Review

The Effect of Earplugs in Preventing Hearing Loss From Recreational Noise Exposure
A Systematic Review

Véronique J. C. Kraaijenga, MD; Geerte G. J. Ramakers, MD; Wilko Grolman, MD, PhD

IMPORTANCE The prevalence of hearing loss among children and adolescents is rising dramatically, caused mainly by increased exposure to recreational noise.

OBJECTIVE To present a systematic overview of the effectiveness of wearing earplugs to music venues, such as nightclubs and concert halls, to prevent hearing loss and tinnitus directly after exposure.

EVIDENCE ACQUISITION PubMed, EMBASE, and the Cochrane Library databases were searched for articles from database inception to June 22, 2015, using the keywords *music* and *earplugs* and all synonyms. Titles, abstracts, and full text of retrieved articles were screened for eligible articles. The directness of evidence (relevance of the assessed articles) and risk of bias of eligible articles were assessed. For the included articles, the study characteristics and data on our outcomes of interest (hearing loss and tinnitus) were extracted. Data analysis occurred from June 22 to July 3, 2015.

FINDINGS Of 228 articles screened, 4 were eligible for critical appraisal. After critical appraisal, 2 studies with a high directness of evidence and low or moderate risk of bias remained for data extraction. Only 1 of these articles was a randomized clinical trial, which found significantly lower postconcert differences in thresholds and a lower proportion of threshold shifts in the group using earplugs compared with the unprotected group. In the other study, only 3 individuals wore earplugs, and no significant differences were found between the 2 groups.

CONCLUSIONS AND RELEVANCE The available evidence on the effectiveness of earplugs in preventing hearing damage directly after recreational music exposure is scarce. Only 1 well-conducted randomized clinical trial was found, which showed that wearing earplugs to concerts is effective in reducing postconcert threshold shifts. There is a need for further research on this topic to strengthen the level of evidence. Physicians should promote awareness on the risks of recreational noise and recommend the use of earplugs among their patients who visit music venues.

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Author Affiliations: Department of Otorhinolaryngology–Head and Neck Surgery, University Medical Center Utrecht, Utrecht, the Netherlands (Kraaijenga, Ramakers, Grolman); Brain Center Rudolf Magnus University Medical Center Utrecht, Utrecht, the Netherlands (Kraaijenga, Ramakers, Grolman).

Corresponding Author: Wilko Grolman MD, PhD, Department of Otorhinolaryngology–Head and Neck Surgery, University Medical Center Utrecht, PO Box 85500, 3508 GA Utrecht, the Netherlands (ENT-research@umcutrecht.nl).

Hearing loss is primarily a disability common among the elderly. However, the prevalence of hearing loss among children and adolescents is rising dramatically according to the National Health and Nutrition Examination Survey, which showed that 1 in 5 adolescents demonstrated any type of hearing loss in 2005 and 2006.[1] This number has increased 31% from 1988 through 1994. An explanation for this development is an increase in recreational noise exposure, such as visiting music venues and listening to music on personal listening devices.

Visiting music venues, such as concert halls, festivals, and nightclubs, has gained popularity over the years. Average sound pressure levels measured at nightclubs range from approximately 100 to 110 dB.[2-5] Music exposure at these venues can cause hearing damage.[6,7] Often, this damage is measured by temporary threshold shifts (TTSs) in audiometric results and subjective hearing loss and tinnitus. Such a TTS is expected to normalize after several minutes to a few hours after the music exposure.[8,9]

However, many animal studies have shown that repeated TTSs can ultimately lead to a permanent threshold shift (PTS) as the outer hair cells and synapses in the cochlea are damaged.[10-12] A recent study investigated the effects of varying intensity levels of repeated noise exposure on the development of PTS in rats.[12] This study found that a single noise exposure of 107 and 110 dB for 90 minutes resulted in a PTS. A high level of evidence on the development of permanent hearing loss after repeated noise exposure in humans is lacking owing to ethical considerations for this type of research. Only cohort studies are performed, such as that by Serra et al,[4] who conducted a longitudinal interdisciplinary cohort study investigating the effect of recreational noise on hearing abilities in adolescents for 4 consecutive years. This study found that, during this period, the hearing level thresholds increased as a result of exposure to recreational noise. A recent prognostic study found that a TTS is the most important predictor of developing a PTS.[13] The risk of noise-induced hearing loss was originally described in employees at noisy workplaces.[14] Multiple educational programs have attempted to increase awareness among employers and employees, and strict rules regarding noise levels were established. A maximum decibel level at workplaces and the obligatory use of hearing protection devices (such as earplugs) were introduced.[14,15]

