-implemented hearing loss prevention programme compared to Less well-implemented hearing loss prevention programme for Hearing Loss; **Summary of findings 3** Hearing loss prevention programme compared to non-exposed workers

Engineering controls, legislation

We found no studies that evaluated the effect of engineering controls for decreasing noise levels, except for 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.

Long term effect

Legislation in the mining industry (ITS)

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 the year 2000 was a 27.7 dB reduction in the median noise level (95% confidence interval (CI) -36.1 to -19.3 dB) compared to that predicted by extrapolation of the pre-intervention slope (Analysis 1.1). 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 dB/year but this was not statistically significant (95% CI -4.9 to 0.7 dB) (Analysis 1.2). For the underground mining noise levels the immediate effect was -16.8 dB (95% CI -23.5 to -10.1 dB) and the long-term effect was -3.8 dB/year (95% CI -6.2 to -1.4 dB). If we took 1999 as the year in which the change of legislation was implemented, the immediate effect was smaller but the change of slope larger and significant. We rated the overall quality of evidence as low (see Summary of findings for the main comparison).

Personal hearing protection devices

Immediate Effects

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

There were two studies in this comparison that could not be combined because they used different outcome measures. Active noise cancellation in the same hearing protector increased the total noise reduction (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 2.1). In another study, the average temporary threshold shift (TTS) was 11.2 dB HL at 4 kHz for conventional protectors without cancellation devices and 5.8 dB HL for different protectors with noise cancellation on (Horie 2002, Analysis 2.2; Analysis 2.3; Analysis 2.4; Analysis 2.5; Analysis 2.6).

Hearing protection with instruction versus hearing protection without instruction (RCT)

Noise attenuation, measured as hearing levels at 4 kHz (REAT), increased slightly after instruction with 0.8 and 0.9 dB HL respectively for two different types of earmuffs following instruction, but increased substantially for two different types of earplugs with 9.1 and 6.0 dB HL respectively (Park 1991a instructions, Analysis 3.1; Analysis 3.2; Analysis 3.3; Analysis 3.4; Analysis 3.5; Analysis 3.6; Analysis 3.7). We rated the quality of evidence as high.

Hearing protection versus alternative hearing protection (RCT, CBA)

In the randomised controlled trial and in the condition 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 4.1). In one study, the EAR plug users had less TTS than those wearing another plug which, according to the authors, was significant but could not be checked due to missing standard deviations (Royster 1980, Analysis 5.1; Analysis 5.2; Analysis 5.3; Analysis 5.4; Analysis 5.5; Analysis 5.6)

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

Long term Effect

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

Workers were divided into high noise exposure and low noise exposure. In the meta-analysis, the OR of sustaining a STS for the muff-wearing workers versus the plug-wearing workers was estimated at 0.8 (95% CI 0.63 to 1.03) for those in high noise levels and at 2.65 (95% CI 0.40 to 17.52) for those in low noise levels (Erlandsson 1980; Nilsson 1980; Analysis 6.1). The results from the low noise group were not homogenous. The overall quality of evidence was rated as very low.

Hearing surveillance, hearing conservation or hearing loss prevention programmes

Long term Effects of Components of Hearing Loss Prevention Programmes

Hearing loss prevention programme versus audiometric testing only (RCT, >five-year follow-up)

Outcome: 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 of 0.85 (95% CI 0.29, 2.44) after three years follow-up and 0.94 (95% CI 0.46, 1.91) after 16 years follow-up (Analysis 7.1, Summary of findings for the main comparison).

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

Outcome: mean hearing threshold at 2, 3, and 4 kHz, controlled for: age, gender, and baseline hearing

In Rabinowitz 2011 there was no effect of the programme immediately after introduction (Analysis 8.1). The trend over time showed a significant yearly decrease of the rate of hearing loss of -1.57 dB (95% CI -2.37 to -0.77) in the intervention group (Analysis 8.2). Similar but smaller improvements over time occurred also 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).

Outcome: mean hearing threshold at 2, 3, and 4 kHz, controlled for: age, gender, baseline hearing, and initial rate of hearing loss

The authors could also control for the initial rate of hearing loss as a potential confounder. The results were similar as in 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 8.2).

The 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.

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

Outcome: change in noise level L_{eq}

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 9.1; Analysis 9.2).

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

Outcome: noise level L_{eq}

In the same study (Seixas 2011), noise levels of workers that received additional extensive information in four tool-box sessions were compared to those of workers that received one baseline information session only but there were no significant differences. The noise level decreased 1.7dB 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, 2.91) compared to the intervention group (Analysis 10.1; Analysis 10.2).

Well-implemented hearing loss prevention programme (HLPP) versus less well-implemented HLPP (CBA, one-year follow-up)

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 14.1).

Well-implemented hearing loss prevention programme versus less well-implemented hearing loss prevention programme (CBA, >5-years follow-up)

Outcome: STS at 4kHz

In the meta-analysis of three studies the effect was estimated as the odds ratio 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 odds ratio (OR) for the risk of sustaining a STS was 0.40 (95% CI 0.23 to 0.69) (Analysis 15.1) 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 low. (Summary of findings 2)

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

In Heyer 2011, only one out of three quality aspects of the hearing loss prevention programme 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 hearing loss prevention programme 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 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.

Long term Effects of Hearing Loss Prevention Programmes compared to No Exposure

Hearing loss prevention programme or hearing protection versus non-exposed workers (CBA, one-year follow-up)

Outcome: hearing levels STS

In Muhr 2006 the risk ratio of sustaining a standard threshold shift (STS) in the total cohort of recruits was 3.0 (95% CI 1.1 to 8.0) compared to recruits waiting for their training and not exposed. The risk increased with the level of exposure to 4.0 at the highest level of exposure (95% CI 1.0 to 16.0) (Analysis 11.1).

Hearing loss prevention programme or hearing protection versus non-exposed workers (CBA, >5-year follow-up)

Outcome: hearing levels at 4 kHz or STS

In the meta-analysis of four studies the summary effect size estimate was 0.05 (95% CI -0.05 to 0.16) (Analysis 12.1). 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 study Pell 1973 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 13.1). 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 hearing loss prevention program have equivalent hearing thresholds as the non-exposed workers. However, the 95% confidence interval 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 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 1.3 to 3.5) for workers with exposure of 80 to 85 dB-years. The HR gradually increased to 6.6 (95% CI 5.6 to 7.8) for workers with an exposure of more than 100 dB-years. Combined in the meta-analysis, this yielded a HR of 3.8 (95% CI 2.7 to 5.3) (Analysis 12.2).

We rated the overall quality of evidence as very low (Summary of findings 3).

Long-term effects of other comparisons

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

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 16.1).

Hearing loss prevention programme for 12-hour shifts versus eight-hour shifts (CBA, one-year follow-up)

In one study the mean difference in change in hearing level over one year at 4 kHz 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)

ADDITIONAL SUMMARY OF FINDINGS [*Explanation*]

Well-implemented hearing loss prevention programme compared to Less well-implemented hearing loss prevention programme for Hearing Loss

Patient or population: patients with Hearing Loss
Settings:
Intervention: Well-implemented hearing loss prevention programme
Comparison: Less well-implemented hearing loss prevention programme

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 hearing loss prevention programme	Well-implemented hearing loss prevention programme				
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]	16302 (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; **OR:** Odds ratio;

GRADE Working Group grades of evidence
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[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 Risk of bias because of lackof adjustment for age and hearing loss

Hearing loss prevention programme compared to non-exposed workers

Patient or population: patients with Hearing Loss
Settings:
Intervention: Hearing loss prevention programme
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	**Hearing loss prevention programme**				
Hearing Loss Change in hearing threshold at 4 KHz Follow-up: mean five years	The mean hearing loss in the control groups was **3.6 dB change at 4 kHz**[1]	The mean hearing loss in the intervention groups was **1.8 higher** (0.6 lower to 4.2 higher)		2231 (5 studies[2])	⊕◯◯◯ **very low**[3,4]	SMD -0.1 (-0.27 to 0.07)

*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: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

[1] Assumed increase of hearing threshold: median of three studies with resp 3.4, 3.6 and 5.2 dB increased in hearing threshold at 4 KHZ after five years follow-up
[2] Only three studies included in meta-analysis and sensitivity analysis
[3] Three studies did not adjust for age and hearing loss at baseline
[4] confidence interval does not exclude a risk of hearing loss similar to exposure to 85 dB(A)

DISCUSSION

Summary of main results

We found low quality evidence from one study which showed that legislation can probably induce technical improvements in the working environment that lead to a measurable reduction in noise exposure levels.

In terms of the immediate effects of hearing protection we found high quality evidence that instructions for inserting earplugs into the ear canal have a relevant and significant effect on the noise attenuation of the devices. Properly inserted earplugs can outperform the noise attenuation of earmuffs and caps, especially in the lower frequencies. 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. Some types of hearing protection examined in the included studies had a relevant and significantly better noise attenuation with instructions than alternative hearing protection. For peak noise, there were no significant differences in the noise attenuation of several types of hearing protection. The long-term evaluation of earmuffs versus earplugs showed that, in high noise levels, earmuffs probably perform better than earplugs and vice versa for low noise levels.

Very low quality evidence of long-term evaluation studies of components of hearing loss prevention programmes showed that the use of hearing protection devices in 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 hearing loss prevention programme showed favourable but non-significant effects both for hearing loss and for daily noise-exposure levels

There was also very low quality evidence that compared to non-exposed workers in long-term follow-up average hearing loss prevention programmes 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 found a hearing loss at 4 kHz of 0.5 dB HL with an upper confidence limit of 1.7 dB HL for studies with a five-year follow-up; after sensitivity analysis this was 1.8 dB HL with an upper limit of 4.2 dB. To be able to assess whether HLPPs are as good as not being exposed 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, 2.1 and 6.1 dB HL, respectively. Based on Hozo 2005, this is equivalent to a mean of 4.2 dB HL 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 HL, 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 hearing loss prevention programme.

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. Other studies on technical noise reduction that we found but did not include were mostly case studies which showed considerable reductions in noise level due to different interventions and within different frequency ranges; for example, 7 to 9 dB(A) in Jelinic 2005, 30 dB(A) in Knothe 1999, 3 to 22 dB(A) in Pingle 2006, 10 to 20 dB(A) in Scannell 1998, 13 dB in Stone 1971, 4 to 15 dB(A) in Kavraz 2009, 3 dB(A) in Smith 2006 and Smith 2009. It might be 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 controlled studies are 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. Comparing before and after measurements without a control condition can, therefore, be easily misleading. That is why we believe that also here more and better efforts should be made to use study designs with greater validity, such as a series of measurements before and after the interventions or a controlled-before-after measurement design. Therefore, we believe that guidance on noise control evaluation (Reeves 2009; Reinke 2010) should take better into account that noise levels can vary. It is also unclear whether the noise levels in the immediate surroundings of machinery also lead to a reduction in the personal noise doses received by workers, and whether such interventions are maintained in the long run. On the contrary, long-term evaluation of hearing loss prevention programmes shows that in spite of these programmes workers still sustain considerable hearing loss. That is why we finally decided, after a long discussion and after contacting the authors, to exclude all studies that evaluated engineering controls but that did not fully fulfil our inclusion criteria for study design such as Bealko 2009 and Smith 2011 (Characteristics of excluded studies).

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, however, was similar to that in a study that is included in our review (Park 1991a instructions) and therefore we assume that any fitting instruction will also improve noise attenuation of hearing protectors in practice. Moreover, we only included studies that compared different devices because the evaluation depends to such a great extent on the wearer. That criterion excluded a great number of studies that evaluated only one device. However we feel that it is justified.

