Interventions to prevent occupational noise induced hearing loss (Review)

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[Intervention Review]

Interventions to prevent occupational noise induced hearing loss

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ABSTRACT

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 strategy

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; Web of Science; BIOSIS Previews; Cambridge Scientific Abstracts; NIOSHTIC, CISDOC and mRCT to 15 December 2008.

Selection criteria

Randomised controlled trials, controlled before-after studies 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 (EK, JV) independently assessed study eligibility and trial quality and extracted data.

Main results

Twenty-one studies were included. One study evaluated a strategy to reduce noise exposure. Fourteen studies with 75,672 participants evaluated hearing loss prevention programmes (HLPPs), and six studies with 169 participants evaluated hearing protection. The overall quality of studies was low.

One ITS study evaluated the effect of new legislation in reducing noise exposure. It found that the median noise level decreased by 27.7 dB(A) (95% confidence interval (CI) -36.1 to -19.3 dB) with a change in trend in time of -2.1 dB per year (95% CI -4.9 to 0.7).

A hearing protection study in army recruits compared those exposed to impulse noise with non-exposed recruits. The odds ratio (OR) for hearing loss was 3.0 (95% CI 1.1 to 8.0) despite hearing protection. In four studies, workers in a HLPP had a 0.5 dB HL greater hearing loss at 4 kHz than non-noise exposed workers (95% CI -0.5 to 1.7). In one study, the hazard ratio of hearing loss was 3.8 (95% CI 2.7 to 5.3) for workers exposed to noise compared to non-exposed workers.

In three studies, a high quality HLPP had a lower risk of hearing loss than lower quality programmes.

Noise attenuation ratings of hearing protection under field conditions were consistently lower than the ratings provided by the manufacturers.

Authors' conclusions

There is low quality evidence that legislation can reduce noise levels in workplaces.The effectiveness of hearing protection devices depends on their proper use. There is contradictory evidence that HLPPs are effective in the long-term. Even though case studies show that substantial reductions can be achieved, there is no evidence that this is realised in practice. Better implementation and reinforcement is needed.

Better evaluations of technical interventions and long-term effects are needed. Audiometric and noise measurement data are potentially valuable for such studies.

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 a change in legislation in the mining industry.

In six studies with 169 workers, hearing protection reduced noise exposure of workers. However, one high quality study showed that if workers lack proper instructions in the use of earplugs, hearing protection is insufficient.

We found 15 studies with 75,672 participants that evaluated the long-term effects of protection against noise exposure. Six studies compared the effects of prevention programmes on workers' hearing loss to hearing levels in non-exposed workers. One of these studies showed that army recruits are at a three-fold increased risk of hearing loss compared to non-exposed controls. Another study found a four-fold increase in hearing loss among workers that were exposed but protected compared to non-exposed workers. In the remaining four studies, there was no difference in hearing loss between protected and non-exposed workers but there is still considerable uncertainty about the validity of this result. In four studies the risk reduction depended on the quality of hearing loss prevention programmes.

There is contradictory evidence on the effectiveness of hearing protection and hearing loss prevention programmes. Higher quality prevention programmes and better implementation of legislation are needed.

SUMMARY OF FINDINGS FOR THE MAIN COMPARISON *[Explanation]*

Comparison/outcome	Study design	Risk of bias in studies	Consistency	Directness	Precision	Publication bias	Overall quality of evidence
Legislation to decrease noise exposure	1 observational study	Unclear risk of bias	-	-	-	-	Low quality
[1.1 - 2.2] HLPP versus non-exposed workers, hearing loss	5 observational studies	3 studies high risk of bias (not age or HL adjusted) not showing difference 2 low risk of bias studies still showing an increased risk for protected workers	Inconsistent results	1 study army recruits	Confidence interval includes substantial HL	Studies might be missing	Very low quality
[3.1 - 4.1] Well-implemented HLPP versus not well-implemented programmes, hearing loss	3 observational studies	2 studies with high risk of bias (not age or HL adjusted)	-	-	-	-	Low quality
[5] Earmuffs versus earplugs, hearing loss	2 observational studies	Both studies high risk of bias	Inconsistent results	-	-	-	Very low quality
[8] Instructions vs no instructions for fitting; noise reduction	1 RCT	Low risk of bias	-	-	-	-	High quality

HL = hearing loss
RCT = randomised controlled trial

BACKGROUND

According to a recent study 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, indicating a loss of hearing ability in the middle of the frequency range of human voices (Nelson 2005). Worldwide, 16% of disabling hearing loss in adults is attributed to occupational noise. Leigh calculated a global annual incidence of noise induced hearing loss of 1,628,000 cases, which means an annual incidence rate of almost two new cases per 1000 older workers (Leigh 1999). Noise induced hearing loss is the second most common self-reported occupational illness or injury, despite decades of study, regulation and workplace interventions (Nelson 2005).

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. Such a hearing loss decreases the capacity for being engaged in conversation in meetings or at social activities, creating a significant barrier in establishing or maintaining emotional relationships. Measured in 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 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, such as solvents and heavy metals, may increase the damaging potential of the 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 preventative potential of reducing noise exposure has led to mandatory hearing loss prevention programmes in many countries. However, the reported high rate of occupational noise induced hearing loss casts doubt upon their effectiveness. 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, by firstly using those measures that eliminate the source of the noise, and, lastly implementing those 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 is studied in another Cochrane Review (El Dib 2006). Also, recently, 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. Randomisation is the best protection against such bias. However, noise reduction is an intervention that is almost never carried out 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, would be 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 in trends in time as a result of interventions can be observed. 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 2002; 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. Studies without a comparison were excluded 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 the attenuation of devices.

Types of participants

Male and female workers and/or workplaces exposed to/with 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

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 consistently using protective equipment. Permanent threshold shifts were considered long-term effects.

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 measurement 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. There were no language, publication year or publication status restrictions. The date of the last search was 15 December 2008.

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, two independent authors (EK and JV) scanned the titles and abstracts of every record retrieved. Full articles were retrieved for further assessment if the information given suggested that the study met all of the following criteria:

1. included workers exposed to noise levels of more 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

Two authors (EK, JV) extracted data independently. Discrepancies in the results were resolved where possible by discussion. Studies with unclear information were often over 20 years old and we refrained from trying to contact the authors. We contacted three authors of recent studies and obtained additional data from two (Davies 2008; Joy 2007).
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

The evaluation of the quality of randomised controlled trials and cohort studies included in the review was done by means of the checklist developed by Downs and Black (Downs 1998). Two evaluators (EK, JV) independently examined the quality of the studies. Any disagreements were resolved by discussion. High quality was defined 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 et al (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 the sensitivity of the human ear to certain frequencies into account and the C weighting is used for peak sound level measurements. In the one study that measured noise exposure the medians of all noise measurements in a year were used as the measure of effect (Joy 2007). 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 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).