These measures should be adopted in the recreational music industry as well.[16] Investigations of the general opinion about earplugs in music venue attendees show that the willingness to wear earplugs is very low.[17-19] It is hypothesized that this low level of willingness is owing to a lack of available information and advice on hearing risks and a scarce availability of ear protectors.[16] Studies concurred that the awareness of hearing damage caused by loud music is low indeed, particularly among young adults.[18,19] Two studies showed that educational programs can be effective in increasing awareness and may result in increased use of earplugs and improved behavior regarding music exposure.[20,21]

To convince concert attendees of the preventive effect of wearing earplugs, this effect should be well assessed and confirmed in the literature. Therefore, this systematic review assesses the current literature on the effectiveness of wearing earplugs to music venues, such as nightclubs, concert halls, and festivals, in protecting against hearing loss and tinnitus directly after exposure.

Methods

Search and Selection

We performed a systematic search in PubMed, EMBASE, and the Cochrane Library databases from database inception to June 22, 2015. We also searched several registries of ongoing trials. The search syntax included relevant synonyms for the search terms *music* and *earplugs* (eTable in the Supplement). After removal of duplicate articles, title and abstract screening was performed independently by 2 of us (V.J.C.K. and G.G.J.R.) according to predetermined inclusion and exclusion criteria. Eligible full-text articles were retrieved through the databases and by emailing authors. Subsequently, the full texts of eligible articles were screened independently (V.J.C.K. and G.G.J.R.). We searched Web of Science for additional relevant articles. Discordances regarding inclusion were resolved by discussion. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement was used as a guideline for setup and writing of this systematic review.[22] As this was a literature review, no patients were involved in the study and no institutional review board approval was sought.

Study Eligibility Criteria

Studies reporting original data on the effect of the use of earplugs on hearing loss or tinnitus after visiting a music venue (such as a nightclub, festival, or concert hall) were included. We were interested in attendees of these venues; therefore, we excluded studies involving musicians because they are exposed to loud music more frequently than are attendees. The outcome measures were all objective or subjective measures of hearing loss or tinnitus measured by a questionnaire.

Quality Assessment

We appraised the selected studies independently for directness of evidence (DoE; relevance of the assessed articles) and risk of bias (RoB) using predefined criteria (**Table 1**). Directness of evidence was scored by evaluation of the study population, intervention, and outcome. Items were scored as satisfactory or unsatisfactory. Studies were classified as having high DoE if they scored 4 to 5 points, moderate DoE if they scored 3 points, and low DoE if they scored fewer than 3 points.

We assessed RoB by the use of several criteria. First, we examined the design of a study and, if it was prospective, whether blinding and randomization were performed. Second, we assessed standardization of earplug use (eg, type of earplug and duration of use). Third, we assessed standardization of outcome measurements. Studies were assessed as satisfactory when an objective measurement of hearing loss or a measurement of tinnitus by questionnaire was performed. Finally, we assessed missing data. Studies were classified as having low RoB if they scored 4 to 5 points, moderate RoB if they scored 2 to 3 points, and high RoB if they scored fewer than 2 points.

Disagreement was resolved by discussion. Only studies that rated high for DoE and low or moderate for RoB were selected for further review.

Data Extraction and Analysis

Two of us (V.J.C.K. and G.G.J.R.) independently extracted descriptive data regarding study population, intervention, and outcome from the selected studies. Data analysis occurred from June 22 to July 3, 2015.