Even though all the studies intended to evaluate a hearing loss prevention programme those programmes were not clearly defined. It is also 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 providing hearing protection devices. Two studies used a randomised design. One was conducted in the construction industry. It shows that, even though it has often been argued that it is difficult to randomise workers, this is feasible even in difficult sectors 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 is made aware of his exposure levels (Rabinowitz 2011; Seixas 2011). Probably due to small sample sizes neither of them found a significant outcome but given the problems in construction industry with varying noise sources, 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. Thus there is a need for better quality studies and that is possible as demonstrated by the one RCT with long term follow-up that we found. Also the interrupted time-series design has potential for evaluating hearing loss prevention programmes because much data is collected routinely. We believe that these studies would provide better quality evidence than comparing hearing loss prevention programmes to non-exposed workers or using a retrospective design.

For the immediate effect evaluation, only one study 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 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 hearing loss prevention programmes with those of poorer quality. It is possible to compare different hearing loss prevention programmes 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 did our best 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.

Publication bias could play a role in the results of the long-term evaluation studies, with four of the studies being funded or carried out by professionals that were part of the company, who could possibly have an interest in publishing studies demonstrating a preventative effect of hearing loss prevention programmes.

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 what the attenuation of hearing protection was when worn by different workers in field conditions. All these studies conclude that there is great variation among workers leading to large standard deviations in the average attenuation values. This is 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 theoretically possible and indicated by the manufacturer. The inherent lack of precision of the methods used since the late 1970s for determining 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 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 US, 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 hearing loss prevention programmes (Dobie 1995). The author acknowledges that he did not perform a systematic search. He included and commented upon both evaluation studies that compared hearing protection users versus non-users and those that compared protected workers to non-exposed workers. He included three long-term evaluation studies, of which two were also included in this review, and of which one was excluded. His conclusions are similar to ours in that the evidence for the effectiveness of hearing loss prevention programmes is not very convincing.

Borchgrevink 2003 reviewed only occupational noise-induced hearing loss data and because hearing loss still occurred he concluded that hearing loss prevention programmes were ineffective. Daniell 2006 evaluated the quality of hearing loss prevention programmes 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 dramatic reductions in noise levels but there are however no controlled 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. 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 can lead to a moderate additional reduction of noise levels in the lower frequency range.

There was very low quality evidence that the use of hearing protection devices in well-implemented 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 hearing loss prevention programme showed a favourable but non-significant effect. There was also very low quality evidence that, compared to non-exposed workers, average hearing loss prevention programmes 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).

Implications for research

Research on the long-term effects of technical noise reducing measures and on the effects of recommendations of measures is needed. This should preferably be performed using a cluster-randomised design in which firms 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.

Hearing loss prevention programmes should also be evaluated in a cluster-randomised design, in which well implemented programmes can be compared to less well implemented programmes. 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 25dB after two to five years (Sulkowski 2007). A detailed process evaluation could reveal how well the measures were implemented. Better use of the available data for retrospective cohort studies is needed, taking into account the hearing status at the beginning of the study, differences in age, and changes in noise exposure levels over time to avoid biased results. Studies evaluating hearing loss prevention programmes with innovative content are especially needed in branches of industry where noise exposure is prevalent and difficult to eliminate such as the construction industry.

ACKNOWLEDGEMENTS

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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	Controlled before-after study
Participants	Various occupations n = 692 US Military
Interventions	Intervention: HLPP in company with apparently good programme (1972 to 1981); n = 93 Comparison: HLPP in study company (1980 to 1989) with poor programme; n = 599
Outcomes	STS / 100 person-years greater or equal than 10 dB in either ear as the mean change at 2, 3 and 4 kHz nine-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

Adera 1993 *(Continued)*

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 gender
26. Incomplete outcome data	Unclear risk	not reported

Adera 2000

Methods	Controlled before-after study
Participants	Various occupations n = 19,640 US one company
Interventions	Intervention: well-implemented HLPP in five companies; n = 4317, after adjustment for design n = 22 Comparison: HLPP in one company with poor quality HLPP; n = 15,323
Outcomes	STS / 100 person-years greater or equal than 10 dB in either ear as the mean change at 2, 3 and 4 kHz five-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

Adera 2000 *(Continued)*

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
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 US 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 or greater 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 three-year and 16-year follow-up
Notes	Long-term Comparability - intervention/control: Mean Age: Intervention 14.5y, Control 14.6y 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
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	Controlled before-after study
Participants	Automobile workers n = 264 US one 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

Brink 2002   (*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	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	Controlled before-after study
Participants	Workers in lumber mills during 1979-1996 who had at least two hearing tests n = 22,376 Canada, British Columbia
Interventions	Intervention: hearing conservation programme; n = 16,347 Control: those exposed to less than 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 or greater 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

Davies 2008   (*Continued*)

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 analyse
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	Controlled before-after study
Participants	Ship yard workers n = 40 Assembly department n = 26 less than 89 dB(A) exposure n = 26 Boiler department n = 24 more than 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 three years at 2, 3, 4, 6, 8kHz Three-year follow-up

Erlandsson 1980 (*Continued*)

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
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	Controlled before-after study
Participants	Various occupations in one company n = 142 US
Interventions	Intervention: HLPP; n = 71 Control: non-exposed workers; n = 71

Gosztonyi 1975   (*Continued*)

Outcomes	Average change in hearing thresholds over 3 years at 0.5, 1, 2, 3, 4, 6 kHz five-year follow-up
Notes	Long-term Comparability - intervention/control: Age: intervention - md 42.8 y; control - md 43.2 y 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
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 program, 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	Controlled before-after study
Participants	Various workers n = 43 US

Hager 1982 *(Continued)*

	one 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 five and ten years
Notes	Long-term Comparability - intervention/control: Age: ? Hearing: intervention 8.1 dB 4kHz; control 0.3 dB 4kHz

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 (5years)
18. Statistical tests	Low risk	t-test
19. Compliance	Unclear risk	nor 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	controlled before-after study (retrospective)
Participants	workers of two automotive plants, one 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) 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

Heyer 2011 *(Continued)*

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	Controlled before-after study
Participants	Steel industry quality check workers n = 12 Japan one company
Interventions	Intervention: hearing protection with active noise cancellation: Proactive PA-3100; n = 12 Control: hearing protection without active noise cancellation; n = 12
Outcomes	Temporary threshold shift after four hours of exposure at 1, 2, 4, 6 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	Low risk	audiometry quality reported

Horie 2002   *(Continued)*

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

Joy 2007

Methods	Interrupted time-series
Participants	Coal mines 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 Permissible Exposure Level which includes all sound pressure levels from 90 dB(A) to 140 dB(A) with a doubling rate of 5 dB as an eight-hour time weighted average
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	Controlled before-after study
Participants	Automobile workers n = 11,435 US one company
Interventions	Intervention: HLPP; n = 11,104, after cluster adjustment n = 97 Control: non-exposed colleagues; n = 331

Lee-Feldstein 1993 *(Continued)*

Outcomes	Rate of STS, average change in mean hearing threshold at 2, 3 and 4 kHz in the worst ear follow-up average five 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
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	Controlled before-after study
Participants	Various occupations n = 1377 US 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 one 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
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

Muhr 2006

Methods	Controlled before-after study
Participants	Army conscripts n = 885 conscripted between 1 June 1999 and 1 June 2000 with less hearing loss than 20 dB average over 2 and 3 kHz and less than 32.5 dB over 4 and 6 kHz or less than 25 dB over 2 and 3 kHz and less than 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 equal to or greater than 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 to 11 months
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 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

Muhr 2006 (*Continued*)

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%

Nilsson 1980

Methods	Controlled before-after study
Participants	Ship builders; n = 231 Highly exposed group with more than 94 dB(A); n = 1838 Low exposed group with less than 88 dB(A); n = 1354 Sweden one shipyard
Interventions	Intervention: workers wearing earmuffs; n = 1883 Control: workers wearing earplugs; n = 1309
Outcomes	STS more than 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-square test
19. Compliance	Unclear risk	not reported
20. Outcome measures	Low risk	audiometry quality reported

Nilsson 1980 *(Continued)*

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	Randomised controlled trial
Participants	Various workers n = 40 US Several companies
Interventions	Intervention: fitting instructions for earplugs and earmuffs during 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 HP 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	High risk	not reported
26. Incomplete outcome data	Low risk	no loss

Park 1991b protection

Methods	Randomised controlled trial
Participants	Various workers n = 40 US Several companies
Interventions	Intervention: four 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 HP checked

Park 1991b protection   (*Continued*)

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	Controlled before-after study Prospective
Participants	Various workers n = 1572 n = 628 less than 20 dB hearing loss at entrance n = 559 between 15 and 35 dB hearing loss at entrance n = 385 with more than 40 dB hearing loss at entrance USA one 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 five-year follow-up
Notes	Long-term Comparability - intervention/control: Average Age: intervention - 34 y; control - 43 y 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	five-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	10 years mean age different
26. Incomplete outcome data	Unclear risk	not reported

Pääkkönen 1998

Methods	Controlled before-after study
Participants	Shots with rifle 762RK62 n = five 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 are 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	Controlled before-after 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 eight minutes LAeq 104 to 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	controlled before-after study / interrupted time-series (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: on-going hearing conservation program (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 y); intervention mean 48.7 y, control mean 48,6 y Hearing: controls matched (C1) and highly matched (C2): C1: baseline hearing = similar high frequency hearing threshold levels (binaural average of 2, 3 and 4 kHz) (within 5 dB) (n= I 78 / C 234)

Rabinowitz 2011 (*Continued*)

	C2: baseline hearing and initial rate of hearing loss during pre-intervention period (n= I 46 / C 138) For risk of bias see Table 2

Reynolds 1990a

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

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	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

Reynolds 1990a (*Continued*)

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	Controlled before-after study
Participants	Various occupations n = 70 US
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
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

Royster 1980 *(Continued)*

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	two out of 72 lost to follow-up

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Seixas 2011

Methods	both cluster and individually randomised RCT, first four 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' onsite training (N=44) Intervention 2: baseline training plus noise 'tool box' onsite training plus personal noise level indicator (N=41) Control: baseline training (N=46)
Outcomes	noise level measured as L_{aeq} at two and four 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	Leq according to NIOSH criteria

Seixas 2011 *(Continued)*

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% to 33%

Simpson 1994

Methods	Controlled before-after study
Participants	Various occupations in 21 companies n = 13283 US
Interventions	Intervention: well-implemented HLPP Control: poor quality HLPP
Outcomes	Rate of standard threshold shifts defined as on average 10 dB or more at 2, 3 and 4 kHz in either ear Follow-up average one 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 month)

Simpson 1994 *(Continued)*

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

? = no information available
HL = hearing loss
HLPP = hearing loss protection programme
HT = hearing threshold
md = median
STS = standard threshold shift
y = years

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: HP 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
Kotarbinska 2009	Study design: immediate effect of HP, but no control group and no comparison of 2 types of HP on the same workers
Lempert 1983	Study design: no control group, only one measurement before intervention
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 build 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 timeseries 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 controlled before-after measurements, no ITS
Smith 2011	Study design: only one measurement before and one after intervention, no ITS, no control group
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

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 General noise 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 General 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 General 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 General noise Int Year 2000	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]
2.4 Underground noise Int Year 2000	1		change in slope (Random, 95% CI)	0.0 [0.0, 0.0]

Comparison 2. Hearing protection with ANC vs hearing protection without ANC (immediate)

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

Comparison 3. Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing levels at 0.5 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
1.1 Ear foam plugs	1	20	Mean Difference (IV, Random, 95% CI)	16.30 [5.93, 26.67]
1.2 Ultra-fit plugs	1	20	Mean Difference (IV, Random, 95% CI)	11.6 [5.89, 17.31]
1.3 Wilson Sound Ban cap	1	20	Mean Difference (IV, Random, 95% CI)	4.1 [-2.47, 10.67]
1.4 Bilsom UF-1 muff	1	20	Mean Difference (IV, Random, 95% CI)	1.80 [-1.86, 5.46]
2 Hearing levels at 1 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
2.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	3.80 [-3.70, 11.30]
2.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	-0.20 [-4.78, 4.38]
3 Hearing levels at 2 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
3.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.70 [-1.89, 7.29]
3.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	2.5 [-1.05, 6.05]
4 Hearing levels at 3 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
4.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	1.60 [-3.01, 6.21]
4.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	2.40 [-0.01, 4.81]
5 Hearing levels at 4 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
5.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	0.90 [-6.18, 7.98]
5.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.80 [-4.26, 5.86]
6 Hearing levels at 6 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
6.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.30 [-7.31, 11.91]
6.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.20 [-4.75, 5.15]
7 Hearing levels at 8 kHz difference with/without	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
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]
7.3 Wilson Sound Ban Cap	1	20	Mean Difference (IV, Random, 95% CI)	2.0 [-8.13, 12.13]