We used the 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.

In all but one study the amount of hearing loss was referred to as the standard threshold shift (STS), which meant a change of more than 10 dB in average hearing level at 2, 3 and 4 kHz between two measurements. 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.

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 immediate effects of noise attenuation authors used the MIRE (microphone in real ear) to measure the difference in noise levels inside and outside hearing protection. They also used REAT (real ear attenuation at threshold) which measures hearing levels with and without protection (Berger 1996). The MIRE and REAT methods yield slightly different results at different frequencies.

For time series, data from the original papers were extracted 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 study, a first order autoregressive time series model was fitted to the data using a modification of the parameters of Ramsay et al (Ramsay 2003). Details of the mode specification are as follows:

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

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 autoregressive 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 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 (Adera 2000; Lee-Feldstein 1993; Simpson 1994). We assumed an intraclass 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 2006).

In one study with multiple intervention arms and for inclusion in the meta-analysis, we chose to include the arm with the most active intervention or the control group with the least noise exposure, thus avoiding including the same control group twice (Hager 1982).

Dealing with missing data

Three authors were asked to provide missing data and we obtained data from two of them (Davies 2008; Joy 2007). In one case we calculated standard deviations (SDs) from P values according to the *Cochrane Handbook for Systematic Reviews of Interventions* (Hager 1982).

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 2008). 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

Studies that were sufficiently homogeneous with regard to interventions, participants, settings and the outcomes measured were included 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 first is a continuous measure and the latter a dichotomous measure we had to use effect sizes to be able to combine these two. We used the mean change in hearing threshold at 4 kHz to calculate 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). These effect sizes and their standard errors were input into the meta-analysis using the Generic Inverse Variance method as implemented in RevMan.

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 2006). In one study (Muhr 2006) the same control group was used in three subgroups of the intervention group. To avoid using the same control data three times we split the control group into three equal subgroups that were subsequently combined in the meta-analysis.

In our protocol we planned a qualitative synthesis however the GRADE approach is now recommended. 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.

Sensitivity analysis

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

RESULTS

Description of studies

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

Results of the search

The search yielded 1360 references, 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. Additional searches in NIOSHTIC and the Cochrane ENT Group Trials Register did not reveal any new references.

The screening of references for eligibility resulted in 104 studies, which we then retrieved in full text.

Following further screening using our eligibility checklist, 20 articles ultimately fulfilled our inclusion criteria. Checking the references of these articles did not identify any new studies. One article described two trials resulting in a total of 21 included 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. One study used a randomised design (Park 1991) and one study used a quasi-randomised design with alternation (Royster 1980). Another study used an interrupted time series design (Joy 2007). All remaining studies used a form of controlled before-after design.

To measure the long-term effects of hearing loss prevention, 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 four 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.

All but one of the long-term studies were retrospective in nature meaning that the data were already gathered before the study was planned. One study claimed to be prospective (Pell 1973). In many studies only the change was reported, which made it difficult to assess baseline comparability of age and hearing loss.

To measure the immediate effects of hearing protection the 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 1991) 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 1991). 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 noise exposure study was 142,735 workplaces measured during 18 years of follow up, with the intervention implemented in the year 2000 and four years post-intervention and 14 year pre-intervention (Joy 2007).

In the long-term evaluation studies, sample sizes ranged from 43 to 22,376 workers, amounting to a total of 75,672 and with an average of 5405 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 totalled 47,498 with an average of 3393 participants per study.

Numbers in the immediate effect studies ranged from 2 to 70, amounting to a total of 169, with an average of 28 workers per study.

Setting

The noise exposure study was carried out in coal mines in the US (Joy 2007).

Of the long-term evaluation studies, the 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.

Ten of the long-term evaluation studies were carried out in the US, one in Canada and three in Sweden, which is of importance because of the different weighting used for summarising noise levels over time.

Of the long-term evaluation studies, four were published after 2000, five in the 1990s, three in the 1980s and two in the 1970s. Since most studies were retrospective, they are based on data gathered in the decade(s) before their publication.

Of the immediate effect studies, one was carried out in Japan, three in Finland and six in the US. 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). Among immediate effect studies two were carried out after 2000, two in the 1990s and one in 1980.

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 in the automobile industry (one study), at a shipyard (two studies), in the chemical industry (two studies), in the military (five studies), in the steel industry (one study), in one unspecified company (three studies) or were gathered from various workplaces (five 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, an Action Level of 85 dB(A) at which enrolment for hearing conservation programmes should be started, and a statutory hearing loss. The legislation officially came into effect in the year 2000 but many employers already prepared themselves in 1999. Nevertheless we choose 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. The outcomes are described for both situations.

In ten studies, a hearing loss prevention programme was evaluated as the intervention of interest. A more detailed description of the contents was difficult to find and the results are shown in Table 1.

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	?	?	?	?	Audiogram taken
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
Hager 1982	Walsh-Healy standard; OSHA	Yes, mandatory use of approved protection	?	Gradual continuous engineering control wherever, whenever economically feasible	?	Audiometric surveys
Lee-Feldstein 1993	?	?	Annual sound surveys	?	?	Automatic audiometer according to ANSI s3.6-1996

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

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

In two studies the long-term effects of using earmuffs were compared to using earplugs (Erlandsson 1980; Nilsson 1980).

In one study the intervention was frequent follow up during one year after a standard threshold shift had been found in a person exposed to noise, with the aim of detecting susceptible persons with increasing hearing loss (Meyer 1993).

In one study the effectiveness of a hearing loss prevention programme for workers on 12-hour work shifts was evaluated (Reynolds 1990a).

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) or alternative hearing protection (Park 1991b; Royster 1980).

Outcomes

In all long-term evaluations, some kind of hearing loss increase was measured. However, the authors used varying definitions of hearing loss. In six studies they used a standard threshold shift, defined as an increase in hearing loss 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). 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. Two studies also included the frequency of 8 kHz (Muhr 2006; Park 1991). In some studies the authors also reported the percentage of workers whose hearing got worse or the percentage of workers whose hearing got better, or used the increase in standard deviations of hearing levels to show the effect of the programme, however we did not use these outcomes because they are similar to the other outcomes.