Table 1. Assessment of Quality of Included Studies

Study	Sample Size, No/Study Design	Directness of Evidence[a]				Level of DoE[b]	RoB[c]				Level of RoB[d]
		Population	Outcome		Follow-up		Randomization for Use of Earplugs	Standardization		Complete Data	
			Hearing Loss	Tinnitus				Intervention	Outcome		
Beach et al,[23] 2015	51/RCT	Visitor of music venues[e]	Loss after music exposure	Tinnitus after music exposure	Absent	High	Unsatisfactory	Unsatisfactory	Objective hearing loss or tinnitus measured by questionnaire	≥10% Data missing	High
Derebery et al,[5] 2012	29/PCS	Visitor of music venues[e]	Loss after music exposure	Tinnitus after music exposure	Assessment before and directly after music exposure	High	Unsatisfactory	Unsatisfactory	Objective hearing loss or tinnitus measured by questionnaire	<10% Data missing	Moderate
Mostafapour et al,[24] 1998	50/PCS	Other	Unclear	Unclear	Absent	Low	Unsatisfactory	Unsatisfactory	Objective hearing loss or tinnitus measured by questionnaire	<10% Data missing	Moderate
Opperman et al,[25] 2006	29/RCT	Visitor of music venues[e]	Loss after music exposure	Absent	Assessment before and directly after music exposure	High	Satisfactory	Same type of earplug and duration of use	Objective hearing loss or tinnitus measured by questionnaire	<10% Data missing	Low

Abbreviations: DoE, directness of evidence; PCS, prospective cohort study; RCT, randomized clinical trial; RoB, risk of bias.

[a] In all studies, hearing protection devices were used as the intervention.

[b] High defined as a positive score on 4 or 5 criteria, moderate defined as a positive score on 3 criteria, and low defined as a positive score on less than 3 criteria.

[c] Blinding was not performed in any of the studies.

[d] Low defined as a positive score on 4 or 5 criteria, moderate defined as a positive score on 2 or 3 criteria, and high defined as a positive score on less than 2 criteria.

[e] Music venues defined as a festival, concert hall, or nightclub.

Results

Search Strategy and Study Selection

Our search identified 242 articles; 14 were duplicates, leaving 228 articles. After screening the title and abstract, 31 articles were left for full-text appraisal. Checking of the reference lists yielded 1 additional relevant article. One reference was published only as a conference abstract, and 27 articles were not eligible because of a noncorresponding population, noise exposure, intervention, or outcome. Consequently, 4 articles were eligible for critical appraisal (**Figure**).

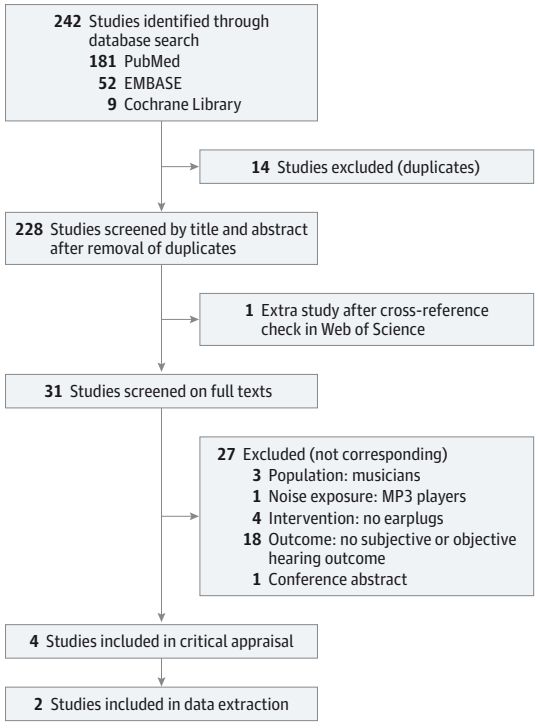
Assessing Quality of Studies

The critical appraisal of the 4 studies is presented in Table 1. Two studies were prospective cohort studies[5,24] and 2 studies were randomized clinical trials.[23,25]

Three studies included only visitors to music venues,[5,23,25] and 1 study included individuals who used personal stereo devices at least 1 hour per day.[24] In the latter study, an extensive history of exposure to noise (including loud noise) was examined.[24] In all studies, hearing protection devices were used in a part of the study population. Two studies reported on both of our outcomes of interest (hearing loss and tinnitus),[5,23] and 1 study reported only on hearing loss.[25] Mostafapour et al[24] did not specify exposure to loud noise; therefore, the hearing loss and tinnitus outcomes could not be extracted for our population of interest. In 2 studies, assessments were performed before and directly after a concert.[5,25] All of the above resulted in a high DoE in 3 studies[5,23,25] and a low DoE in 1 study.[24]

Blinding was not performed in any of the studies. Only the study by Opperman et al[25] randomized individuals for the use of hearing protection devices. The study by Beach et al[23] was a randomized clinical trial on the behavior of music venue attendees after education about the risks associated with music exposure, and participants

Figure. Flowchart of Study Selection



The search used the keywords *music* and *earplugs*, as well as all synonyms.

