frontiers | Frontiers in Public Health

TYPE Systematic Review
PUBLISHED 13 February 2025
DOI 10.3389/fpubh.2025.1472134

A scoping review of the prevalence of musicians' hearing loss

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RECEIVED 28 July 2024
ACCEPTED 17 January 2025
PUBLISHED 13 February 2025

CITATION
Firle C and Richter AH (2025) A scoping review of the prevalence of musicians' hearing loss.
Front. Public Health 13:1472134.
doi: 10.3389/fpubh.2025.1472134

Introduction: Hearing loss is the most commonly recognized occupational disease in Germany. Musicians are also affected, as playing classical music can expose them to high or very high sound volumes. With this scoping review, we aimed to assess the prevalence of noise-induced hearing loss among professional musicians and evaluate its characteristics.

Methods: The databases such as MEDLINE, Embase, Cochrane Library, and Google Scholar were searched using the terms *(hearing loss OR hearing impairment OR hearing difficulties OR acoustic trauma) AND (musician)* on 14 August 2023 and 2 January 2025. Only original studies with audiometric examination results were included.

Results: A total of 79 studies were retrieved for descriptive analysis. The median number of participants was 52 (IQR 30-109). The majority of the retrieved studies included participants with at least 5 years of experience as practicing musicians. The proportion of men was significantly higher than that of women, with the median$_{\text{men portion}}$ of 69% (IQR 53–83%). Students were a common study population, indicating that the data on older and retired musicians were either rare or missing. As a result, the lifetime prevalence of hearing loss in musicians could not be determined. The data analysis showed an increased risk of hearing loss >15–20 dB in the frequency range of 4,000–6,000 Hz among participants in the classical genre group. Studies with participants having normal hearing were also found within that genre. Rock, pop, and jazz musicians had an increased risk of hearing loss >20 dB in the frequency range of 3,000–8,000 Hz. The data for military and marching band music and traditional music genres were limited. The retrieved studies indicated a higher risk of hearing loss >20 dB in the frequency range of 4,000–6,000 Hz. A total of 17 studies adjusted the audiogram results for age, 2 did not, and 59 had no report. Data extraction yielded a prevalence of notch configurations in 20–50% of the classical musicians, with hearing loss affecting 5–70% of them. Up to 40% of rock, pop, and jazz musicians showed notch configurations, with 20–60% experiencing hearing loss.

Conclusion: Overall, a definitive assessment of the prevalence of musicians' hearing loss cannot be drawn from the available data. Prospective, longitudinal studies with reliable sample sizes and representative populations are essential. A multicenter study would also be valuable.

KEYWORDS

noise-induced hearing loss, music-induced hearing loss, musician, orchestra, hearing protection

Introduction

Noise-induced hearing loss is a widespread condition in occupational health (1). The WHO attributes 16% of global hearing loss to occupational noise exposure (2). In Germany, noise-induced hearing loss is the most commonly recognized occupational disease (3) and is often a result of chronic occupational noise exposure and insufficient protection measures (4). In addition, musicians can be affected, even though music is a very special type of noise (5). Occupational examinations reveal an elevated risk of hearing loss for musicians playing in an orchestra: 8 h exposure levels may exceed L_{Aeq8h} 85 dB(A) or peak values of 137 dB(C), depending on the instrument and orchestra position (6). The law mandates that at these noise levels, employers must provide protective measures (7, 8), which are often inappropriate for musical activities. For instance, hearing protection devices can distort the sound frequency range (9) and lead to the occlusion effect, which affects musicians' perception of the music (10). Thus, the use of hearing protection devices is low among musicians (11). Partition and sound baffles may worsen sound exposure through reflection effects or by causing inhomogeneous sound dispersion (12). Substituting loud sections of music is not an option, and administrative measures to reduce the volume during rehearsal or concerts are limited.

Given these facts, it is important to determine whether musicians have an increased prevalence of music-induced hearing loss. Previous studies have provided an overview of the topic but lack a systematic literature search. For instance, Marquard and Schäcke reported in detail in 1998 on the heterogeneity of the published studies assessing musicians' hearing loss (13). They found major differences in outcome parameters, methodical approaches, examination conditions, and participant groups. More recent reviews assessed a broad range of musicians' diseases and briefly reported on hearing loss (14, 15). Other reviews focused on noise as the factor inducing hearing loss in musicians (16, 17). Pharmaceutical interventions for the treatment of musicians' hearing loss have been proposed by Wartinger et al. (18). Behar et al. reported on studies using pure tone audiometry but focused on the technique of noise measurement (19). They provided recommendations about noise measurement but did not draw conclusions about the prevalence of musicians' hearing loss. All of the mentioned studies are not systematic reviews. The only systematic review on the topic is by Di Stadio et al., published in 2018 (20). This thorough review involved a subgroup analysis of pop/rock and classical music musicians. The review included 41 studies and pooled the results from a sample of 4,618 professional musicians. The authors reported a prevalence of musicians' hearing loss of 63.5% for pop/rock musicians and 32.8% for classical music performers in the frequency range of 3,000–6,000 Hz. A limitation of the review was the heterogeneity of the retrieved studies. The pooling of the results includes a high risk of bias since studies with low quality have a high impact. Furthermore, the proportion of affected individuals relative to the original sample size (prevalence) can be obscured by pooling the results, as well as by grouping the results into different subgroups containing different instrumentalists. With a new methodical approach that preserves the original prevalence findings, we sought to update the research question.

Furthermore, it is important to consider the criteria that distinguish a well-conducted study and the publication of meaningful data. This starts with the design of the study (e.g., cohort size) and extends to the execution of audiometry (e.g., environment, noise breaks, and use of a standardized audiometer), evaluation of the raw data (e.g., age correction or at least its reporting), and preparation of the data for publication (e.g., reporting hearing loss in dB and by frequency).

We did not aim to compare occupational risk assessments; rather, our goal was to determine the prevalence of music-induced hearing loss and its characteristics among musicians.

Methods

We conducted a literature search following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (21), using the search terms *(hearing loss OR hearing impairment OR hearing difficulties OR acoustic trauma) AND (musician)*. This search was performed between 14 August 2023 and 2 January 2025, for a final update. We searched the databases such as MEDLINE, Embase, Cochrane Library, and Google Scholar. For the latter, we restricted the search results to a total of 300 entries. The abstracts and titles from the Google Scholar result list were excluded from HTML files using Wolfram Mathematica 13.1. URLs were used when digital object identifiers (DOIs) could not be retrieved. Each Google Scholar entry was added to the screening list. We also included theses and comparable university works to reduce the risk of bias. We applied no filters and included all years of publication. The review was not registered, and the protocol was not published in advance.

The inclusion criteria were as follows: an examination of musicians (mostly professional), and majority age of participants (population), exposure to music performance (exposure), and original research that included the use of pure tone audiometry (outcome).

The exclusion criteria included singers as the study population, music exposure in a leisure context, and publication types such as case report studies, systematic reviews, reports, grey literature, and languages other than English or German. Computational translations for other languages yielded inappropriate results. The study design was not a selection criterion as long as audiometry data were reported for musicians. A control group was not required since we focused on the prevalence of noise-induced hearing loss.

During the review process, we never used automation tools or citation tracking tools. The screening was performed independently by the two authors as reviewers, using xlsx-files. First, the abstracts were screened. The unclear and deviating titles were discussed. In the second step, the full texts were screened in the same manner. The reference lists were not searched systematically, and we did not add any manual entries. The flowchart is presented in Figure 1.

Data extraction was conducted simultaneously and under the constant observation of the other reviewer. The data extraction was based on the following categories: musical genre, study population, number of participants (including the female-to-male ratio) age range of study population, minimum years of musical practice, inclusion and exclusion criteria of the study, instruments used (pure tone audiometry), and results. The results were further specified by the findings (normal hearing, notch, and hearing loss), the affected side of the ear, affected participants or subgroups, and the proportion of the affected participants to the study population. Finally, we assessed the data reporting to determine whether it was detailed and sufficient or poorly done with regard to the specified criteria, including reporting of frequency range, hearing loss in dB, and age correction. In addition, the study design (cross-sectional vs. longitudinal), the kind of data acquisition, and the reporting of raw data were also evaluated. Assessing the risk of bias was not necessary because of the descriptive epidemiological approach.

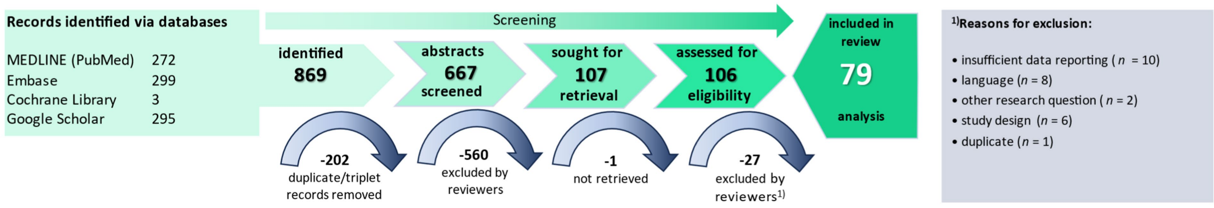


FIGURE 1
Flowchart. Review process according to the PRISMA guidelines. There were no additional records.

We did not aim to conduct statistical subgroup analyses *a priori* but focused on the results of the musicians' pure tone audiometry, as described previously using the PEO criteria. As there are no formal quality assessment tools for pure tone audiometry, we decided to limit the results to a descriptive evaluation based on the recommendations of the American Speech–Language–Hearing Association (ASHA). Except for the criterion "age correction," which was added *post hoc*, all extracted categories were defined primarily.