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 protector (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; Park 1991b).

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 an empirical study or because the authors did not make use of 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). Other identified studies of noise reduction were either case studies (Jelinic 2005; Knothe 1999; Pingle 2006; Scannell 1998; Stone 1971), consisted of descriptions of a noise abatement strategy but without a control group (Groothoff 1999), recommended noise reductions without evaluating them (Bowes 1990; Kardous 2003) or were not carried out under field conditions (Ackermann 2005). 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 (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 quality rating, based on the Downs and Black checklist, is shown in Table 2. Most studies scored poorly on all aspects of the checklist.

Table 2. Quality rating of included studies

Study	Reporting quality	External validity	Internal validity total	Blinding subjects	Blinding outcomes	Blinding allocation	Randomised	Adj confounding	Adj lost follow up
Adera 1993	7	0	5	0	0	0	0	1	1
Adera 2000	7	0	5	0	0	0	0	1	0
Brink 2002	4	0	4	0	0	0	0	0	0
Erlandsson 1980	5	0	5	0	0	0	0	0	0
Gosztonyi 1975	7	2	6	0	0	0	0	0	0
Hager 1982	6	1	6	0	0	0	0	1	0

Table 2. Quality rating of included studies *(Continued)*

Horie 2002	9	3	7	0	0	0	0	1	0
Lee-Feldstein 1993	6	1	6	0	0	0	0	1	0
Meyer 1993	4	1	3	0	0	0	0	0	0
Nilsson 1980	5	1	4	0	0	0	0	0	0
Park 1991	8	0	10	0	0	1	0	1	1
Pell 1973	8	1	6	0	0	0	0	0	0
Pääkkönen 1998	9	0	6	0	0	0	0	0	0
Pääkkönen 2001	5	3	0	0	0	0	0	0	0
Reynolds 1990a	5	1	5	0	0	0	0	0	0
Royster 1980	7	3	6	0	0	0	0	1	0
Simpson 1994	5	2	2	0	0	0	0	0	0
Davies 2008	5	1	6	0	0	0	0	1	0
Muhr 2006	10	3	7	0	0	0	0	1	1

The ITS study 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 3).

Table 3. Quality of interrupted time series

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

Three studies (two 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 1991; Muhr 2006). None of the studies used blinded outcome assessment.

The average scores were 40% for methodological quality, 35% for external validity and 62% for reporting quality. The low score for external validity was due to the lack of description of study participants. This was probably due to the notion that for technical measurements such as the attenuation of hearing protection such description is not necessary. The quality of reporting was not related to the date of publication.

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 three studies (Davies 2008; Lee-Feldstein 1993; Muhr 2006), of age only in one study (Gosztonyi 1975), of hearing loss only in one study (Pell 1973) and of neither age nor hearing loss in one study (Hager 1982). In Pell 1973 there was a difference of 10 years between the protected and the non-exposed group, artificially increasing the risk in the non-exposed group. In Hager 1982 there was a 7.8 dB difference in hearing level at entrance 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, in only three long-term evaluation studies could a substantial risk of bias be excluded. The average score for internal validity was 34% for long-term evaluation studies.

Reporting bias

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

Effects of interventions

See: **Summary of findings for the main comparison** Summary of findings table

Noise reduction studies

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. 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). For the underground 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 (Table 4). The overall quality of evidence was rated as low (see 'Summary of findings for the main comparison').

Table 4. Results of interrupted time series

Study ID	Immediate change in level	95% confidence interval	Change in slope	95% confidence interval

Table 4. Results of interrupted time series (*Continued*)

Joy 2007 General noise Int Year 1999	-14.5 dB	-25.2 to -3.8 dB	-5.6 dB	-8.4 to -2.8 dB
Joy 2007 Underground noise Int Year 1999	0.2 dB	-8.7 to +9.2 dB	-6.1 dB	-9.0 to -3.2 dB
Joy 2007 General noise Int Year 2000	-27.7 dB	-36.1 to -19.3 dB	-2.1 dB	- 4.9 to +0.7 dB
Joy 2007 Underground noise Int Year 2000	-16.8 dB	-23.5 to -10.1 dB	-3.7 dB	-6.1 to -1.3 dB

Immediate effect hearing protection studies

Hearing protection with noise cancelling devices versus without noise cancelling devices

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). 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).

Hearing protection with instruction versus hearing protection without instruction

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). The quality of evidence was rated as high.

Hearing protection versus alternative hearing protection

In the randomised controlled trial 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 1991a).
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 was significant (Pääkkönen 1998). In one study, the EAR plug had a smaller TTS than another plug which, according to the authors, was significant but could not be checked due to missing standard deviations (Royster 1980).
All hearing protectors performed less well than the official attenuation ratings provided by the manufacturers.

Long-term hearing loss prevention programme evaluation studies

Hearing loss prevention programme or hearing protection: comparison with non-exposed workers with follow up for one year

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).

Hearing loss prevention programme or hearing protection: comparison with non-exposed workers with follow up of more than five years

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 2.1). 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 loss (calculated based on ISO 1990). This yielded

an effect size of 0.17 (95% CI -0.06 to 0.40) (Analysis 12.1). 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 protected workers have the same amount of hearing loss as the non-exposed workers. However, the 95% confidence interval still includes the possibility of a hearing loss as great as 4.2 dB. This is equivalent to hearing loss sustained after 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

In Davies 2008 the time to a STS was measured and the hazard ratio (HR) compared to a non-exposed group was 2.1 (95% CI 1.3 to 3.5) for workers with exposure of 80 to 85 dB-years and 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 2.2).

The overall quality of evidence was rated as very low (see 'Summary of findings for the main comparison').

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

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 4.1).

Well-implemented hearing loss prevention programme versus less well-implemented hearing loss prevention programme with follow up for more than five years

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 3.1) for workers covered by well-implemented programmes. The results were statistically not homogeneous, with an I^2 of 66%. The overall quality of evidence was rated as low.

Earmuffs versus earplugs (three-year long-term follow up)

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 (Analysis 5.1). The results from the low noise group were not homogenous. The overall quality of evidence was rated as very low.

Follow-up examinations after STS versus no follow up in one year

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 6.1).

Hearing loss prevention programme for 12-hour shifts versus eight-hour shifts

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)

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.

One long-term evaluation study found that despite a military hearing loss prevention programme, the risk of sustaining hearing loss from exposure to impulse noise from shooting was considerably higher than among non-exposed recruits after 11 months follow up.