7.4 Bilsom UF-1 Muff	1	20	Mean Difference (IV, Random, 95% CI)	0.90 [-4.45, 6.25]

Comparison 4. Various hearing protectors (immediate)

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noise attenuation (inside hearing protection minus outside hearing protection measurement)	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]

Comparison 5. 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 (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]
3 TTS at 2 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
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]
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]

Comparison 6. Hearing muffs vs hearing plugs (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)	1.20 [0.69, 2.07]
1.1 High noise exposure > 89 dB(A)	2		OR (Random, 95% CI)	0.80 [0.63, 1.03]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1.2 Low noise exposure < 89 dB(A)	2		OR (Random, 95% CI)	2.65 [0.40, 17.52]

Comparison 7. Hearing loss prevention programme vs audiometric testing (agriculture students, long-term, 3-years and 16-years 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-years follow-up	1		Odds Ratio (Fixed, 95% CI)	0.85 [0.29, 2.44]
1.2 16-years follow-up	1		Odds Ratio (Fixed, 95% CI)	0.94 [0.46, 1.91]

Comparison 8. 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]
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]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
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]

Comparison 9. 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]

Comparison 10. 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

Comparison 11.   Hearing loss prevention programme 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	885	Risk Ratio (M-H, Fixed, 95% CI)	2.98 [1.11, 7.99]
1.1 Low exposed engineers	1	337	Risk Ratio (M-H, Fixed, 95% CI)	1.74 [0.23, 13.15]
1.2 Medium exposed infantry	1	298	Risk Ratio (M-H, Fixed, 95% CI)	2.37 [0.32, 17.70]
1.3 High exposed artillery	1	250	Risk Ratio (M-H, Fixed, 95% CI)	3.95 [0.98, 15.82]

Comparison 12.   Hearing loss prevention programme 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]

Comparison 13.   Hearing loss prevention programme 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]

Comparison 14. Well-implemented hearing loss prevention programme 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]

Comparison 15. Well-implemented hearing loss prevention programme 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]

Comparison 16. 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]

Comparison 17. Hearing loss prevention programme 12-hour shift vs hearing loss prevention programme 8-hour shift (long-term 1-year)

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	852	Mean Difference (IV, Fixed, 95% CI)	-0.68 [-1.85, 0.49]

Review: Interventions to prevent occupational noise-induced hearing loss

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

Outcome: 1 Immediate change in level

Study or subgroup	immediate change in level (SE)	immediate change in level IV,Random,95% CI	immediate change in level IV,Random,95% CI
1 General noise Int Year 1999			
Joy 2007	-14.5 (5.4593)		-14.50 [-25.20, -3.80]
2 Underground noise Int Year 1999			
Joy 2007	0.2 (4.5664)		0.20 [-8.75, 9.15]
3 General noise Int Year 2000			
Joy 2007	-27.7 (4.2858)		-27.70 [-36.10, -19.30]
4 Underground noise Int Year 2000			
Joy 2007	-16.8 (3.4184)		-16.80 [-23.50, -10.10]

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        -20    -10    0    10    20
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Favours experimental   Favours control
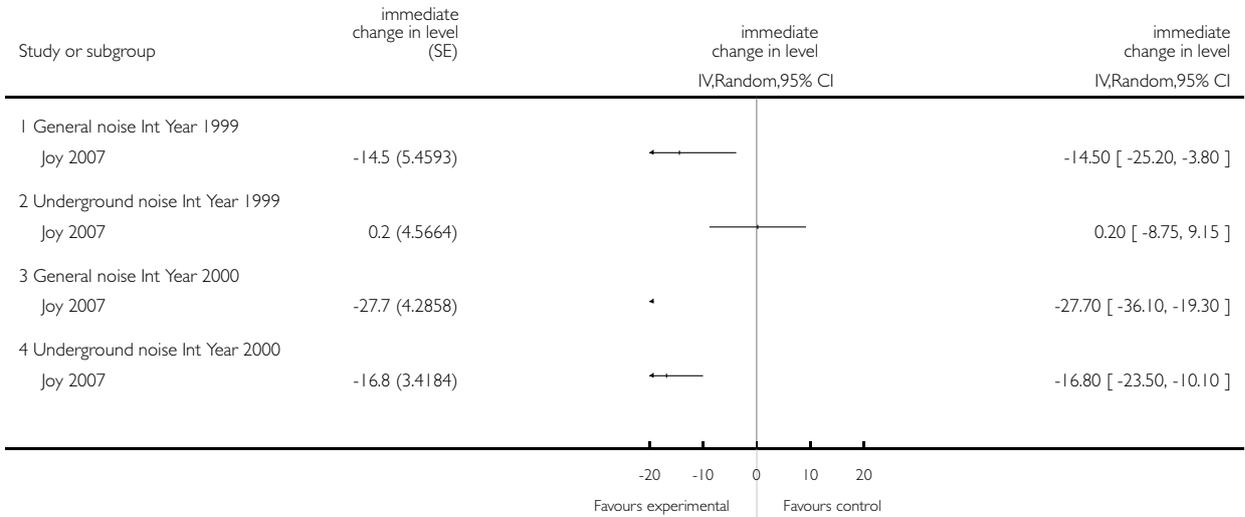
Analysis 1.2. Comparison 1 Legislation to decrease noise exposure (long-term) - ITS, Outcome 2 Change in slope.

Review: Interventions to prevent occupational noise-induced hearing loss

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

Outcome: 2 Change in slope

Study or subgroup	change in slope (SE)	change in slope IV,Random,95% CI	change in slope IV,Random,95% CI
1 General noise Int Year 1999			
Joy 2007	-5.6 (1.4286)		-5.60 [-8.40, -2.80]
2 Underground noise Int Year 1999			
Joy 2007	-6.1 (1.4796)		-6.10 [-9.00, -3.20]
3 General noise Int Year 2000			
Joy 2007	-2.1 (1.4286)		-2.10 [-4.90, 0.70]
4 Underground noise Int Year 2000			
Joy 2007	-3.7 (1.2245)		-3.70 [-6.10, -1.30]

-10   -5   0   5   10

Favours experimental   Favours control
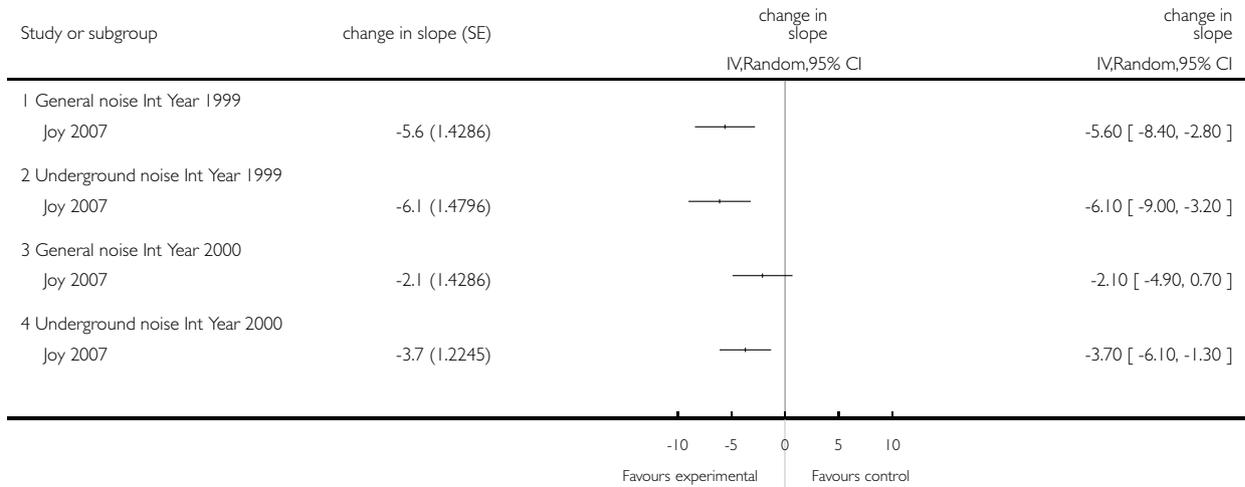
Analysis 2.1. Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 1 Attenuation of noise (dB outside minus inside).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 1 Attenuation of noise (dB outside minus inside)

Study or subgroup	Intervention		Control		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Fixed,95% CI	IV,Fixed,95% CI
1 Alpha-200 series with Active Noise Cancelling						
Pääkkönen 2001	1	25 (0)	1	17 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**1**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 Gentex/Bose Active Noise Cancelling						
Pääkkönen 2001	1	24 (0)	1	20 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**1**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Total (95% CI)	**2**		**2**			**0.0 [0.0, 0.0]**
Heterogeneity: Chi² = 0.0, df = 0 (P<0.00001); I² =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.0, df = -1 (P = 0.0), I² =0.0%						

```
        -10    -5    0    5    10
     Favours Control    Favours Intervention
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Analysis 2.2. Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 2 TTS at 1 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 2 TTS at 1 kHz (before exposure - after exposure)

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
Horie 2002	12	-2.5 (0)	12	-4.17 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**0**		**0**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-100   -50   0   50   100

Favours Control   Favours Intervention
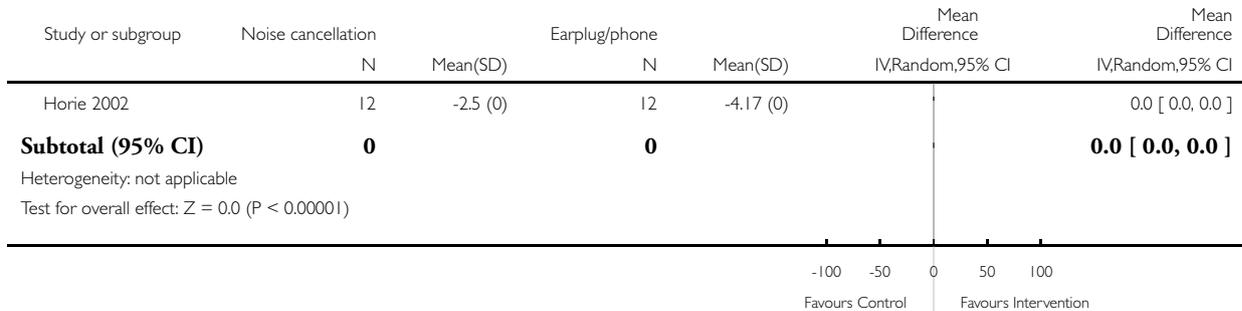
Analysis 2.3. Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 3 TTS at 2 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 3 TTS at 2 kHz (before exposure - after exposure)

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
Horie 2002	12	-3 (0)	12	-7.08 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**0**		**0**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-100   -50   0   50   100

Favours Control   Favours Intervention
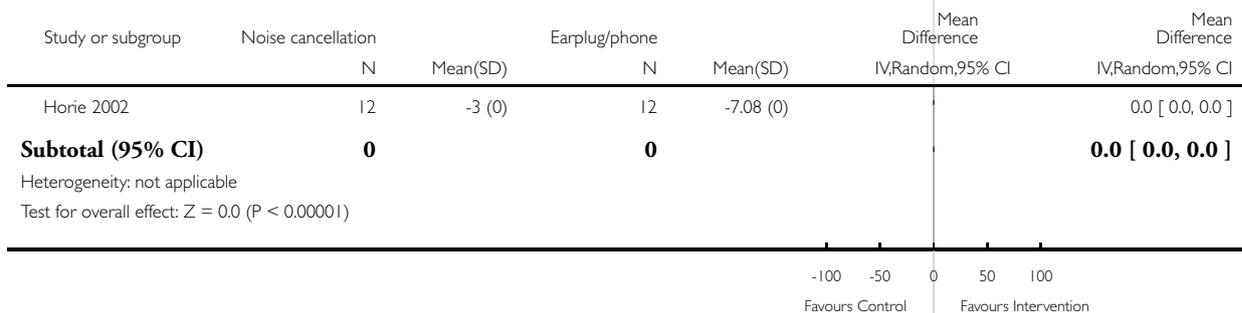
Analysis 2.4.   Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 4 TTS at 4 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 4 TTS at 4 kHz (before exposure - after exposure)

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
Horie 2002	12	-5.8 (0)	12	-11.25 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**0**		**0**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

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          -100    -50     0      50    100
          Favours Control     Favours Intervention
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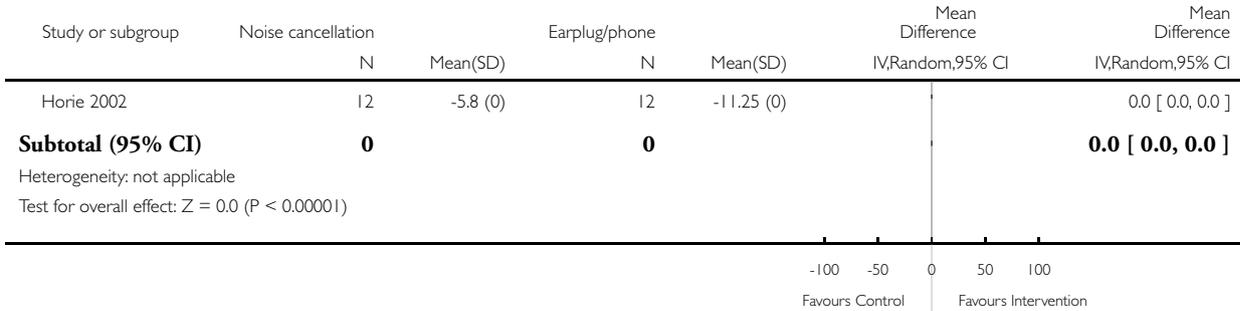
Analysis 2.5.   Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 5 TTS at 6 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 5 TTS at 6 kHz (before exposure - after exposure)

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
Horie 2002	12	-3.75 (0)	12	-8.08 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**0**		**0**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