Studies that included only healthy participants for another primary research issue (e.g., tinnitus) were not included in the final analysis since the prevalence of hearing loss may be biased. Furthermore, the findings that were solely based on comparisons (subgroup, ear side) were excluded since they did not contain prevalence data for the study population.

To conduct a systematic analysis, we grouped the findings into four musical genres: classical music, rock/pop/jazz, traditional music, and military and marching band music. The unreported studies were assigned to the group "unknown."

For statistics and graphs, we used Wolfram Mathematica 13.1. Descriptive statistics consisted of stacked histograms showing the distribution of quantitative data (number of participants and years of practice). For the distribution of sex, we calculated the percentage values and plotted them in a sorted bar chart. The pure tone audiometry results were categorized into four groups as follows: (1) values with frequency and hearing loss reporting, (2) values with frequency but without hearing loss in dB reporting, (3) values without frequency but with dB hearing loss reporting, and (4) values with neither frequency nor hearing loss reporting. All plot data were categorized by genre, and the resulting counts were collected. A color scale was used for visual coding of the count numbers. These values were plotted in a "conventional" audiogram layout. This approach ensured that no data had to be transformed and that partially missing data could also be reported.

For the visualization of the proportion of the affected persons, we calculated the percentage values and plotted sorted bar charts with opacity decreasing in relation to the maximum study population. Inferential statistics were employed where necessary, using Wolfram Mathematica 13.1. To compare the distribution of categorical variables with more than 50 values (e.g., sex distribution), we used Pearson's chi-squared test, with $\alpha = 0.05$.

Results

Selection of the sources of evidence

Reviewer 1 included 89 studies after screening the titles and abstracts and discussing all unclear cases during the retrieval process ($n = 72$, 14% of all screened studies), while reviewer 2 included 109 studies. The intersection rate for the 89 retrievals was 100%, whereas the final inclusion rate was 89/107 and 109/107 after clarifying the 20 remaining titles. One title could not be retrieved in full text; therefore, 106 titles were assessed in full text. After discussing 19 unclear retrievals, both reviewers included the same 79 studies (see Figure 1).

Some studies did not report pure-tone audiometry results in the context of noise-induced hearing loss because of other research questions (22–27). One case report was excluded because it lacked representativeness (28). One study included a mixed occupational cohort and did not report results specific to the musicians' subgroup (29). Another study only included healthy participants (30). One study (31) reported the same data as another study already included in this review (32).

Characteristics of the sources of evidence

The majority of the studies assessed classical music, rock, pop and jazz. Some studies focused on traditional instruments and military or marching band music (see Figure 2). Four studies assessed different genre groups, whereas six studies did not report the genre. We regrouped the genres into five main categories (see Figure 3).

The overall median number of participants was 52 (IQR 30-109). The distribution is shown in Figure 4. We selected a stacked histogram to visualize the overall distribution and the subgroup results. Compared to the overall distribution, there were more studies in the classical genre in the fourth quartile, with 11 studies having >111 participants (32.4% of $n_{\text{classical music}}$).

The sex distribution showed a significant majority of male participants, with a median value of 69% (IQR 53–83%) (see Figure 5). The analysis yielded $\chi^2(9) = 36.3$, $p < 0.001$. The median female proportion was 31% (IQR 17–47%). Figure 5 shows a sorted bar chart displaying the data from all retrieved studies reporting the sex distribution. The 50% value is marked by a bold line as a visual guide. The subgroup analysis showed a similar distribution and is included in the online supplementary material in our repository (33).

The age range differed significantly. Figure 6 plots the number lines for the retrieved age ranges grouped by genre. As can be seen, many studies focused on young participants (students). Studies on rock, pop, and jazz genres did not include participants over 50 years of age, and studies on classical music did not include those over 60–70 years. None of the studies investigated retired musicians.

Some studies reported the number of years spent as practicing musicians is minimal, as shown in Figure 7, which presents a stacked histogram of the subgroup results. The majority of these studies included participants with more than 5 years of musical practice. As

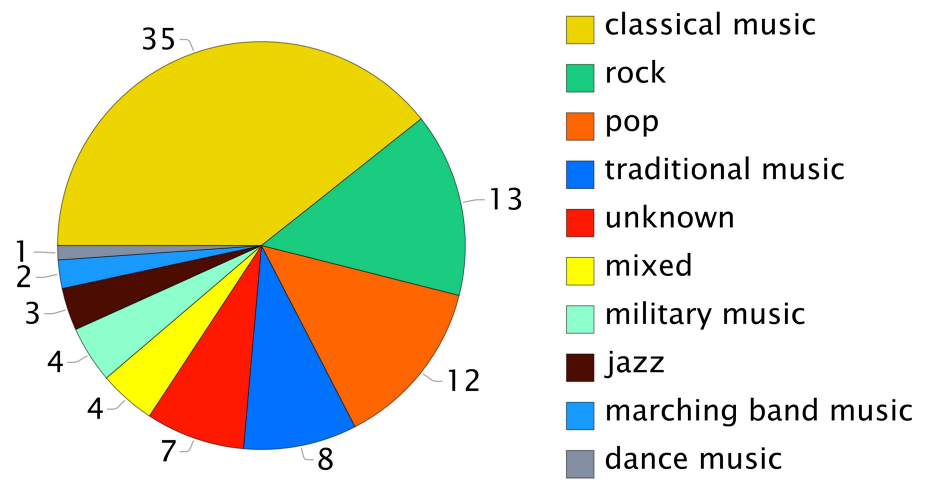


FIGURE 2
Pie chart showing the distribution of the identified studies by genre.

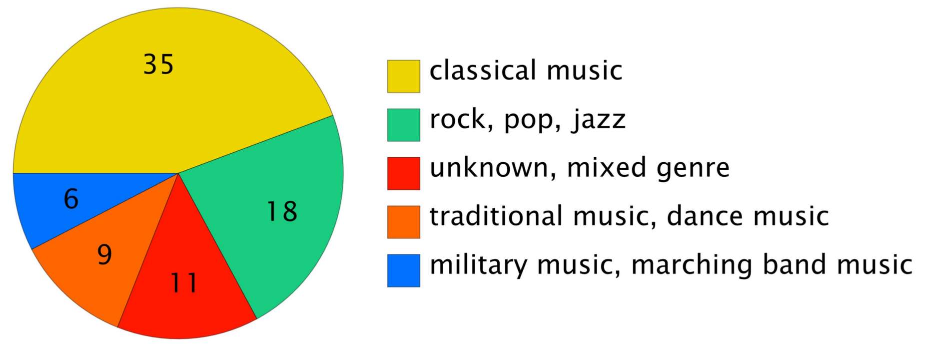


FIGURE 3
Pie chart of grouping. The retrieved studies were categorized into five genre groups.

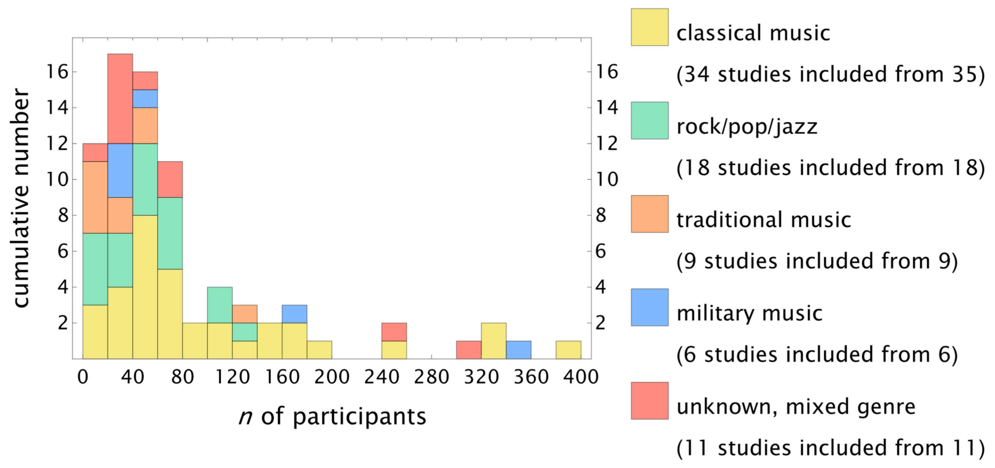


FIGURE 4
Stacked histogram showing the number of participants. The median was 56 (IQR 31–111).