Table 2. Study Characteristics

Study	Sample Size, No.	Participants	Setting	Sound Level of Concert, Mean (SD) [Range], dB	Type of Earplug	Participants With Earplugs, No.	Hearing Loss Measurement	Tinnitus Measurement
Derebery et al,[5] 2012	29	13-20 y, Normal hearing, attending a concert	1 Rock and pop music concert in a large sports arena	99 (3.8) [82-110]	Foam earplugs	3	Pure-tone thresholds 0.5-8 kHz and DPOAE measured before and after the concert	Questionnaire administered before and after the concert
Opperman et al,[25] 2006	29	17-59 y, Normal hearing, attending a concert	3 Concerts: pop, heavy metal and rockabilly music in the same venue	[95-107][a] [54-126][b]	Mack's Hear Plugs, NRR 21	15	Pure-tone thresholds 0.5-8 kHz measured before and after the concert	Not performed

Abbreviations: DPOAE, distortion product otoacoustic emission; NRR, noise reduction rating.

[a] Range of mean sound levels measured during the 3 different concerts at different venues.

[b] Minimum to maximum sound levels measured during the 3 different concerts at different venues.

were allocated to a low- or high-information group. The study by Opperman et al[25] was the only one in which all earplug users wore the same type of earplug for the duration of the concert. One study scored unsatisfactory on completeness of data.[23] All of the above resulted in a high RoB in 1 study,[23] moderate RoB in 2 studies,[5,24] and low RoB in 1 study.[25] After assessment of the studies, 2 with a high DoE and low or moderate RoB remained for data extraction.[5,25]

Data Extraction

We were unable to pool data because only 2 studies remained, and there was substantial clinical heterogeneity between these studies. Therefore, we provided a descriptive analysis.

Study Characteristics

The characteristics of the remaining 2 studies are presented in Table 2. Both studies had a sample size of 29 concert attendees with normal hearing. Derebery et al[5] investigated hearing in teenagers and young adults before and after a rock and pop music concert. Before the concert, all attendees were offered foam earplugs; however, the decision to use them was left up to the individual. Opperman et al[25] investigated the protective value of Mack's Hear Plugs (McKeon Products, Inc) in concert attendees aged between 17 and 59 years during 3 concerts of different genres of music. In the study by Derebery et al,[5] only 3 attendees chose to wear the earplugs. In the study by Opperman et al,[25] a total of 15 attendees were allocated to the earplug group. Average sound pressure levels during the concerts were 99 dB in the study by Derebery et al[5] and between 95 and 107 dB for the 3 concerts in the study by Opperman et al.[25] Both studies performed audiometry before and after the concerts. Derebery et al[5] performed distortion product otoacoustic emission tests and administered tinnitus questionnaires as well.

Outcomes

The results were reported separately for attendees with and without earplugs only in the study by Opperman et al.[25] Significantly higher postconcert hearing levels at 0.5, 3, and 4 kHz were found in the group without earplugs compared with the group with earplugs when adjusted for seating location and type of concert. In this study, different criteria were used to report a TTS after the concert: Occupational Safety and Health Act Standard Threshold Shift criteria, American Speech-Language-Hearing Association criteria, and multinomial criteria.[25] According to all criteria, the proportion of TTSs was higher in the group without earplugs, but no significance was reported. In all outcomes, Derebery et al[5] found no significant differences between the 3 individuals who wore earplugs and the 26 who did not (Table 3).