```
          -100    -50     0      50    100
          Favours Control     Favours Intervention
```
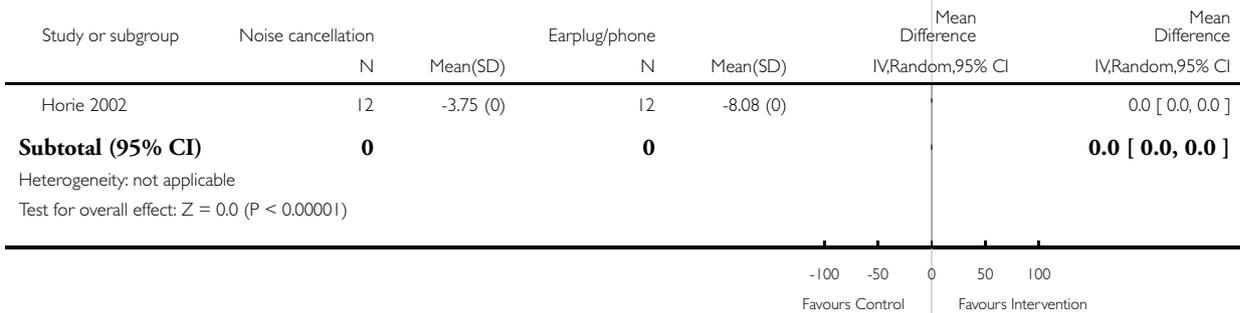
Analysis 2.6. Comparison 2 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 6 TTS at 8 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 2 Hearing protection with ANC vs hearing protection without ANC (immediate)

Outcome: 6 TTS at 8 kHz (before exposure - after exposure)

Study or subgroup	Noise cancellation		Earplug/phone		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
Horie 2002	12	-4.58 (0)	12	-5.42 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**0**		**0**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-100   -50   0   50   100

Favours Control   Favours Intervention

Analysis 3.1.   Comparison 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT, Outcome 1 Hearing levels at 0.5 kHz difference with/without.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 1 Hearing levels at 0.5 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
1 Ear foam plugs							
Park 1991b protection	10	33.2 (7.2)	10	16.9 (15.1)		100.0 %	16.30 [5.93, 26.67]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**16.30 [5.93, 26.67]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.08 (P = 0.0021)							
2 Ultra-fit plugs							
Park 1991b protection	10	19 (6.1)	10	7.4 (6.9)		100.0 %	11.60 [5.89, 17.31]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**11.60 [5.89, 17.31]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.98 (P = 0.000068)							
3 Wilson Sound Ban cap							
Park 1991b protection	10	16.5 (6.2)	10	12.4 (8.6)		100.0 %	4.10 [-2.47, 10.67]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**4.10 [-2.47, 10.67]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.22 (P = 0.22)							
4 Bilsom UF-1 muff							
Park 1991b protection	10	20.8 (2.6)	10	19 (5.3)		100.0 %	1.80 [-1.86, 5.46]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**1.80 [-1.86, 5.46]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.96 (P = 0.33)							

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        -100    -50      0      50    100
            Favours Control    Favours Intervention
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Analysis 3.2. Comparison 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT, Outcome 2 Hearing levels at 1 kHz difference with/without.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 2 Hearing levels at 1 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference IV,Random,95% CI	Weight	Mean Difference IV,Random,95% CI
	N	Mean(SD)	N	Mean(SD)			
1 EAR foam plugs							
Park 1991b protection	10	32.3 (6)	10	16.9 (14.6)		100.0 %	15.40 [5.62, 25.18]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**15.40 [5.62, 25.18]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.09 (P = 0.0020)							
2 UltraFit plugs							
Park 1991b protection	10	22.2 (5)	10	9.7 (8.5)		100.0 %	12.50 [6.39, 18.61]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**12.50 [6.39, 18.61]**
Heterogeneity: not applicable							
Test for overall effect: Z = 4.01 (P = 0.000061)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	16 (6.5)	10	12.2 (10.2)		100.0 %	3.80 [-3.70, 11.30]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**3.80 [-3.70, 11.30]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.99 (P = 0.32)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	27.3 (3.7)	10	27.5 (6.4)		100.0 %	-0.20 [-4.78, 4.38]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**-0.20 [-4.78, 4.38]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.09 (P = 0.93)							

-100   -50   0   50   100

Favours Control   Favours Intervention

Analysis 3.3. Comparison 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT, Outcome 3 Hearing levels at 2 kHz difference with/without.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 3 Hearing levels at 2 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
1 EAR foam plugs							
Park 1991b protection	10	34.9 (3.8)	10	27 (14.2)		100.0 %	7.90 [-1.21, 17.01]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**7.90 [-1.21, 17.01]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.70 (P = 0.089)							
2 UltraFit plugs							
Park 1991b protection	10	27.3 (5.6)	10	16.9 (8.2)		100.0 %	10.40 [4.25, 16.55]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**10.40 [4.25, 16.55]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.31 (P = 0.00093)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	30.3 (3.9)	10	27.6 (6.3)		100.0 %	2.70 [-1.89, 7.29]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**2.70 [-1.89, 7.29]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.15 (P = 0.25)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	29.4 (4)	10	26.9 (4.1)		100.0 %	2.50 [-1.05, 6.05]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**2.50 [-1.05, 6.05]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.38 (P = 0.17)							

-100   -50   0   50   100

Favours Control   Favours Intervention

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 4 Hearing levels at 3 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
1 EAR foam plugs							
Park 1991b protection	10	38.5 (3.1)	10	32.3 (12.1)		100.0 %	6.20 [-1.54, 13.94]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**6.20 [-1.54, 13.94]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.57 (P = 0.12)							
2 UltraFit plugs							
Park 1991b protection	10	28.9 (4.9)	10	22 (5.9)		100.0 %	6.90 [2.15, 11.65]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**6.90 [2.15, 11.65]**
Heterogeneity: not applicable							
Test for overall effect: Z = 2.85 (P = 0.0044)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	34.3 (5.5)	10	32.7 (5)		100.0 %	1.60 [-3.01, 6.21]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**1.60 [-3.01, 6.21]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.68 (P = 0.50)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	36.5 (2.7)	10	34.1 (2.8)		100.0 %	2.40 [-0.01, 4.81]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**2.40 [-0.01, 4.81]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.95 (P = 0.051)							

```
           -100   -50    0    50   100
         Favours control    Favours intervention
```

Analysis 3.5. Comparison 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT, Outcome 5 Hearing levels at 4 kHz difference with/without.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 5 Hearing levels at 4 kHz difference with/without

Study or subgroup	Intervention N	Mean(SD)	Control N	Mean(SD)	Mean Difference IV,Random,95% CI	Weight	Mean Difference IV,Random,95% CI
1 EAR foam plugs							
Park 1991b protection	10	36.3 (3.6)	10	30.3 (11.1)		100.0 %	6.00 [-1.23, 13.23]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**6.00 [-1.23, 13.23]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.63 (P = 0.10)							
2 UltraFit plugs							
Park 1991b protection	10	28.1 (5.4)	10	19 (7)		100.0 %	9.10 [3.62, 14.58]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**9.10 [3.62, 14.58]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.25 (P = 0.0011)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	32.7 (8.7)	10	31.8 (7.4)		100.0 %	0.90 [-6.18, 7.98]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**0.90 [-6.18, 7.98]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.25 (P = 0.80)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	38.2 (5.2)	10	37.4 (6.3)		100.0 %	0.80 [-4.26, 5.86]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**0.80 [-4.26, 5.86]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.31 (P = 0.76)							

-100   -50   0   50   100

Favours control   Favours intervention

Analysis 3.6. Comparison 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT, Outcome 6 Hearing levels at 6 kHz difference with/without.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 6 Hearing levels at 6 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
1 EAR foam plugs							
Park 1991b protection	10	38.5 (9.2)	10	29.3 (15.3)		100.0 %	9.20 [-1.87, 20.27]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**9.20 [-1.87, 20.27]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.63 (P = 0.10)							
2 UltraFit plugs							
Park 1991b protection	10	30.2 (6.7)	10	16.9 (9.1)		100.0 %	13.30 [6.30, 20.30]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**13.30 [6.30, 20.30]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.72 (P = 0.00020)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	34 (9.7)	10	31.7 (12.1)		100.0 %	2.30 [-7.31, 11.91]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**2.30 [-7.31, 11.91]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.47 (P = 0.64)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	37.2 (5.6)	10	37 (5.7)		100.0 %	0.20 [-4.75, 5.15]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**0.20 [-4.75, 5.15]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.08 (P = 0.94)							