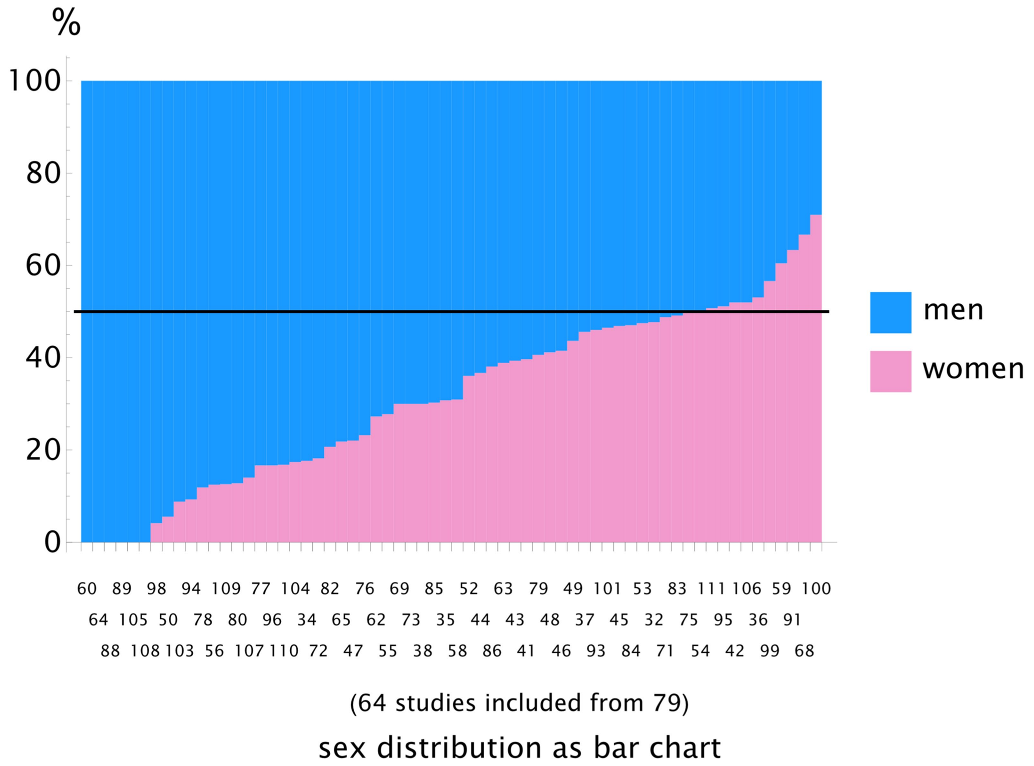


FIGURE 5
Bar chart showing the sex distribution across all studies. Only a few studies included more female participants than male participants. The majority of the studies had a significantly higher proportion of male participants. The genre subgroup analysis revealed the same distribution, making this overall distribution representative. The numbers on the bars correspond to the literature reference list.

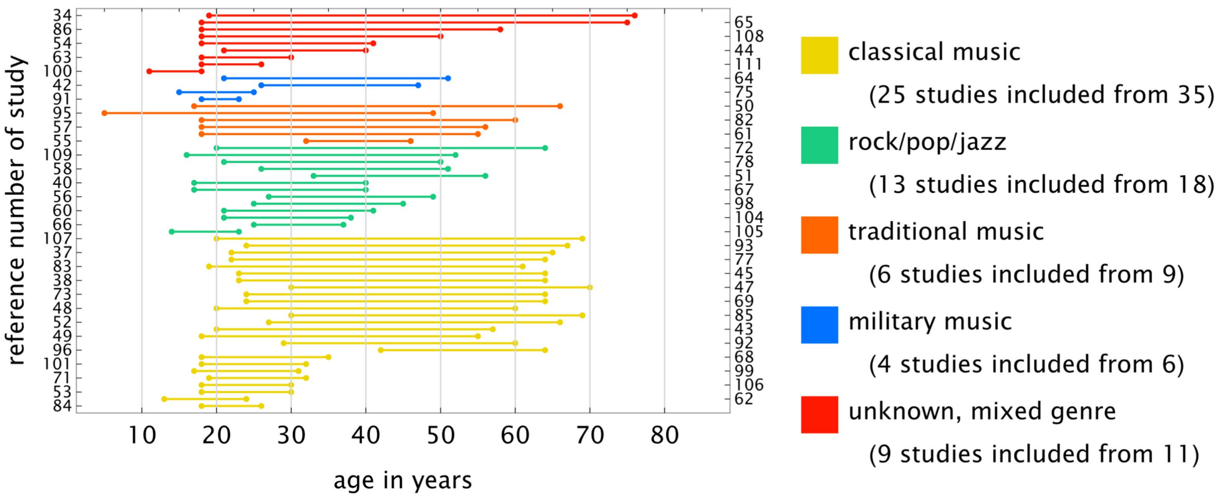


FIGURE 6
Age range distribution. Many studies focused exclusively on students. Genre-specific studies including individuals over 70 years were lacking. In particular, the studies on non-classical music genres lacked a representative age range. The numbers on the lines correspond to the literature reference list.

mentioned, some studies focused on students with less exposure to music. Only six studies included study participants with more than 10 years of musical practice.

A total of 17 studies reported that they performed age correction for audiometry data (34–50), while 2 reported that they did not (51, 52). Additionally, 60 studies did not specify whether they corrected for age (32, 53–111).

Results of the sources of evidence

For further analysis, we extracted key results from the retrieved studies, as described in Methods. The summary table is published online in the repository (33). Initially, we aimed to determine whether the results of the studies, which could be numerous, formed clusters based on frequency and threshold shift. As shown in the summary

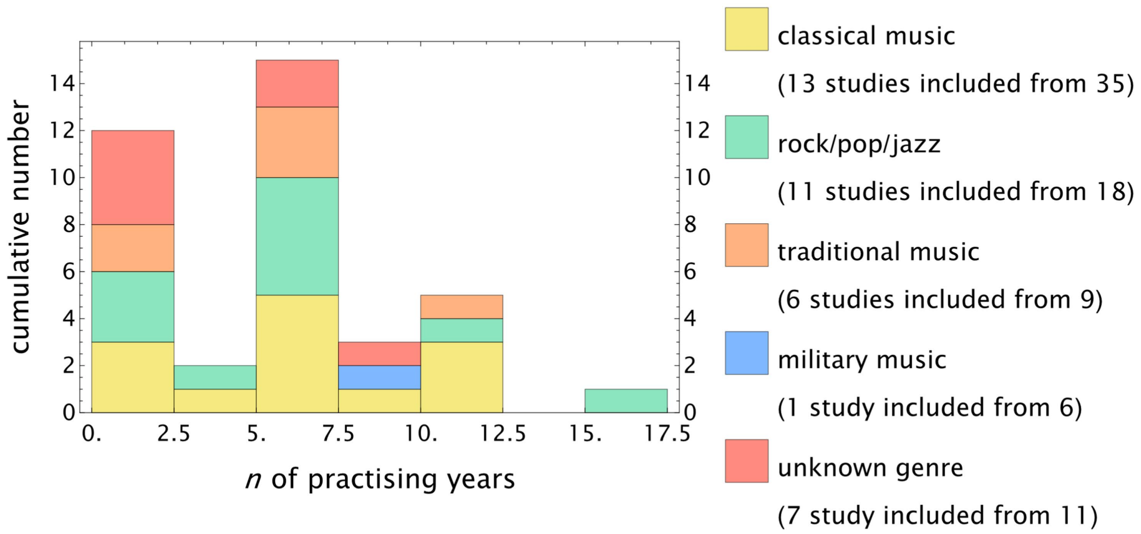


FIGURE 7
Stacked histogram of minimum years as a practicing musician. The majority of the studies reported a minimum of 5 years of musical practice. Only a few studies investigated longer minimum exposure times.

table in the repository[1], the reporting of hearing loss in relation to frequency range and hearing loss in dB was not consistent. We counted each report in a two-dimensional array for the two parameters and included missing values as well. Afterward, we plotted the results in a bubble plot, with a color scale indicating the frequency of the retrieved findings for each genre (see Figure 8). A total of 10 studies found normal hearing in audiometry of the participants in the classical music group (37, 43, 48, 53, 71, 73, 79, 84, 99, 106). In addition, 10 studies reported a notch configuration in the frequency range of 4,000–6,000 Hz (36, 38, 41, 45, 46, 62, 70, 71, 76, 93, 101), and up to 12 results from 7 studies showed a hearing loss >15–20 dB in the same frequency range (39, 44, 52, 83, 92, 96, 107). The intersection range of the results without dB hearing loss reporting (32, 35, 38, 39, 47, 85, 90, 101, 107) and those without frequency reporting (49, 99) lay exactly in the same area. This cluster suggested an increased risk for musicians in the classical genre to develop hearing loss in the predisposed frequency range.

Concerning the musicians in the rock, pop, and jazz genres, only one study found normal hearing for all participants (51). The majority of the studies showed hearing loss or notch configurations in the frequency range of 3,000–8,000 Hz (56, 66, 74, 78, 94, 101, 104). The frequency range was broader, and hearing loss >20 dB was more frequent in musicians of these genres than in the classical genre group, as commonly expected.

The data availability for the genres of military music and marching band music was limited. A cluster of hearing loss was observed in the frequency range of 4,000–6,000 Hz (41, 75, 89, 91, 103, 107). The same was true for the traditional genre (44, 50, 55, 57, 59, 61, 82, 88, 108, 110), as shown in Figure 8.

1 https://github.com/Carl-Firle/Review_Musicians-_Hearing_Loss/blob/main/Summary%20Table.md

Descriptive synthesis of the results

For a more detailed analysis, we published the complete list of the study results and the summary table in our repository with valid DOIs for each study (33). An extract is presented in Figure 9 for the classical music genre. We plotted the prevalence values of the studies reporting notch configurations and those reporting hearing loss. To highlight the sample size, we used transparency that increased with the decreasing number of the participants. Notch configurations were observed in 20–50% of the musicians, whereas hearing loss prevalence was more scattered, ranging from 5 to 70% (see Figure 9). The rock, pop, and jazz musicians showed notch configurations in 20–100% of the cases, with hearing loss within the range of 20–60% (Figure 10). The number of retrieved studies for the military music and traditional music genre groups was low. The prevalence of hearing loss ranged from 10 to 60% for the military music group and from 10 to 100% for the traditional music group (Figures 11, 12). Some studies did not report the genre or had mixed genres without subgroup reporting. These are listed separately (Figure 13). A clear allocation of hearing loss to one ear could not be systematically detected in all subgroup analyses, as reported in the bar chart tables.