Discussion

In this study, we described the results of a systematic review on the effectiveness of earplugs in preventing hearing damage directly after exposure to recreational music. The most important finding is that the current best available evidence on this topic consists of only 2 articles. One of these articles is a well-conducted randomized clinical trial, in which investigators found significantly lower postconcert differences in thresholds and a lower proportion of TTSs in the group who wore earplugs compared with the group who did not.[25] Although earplugs were effective in reducing hearing loss directly after the concert, hearing loss was not eliminated with the use of earplugs. In the other study, no significant differences were found between the 2 subgroups.[5]

The included studies conducted hearing tests only shortly after exposure to music and lack information about long-term hearing performance. From an ethical point of view, it is questioned whether it is possible to repeatedly expose humans to high sound levels to investigate the development of a PTS. Animal studies have shown that single or repeated TTSs can lead to a PTS.[10-12] Therefore, the TTSs found in this review are likely to become PTSs after repeated exposure to music. The preventive effect of earplugs on TTSs could therefore be considered preventive for the development of permanent hearing loss.

Our systematic review highlights possible prevention for an important and increasing problem in the adolescent and adult population. Unfortunately, the proportion of music venue attendees who wear earplugs is rather small. Educational programs for the awareness of concert attendees regarding hearing damage induced by recreational music are important. Awareness will be increased by presenting recent literature on the effectiveness of earplugs and by

Table 3. Study Results

Study	Difference in Hearing Levels (After–Before the Concert), Mean (SD), dB							Participants With Temporary Threshold Shifts, No.				
	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz	OSHA STS	ASHA	Multinomial	DPOAE	Tinnitus
Derebery et al,[5] 2012												
Statistics[a]	NS	NS	NS	NS	NS	NS	NS	NS	NA	NA	NS	NS
Opperman et al,[25] 2006												
Earplug	−0.17 (2.75)	0.83 (2.94)	1.50 (2.96)	2.67 (7.76)	3.33 (6.17)	−1.00 (6.25)	0.33 (5.89)	3	4	4	NA	NA
Control	2.86 (3.08)	3.04 (5.30)	5.36 (7.96)	10.18 (9.12)	11.61 (10.22)	8.46 (14.38)	3.57 (7.89)	9	9	9	NA	NA
Statistics[b]	.01	.21	.12	.02	.04	.38	.29	NA	NA	NA	NA	NA

Abbreviations: ASHA, American Speech-Language-Hearing Association; DPOAE, distortion product otoacoustic emissions; NA, not applicable; NS, nonsignificant; OSHA STS, Ocupational Safety and Health Act standard threshold shift.

[a] All outcomes were not separated for wearing earplugs. Only statistics between the subgroups were reported.

[b] Adjusted *P* value for seating location and concert.

showing that hearing damage starts immediately after visiting a concert hall, festival, or nightclub.[6,7]

Some limitations of the included studies must be acknowledged. In the study by Derebery et al,[5] only 3 of 29 patients chose to wear earplugs during the concert, and no data were reported about the duration of use. In addition, the results of the subgroups (with or without earplugs) were not separated. Therefore, we could not draw firm conclusions about the effectiveness of earplugs during a concert. Opperman et al[25] investigated only hearing levels before and after concerts and did not report on our other outcome of interest—tinnitus. Because of the small number of included studies, the clinical heterogeneity between these studies, and the inability to extract some relevant data from 1 of the studies,[5] we were unable to perform a meta-analysis.

Strengths of our review include the transparent and thorough search strategy, critical appraisal, and data extraction with multiple outcome measurements. A possible limitation of our review is that the cross-reference check yielded 1 additional article for full-text screening. This article was not retrieved in the initial search because "music" or one of its synonyms was not mentioned in the title or abstract; the more general term "entertainment venue" was used. After screening the full text, we excluded this article because the outcome did not correspond with our research question.

Because the available evidence is scarce and not conclusive for all outcomes of interest, there is need for further research to provide additional evidence to strengthen the conclusion of the existing knowledge on this topic. Another randomized clinical trial could investigate the effectiveness of earplugs in a larger sample size, with tinnitus and hearing loss (subjective as well as objective measures) as outcome measures.

Conclusions

The available evidence on the effectiveness of earplugs in preventing hearing damage directly after exposure to recreational music is scarce. Only 1 well-conducted randomized clinical trial was found, which showed that wearing earplugs to a concert is effective in reducing TTs after a concert. There is need for further research on this topic to strengthen the level of evidence. Physicians should increase awareness on the risks of recreational noise and promote the use of earplugs among their patients who visit music venues.

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Study concept and design: All authors.
Acquisition, analysis, or interpretation of data: Kraaijenga, Ramakers.
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