```
        -100   -50    0    50   100
        Favours control    Favours intervention
```

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 3 Hearing protection with instructions vs hearing protection without instructions (immediate) - RCT

Outcome: 7 Hearing levels at 8 kHz difference with/without

Study or subgroup	Intervention		Control		Mean Difference	Weight	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI		IV,Random,95% CI
1 EAR foam plugs							
Park 1991b protection	10	36.3 (6.1)	10	28.7 (12.4)		100.0 %	7.60 [-0.97, 16.17]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**7.60 [-0.97, 16.17]**
Heterogeneity: not applicable							
Test for overall effect: Z = 1.74 (P = 0.082)							
2 UltraFit plugs							
Park 1991b protection	10	32.1 (7.6)	10	17.8 (10.8)		100.0 %	14.30 [6.11, 22.49]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**14.30 [6.11, 22.49]**
Heterogeneity: not applicable							
Test for overall effect: Z = 3.42 (P = 0.00062)							
3 Wilson Sound Ban Cap							
Park 1991b protection	10	32.9 (10.3)	10	30.9 (12.7)		100.0 %	2.00 [-8.13, 12.13]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**2.00 [-8.13, 12.13]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.39 (P = 0.70)							
4 Bilsom UF-1 Muff							
Park 1991b protection	10	36 (5.9)	10	35.1 (6.3)		100.0 %	0.90 [-4.45, 6.25]
Subtotal (95% CI)	**10**		**10**			**100.0 %**	**0.90 [-4.45, 6.25]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.33 (P = 0.74)							

-100   -50   0   50   100

Favours control   Favours intervention

Analysis 4.1. Comparison 4 Various hearing protectors (immediate), Outcome 1 Noise attenuation (inside hearing protection minus outside hearing protection measurement).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 4 Various hearing protectors (immediate)

Outcome: 1 Noise attenuation (inside hearing protection minus outside hearing protection measurement)

Study or subgroup	Intervention		Control		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Fixed,95% CI	IV,Fixed,95% CI
1 Peltor H61 Muff Elec						
Pääkkönen 1998	5	24 (13)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 Peltor H7 Muff elec						
Pääkkönen 1998	5	26 (16)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 Peltor H6 Muff elec						
Pääkkönen 1998	5	25 (13)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 Bilsom Marksman Muff Elec						
Pääkkönen 1998	5	26 (17)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
5 Silenta Hunter Muff Elec						
Pääkkönen 1998	5	27 (16)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
6 EAR Ultra 9000 Plug						
Pääkkönen 1998	5	22 (14)	1	0 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**5**		**1**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Total (95% CI)	**30**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: Chi² = 0.0, df = 0 (P<0.00001); I² =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.0, df = -1 (P = 0.0), I² =0.0%						

```
        -10   -5    0    5    10
     Favours intervention   Favours control
```

Analysis 5.1. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 1 TTS at 0.5 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 V-51-R plug versus EAR plug (immediate)

Outcome: 1 TTS at 0.5 kHz (before exposure - after exposure)

Study or subgroup	V-51-R plug		EAR plug		Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
	N	Mean(SD)	N	Mean(SD)		
1 After 8 minutes out of noise						
Royster 1980	9	-0.78 (0)	9	-1.33 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	-0.63 (0)	10	-1 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	-1.36 (0)	10	-0.75 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	-0.46 (0)	6	-1.58 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Total (95% CI)	**35**		**35**			**0.0 [0.0, 0.0]**
Heterogeneity: Tau² = ; Chi² = 0.0, df = 0 (P<0.00001); I² =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.0, df = -1 (P = 0.0), I² =0.0%						

```
        -100    -50      0      50    100
       Favours Control      Favours Intervention
```

Analysis 5.2. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 2 TTS at 1 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 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		EAR plug		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
1 After 8 minutes out of noise						
Royster 1980	9	-2.83 (0)	9	-2.28 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	-0.19 (0)	10	-0.15 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	-0.43 (0)	10	-0.35 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	-0.5 (0)	6	0.42 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

```
        -100   -50    0    50   100
     Favours Control      Favours Intervention
```

Analysis 5.3. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 3 TTS at 2 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 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		EAR plug		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
1 After 8 minutes out of noise						
Royster 1980	9	-3.89 (0)	9	-0.5 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	-0.13 (0)	10	-0.8 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	-0.36 (0)	10	0.15 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	0.86 (0)	6	2.75 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

```
          -100   -50    0    50   100
       Favours Control      Favours Intervention
```

Analysis 5.4. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 4 TTS at 3 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 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		EAR plug		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
1 After 8 minutes out of noise						
Royster 1980	9	-3.17 (0)	9	0.22 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	0.13 (0)	10	0.1 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	1.64 (0)	10	0.25 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	1.68 (0)	6	3 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

```
        -100   -50    0     50    100
        Favours Control    Favours Intervention
```

Analysis 5.5. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 5 TTS at 4 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 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		EAR plug		Mean Difference	Mean Difference
	N	Mean(SD)	N	Mean(SD)	IV,Random,95% CI	IV,Random,95% CI
1 After 8 minutes out of noise						
Royster 1980	9	-2.44 (0)	9	-0.22 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	1.56 (0)	10	1.15 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	-0.64 (0)	10	1.5 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	1.86 (0)	6	3.42 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-100   -50   0   50   100

Favours Control   Favours Intervention

Analysis 5.6. Comparison 5 V-51-R plug versus EAR plug (immediate), Outcome 6 TTS at 6 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 5 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	Mean(SD)	EAR plug N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
1 After 8 minutes out of noise						
Royster 1980	9	-4.11 (0)	9	0.06 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**9**		**9**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
2 After 14.6 minutes out of noise						
Royster 1980	8	0.94 (0)	10	0.2 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**8**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
3 After 20 minutes out of noise						
Royster 1980	7	1.57 (0)	10	0.25 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**7**		**10**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						
4 After 27.2 minutes out of noise						
Royster 1980	11	2 (0)	6	1.33 (0)		0.0 [0.0, 0.0]
Subtotal (95% CI)	**11**		**6**			**0.0 [0.0, 0.0]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.0 (P < 0.00001)						

```
        -100   -50    0    50   100
     Favours Control      Favours Intervention
```

Analysis 6.1.   Comparison 6 Hearing muffs vs hearing plugs (long-term), Outcome 1 Hearing loss change over 3 years (4 kHz / STS).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 6 Hearing muffs vs hearing plugs (long-term)

Outcome: 1 Hearing loss change over 3 years (4 kHz / STS)

Study or subgroup	log [OR] (SE)	OR IV,Random,95% CI	Weight	OR IV,Random,95% CI
1 High noise exposure > 89 dB(A)				
Erlandsson 1980	-0.58 (0.4311)		18.9 %	0.56 [0.24, 1.30]
Nilsson 1980	-0.1858 (0.132)		32.1 %	0.83 [0.64, 1.08]
Subtotal (95% CI)			**51.0 %**	**0.80 [0.63, 1.03]**
Heterogeneity: Tau² = 0.0; Chi² = 0.76, df = 1 (P = 0.38); I² =0.0%				
Test for overall effect: Z = 1.74 (P = 0.082)				
2 Low noise exposure < 89 dB(A)				
Erlandsson 1980	2 (0.4974)		16.5 %	7.39 [2.79, 19.59]
Nilsson 1980	0.0676 (0.1192)		32.5 %	1.07 [0.85, 1.35]
Subtotal (95% CI)			**49.0 %**	**2.65 [0.40, 17.52]**
Heterogeneity: Tau² = 1.74; Chi² = 14.27, df = 1 (P = 0.00016); I² =93%				
Test for overall effect: Z = 1.01 (P = 0.31)				
Total (95% CI)			**100.0 %**	**1.20 [0.69, 2.07]**
Heterogeneity: Tau² = 0.23; Chi² = 20.27, df = 3 (P = 0.00015); I² =85%				
Test for overall effect: Z = 0.65 (P = 0.51)				
Test for subgroup differences: Chi² = 1.50, df = 1 (P = 0.22), I² =34%				

```
        0.01   0.1    1    10   100
          Favours Muffs    Favours Plugs
```

Analysis 7.1. Comparison 7 Hearing loss prevention programme vs audiometric testing (agriculture students, long-term, 3-years and 16-years follow-up) - RCT, Outcome 1 STS.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 7 Hearing loss prevention programme vs audiometric testing (agriculture students, long-term, 3-years and 16-years follow-up) - RCT

Outcome: 1 STS

Study or subgroup	log [Odds Ratio] (SE)	Odds Ratio IV,Fixed,95% CI	Weight	Odds Ratio IV,Fixed,95% CI
1 3-years follow-up				
Berg 2009	-0.16551 (0.539636)		100.0 %	0.85 [0.29, 2.44]
Subtotal (95% CI)			**100.0 %**	**0.85 [0.29, 2.44]**
Heterogeneity: not applicable				
Test for overall effect: Z = 0.31 (P = 0.76)				
2 16-years follow-up				
Berg 2009	-0.06188 (0.360486)		100.0 %	0.94 [0.46, 1.91]
Subtotal (95% CI)			**100.0 %**	**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 =0.0%				

```
        0.1  0.2  0.5   1   2   5  10
       Favours HLPP      Favours control
```

Analysis 8.1. Comparison 8 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.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 8 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	rate of hearing loss (SE)	rate of hearing loss IV,Random,95% CI	rate of hearing loss IV,Random,95% CI
1 intervention - controlled for age, gender, baseline hearing			
Rabinowitz 2011	-0.52 (2.58)		-0.52 [-5.58, 4.54]
2 control - controlled for age, gender, baseline hearing			
Rabinowitz 2011	0.79 (0.78)		0.79 [-0.74, 2.32]
3 intervention minus control - controlled for age, gender, baseline hearing			
Rabinowitz 2011	-1.35 (1.9)		-1.35 [-5.07, 2.37]
4 intervention - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-1.31 (2.5)		-1.31 [-6.21, 3.59]
5 control - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-0.59 (1.52)		-0.59 [-3.57, 2.39]
6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-0.67 (1.47)		-0.67 [-3.55, 2.21]

```
       -2    -1    0     1     2
  Favours after Interv.   Favours before Interv.
```

Analysis 8.2. Comparison 8 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.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 8 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	rate of hearing loss (SE)	rate of hearing loss IV,Fixed,95% CI	rate of hearing loss IV,Fixed,95% CI
1 intervention - controlled for age, gender, baseline hearing			
Rabinowitz 2011	-1.57 (0.41)		-1.57 [-2.37, -0.77]
2 control - controlled for age, gender, baseline hearing			
Rabinowitz 2011	-0.23 (0.08)		-0.23 [-0.39, -0.07]
3 intervention minus control - controlled for age, gender, baseline hearing			
Rabinowitz 2011	-1.35 (0.38)		-1.35 [-2.09, -0.61]
4 intervention - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-1.31 (0.42)		-1.31 [-2.13, -0.49]
5 control - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-0.48 (0.16)		-0.48 [-0.79, -0.17]
6 intervention minus control - controlled for age, gender, baseline hearing and initial rate of HL			
Rabinowitz 2011	-0.82 (0.53)		-0.82 [-1.86, 0.22]

```
        -2   -1   0    1    2
   Favours after Intervent.   Favours before Intervent.
```

Analysis 9.1. Comparison 9 HLPP with Noise Level Indicator vs No Noise Level Indicator, Outcome 1 Change in Noise Levels at 2 months follow-up.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 9 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)	IV,Random,95% CI		IV,Random,95% CI
1 Extensive information plus NLI vs information only							
Seixas 2011	41	-2.2 (6.788)	23	-1.8 (8.2738)		48.3 %	-0.40 [-4.37, 3.57]
Subtotal (95% CI)	**41**		**23**			**48.3 %**	**-0.40 [-4.37, 3.57]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.20 (P = 0.84)							
2 Information plus NLI vs Information only							
Seixas 2011	45	-0.8 (6.2225)	23	-1.8 (8.2738)		51.7 %	1.00 [-2.84, 4.84]
Subtotal (95% CI)	**45**		**23**			**51.7 %**	**1.00 [-2.84, 4.84]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.51 (P = 0.61)							
Total (95% CI)	**86**		**46**			**100.0 %**	**0.32 [-2.44, 3.08]**
Heterogeneity: Tau² = 0.0; Chi² = 0.25, df = 1 (P = 0.62); I² =0.0%							
Test for overall effect: Z = 0.23 (P = 0.82)							
Test for subgroup differences: Chi² = 0.25, df = 1 (P = 0.62), I² =0.0%							