Discussion

The peer review process with two blinded reviewers yielded 79 studies, according to the PRISMA guidelines. The studies were heterogeneous in terms of the genre, publication of the results, and audiogram data corrected for age. The majority of the retrieved studies focused on young, male musicians with little exposure time. Older or retired musicians, as well as women, were underrepresented or missing. The summary table can be found as an online supplementary material in our repository (33).

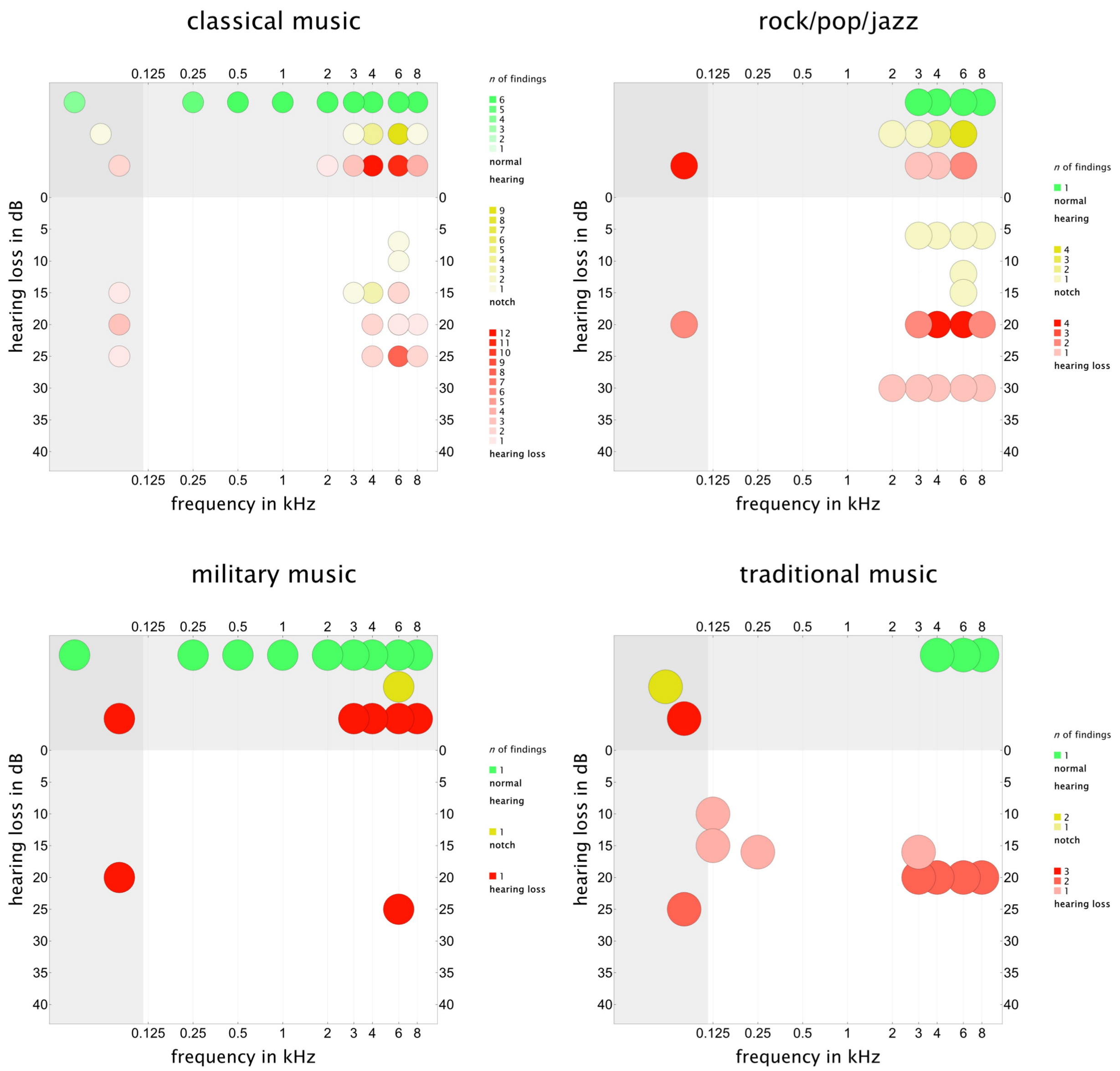
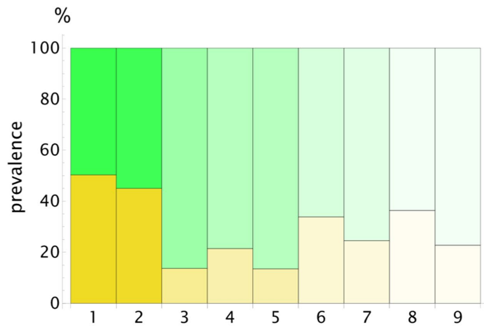


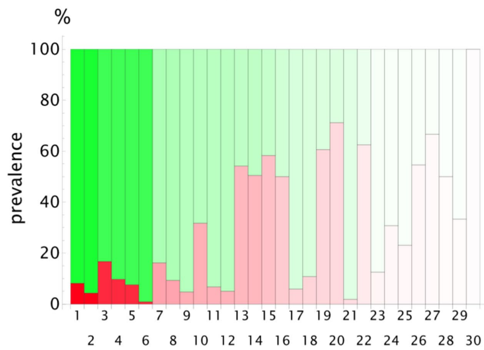
FIGURE 8
Frequency distribution of the retrieved hearing examination results in the audiogram according to the genre subgroups. Values in the left grey box were published without frequency reporting. Values in the upper grey box lacked dB reporting. Values in the overlapping region, the dark grey box at the top left corner, were reported without frequency and hearing loss in dB. The color scale indicates the number of results found for the corresponding point value. For this purpose, we distinguished between the findings with normal hearing (green), notch (yellow), and hearing loss (red) in the audiogram. Some studies had numerous findings, each counted to detect a common cluster. The corresponding summary table is available online in the repository. This figure should not be interpreted as a prevalence cluster. To analyze the prevalence of music-induced hearing loss, refer to Figures 9–13.

For the classical genre, some studies found no hearing loss in their study population, while others found notch configurations or hearing loss >15 dB in the frequency range of 4,000–6,000 Hz. This indicates a higher risk of hearing loss for classical musicians. The prevalence of notch configurations and hearing loss varied between 5 and 70%. A total of 20–60% of rock, pop, and jazz musicians tended to have a higher risk of hearing loss >20 dB in the range of 3,000–8,000 Hz, as expected. The data for military music and traditional music were limited, although an increased risk of hearing loss was also found in the 4,000–6,000 Hz range.

These findings are consistent with an analysis of diagnoses from 2,227 musicians based on data from 7 million German health-insured individuals, which found a hazard ratio of 3.51 (95% Confidence Interval: 2.82 to 4.21) for noise-induced hearing loss in musicians compared to non-insured musicians (5). Concerning the prevalence of noise-induced hearing loss in musicians, a report published in 2009 showed that 58% of musicians in the classical genre and up to 49% in the rock/pop genre were affected (112). The systematic review by Di Stadio et al., presented in the Introduction section, reported hearing loss in 63.5% of rock/pop musicians and 32.8% of classical music



bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	music students	170	338	notch	–	6000	n/a	70
2	music students (classical music, 19 jazz)	148	329	notch >15 dB	r/l	4000–6000	n/a	101
3	music students	23	168	notch >15 dB	–	4000–6000	n/a	71
4	symphony orchestra musicians	27	126	notches	l	4000–6000	n/a	93
5	symphony orchestra musicians	17	126	notches	r	4000–6000	n/a	93
6	orchestra musicians [ears reported for affected persons and sample size]	23	68	notches	–	–	n/a	92
7	orchestra musicians	13	53	notch 15 dB	r+l	3000–6000	yes	46
8	adolescent musicians	8	22	notches	l	3000–6000	n/a	62
9	adolescent musicians	5	22	notches	r	4000–6000	n/a	62