For the long-term evaluation of hearing loss prevention programmes (HLPPs) 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 asses 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, we found one study with a large sample size and a low risk of bias which showed that workers exposed to noise and included in a HLPP still have a substantial risk of sustaining hearing loss based on the standard threshold shift (STS). The study also showed that better use of hearing protection and more recent exposure to noise reduced the risk. However, despite this reduction and despite protection, the risk of hearing loss was still substantially greater than among non-exposed workers.

Studies based on comparisons between well and less well-performing companies show that there is substantial variation in the effectiveness of hearing loss prevention programmes.

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. Longer exposure over 12-hour shifts did not influence the effectiveness of hearing loss prevention. More frequent follow up did not prevent more hearing loss.

Overall completeness and applicability of evidence

It is striking that only one study evaluated measures to reduce noise exposure at the macro-level. No controlled studies were found in which technical measures to reduce noise levels were evaluated at the company level. Other studies on noise reduction that we found but did not include were mostly case studies which showed considerable reductions in noise level; 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 and 13 dB in Stone 1971. 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, it is unclear whether the noise levels in the immediate surroundings of machinery also lead to a reduction in the personal noise doses received by workers, especially if they 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.

No studies evaluated the effectiveness of the widespread practice of advice from occupational health services 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 surrounding (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 1991) and we assume, therefore, 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.

There were only a few studies that evaluated the long-term effects of noise induced hearing loss prevention programmes. Even though four out of six studies did not find a statistically significant increased risk of hearing loss among workers in a hearing loss prevention programme, it is clear that in practice there is still a large variation in implementation as can be inferred from the implementation studies. If we assume that only the best programmes were evaluated then this means that most programmes in practice perform much less effectively. This can explain the persistent high levels of occupational hearing loss reported and is line with the finding of Daniell 2006 that many programmes are of poor quality.

We know that noise is hazardous to hearing therefore it is difficult to use research designs which differ from studies in which noise exposed workers are compared to non-noise exposed workers. Audiometry is mandatory in many countries and thus there are likely to be large amounts of data available that could be used to carry out studies of higher methodological quality. However, for the data to be of value, we must also possess up-to-date data on hearing status in a comparable non-noise exposed control group.

Even though all the studies intended to evaluate a hearing loss prevention programme it was not entirely clear if measures were taken (and if so of what kind) in addition to providing hearing protection devices to workers.

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.

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 personal factors, such as the skills to insert and use hearing protection, have an important effect on the outcome, it is important that there are no baseline differences. Randomisation would be the only way to assure 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 hearing loss prevention programmes of differing intensity 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 which 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 deviation 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 impulsive 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 versus 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. However, there are no controlled evaluation studies on technical measures to reduce noise levels in companies, nor on advice to take such measures. Case studies show that technical measures can yield dramatic reductions in noise levels but these are apparently not well-implemented. 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 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 claimed 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 contradictory evidence that hearing protection, as provided in average hearing loss prevention programmes, reduces 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.

Hearing loss prevention programmes should also be evaluated in a cluster-randomised design, in which intensive programmes can be compared to less intensive programmes. Since most hearing loss occurs at the beginning of exposure, a five-year follow up should be sufficient, which would make such a study feasible. 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 and differences in age.

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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 9-year follow up
Notes	Long-term Comparability - intervention/control: Age: adjusted Hearing level: ?

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	No	D - Not used

Adera 2000

Methods	Controlled before-after study
Participants	Various occupations n = 19,640 US 1 company
Interventions	Intervention: well-implemented HLPP in 5 companies; n = 4317, after adjustment for design n = 22 Comparison: HLPP in 1 company with poor quality HLPP; n = 15,323
Outcomes	STS / 100 person-years greater or equal than 10 dB in either ear as the mean change at 2, 3 and 4 kHz 5-year follow up

Adera 2000 *(Continued)*

Notes	Long-term Comparability - intervention/control: Age: adjusted Hearing: adjusted

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	No	D - Not used

Brink 2002

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

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	No	D - Not used

Davies 2008

Methods	Controlled before-after study

Davies 2008 *(Continued)*

Participants	Workers in lumber mills during 1979-1996 who had at least 2 hearing tests n = 22,376 Canada, British Columbia
Interventions	Intervention: hearing conservation programme; n = 16,347 Control: those exposed to 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 2000, 3000 or 4000 Hz in the better ear
Notes	Long-term Comparability - intervention/control: Proportional hazards model to adjust for age and hearing ability at baseline

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 3 years at 2, 3, 4, 6, 8kHz 3-year follow up
Notes	Long-term Comparability - intervention/control: Age: matched Hearing: ?

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Gosztonyi 1975

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

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Hager 1982

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

Risk of bias

Hager 1982 *(Continued)*

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Horie 2002

Methods	Controlled before-after study
Participants	Steel industry quality check workers n = 12 Japan 1 company
Interventions	Intervention: hearing protection with active noise cancellation: Proactive PA-3100; n = 12 Control: hearing protection without active noise cancellation; n = 12
Outcomes	Temporary threshold shift after 4 hours of exposure at 1, 2, 4, 6 kHz (HT after - HT before) (immediate)
Notes	Immediate

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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 8-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 1 company
Interventions	Intervention: HLPP; n = 11,104, after cluster adjustment n = 97 Control: non-exposed colleagues; n = 331
Outcomes	Rate of STS, average change in mean hearing threshold at 2, 3 and 4 kHz in the worst ear Follow up average 5 years
Notes	Long-term Comparability - intervention/control: Age: adjusted Hearing: adjusted

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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

Meyer 1993 *(Continued)*

Outcomes	Rate of new STS; before 1990 defined as a change of 20 dB or more at 1, 2, 3 or 4 kHz, after 1990 an average change of 10 dB or more at 2, 3 and 4 kHz in either ear 1 year follow up
Notes	Long-term Comparability - intervention/control: Age: ? Hearing: ?