```
        -4    -2    0    2    4
     Favours experimental    Favours control
```

Analysis 9.2. Comparison 9 HLPP with Noise Level Indicator vs No Noise Level Indicator, Outcome 2 Change in Noise Levels at 4 months follow-up.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 9 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		No noise level indicator		Mean Difference IV,Fixed,95% CI	Weight	Mean Difference IV,Fixed,95% CI
	N	Mean(SD)	N	Mean(SD)			
1 Extensive information plus NLI vs information only							
Seixas 2011	41	-2.2 (7.3002)	23	-1.9 (7.0726)		47.6 %	-0.30 [-3.95, 3.35]
Subtotal (95% CI)	**41**		**23**			**47.6 %**	**-0.30 [-3.95, 3.35]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.16 (P = 0.87)							
2 Information plus NLI vs information only							
Seixas 2011	45	-1.9 (6.6606)	23	-1.9 (7.0726)		52.4 %	0.0 [-3.48, 3.48]
Subtotal (95% CI)	**45**		**23**			**52.4 %**	**0.0 [-3.48, 3.48]**
Heterogeneity: not applicable							
Test for overall effect: Z = 0.0 (P = 1.0)							
Total (95% CI)	**86**		**46**			**100.0 %**	**-0.14 [-2.66, 2.38]**
Heterogeneity: Chi² = 0.01, df = 1 (P = 0.91); I² =0.0%							
Test for overall effect: Z = 0.11 (P = 0.91)							
Test for subgroup differences: Chi² = 0.01, df = 1 (P = 0.91), I² =0.0%							

-4   -2   0   2   4

Favours experimental   Favours control

Analysis 10.1. Comparison 10 HLPP with extensive information vs information only, Outcome 1 Change in Noise Levels at 2 months follow-up.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 10 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)	IV,Fixed,95% CI	IV,Fixed,95% CI
Seixas 2011	44	-0.1 (5.8001)	46	-1.8 (8.2738)		1.70 [-1.24, 4.64]

```
         -4    -2    0    2    4
      Favours Intervention   Favours BL only
```
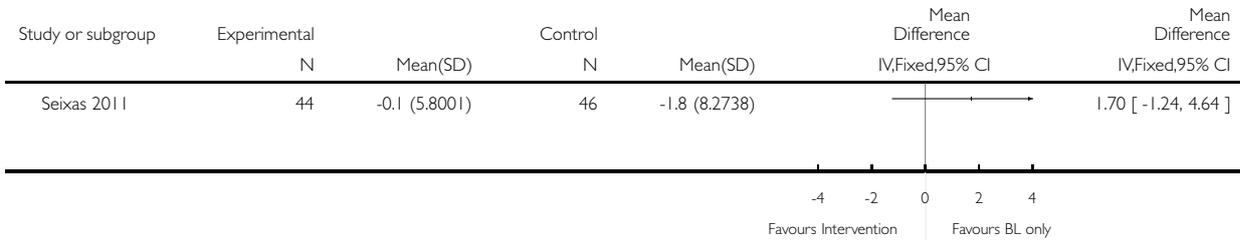
Analysis 10.2. Comparison 10 HLPP with extensive information vs information only, Outcome 2 Change in Noise Levels at 4 months follow-up.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 10 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)	IV,Random,95% CI	IV,Random,95% CI
Seixas 2011	44	-1.6 (5.4671)	46	-1.9 (7.0726)		0.30 [-2.31, 2.91]