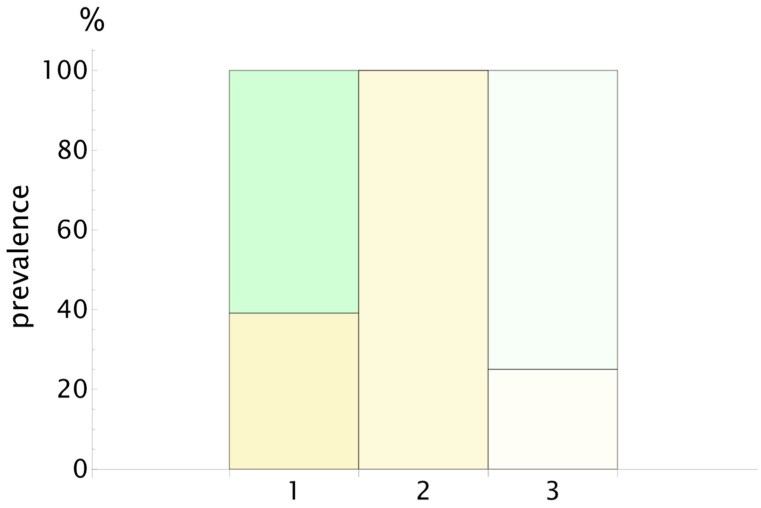


bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	flute players	17	392	loss 20 dB	r+l	4000–8000	n/a	107
2	double bass players	32	392	loss	l	4000–8000	n/a	107
3	music students (classical music, 19 jazz)	55	329	loss	l	6000	n/a	101
4	music students (classical music, 19 jazz)	32	329	loss	r	6000	n/a	101
5	music students (classical music, 19 jazz)	25	329	loss	r+l	6000	n/a	101
6	music students (classical music, 19 jazz)	3	329	loss	r+l	4000	n/a	101
7	french horn players	23	142	loss	–	–	yes	49
8	7 musicians playing small strings, 3 woodwind players, 2 brasswind players and 1 percussionist	13	140	loss	–	3000–8000	yes	38
9	symphony orchestra musicians (88.9% are older musicians that have the loss)	6	126	loss >25 dB	–	–	n/a	93
10	musicians in 6 year follow-up who are 50–59 years	39	123	loss	–	4000–6000	n/a	107
11	orchestra musicians	8	119	loss >15 dB	l	6000	n/a	83
12	orchestra musicians	6	119	loss >15 dB	r	6000	n/a	83
13	strings from classical music orchestra (positively age correlated)	59	109	loss	l	4000–6000	n/a	85
14	orchestra musicians	55	109	loss >15 dB	–	–	n/a	85
15	orchestra musicians (theatre)	56	96	loss >20 dB	r+l/r/l	–	n/a	77
16	male orchestra musicians (theatre)	40	80	loss >20 dB	r+l/r/l	–	n/a	77
17	orchestra musicians [ears reported for affected persons and sample size]	4	68	loss >20 dB	–	4000	n/a	92
18	symphony orchestra members	7	65	loss	r+l	4000	yes	35
19	symphony orchestra members	37	61	loss > 25 dB	r+l/r/l	predominately 6000	no	52
20	symphony orchestra players	42	59	loss	r/l/r+l	2000–8000	yes	47
21	music students (classical music)	1	53	loss	–	–	n/a	99
22	symphony orchestra members — small string instrument group	20	32	loss > 25 dB	r+l/r/l	predominately 6000	no	52
23	female orchestra musicians (theatre)	2	16	loss >20 dB	r+l/r/l	–	n/a	77
24	members of orchestra	4	13	loss	r+l/r/l	~4000–8000	yes	39
25	members of orchestra	3	13	loss >25 dB	r/l	~4000–8000	yes	39
26	symphony orchestra members — string instrument group	6	11	loss > 25 dB	r+l/r/l	predominately 6000	no	52
27	symphony orchestra members — brass instrument group	6	9	loss > 25 dB	r+l/r/l	predominately 6000	no	52
28	symphony orchestra members — woodwind instrument group	2	6	loss > 25 dB	r+l/r/l	predominately 6000	no	52
29	symphony orchestra members	3	6	loss >25 dB	r+l	4000–8000	n/a	96
30	symphony orchestra members — percussion group	3	3	loss > 25 dB	r+l/r/l	predominately 6000	no	52

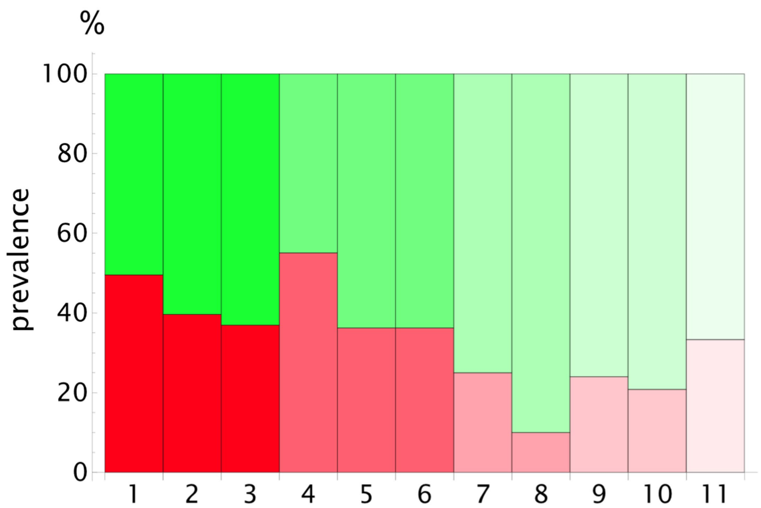
FIGURE 9
Bar chart showing the number of individuals with notch configurations (yellow) and hearing loss (red) in relation to the sample size for the **classical music group**. The opacity decreases in relation to the study with the maximum sample size (n_{study}/n_{max}), meaning that the bars with higher transparency represent the studies with lower validity. The bar number corresponds to the table row below the chart. In this way, the finding can be attributed to the corresponding publication. A detailed result list with DOI links is available in the repository (33).

performers. Instead of focusing on a mean value, we adopted a holistic approach for reporting the range of the prevalence findings. The findings from the other studies are consistent with the range of our results, as shown in Figure 9 through Figure 12.

Notch configurations and hearing loss in the high-frequency range of 4,000–6,000 Hz are characteristic of noise-induced hearing loss (113–115). Speech-frequency hearing impairment in the range of 500–4,000 Hz is much more common in the general population, with a prevalence of 14.1% in the USA (116). This study also assessed the prevalence of bilateral hearing impairment in relation to occupational noise exposure, defined as exposure "at work to loud sounds or noise for four or more hours, several days a week". The findings were as follows: no exposure: 14% (95% CI: 13–16), exposure to noise "so loud that they had to raise their voice to be heard" for more than 5 years: 28% (95% CI: 21–37), and exposure to noise "so loud that they had to shout to be heard" for more than



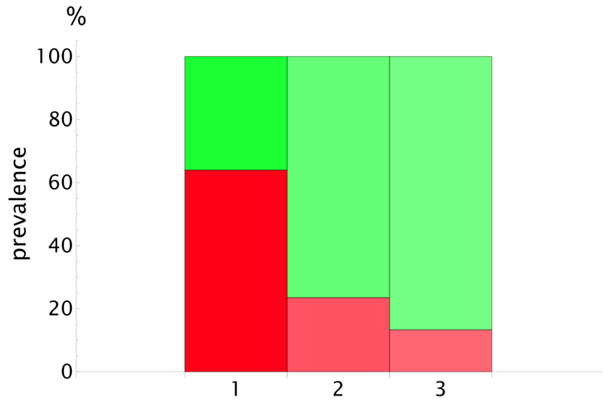
bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	rock musicians	9	23	notch	–	4000–6000	n/a	104
2	16 non–professional musicians	16	16	notch	r+l	6000	n/a	56
3	heavy metal band members	1	4	notch	r+l	6000	n/a	66



bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	rock musicians	41	111	loss	–	–	n/a	80
2	male rock musicians	44	111	loss	–	–	n/a	80
3	female rock musicians	55	111	loss	–	–	n/a	80
4	pop musicians	38	69	loss >20 dB	r/l	–	n/a	67
5	pop musicians	25	69	loss >20 dB	r+l/r/l	3000–8000	n/a	97
6	pop musicians	25	69	loss > 20 dB	r/l	3000–8000	yes	40
7	pop musicians	10	40	loss > 20 dB	r/l	4000–6000	no	51
8	pop musicians	4	40	loss > 20 dB	r+l	4000–6000	no	51
9	rock musicians	6	25	loss >20 dB	–	–	n/a	81
10	rock & pop musicians	5	24	loss	r+l	3000–6000	n/a	98
11	rock band members	3	9	loss >30 dB	–	2000–8000	n/a	105

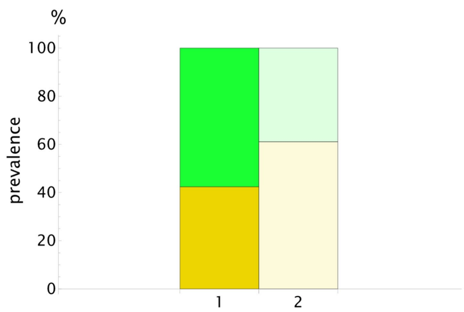
FIGURE 10
Bar chart showing the number of individuals with notch configurations (yellow) and hearing loss (red) in relation to the sample size for the genre **rock/pop/jazz**. The opacity decreases in relation to the study with the maximum sample size (n_{study}/n_{max}), meaning that the bars with higher transparency represent the studies with lower validity. The bar number corresponds to the table row below the chart. In this way, the finding can be attributed to the corresponding publication. A detailed result list with DOI links is available in the repository (33).

5 years: 43% (95% CI: 35–51). Compared to the retrieved studies, which mostly focused on exposure for more than 5 years, musicians may have an increased prevalence of hearing loss, especially in the rock, pop, and jazz genres (20–60% vs. 14.1%). This prevalence is within the range observed in occupationally exposed individuals: 28 and 43%. However, in our results, the prevalence of hearing loss among musicians in the classical music genre was too broad to draw meaningful conclusions (5–70%). All the studies identified in this

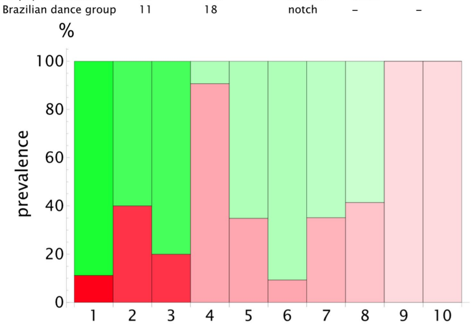


bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	musicians from police band	32	50	loss	–	–	n/a	64
2	musicians from police band	8	34	loss >25 dB	r+l/r/l	~6000	n/a	103
3	marching band members	4	30	loss > 20 dB	–	–	n/a	91

FIGURE 11
Bar chart showing the number of individuals with hearing loss (red) in relation to the sample size for the genre **military music**. The opacity decreases in relation to the study with the maximum sample size (n_{study}/n_{max}), meaning that the bars with higher transparency represent the studies with lower validity. The bar number corresponds to the table row below the chart. In this way, the finding can be attributed to the corresponding publication. A detailed result list with DOI links is available in the repository (33).