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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	-

Nilsson 1980

Methods	Controlled before-after study
Participants	Shipbuilders; 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 1 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

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Park 1991

Methods	Randomised controlled trial
Participants	Various workers n = 40 US Several companies
Interventions	See Park 1991a and Park 1991b
Outcomes	See Park 1991a and Park 1991b
Notes	-

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Park 1991a

Methods	Randomised controlled trial

Park 1991a *(Continued)*

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

Item	Authors' judgement	Description
Allocation concealment?	Unclear	B - Unclear

Park 1991b

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

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	B - Unclear

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 1 company
Interventions	Intervention: HLPP mainly hearing protection; n = 399 Control: non-exposed colleagues; n = 1173
Outcomes	Average change in hearing thresholds last - entrance measurement at 0.5, 1, 2, 3, 4, 6 kHz 5-year follow up
Notes	Long-term Comparability - intervention/control: Age: intervention - md 34 y; control - 43 y Hearing: stratified according to HL at start

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Pääkkönen 1998

Methods	Controlled before-after study
Participants	Shots with rifle 762RK62 n = 5 shots Finland Military
Interventions	Intervention: Hearing Protector Earmuffs: Peltor H61, Peltor H7, Peltor H6, Bilsom Marksman, Silenta Hunter at 156 Lcpeak dB(C); n=5
Outcomes	Difference in noise level outside versus inside the protectors
Notes	Immediate

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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 8 minutes LAeq 104 to 106 dB(A)
Outcomes	Difference in noise level outside versus inside the helmets
Notes	Immediate

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

Reynolds 1990a

Methods	Controlled before-after study
Participants	Various workers n = 852 US 1 chemical industry
Interventions	Intervention: HLPP at 12-hour shifts; n = 272, adjusted for design effect n = 218 Control: HLPP at 8-hour shifts; n = 580
Outcomes	Average change in hearing thresholds at 0.5, 1, 2, 3, 4, 6 kHz 1-year follow up

Notes	Long-term Comparability - intervention/control: Age: ? Hearing: similar loss

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

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

Simpson 1994 *(Continued)*

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 1 year
Notes	Long-term Comparability - intervention/control: Age: ? Hearing: ?

Risk of bias

Item	Authors' judgement	Description
Allocation concealment?	Unclear	D - Not used

? = 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]*

Ackermann 2005	Case study on noise reduction
Bowes 1990	Only noise measurements and recommendations, no evaluation of measures taken
Brühl 1994	Control group taken from database
Franks 2000	Not a field study with workers
Giardino 1996	Not the same workers using different hearing protection
Groothoff 1999	Several case studies on noise reduction but no control group
Jelinic 2005	Case study only
Kardous 2003	Case study on noise reduction

(Continued)

Karlsmose 2001	No noise exposed workers included
Knothe 1999	Case study on noise reduction
Mechfske 2002	Noise reduction for patients not for healthcare personnel
Merry 1992	Not a field study with workers
Neitzel 2005	Not the same workers using different hearing protection
Pingle 2006	Case study only
Pääkkönen 2005	Similar results as in Pääkkönen 1998 Not the same workers using different hearing protection
Reynolds 1990b	Not the same workers using hearing protection
Scannell 1998	Case study on technical noise reducing measures
Schaefer 1992	Case study on technical noise reducing measures
Stone 1971	Case study on technical noise reducing measures
Toivonen 2002	Not a field study with workers
Williams 2004	Not a field study with workers

DATA AND ANALYSES

Comparison 1. 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 2. 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 3. 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 4. 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 5. 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]
1.2 Low noise exposure < 89 dB(A)	2		OR (Random, 95% CI)	2.65 [0.40, 17.52]

Comparison 6. 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 7. Hearing loss prevention programme 12-hour shift vs hearing loss prevention programme 8-hour shift (long-term)

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]

Comparison 8. Hearing protection with instructions vs hearing protection without instructions (immediate)

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 9. 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)	Not estimable
1.1 Alpha-200 series with Active Noise Cancelling	1	2	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.2 Gentex/Bose Active Noise Cancelling	1	2	Mean Difference (IV, Fixed, 95% CI)	Not estimable
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
6 TTS at 8 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only

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

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 TTS at 0.5 kHz (before exposure - after exposure)	1	70	Mean Difference (IV, Random, 95% CI)	Not estimable
1.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
1.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
1.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
1.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
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)	Not estimable
2.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
2.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
2.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable

3 TTS at 2 kHz (before exposure - after exposure)	1		Mean Difference (IV, Random, 95% CI)	Subtotals only
3.1 After 8 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
3.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
3.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
3.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
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)	Not estimable
4.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
4.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
4.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
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)	Not estimable
5.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
5.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
5.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
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)	Not estimable
6.2 After 14.6 minutes out of noise	1	18	Mean Difference (IV, Random, 95% CI)	Not estimable
6.3 After 20 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable
6.4 After 27.2 minutes out of noise	1	17	Mean Difference (IV, Random, 95% CI)	Not estimable

Comparison 11. 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)	Not estimable
1.1 Peltor H61 Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.2 Peltor H7 Muff elec	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.3 Peltor H6 Muff elec	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.4 Bilsom Marksman Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.5 Silenta Hunter Muff Elec	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable
1.6 EAR Ultra 9000 Plug	1	6	Mean Difference (IV, Fixed, 95% CI)	Not estimable

Comparison 12. Hearing loss prevention programme vs non-exposed sensitivity analysis

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Hearing loss change at 4kHz / STS (5-year follow up)	3		effect size (Fixed, 95% CI)	0.17 [-0.06, 0.40]
1.1 Lee-Feldstein	1		effect size (Fixed, 95% CI)	0.29 [-0.07, 0.66]
1.2 Hager	1		effect size (Fixed, 95% CI)	-0.1 [-0.72, 0.52]
1.3 Gosztonyi	1		effect size (Fixed, 95% CI)	0.15 [-0.18, 0.48]

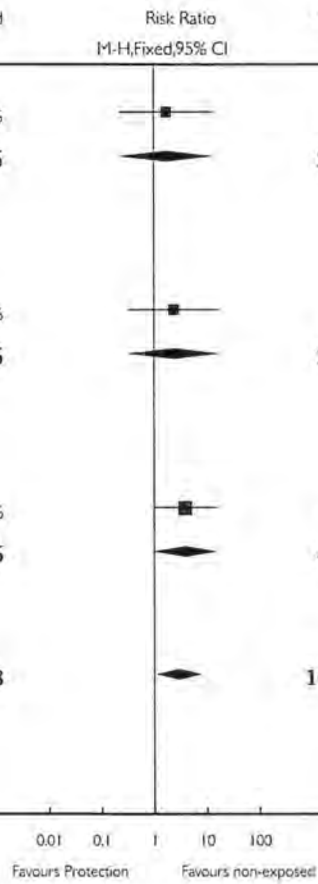
Analysis 1.1. Comparison 1 Hearing loss prevention programme vs non-exposed workers (long-term 1-year follow up), Outcome 1 Hearing loss STS.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 1 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	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)				