```
         -4    -2    0    2    4
      Favours experimental   Favours control
```
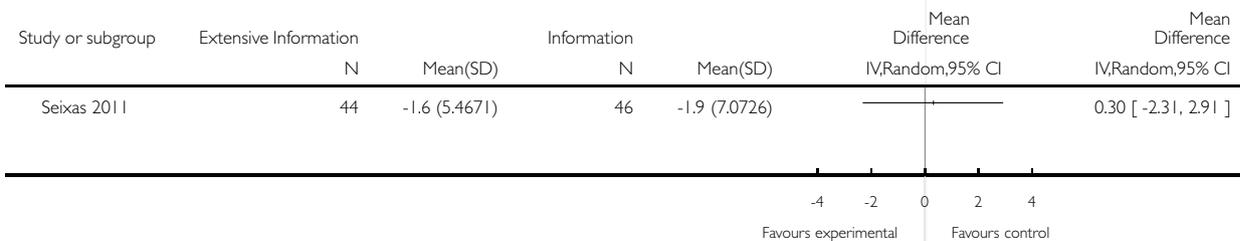
Analysis 11.1. Comparison 11 Hearing loss prevention programme vs non-exposed workers (long-term 1-year follow up), Outcome 1 Hearing loss STS.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 11 Hearing loss prevention programme vs non-exposed workers (long-term 1-year follow up)

Outcome: 1 Hearing loss STS

Study or subgroup	Favours protection n/N	Favours Non-exposed n/N	Risk Ratio M-H,Fixed,95% CI	Weight	Risk Ratio M-H,Fixed,95% CI
1 Low exposed engineers					
Muhr 2006	11/291	1/46		25.8 %	1.74 [0.23, 13.15]
Subtotal (95% CI)	**291**	**46**		**25.8 %**	**1.74 [0.23, 13.15]**
Total events: 11 (Favours protection), 1 (Favours Non-exposed)					
Heterogeneity: not applicable					
Test for overall effect: Z = 0.54 (P = 0.59)					
2 Medium exposed infantry					
Muhr 2006	13/252	1/46		25.3 %	2.37 [0.32, 17.70]
Subtotal (95% CI)	**252**	**46**		**25.3 %**	**2.37 [0.32, 17.70]**
Total events: 13 (Favours protection), 1 (Favours Non-exposed)					
Heterogeneity: not applicable					
Test for overall effect: Z = 0.84 (P = 0.40)					
3 High exposed artillery					
Muhr 2006	35/204	2/46		48.8 %	3.95 [0.98, 15.82]
Subtotal (95% CI)	**204**	**46**		**48.8 %**	**3.95 [0.98, 15.82]**
Total events: 35 (Favours protection), 2 (Favours Non-exposed)					
Heterogeneity: not applicable					
Test for overall effect: Z = 1.94 (P = 0.053)					
Total (95% CI)	**747**	**138**		**100.0 %**	**2.98 [1.11, 7.99]**
Total events: 59 (Favours protection), 4 (Favours Non-exposed)					
Heterogeneity: Chi^2 = 0.48, df = 2 (P = 0.79); I^2 =0.0%					
Test for overall effect: Z = 2.17 (P = 0.030)					
Test for subgroup differences: Chi^2 = 0.47, df = 2 (P = 0.79), I^2 =0.0%					

0.1 0.2 0.5 1 2 5 10

Favours Protection   Favours non-exposed

Analysis 12.1.   Comparison 12 Hearing loss prevention programme vs non-exposed workers (long-term > 5-year follow up), Outcome 1 Hearing loss change at 4 kHz / STS (5-year follow up).

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 12 Hearing loss prevention programme 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
1 Pell hearing loss 10 dB						
Pell 1973	193	435	-0.1 (0.0867)		36.2 %	-0.10 [-0.27, 0.07]
Subtotal (95% CI)					**36.2 %**	**-0.10 [-0.27, 0.07]**
Heterogeneity: not applicable						
Test for overall effect: Z = 1.15 (P = 0.25)						
2 Pell hearing loss 15 to 35 dB						
Pell 1973	125	434	0.09 (0.102)		26.2 %	0.09 [-0.11, 0.29]
Subtotal (95% CI)					**26.2 %**	**0.09 [-0.11, 0.29]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.88 (P = 0.38)						
3 Pell hearing loss 40 dB						
Pell 1973	81	304	0.18 (0.125)		17.4 %	0.18 [-0.06, 0.42]
Subtotal (95% CI)					**17.4 %**	**0.18 [-0.06, 0.42]**
Heterogeneity: not applicable						
Test for overall effect: Z = 1.44 (P = 0.15)						
4 Lee-Feldstein						
Lee-Feldstein 1993	111	363	0.2913 (0.1858)		7.9 %	0.29 [-0.07, 0.66]
Subtotal (95% CI)					**7.9 %**	**0.29 [-0.07, 0.66]**
Heterogeneity: not applicable						
Test for overall effect: Z = 1.57 (P = 0.12)						
5 Hager						
Hager 1982	27	16	-0.1 (0.3163)		2.7 %	-0.10 [-0.72, 0.52]
Subtotal (95% CI)					**2.7 %**	**-0.10 [-0.72, 0.52]**
Heterogeneity: not applicable						
Test for overall effect: Z = 0.32 (P = 0.75)						
6 Gosztonyi						
Gosztonyi 1975	71	71	0.15 (0.1684)		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 %**	**0.05 [-0.05, 0.16]**
Heterogeneity: Chi² = 6.49, df = 5 (P = 0.26); I² =23%						
Test for overall effect: Z = 1.02 (P = 0.31)						
Test for subgroup differences: Chi² = 6.49, df = 5 (P = 0.26), I² =23%						

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

Analysis 12.2. Comparison 12 Hearing loss prevention programme vs non-exposed workers (long-term > 5-year follow up), Outcome 2 Hazard of STS.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 12 Hearing loss prevention programme vs non-exposed workers (long-term > 5-year follow up)

Outcome: 2 Hazard of STS

Study or subgroup	log [Hazard Ratio] (SE)	Hazard Ratio IV,Random,95% CI	Weight	Hazard Ratio IV,Random,95% CI
1 80 to 85 dB-years				
Davies 2008	0.741937 (0.259839)		15.2 %	2.10 [1.26, 3.49]
Subtotal (95% CI)			**15.2 %**	**2.10 [1.26, 3.49]**
Heterogeneity: not applicable				
Test for overall effect: Z = 2.86 (P = 0.0043)				
2 85 to 90 dB-years				
Davies 2008	1.098612 (0.14117)		19.9 %	3.00 [2.27, 3.96]
Subtotal (95% CI)			**19.9 %**	**3.00 [2.27, 3.96]**
Heterogeneity: not applicable				
Test for overall effect: Z = 7.78 (P < 0.00001)				
3 90 to 95 dB-years				
Davies 2008	1.193922 (0.090989)		21.6 %	3.30 [2.76, 3.94]
Subtotal (95% CI)			**21.6 %**	**3.30 [2.76, 3.94]**
Heterogeneity: not applicable				
Test for overall effect: Z = 13.12 (P < 0.00001)				
4 95 to 100 dB-years				
Davies 2008	1.526056 (0.089642)		21.6 %	4.60 [3.86, 5.48]
Subtotal (95% CI)			**21.6 %**	**4.60 [3.86, 5.48]**
Heterogeneity: not applicable				
Test for overall effect: Z = 17.02 (P < 0.00001)				
5 More than 100 dB-years				
Davies 2008	1.88707 (0.08778)		21.7 %	6.60 [5.56, 7.84]
Subtotal (95% CI)			**21.7 %**	**6.60 [5.56, 7.84]**
Heterogeneity: not applicable				
Test for overall effect: Z = 21.50 (P < 0.00001)				
Total (95% CI)			**100.0 %**	**3.78 [2.69, 5.31]**
Heterogeneity: Tau² = 0.13; Chi² = 46.94, df = 4 (P<0.00001); I² =91%				
Test for overall effect: Z = 7.65 (P < 0.00001)				
Test for subgroup differences: Chi² = 46.94, df = 4 (P = 0.00), I² =91%				

0.1 0.2 0.5 1 2 5 10

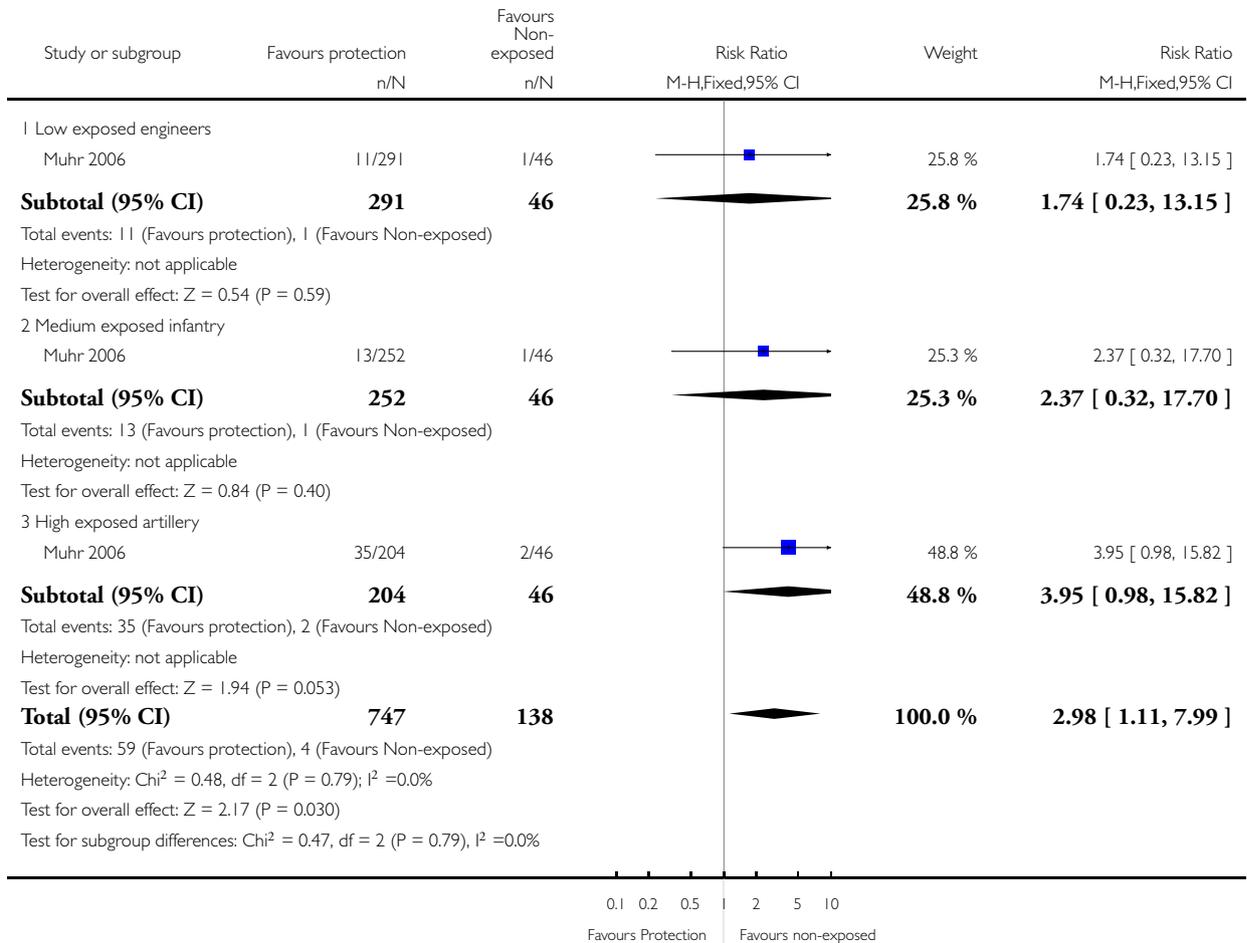Favours experimental   Favours control

Analysis 13.1. Comparison 13 Hearing loss prevention programme vs non-exposed sensitivity analysis (long-term 5-year follow up), Outcome 1 Hearing loss change at 4kHz / STS.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 13 Hearing loss prevention programme vs non-exposed sensitivity analysis (long-term 5-year follow up)
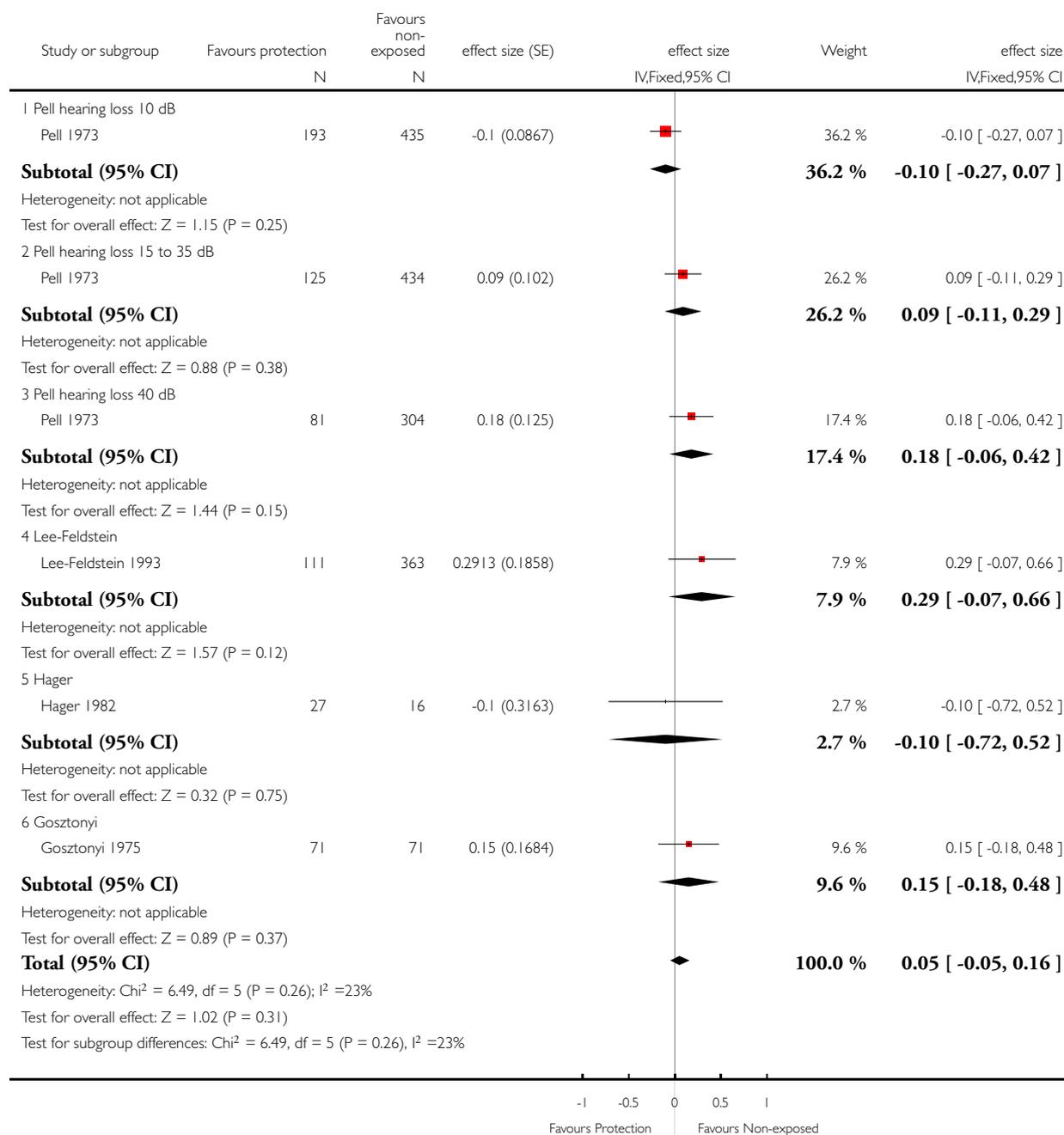
Outcome: 1 Hearing loss change at 4kHz / STS

Study or subgroup	effect size (SE)	effect size IV,Fixed,95% CI	Weight	effect size IV,Fixed,95% CI
1 Lee-Feldstein				
Lee-Feldstein 1993	0.2913 (0.1858)		39.0 %	0.29 [-0.07, 0.66]
Subtotal (95% CI)			**39.0 %**	**0.29 [-0.07, 0.66]**
Heterogeneity: not applicable				
Test for overall effect: Z = 1.57 (P = 0.12)				
2 Hager				
Hager 1982	-0.1 (0.3163)		13.5 %	-0.10 [-0.72, 0.52]
Subtotal (95% CI)			**13.5 %**	**-0.10 [-0.72, 0.52]**
Heterogeneity: not applicable				
Test for overall effect: Z = 0.32 (P = 0.75)				
3 Gosztonyi				
Gosztonyi 1975	0.15 (0.1684)		47.5 %	0.15 [-0.18, 0.48]
Subtotal (95% CI)			**47.5 %**	**0.15 [-0.18, 0.48]**
Heterogeneity: not applicable				
Test for overall effect: Z = 0.89 (P = 0.37)				
Total (95% CI)			**100.0 %**	**0.17 [-0.06, 0.40]**
Heterogeneity: Chi² = 1.17, df = 2 (P = 0.56); I² =0.0%				
Test for overall effect: Z = 1.48 (P = 0.14)				
Test for subgroup differences: Chi² = 1.17, df = 2 (P = 0.56), I² =0.0%				

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

Analysis 14.1. Comparison 14 Well-implemented hearing loss prevention programme vs less well-implemented (long-term, 1-year follow up), Outcome 1 STS.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 14 Well-implemented hearing loss prevention programme vs less well-implemented (long-term, 1-year follow up)

Outcome: 1 STS

Study or subgroup	Well implemented n/N	Not well imple-mented 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 %	0.36 [0.09, 1.42]
Total (95% CI)	**45**	**296**	◆	**100.0 %**	**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)

Test for subgroup differences: Not applicable