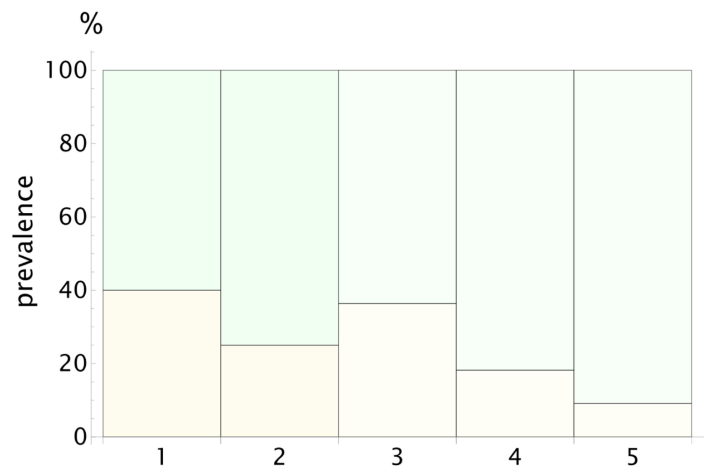


bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	traditional and/or pop musicians	53	125	notches	r+l/r/l	–	n/a	110
2	musicians in a Brazilian dance group	11	18	notch	–	–	n/a	61

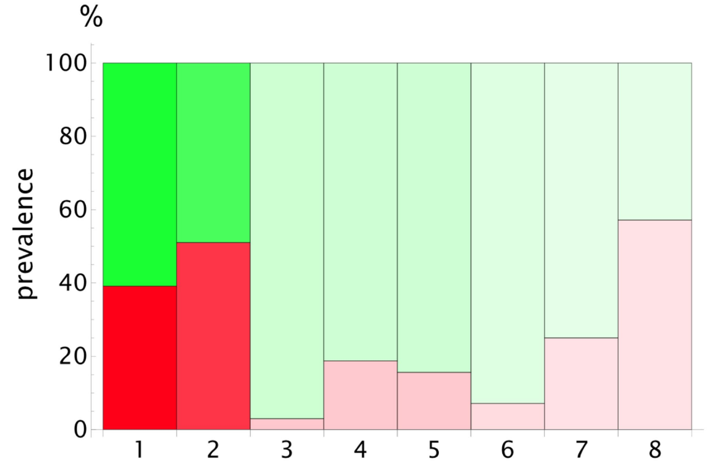


bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	violin players	14	125	loss (not significant to other instrument groups)	l	–	n/a	110
2	band of dance members	40	100	loss (slight to moderate)	l	–	n/a	57
3	band of dance members	20	100	loss (slight to moderate)	r+l	–	n/a	57
4	students and teachers from Valencia drum school	39	43	loss 10 dB	–	125	n/a	59
5	students and teachers from Valencia drum school	15	43	loss >25 dB	r+l/r/l	–	n/a	59
6	students and teachers from Valencia drum school	4	43	loss 15 dB	–	125	n/a	59
7	Jegog players (traditional instrument of Indonesia)	13	37	loss >25 dB	–	–	n/a	88
8	traditional steel band musicians	12	29	loss >20 dB	–	3000–8000	n/a	82
9	18 Daf Musicians	18	18	loss >16 dB	–	3000	n/a	55
10	18 Daf Musicians	18	18	loss >16 dB	–	250	n/a	55

FIGURE 12
Bar chart showing the number of individuals with notch (yellow) and hearing loss (red) in relation to the sample size for the genre **traditional music**. The opacity decreases in relation to the study with the maximum sample size (n_{study}/n_{max}), meaning that the bars with higher transparency represent the studies with lower validity. The bar number corresponds to the table row below the chart. In this way, the finding can be attributed to the corresponding publication. A detailed result list with DOI links is available in the repository (33).



bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	high school band members	8	20	notch	r+l	4000–6000	n/a	100
2	high school band members	5	20	notch	r	4000–6000	n/a	100
3	middle school band members	4	11	notch	r+l	4000–6000	n/a	100
4	high school band members	2	11	notch	r	4000–6000	n/a	100
5	high school band members	1	11	notch	l	4000–6000	n/a	100



bar no	affected group	affected persons	total sample size	finding	ear side	frequency range [Hz]	age correction	publication [ref no]
1	percussionists	119	304	loss >25 dB	r+l	250–8000	n/a	65
2	musicians	123	241	loss	–	–	n/a	102
3	music students at T0	2	67	loss >25 dB	–	8000	n/a	111
4	music students (mixed genre)	12	64	loss > 20 dB	r+l/r/l	3000–6000	yes	44
5	music students (mixed genre)	10	64	loss >20 dB	r+l/r/l	3000–8000	yes	44
6	music students	3	42	loss >25 dB	r+l/r/l	6000–8000	n/a	86
7	city band members	9	36	loss >25 dB	r+l	4000–6000	yes	34
8	musicians from Yogyakarta, Indonesia	20	35	loss	–	–	n/a	108

FIGURE 13
Bar chart showing the number of individuals with notch (yellow) and hearing loss (red) in relation to the sample size for the **unknown and mixed genre** group. The opacity decreases in relation to the study with the maximum sample size (n_{study}/n_{max}), meaning that the bars with higher transparency represent the studies with lower validity. The bar number corresponds to the table row below the chart. In this way, the finding can be attributed to the corresponding publication. A detailed result list with DOI links is available in the repository (33).

review were original works investigating musicians. Only a few had sample sizes >300 and a cohort study design, such as the study by Karlson et al. (107). As shown in Figure 9 through Figure 12, the reporting of hearing loss prevalence depends on different factors. These include the composition of the affected group, which may consist of different instrumentalists; the reporting of audiometry results, which may include dB hearing loss and frequency range; and the type of age correction applied. To discuss these factors, we need to take a closer look at some publications from the classical genre that provide detailed information about them.

Obeling and Poulsen found no signs of hearing loss in 57 musicians from four Danish orchestras (37). They corrected the audiograms using ISO 1999, taking into account the number of years of musical practice, playing hours per week, and the average sound level. The authors published averaged audiogram plots with standard deviations. They reported results for ear-side and instrument groups but did not include a comparison by sex. The authors emphasized that the data were not representative since the sample size was small. Assuming 90 musicians in a symphony orchestra, the participation rate in this study was 15%.

Toppila et al. assessed 63 musicians from 4 symphony orchestras, resulting in a participation rate of approximately 17% (41). The authors corrected for age, noise exposure, and sex using ISO 1999-1990. The audiometry results for both ears were plotted with 95% confidence intervals. Box and whisker charts reported the corresponding z-scores for comparison between a noise-exposed and a non-exposed standard population. They did not find any differences in the musician group compared to the non-exposed population. The authors compared the mean differences in hearing loss between two subgroups: musicians with high exposure ($L_{ex} > 100$) and musicians with low exposure ($L_{ex} < 100$). The hearing loss values were significantly higher in the range of 1,000–6,000 Hz for the high-exposure subgroup.

Wegner et al. assessed 40 classical music instrumentalists and reported a participation rate of 30% (48). They reported averaged hearing levels with standard deviations for both ears for the instrumental groups, as well as the use of hearing protection devices. The values were age-corrected based on a preceding study from 1967. Sex comparison was not reported. The authors found normal hearing in the sample.

Eaton and Gillis found notch configurations in the high-frequency range in 13 of 53 musicians from a Canadian symphony orchestra (46). The participation rate was approximately 50%. The audiogram data were corrected using ISO 1999-1990 (as described previously). The averaged audiometry results were compared for sex and instrument groups. Differences in the ear side could not be found.

Kähäri et al. had a sample size of 140 participants from two Swedish orchestras, with a participation rate of 79% (38). They reported mean values with standard deviations, as well as median and range for both ears. The plots show the 10th and 90th percentiles, as well as groupings by musical instrument, sex, and age. The data were not corrected for age, but the age groups are reported in detail. The findings indicated no severe hearing loss among musicians but highlighted a more frequent notch configuration in the men's audiogram and slightly worse hearing in the percussion and woodwind players.

Participation rates are often low, which may introduce a bias, with individuals experiencing hearing loss less likely to participate in the study. Reporting averaged hearing loss values carries the risk of underestimating subgroup differences and may result in the loss of information about the distribution of the original audiogram data. Age correction often relies on ISO 1999-1990 references (37, 41, 46), and noise exposure must be calculated beforehand (37). The heterogeneity of assessments demands standardized methods and prospective study designs. Longitudinal studies are completely lacking, making it impossible to assess the lifetime prevalence of hearing loss among musicians. Prospective multicenter studies are needed to address this research question.