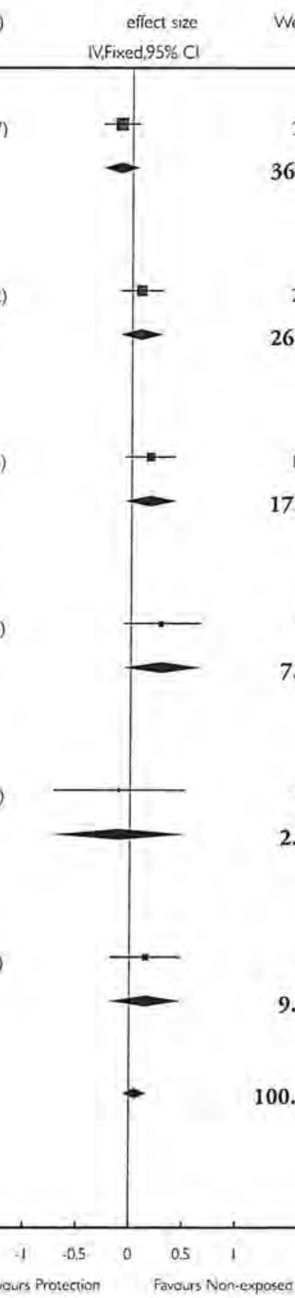
Analysis 2.1. Comparison 2 Hearing loss prevention programme vs non-exposed workers (long-term > 5-year follow up), Outcome 1 Hearing loss change at 4 kHz / STS (5-year follow up).

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 2 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)	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: $Chi^2 = 6.49$, df = 5 (P = 0.26); I^2 =23%					
Test for overall effect: Z = 1.02 (P = 0.31)					
Test for subgroup differences: $Chi^2 = 6.49$, df = 5 (P = 0.26), I^2 =23%					

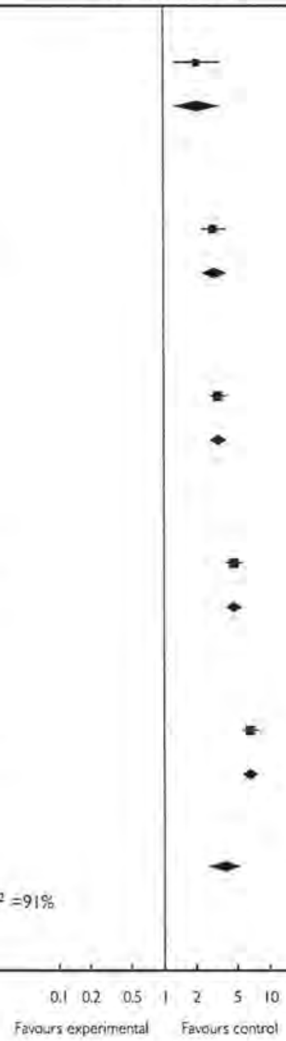


Analysis 2.2. Comparison 2 Hearing loss prevention programme vs non-exposed workers (long-term > 5-year follow up), Outcome 2 Hazard of STS.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 2 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: $Tau^2 = 0.13$; $Chi^2 = 46.94$, df = 4 (P<0.00001); $I^2 = 91\%$				
Test for overall effect: Z = 7.65 (P < 0.00001)				

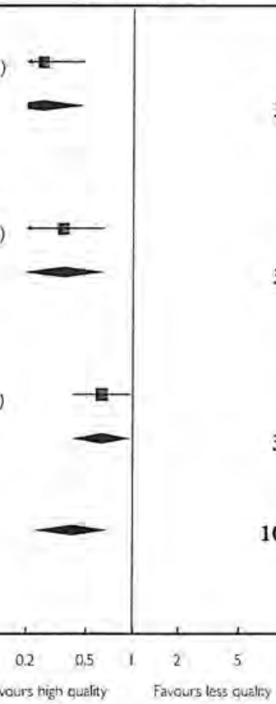
Analysis 3.1. Comparison 3 Well-implemented hearing loss prevention programme vs less well-implemented (long-term > 5-year follow up), Outcome 1 Hearing loss change STS / at 4 kHz.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 3 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: $Tau^2 = 0.16$; $Chi^2 = 5.84$, df = 2 (P = 0.05); $I^2 = 66\%$						
Test for overall effect: Z = 3.29 (P = 0.00099)						



Analysis 4.1. Comparison 4 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: 4 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 implemented n/N	Risk Ratio M-H,Fixed,95% CI	Weight	Risk Ratio M-H,Fixed,95% CI
Simpson 1994	2/45	37/296		100.0 %	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)

0.2 0.5 1 2 5

Well implemented | Less quality

Analysis 5.1. Comparison 5 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: 5 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%				

0.2 0.5 1 2 5

Favours Muffs | Favours Plugs

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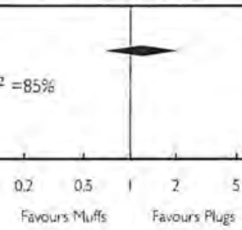
Study or subgroup	log [OR] (SE)	OR IV,Random,95% CI	Weight	OR IV,Random,95% CI
Test for overall effect: Z = 1.01 (P = 0.31)				
Total (95% CI)			**100.0 %**	**1.20 [0.69, 2.07]**
Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 20.27$, df = 3 (P = 0.00015); $I^2 = 85\%$				
Test for overall effect: Z = 0.65 (P = 0.51)				



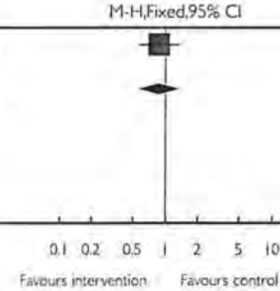
Analysis 6.1. Comparison 6 Follow-up exam after initial STS vs no exam (long-term), Outcome 1 Hearing loss change (STS).