```
        0.02   0.1      1      10    50
        Well implemented     Less quality
```
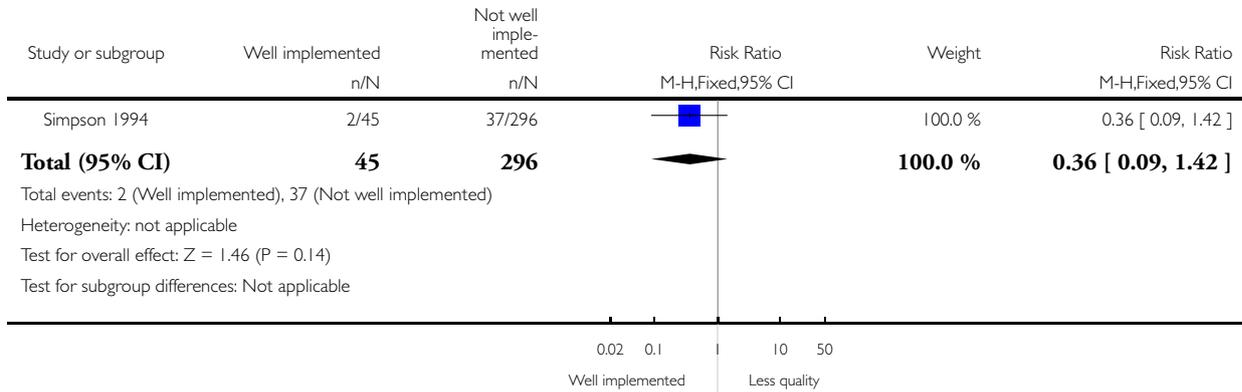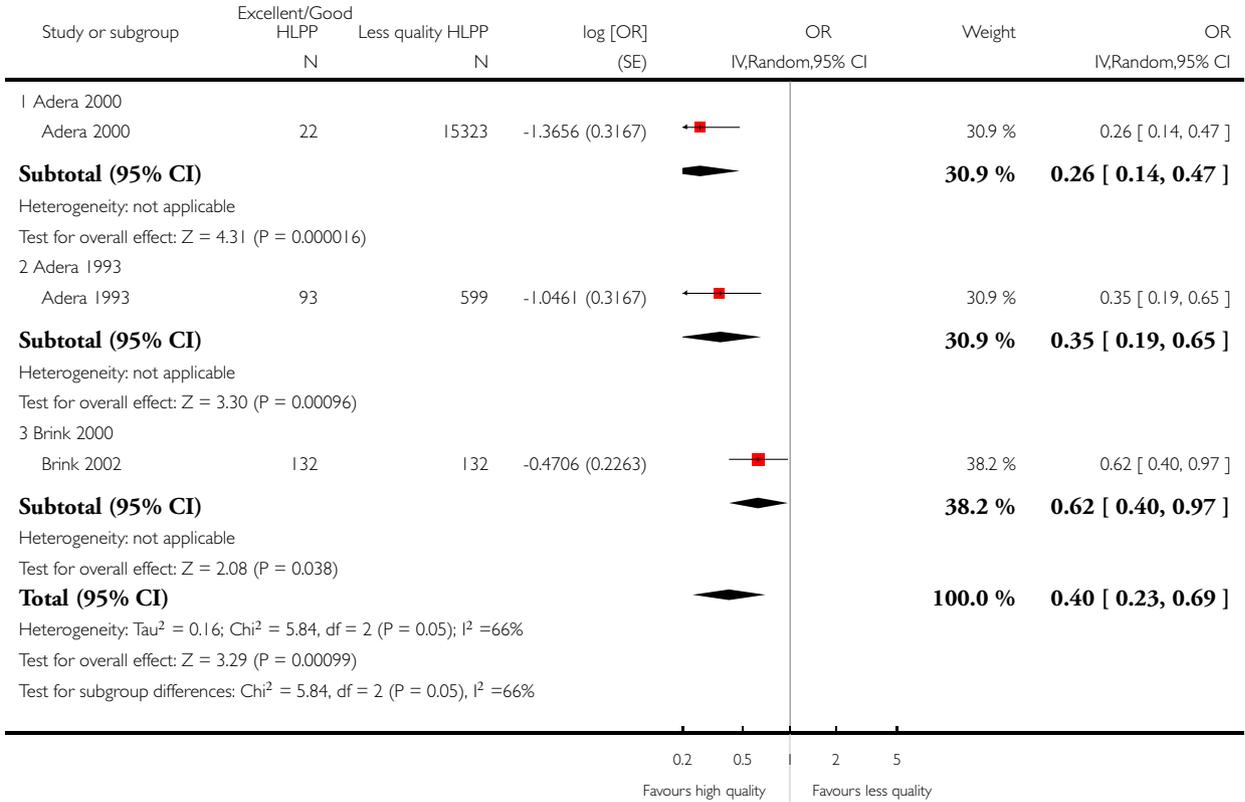
Analysis 15.1. Comparison 15 Well-implemented hearing loss prevention programme vs less well-implemented (long-term > 5-year follow up), Outcome 1 Hearing loss change STS / at 4 kHz.

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 15 Well-implemented hearing loss prevention programme vs less well-implemented (long-term > 5-year follow up)
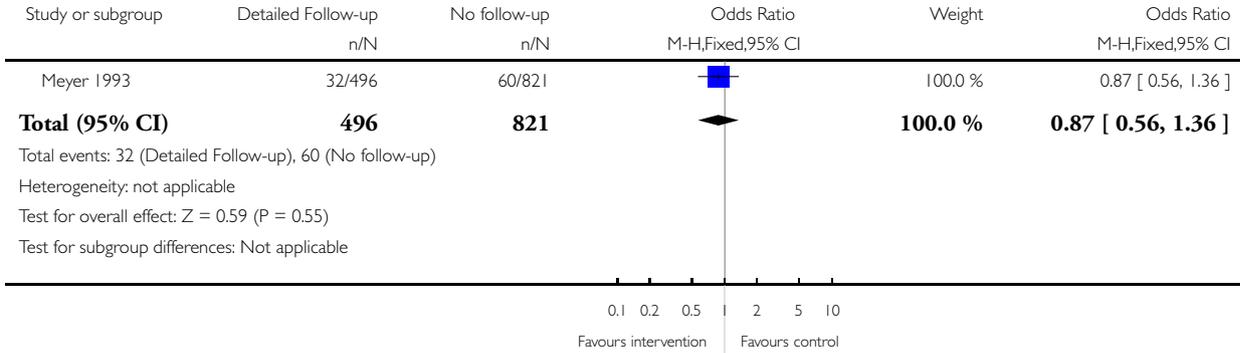
Outcome: 1 Hearing loss change STS / at 4 kHz

Study or subgroup	Excellent/Good HLPP N	Less quality HLPP N	log [OR] (SE)	OR IV,Random,95% CI	Weight	OR IV,Random,95% CI
1 Adera 2000						
Adera 2000	22	15323	-1.3656 (0.3167)		30.9 %	0.26 [0.14, 0.47]
Subtotal (95% CI)					**30.9 %**	**0.26 [0.14, 0.47]**
Heterogeneity: not applicable						
Test for overall effect: Z = 4.31 (P = 0.000016)						
2 Adera 1993						
Adera 1993	93	599	-1.0461 (0.3167)		30.9 %	0.35 [0.19, 0.65]
Subtotal (95% CI)					**30.9 %**	**0.35 [0.19, 0.65]**
Heterogeneity: not applicable						
Test for overall effect: Z = 3.30 (P = 0.00096)						
3 Brink 2000						
Brink 2002	132	132	-0.4706 (0.2263)		38.2 %	0.62 [0.40, 0.97]
Subtotal (95% CI)					**38.2 %**	**0.62 [0.40, 0.97]**
Heterogeneity: not applicable						
Test for overall effect: Z = 2.08 (P = 0.038)						
Total (95% CI)					**100.0 %**	**0.40 [0.23, 0.69]**

Heterogeneity: Tau² = 0.16; Chi² = 5.84, df = 2 (P = 0.05); I² =66%

Test for overall effect: Z = 3.29 (P = 0.00099)

Test for subgroup differences: Chi² = 5.84, df = 2 (P = 0.05), I² =66%

```
         0.2   0.5    1    2    5
      Favours high quality   Favours less quality
```

**Analysis 16.1. Comparison 16 Follow-up exam after initial STS vs no exam (long-term), Outcome 1
Hearing loss change (STS).**

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 16 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 %	0.87 [0.56, 1.36]
Total (95% CI)	**496**	**821**		**100.0 %**	**0.87 [0.56, 1.36]**

Total events: 32 (Detailed Follow-up), 60 (No follow-up)

Heterogeneity: not applicable

Test for overall effect: Z = 0.59 (P = 0.55)

Test for subgroup differences: Not applicable

```
        0.1  0.2  0.5   1    2    5   10
        Favours intervention   Favours control
```
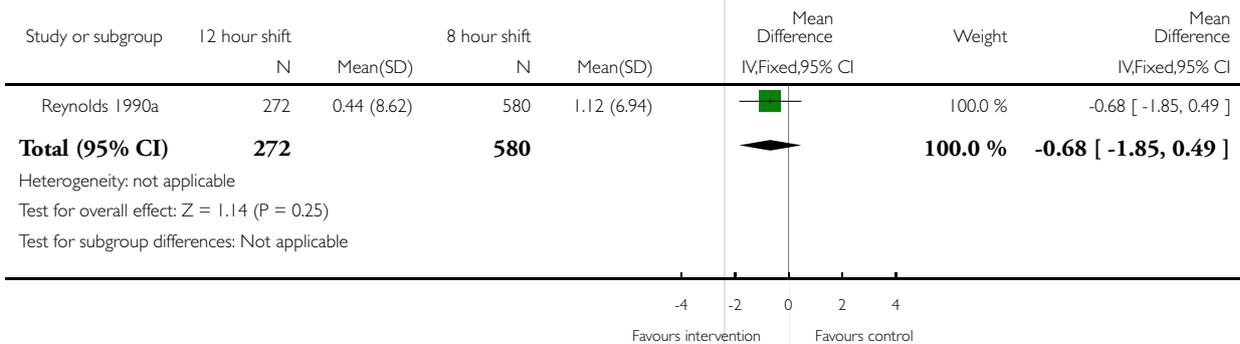
**Analysis 17.1. Comparison 17 Hearing loss prevention programme 12-hour shift vs hearing loss prevention
programme 8-hour shift (long-term 1-year), Outcome 1 Hearing loss change over 1 year at 4 kHz.**

Review: Interventions to prevent occupational noise-induced hearing loss

Comparison: 17 Hearing loss prevention programme 12-hour shift vs hearing loss prevention programme 8-hour shift (long-term 1-year)

Outcome: 1 Hearing loss change over 1 year at 4 kHz

Study or subgroup	12 hour shift N	Mean(SD)	8 hour shift N	Mean(SD)	Mean Difference IV,Fixed,95% CI	Weight	Mean Difference IV,Fixed,95% CI
Reynolds 1990a	272	0.44 (8.62)	580	1.12 (6.94)		100.0 %	-0.68 [-1.85, 0.49]
Total (95% CI)	**272**		**580**			**100.0 %**	**-0.68 [-1.85, 0.49]**

Heterogeneity: not applicable

Test for overall effect: Z = 1.14 (P = 0.25)

Test for subgroup differences: Not applicable

```
        -4    -2    0    2    4
        Favours intervention   Favours control
```

ADDITIONAL TABLES

Table 1. 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 program	not part of the program	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 is one element	Noise monitoring is one element	Engineering controls are one element	Administrative controls are 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

Table 1. Contents of hearing loss prevention programmes (*Continued*)

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 reported by focus group	stated as part of the program but not possible to evaluate with the study data	training and education stated as part of the program but not possible to evaluate with study data	Audiometric testing, quality varies, evaluated as days between two tests, audiometry method not reported
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
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
HLPP = hearing loss prevention programme
HPD = hearing protection device
ISO = International Organization for Standardization
OSHA =Occupation Safety and Health Administration
SNR = Single Number Rating

Table 2. Risk of bias of interrupted time-series

Study	Indepen-dence other changes	Sufficient data points	Formal test for trend	Interven-tion does not affect data	Blinded assessment of outcome	Complete data set	Reli-able 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

A P P E N D I C E S

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)

Appendix 2. Search strategies for other databases

PubMed	EMBASE	CINAHL
2009 #1 noise [tiab] AND (reduction [tiab] OR abatement [tiab] OR diminishment [tiab] OR elimination [tiab] OR "engineering	**2009** 1 industrial noise/ 2 (protective adj equipment).tw. 3 1 and 2	**2009 and 2012** #1 (noise AND (reduction OR abatement OR diminishment OR elimination OR "engineering controls" OR "administrative

(Continued)

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 #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

2012

#12 2008:2012[dp]

#13 #11 AND #12

4 (noise and (reduction or abatement or diminishment or elimination or (engineering adj controls) or (administrative adj controls))).t.w

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 dimishment 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 dimishment:ab,ti OR elimination:ab,ti OR 'engineering controls':ab,ti OR 'administrative controls':ab,ti) AND [2008-2012]/py

#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

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)

	#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	

BIOSIS/CAB Abstracts	Web of Science	NIOSHTIC
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 protecto) 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	**2009 and 2012** #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*)) #6 #5 AND #4 in **2012** time span 2008-2012	**2009 and 2012** (noise AND (induced OR hearing)) in **2012** time span 01-2008 to 01-2012

(Continued)

7 6 and 5		

WHAT'S NEW

Last assessed as up-to-date: 21 June 2012.

Date	Event	Description
8 May 2012	New citation required and conclusions have changed	New search and study selection conducted. Four new studies included. Methods improved. Conclusions changed

HISTORY

Protocol first published: Issue 1, 2007

Review first published: Issue 3, 2009

CONTRIBUTIONS OF AUTHORS

All: Comment on drafts of protocol and review.

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

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

W.A Dreschler: Eligibility screening.

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

C. Mischke: Searching, eligibility screening, quality assessment, data extraction, data analysis, update of the text.

DECLARATIONS OF INTEREST

None known.

SOURCES OF SUPPORT

Internal sources

- No sources of support supplied

External sources

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

The second author received a grant.

- Finnish Ministry of Social Affairs and Health, Finland.

Supported the Cochrane Occupational Safety and Health Review Group financially.

- The Cochrane Occupational Safety and Health Review Group, Finland.

Provided support in kind.

- Stichting Arbouw, Netherlands.

Provided EURO5000 for the 2012 update of the review

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 qualitative 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)

Hearing Loss, Noise-Induced [*prevention & control]; Noise, Occupational [*adverse effects; prevention & control]; Occupational Diseases [*prevention & control]; Randomized Controlled Trials as Topic

MeSH check words

Humans