Knowledge about music-induced hearing loss is crucial since hearing ability is essential for a musician's work. Occupational hearing loss often results from continuous exposure and may go unnoticed by the affected person (12, 117). This highlights the importance of regular audiometric examinations for musicians, in accordance with the laws of the respective country. Only through this approach can music-induced hearing loss be detected and preventive measures be implemented. For the latter, systematic and scientific evaluation is needed to avoid accidental harm. Organizational measures should also be considered since they are easy to implement. For example, reducing the playing volume during rehearsals could help mitigate risk. To avoid temporary threshold shifts from prolonged exposure, loud passages could be played at the end of a rehearsal. After rehearsal, sufficient recuperation time should be ensured. Music presents a complex challenge that rarely allows for the use of conventional preventive hearing protection measures typical in occupational health.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: Firle C, Richter AH. Repository for supplementary data to A scoping review of the prevalence of musicians' hearing loss (https://doi.org/10.5281/zenodo.11225123).

Author contributions

CF: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. AR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Chen K-H, Su S-B, Chen K-T. An overview of occupational noise-induced hearing loss among workers: epidemiology, pathogenesis, and preventive measures. *Environ Health Prev Med.* (2020) 25:65. doi: 10.1186/s12199-020-00906-0

2. World Health Organization. The world health report: World health report: Reducing risks to health noncommunicable diseases. Geneva: World Health Organization (2002).

3. German Social Accident Insurance. DGUV: BK-Anerkennungen. (2023). Available at: https://www.dguv.de/de/zahlen-fakten/bk-geschehen/anerkannte-bken/index.jsp (Accessed July 25, 2024).

4. Fauzan NS, Sukadarin EH, Widia M, Irianto I, Ghazali I. A systematic literature review of the factors influencing hearing protection device usage among industrial workers. *Int J Environ Res Public Health*. (2023) 20:2934. doi: 10.3390/ijerph20042934

5. Schink T, Kreutz G, Busch V, Pigeot I, Ahrens W. Incidence and relative risk of hearing disorders in professional musicians. *Occup Environ Med*. (2014) 71:472–6. doi: 10.1136/oemed-2014-102172

6. Schmidt JH, Pedersen ER, Juhl PM, Christensen-Dalsgaard J, Andersen TD, Poulsen T, et al. Sound exposure of symphony orchestra musicians. *Ann Occup Hyg*. (2011) 55:893–905. doi: 10.1093/annhyg/mer055

7. Chan HS. Occupational noise exposure; criteria for a recommended standard DHHS Publication (1998) Available at: https://stacks.cdc.gov/view/cdc/6376 (Accessed January 28, 2025).

8. European Union Law. Directive 2003/10/EC of the European Parliament and of the council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (seventeenth individual directive within the meaning of article 16(1) of directive 89/391/EEC). (2003); (OJ L 42):38–44. Available at: http://data.europa.eu/eli/dir/2003/10/oj (Accessed January 28, 2025).

9. Dyrba P, Dantscher S, Fritsch T, Sickert P. Comparison of different measurement systems for the assessment of the individual noise attenuation of earplugs. *Hear Prot*. (2015) 9:255–65. Available at: https://www.dguv.de/medien/ifa/en/pub/grl/pdf/2015_265.pdf

10. Bernier A, Voix J. An active hearing protection device for musicians. *Proc Meet Acoust*. (2013) 19:40015. doi: 10.1121/1.4800066

11. Crawford K, Willenbring K, Nothwehr F, Fleckenstein S, Anthony TR. Evaluation of hearing protection device effectiveness for musicians. *Int J Audiol*. (2023) 62:238–44. doi: 10.1080/14992027.2022.2035831

12. Federal Institute for Occupational Safety and Health. Safe and sound: Guide to hearing conservation in the music and entertainment industry. *1st* ed Wirtschaftsverlag NW Verlag für neue Wissenschaft GmbH (2011) Available at: https://www.baua.de/DE/Angebote/Publikationen/Berichte/Gd10.pdf?__blob=publicationFile&v=8 (Accessed January 28, 2025).

13. Marquard U, Schäcke G. Hearing impairment in orchestra musicians. *Zentralblatt fur Arbeitsmedizin, Arbeitsschutz und Ergonomie*. (1998) 48:188–204. Available at: https://www.embase.com/records?subaction=viewrecord&id=L28298022

14. Elam T, Mowen S, Jonas C. Occupational injuries in musicians: a literature review. *Mil Med*. (2022) 187:e619–23. doi: 10.1093/milmed/usab499

15. Zuskin E, Schachter EN, Kolcić I, Polasek O, Mustajbegović J, Arumugam U. Health problems in musicians—a review. *Acta Dermatovenerol Croat*. (2005) 13:247–51.

16. Owens DT. Hearing loss: a primer for the performing arts. *Med Probl Perform Art*. (2008) 23:147–54. doi: 10.21091/mppa.2008.4031

17. Reynolds A, Bielefeld EC. Music as a unique source of noise-induced hearing loss. *Hear Res*. (2023) 430:108706. doi: 10.1016/j.heares.2023.108706

18. Wartinger F, Malyuk H, Portnuff CDF. Human exposures and their associated hearing loss profiles: music industry professionals. *J Acoust Soc Am*. (2019) 146:3906–10. doi: 10.1121/1.5132541

19. Behar A, Wong W, Kunov H. Risk of hearing loss in orchestra musicians: review of the literature. *Med Probl Perform Art*. (2006) 21:164–8. doi: 10.21091/mppa.2006.4035

20. di A, Dipietro L, Ricci G, Della A, Minni A, Greco A, et al. Hearing loss, tinnitus, hyperacusis, and diplacusis in professional musicians: a systematic review. *Int J Environ Res Public Health*. (2018) 15:2120. doi: 10.3390/ijerph15102120

21. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. (2021) 372:n71. doi: 10.1136/bmj.n71

22. Poissant SF, Freyman RL, MacDonald AJ, Nunes HA. Characteristics of noise exposure during solitary trumpet playing: immediate impact on distortion-product otoacoustic emissions and long-term implications for hearing. *Ear Hear*. (2012) 33:543–53. doi: 10.1097/AUD.0b013e31824c0935

23. Schmidt JH, Paarup HM, Bælum J. Tinnitus severity is related to the sound exposure of symphony orchestra musicians independently of hearing impairment. *Ear Hear*. (2019) 40:88–97. doi: 10.1097/AUD.0000000000000594

24. Vardonikolaki A, Kikidis D, Iliadou E, Markatos N, Pastiadis K, Bibas A. Audiological findings in professionals exposed to music and their relation with tinnitus. *Prog Brain Res*. (2021) 260:327–53. doi: 10.1016/bs.pbr.2020.08.002

25. Kreutz G, Busch V, Schink T, Pigeot I, Ahrens W. Do professional musicians carry a risk of hearing disorders?: Poster presented a the Jahrestagung der Deutschen Gesellschaft für Musikpsychologie, Bremen, 28–30 September 2012; (2012). Available at: https://www.researchgate.net/publication/282607862 (Accessed January 28, 2025).

26. Smith C, Beamer S, Hall S, Helfer T, Kluchinsky TA. A preliminary analysis of noise exposure and medical outcomes for department of defense military musicians. *US Army Med Dep J*. (2015):76–82. Available at: https://pubmed.ncbi.nlm.nih.gov/26276949/

27. Fourie C. Early detection of music-induced hearing loss through a comparison of transient evoked and distortion product otoacoustic emission data among university music and non-music majors with normal hearing. A thesis. MD: Towson University (2017).

28. Brusis T. Acute hearing loss in the orchestral musician: noise trauma or idiopathic sudden deafness? *HNO*. (2011) 59:664–73. doi: 10.1007/s00106-010-2173-z

29. Bhatt IS, Guthrie O. Analysis of audiometric notch as a noise-induced hearing loss phenotype in US youth: data from the National Health and Nutrition Examination Survey, 2005-2010. *Int J Audiol*. (2017) 56:392–9. doi: 10.1080/14992027.2017.1278799

30. Otsuka S, Tsuzaki M, Sonoda J, Tanaka S, Furukawa S. A role of medial olivocochlear reflex as a protection mechanism from noise-induced hearing loss revealed in short-practicing violinists. *PLoS One*. (2016) 11:e0146751. doi: 10.1371/journal.pone.0146751

31. Behar A, Russo FA, Chasin M, Mosher S. Hearing loss in classical orchestra musicians. *Can Acoust*. (2012) 40:108–9. Available at: https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2562

32. Russo FA, Behar A, Chasin M, Mosher S. Noise exposure and hearing loss in classical orchestra musicians. *Int J Ind Ergon*. (2013) 43:474–8. doi: 10.1016/j.ergon.2012.11.001

33. Firle C, Richter AH. Repository for supplementary data to "a scoping review of the prevalence of musicians' hearing loss" (2024). Available at: https://github.com/Carl-Firle/Review_Musicians-_Hearing_Loss (Accessed January 28, 2025).

34. Mendes MH, Morata TC, Marques JM. Acceptance of hearing protection aids in members of an instrumental and voice music band. *Braz J Otorhinolaryngol*. (2007) 73:785–92. doi: 10.1016/S1808-8694(15)31175-7

35. Morais D, Benito JI, Almaraz A. Acoustic trauma in classical music players. *Acta Otorrinolaringol Esp*. (2007) 58:401–7. doi: 10.1016/S2173-5735(07)70378-2

36. Backus BC, Williamon A. Evidence of noise-induced hearing loss among orchestral musicians. International symposium on performance science 2009 (2009). Available at: http://researchonline.rcm.ac.uk/id/eprint/367/ (Accessed January 28, 2025).