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 6 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)					



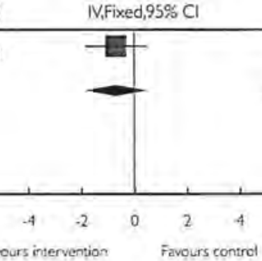
Analysis 7.1. Comparison 7 Hearing loss prevention programme 12-hour shift vs hearing loss prevention programme 8-hour shift (long-term), Outcome 1 Hearing loss change over 1 year at 4 kHz.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 7 Hearing loss prevention programme 12-hour shift vs hearing loss prevention programme 8-hour shift (long-term)

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)							



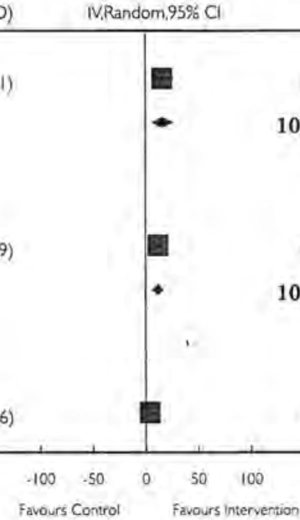
Analysis 8.1. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 1 Hearing levels at 0.5 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 1 Hearing levels at 0.5 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	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	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	10	16.5 (6.2)	10	12.4 (8.6)		100.0 %	4.10 [-2.47, 10.67]



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Study or subgroup	Intervention N	Mean(SD)	Control N	Mean(SD)	Mean Difference IV,Random,95% CI	Weight	Mean Difference IV,Random,95% CI
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	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)							

-100 -50 0 50 100

Favours Control Favours Intervention

Analysis 8.2. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 2 Hearing levels at 1 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 2 Hearing levels at 1 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	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	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	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							

-100 -50 0 50 100

Favours Control Favours Intervention

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Study or subgroup	Intervention N	Mean(SD)	Control N	Mean(SD)	Mean Difference IV,Random,95% CI	Weight	Mean Difference IV,Random,95% CI
Park 1991b	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 8.3. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 3 Hearing levels at 2 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 3 Hearing levels at 2 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	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	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	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	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

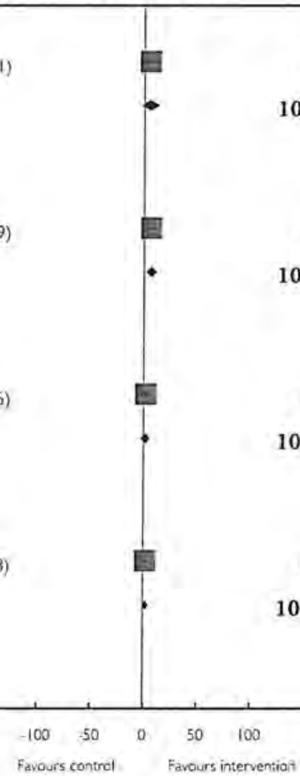
Analysis 8.4. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 4 Hearing levels at 3 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 4 Hearing levels at 3 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	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	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	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	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)							



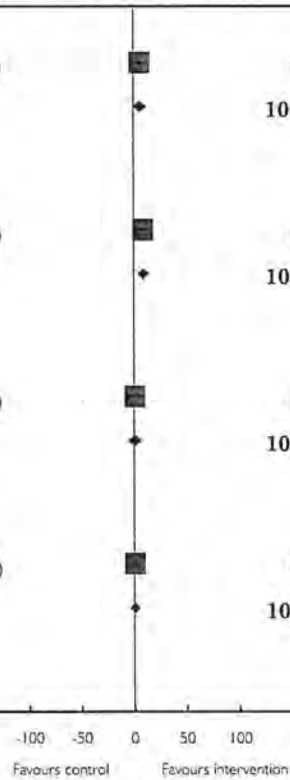
Analysis 8.5. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 5 Hearing levels at 4 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

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

Study or subgroup	Intervention N	Intervention Mean(SD)	Control N	Control Mean(SD)	Mean Difference IV,Random,95% CI	Weight	Mean Difference IV,Random,95% CI
1 EAR foam plugs							
Park 1991b	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	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	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	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)							



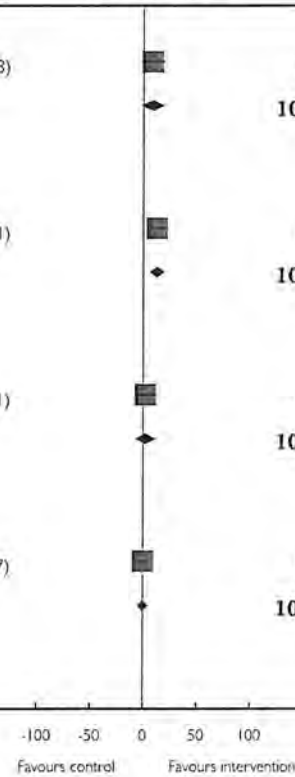
Analysis 8.6. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 6 Hearing levels at 6 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 6 Hearing levels at 6 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	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	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	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	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)							



Analysis 8.7. Comparison 8 Hearing protection with instructions vs hearing protection without instructions (immediate), Outcome 7 Hearing levels at 8 kHz difference with/without.

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 8 Hearing protection with instructions vs hearing protection without instructions (immediate)

Outcome: 7 Hearing levels at 8 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	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	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	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	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 9.1. Comparison 9 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: 9 Hearing protection with ANC vs hearing protection without ANC (immediate)

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

Study or subgroup	Intervention N	Mean(SD)	Control N	Mean(SD)	Mean Difference IV,Fixed,95% CI	Mean Difference IV,Fixed,95% CI
1 Alpha-200 series with Active Noise Cancelling						
Pkknen 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						
Pkknen 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: Chi^2 = 0.0, df = 0 (P<0.00001); I^2 =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-10 -5 0 5 10

Favours Control Favours Intervention

Analysis 9.2. Comparison 9 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: 9 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 N	Mean(SD)	Earplug/phone N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
Horie 2002	12	-2.5 (0)	12	-4.17 (0)		0.0 [0.0, 0.0]

-100 -50 0 50 100

Favours Control Favours Intervention

Analysis 9.3. Comparison 9 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: 9 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 N	Mean(SD)	Earplug/phone N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
Horie 2002	12	-3 (0)	12	-7.08 (0)		0.0 [0.0, 0.0]

-100 -50 0 50 100

Favours Control Favours Intervention

Analysis 9.4. Comparison 9 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: 9 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 N	Mean(SD)	Earplug/phone N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
Horie 2002	12	-5.8 (0)	12	-11.25 (0)		0.0 [0.0, 0.0]

-100 -50 0 50 100

Favours Control Favours Intervention

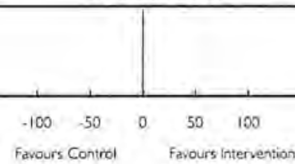
Analysis 9.5. Comparison 9 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 5 TTS at 6 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 9 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 N	Mean(SD)	Earplug/phone N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
Horie 2002	12	-3.75 (0)	12	-8.08 (0)		0.0 [0.0, 0.0]



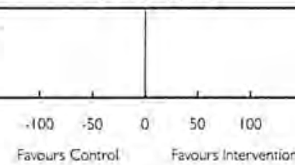
Analysis 9.6. Comparison 9 Hearing protection with ANC vs hearing protection without ANC (immediate), Outcome 6 TTS at 8 kHz (before exposure - after exposure).

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 9 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 N	Mean(SD)	Earplug/phone N	Mean(SD)	Mean Difference IV,Random,95% CI	Mean Difference IV,Random,95% CI
Horie 2002	12	-4.58 (0)	12	-5.42 (0)		0.0 [0.0, 0.0]



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

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 10 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 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	-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: Tau^2 = ï½; Chi^2 = 0.0, df = 0 (P<0.00001); I^2 =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-100 -50 0 50 100

Favours Control Favours Intervention

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

Review: Interventions to prevent occupational noise induced hearing loss

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

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

Study or subgroup	V-51-R plug N	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	-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 10.3. Comparison 10 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: 10 V-51-R plug versus EAR plug (immediate)

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

Study or subgroup	V-51-R plug N	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	-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 10.4. Comparison 10 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: 10 V-51-R plug versus EAR plug (immediate)

Outcome: 4 TTS at 3 kHz (before exposure - after exposure)

Study or subgroup	V-51-R plug N	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	-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 10.5. Comparison 10 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: 10 V-51-R plug versus EAR plug (immediate)

Outcome: 5 TTS at 4 kHz (before exposure - after exposure)

Study or subgroup	V-51-R plug N	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	-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 10.6. Comparison 10 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: 10 V-51-R plug versus EAR plug (immediate)

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

Study or subgroup	V-51-R plug N	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 11.1. Comparison 11 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: 11 Various hearing protectors (immediate)

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

Study or subgroup	Intervention N	Mean(SD)	Control N	Mean(SD)	Mean Difference IV,Fixed,95% CI	Mean Difference IV,Fixed,95% CI
1 Peltor H61 Muff Elec						
Pkknen 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						
Pkknen 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						
Pkknen 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						
Pkknen 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						
Pkknen 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						
Pkknen 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: Chi^2 = 0.0, df = 0 (P<0.00001); I^2 =0.0%						
Test for overall effect: Z = 0.0 (P < 0.00001)						

-10 -5 0 5 10

Favours intervention Favours control

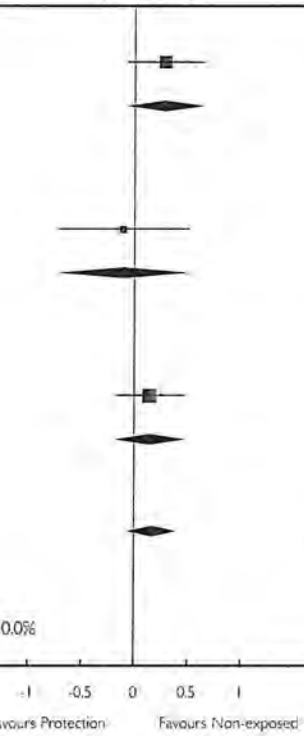
Analysis 12.1. Comparison 12 Hearing loss prevention programme vs non-exposed sensitivity analysis, Outcome 1 Hearing loss change at 4kHz / STS (5-year follow up).

Review: Interventions to prevent occupational noise induced hearing loss

Comparison: 12 Hearing loss prevention programme vs non-exposed sensitivity analysis

Outcome: 1 Hearing loss change at 4kHz / STS (5-year follow up)

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%				



APPENDICES

Appendix 1. Search strategy for CENTRAL

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

Appendix 2. Search strategies for other databases

PubMed	EMBASE	CINAHL
#1 noise [tiab] AND (reduction [tiab] OR abatement [tiab] OR diminishment [tiab] OR elimination [tiab] OR "engineering controls" [tiab] OR "administrative controls"[tiab]) #2 "hearing loss prevention" [tiab] OR "hearing conservation" [tiab] OR "hearing surveillance" [tiab] #3 "ear protective device" [tiab] OR "ear protective devices" [tiab] OR "hearing protective device" [tiab] OR "hearing protective devices" [tiab] OR "hearing protector" [tiab] OR "hearing protectors" [tiab] OR "hearing protection" [tiab] OR "ear muffs" [tiab] OR "ear plugs" [tiab] OR "ear defenders" [tiab] #4 ("noise reduction" [tiab] AND "protective equipment" [tiab]) #5 "Noise, Occupational/prevention and control"[Mesh] #6 "Noise, Occupational"[Mesh] #7 "protective equipment" [tiab] #8 #6 AND #7 #9 #1 OR #2 OR #3 #4 OR #5 OR #8 #10 (effect*[tiab] OR control*[tiab] OR evaluation*[tiab] OR program*[tiab]) AND (work*[tiab] OR worker*[tiab] OR workplace*[tiab] OR occupation*[tiab] OR prevention*[tiab] OR protect*[tiab]) #11 #9 AND #10	1 industrial noise/ 2 (protective adj equipment).tw. 3 1 and 2 4 (noise and (reduction or abatement or diminishment or elimination or (engineering adj controls) or (administrative adj controls))).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	#1 (noise AND (reduction OR abatement OR diminishment OR elimination OR "engineering controls" OR "administrative controls")) OR "hearing loss prevention" OR "hearing conservation" OR "hearing surveillance" #2 "ear protective device" OR "ear protective devices" OR "hearing protective device" OR "hearing protective devices" OR "hearing protector" OR "hearing protectors" OR "hearing protection" OR "ear muffs" OR "ear plugs" OR "ear defenders" #3 (noise(mh) AND "protective equipment") OR ("noise reduction" AND "protective equipment") #4 (effect* OR control* OR evaluation* OR program*) AND (work* OR worker* OR workplace* OR working OR occupation* OR prevention* OR protect*) #5 (#1 OR #2 OR #3) #6 (#4 AND #5)
BIOSIS/CAB Abstracts	**Web of Science**	**NIOSHTIC**
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 pro-	#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	(noise AND (induced OR hearing))

(*Continued*)

tective 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 7 6 and 5	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

HISTORY

Protocol first published: Issue 1, 2007

Review first published: Issue 3, 2009

CONTRIBUTIONS OF AUTHORS

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

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

Dr. B. Sorgdrager: Comments on drafts.

Prof. Dr. W.A Dreschler: Comments on drafts.

T.C. Morata: Comments on drafts, searching for studies.

All: Comment on drafts of protocol and review.

DECLARATIONS OF INTEREST

None known.

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- No sources of support supplied

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- The Cochrane Occupational Health Field, Finland.
  The Cochrane Occupational Health Field provided support in kind.

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.