37. Obeling L, Poulsen T. Hearing ability in Danish symphony orchestra musicians. *Noise Health*. (1999) 1:43–9. Available at: https://pubmed.ncbi.nlm.nih.gov/12689507

38. Kähäri KR, Axelsson A, Hellström PA, Zachau G. Hearing assessment of classical orchestral musicians. *Scand Audiol*. (2001) 30:13–23. doi: 10.1080/010503901750069536

39. Woolford DH, Carterette EC, Morgan DE. Hearing impairment among orchestral musicians. *Music Percept*. (1988) 5:261–84. doi: 10.2307/40285400

40. Axelsson A, Lindgren F. Hearing in pop musicians. *Acta Otolaryngol*. (1978) 85:225–31. doi: 10.3109/00016487809121444

41. Toppila E, Koskinen H, Pyykkö I. Hearing loss among classical-orchestra musicians. *Noise Health*. (2011) 13:45–50. doi: 10.4103/1463-1741.74001

42. Patil ML, Sadhra S, Taylor C, Folkes SEF. Hearing loss in British Army musicians. *Occup Med (Lond)*. (2013) 63:281–3. doi: 10.1093/occmed/kqt026

43. Schmidt JH, Pedersen ER, Paarup HM, Christensen-Dalsgaard J, Andersen T, Poulsen T, et al. Hearing loss in relation to sound exposure of professional symphony orchestra musicians. *Ear Hear*. (2014) 35:448–60. doi: 10.1097/AUD.0000000000000029

44. Schmidt JM, Verschuure J, Brocaar MP. Hearing loss in students at a conservatory. *Audiology*. (1994) 33:185–94. doi: 10.3109/00206099409071879

45. Jansen EJM, Helleman HW, Dreschler WA, De LJAPM. Noise induced hearing loss and other hearing complaints among musicians of symphony orchestras. *Int Arch Occup Environ Health*. (2009) 82:153–64. doi: 10.1007/s00420-008-0317-1

46. Eaton S, Gillis H. Review of orchestra musicians' hearing loss riskss. *Can Acoust*. (2002) 5:5–12. Available at: http://jcaa.caa-aca.ca/index.php/jcaa/article/view/1429

47. Royster JD, Royster LH, Killion MC. Sound exposures and hearing thresholds of symphony orchestra musicians. *J Acoust Soc Am*. (1991) 89:2793–803. doi: 10.1121/1.400719

48. Wegner R, Wendlandt P, Poschadel B, Olma K, Szadkowski D. Studies of the effectiveness and degree of acceptance of earplugs in orchestral musicians. *Arbeitsmedizin Sozialmedizin Umweltmedizin*. (2000) 35:486–97. Available at: https://www.embase.com/records?subaction=viewrecord&id=L30783003

49. Wilson WJ, O'Brien I, Bradley AP. The audiological health of horn players. *J Occup Environ Hyg*. (2013) 10:590–6. doi: 10.1080/15459624.2013.818227

50. García L, Parra L, Gomis BP, Cavallé L, Pérez Guillén V, Pérez Garrigues H, et al. Valencia's cathedral church bell acoustics impact on the hearing abilities of bell ringers. *Int J Environ Res Public Health*. (2019) 16:1564. doi: 10.3390/ijerph16091564

51. Axelsson A, Eliasson A, Israelsson B. Hearing in pop/rock musicians: a follow-up study. *Ear Hear*. (1995) 16:245–53. doi: 10.1097/00003446-199506000-00001

52. Sivaraj S. Hearing in various age groups of orchestral musicians and progression of hearing loss with increased number of years of music exposure: A thesis […]. Wellington, New Zealand: Massey University (2011) Available at: https://mro.massey.ac.nz/handle/10179/3681 (Accessed January 28, 2025).

53. Dreyer B, Pottas L, Soer ME, Graham MA. A comparison of the digits-in-noise test and extended high frequency response between formally trained musicians and non-musicians. *Aud Vestib Res*. (2023) 32:145–58. doi: 10.18502/avr.v32i2.12185

54. Kikidis D, Vardonikolaki A, Zachou Z, Razou A, Pantos P, Bibas A. ABR findings in musicians with normal audiogram and otoacoustic emissions: evidence of cochlear synaptopathy? *Hear Balance Commun*. (2020) 18:36–45. doi: 10.1080/21695717.2019.1663054

55. Emami SF. Acoustic sensitivity of the saccule and daf music. *Iran J Otorhinolaryngol*. (2014) 26:105–10. Available at: https://pubmed.ncbi.nlm.nih.gov/24744999/

56. Schmuziger N, Patscheke J, Probst R. An assessment of threshold shifts in nonprofessional pop/rock musicians using conventional and extended high-frequency audiometry. *Ear Hear*. (2007) 28:643–8. doi: 10.1097/AUD.0b013e31812f7144

57. Cândido PEF, Merino EAD, Gontijo LA. An auditive protection for professional musicians. *Work*. (2012) 41:3260–8. doi: 10.3233/WOR-2012-0592-3260

58. Kähäri K, Zachau G, Eklöf M, Sandsjö L, Möller C. Assessment of hearing and hearing disorders in rock/jazz musicians. *Int J Audiol*. (2003) 42:279–88. doi: 10.3109/14992020309078347

59. Parra L, Torres M, Lloret J, Campos A, Bosh I. Assisted protection headphone proposal to prevent chronic exposure to percussion instruments on musicians. *J Healthc Eng*. (2018) 2018:9672185. doi: 10.1155/2018/9672185

60. Samelli AG, Matas CG, Carvallo RMM, Gomes RF, de CS, Magliaro FCL, et al. Audiological and electrophysiological assessment of professional pop/rock musicians. *Noise Health*. (2012) 14:6–12. doi: 10.4103/1463-1741.93314

61. Carneiro C, da S, Façanha RC, Bassi-Dibai D, Silva FB, Felipe IMA, et al. Audiological and noise exposure findings among members of a Brazilian folklore music group. *Work*. (2021) 68:235–41. doi: 10.3233/WOR-203370

62. Passos PS, Dos Santos TA, Fiorini AC, de Oliveira Barreto AC. Auditory effects of music exposure in young musicians of a philharmonic band. *Disturbios da Comunicacao*. (2016) 28:539–46. Available at: https://revistas.pucsp.br/dic/article/viewFile/28502/21801

63. Washnik NJ, Bhatt IS, Sergeev AV, Prabhu P, Suresh C. Auditory electrophysiological and perceptual measures in student musicians with high sound exposure. *Diagnostics (Basel)*. (2023) 13:1–21. doi: 10.3390/diagnostics13050934

64. Gonçalves CGO, Lacerda ABM, Zeigelboim BS, Marques JM, Luders D. Auditory thresholds among military musicians: conventional and high frequency. *Codas*. (2013) 25:181–7. doi: 10.1590/s2317-17822013000200015

65. Hoffman JS, Cunningham DR, Lorenz DJ. Auditory thresholds and factors contributing to hearing loss in a large sample of percussionists. *Med Probl Perform Art*. (2006) 21:47–58. doi: 10.21091/mppa.2006.2011

66. Drake-Lee AB. Beyond music: auditory temporary threshold shift in rock musicians after a heavy metal concert. *J R Soc Med*. (1992) 85:617–9. doi: 10.1177/014107689208501010

67. Axelsson A, Lindgren F. Does pop music cause hearing damage? Audiology: official organ of the international society of. *Audiology*. (1977) 16:432–7. doi: 10.3109/00206097709071856

68. Devi N, Swathi CS. Effect of musical training on masking paradigm. *Indian J Otol*. (2016) 22:85. doi: 10.4103/0971-7749.182280

69. Johnson DW, Sherman RE, Aldridge J, Lorraine A. Effects of instrument type and orchestral position on hearing sensitivity for 0.25 to 20 kHz in the orchestral musician. *Scand Audiol*. (1985) 14:215–21. doi: 10.3109/01050398509045944

70. Phillips SL, Shoemaker J, Mace ST, Hodges DA. Environmental factors in susceptibility to noise-induced hearing loss in student musicians. *Med Probl Perform Art*. (2008) 23:20–8. doi: 10.21091/mppa.2008.1005

71. Pawlaczyk-Łuszczyńska M, Zamojska-Daniszewska M, Dudarewicz A, Zaborowski K. Exposure to excessive sounds and hearing status in academic classical music students. *Int J Occup Med Environ Health*. (2017) 30:55–75. doi: 10.13075/ijomeh.1896.00709

72. Halevi-Katz DN, Yaakobi E, Putter-Katz H. Exposure to music and noise-induced hearing loss (NIHL) among professional pop/rock/jazz musicians. *Noise Health*. (2015) 17:158–64. doi: 10.4103/1463-1741.155848

73. Johnson DW, Sherman RE, Aldridge J, Lorraine A. Extended high frequency hearing sensitivity. A normative threshold study in musicians. *Ann Otol Rhinol Laryngol*. (1986) 95:196–202. doi: 10.1177/000348948609500219

74. Axelsson A, Lindgren F. Factors increasing the risk for hearing loss in "pop" musicians. *Scand Audiol*. (1977) 6:127–31. doi: 10.3109/01050397709043112

75. Jin S-H, Nelson PB, Schlauch RS, Carney E. Hearing conservation program for marching band members: a risk for noise-induced hearing loss? *Am J Audiol*. (2013) 22:26–39. doi: 10.1044/1059-0889(2012/11-0030)

76. Kähäri KR, Axelsson A, Hellström PA, Zachau G. Hearing development in classical orchestral musicians. A follow-up study. *Scand Audiol*. (2001) 30:141–9. doi: 10.1080/010503901316914511

77. Ostri B, Eller N, Dahlin E, Skylv G. Hearing impairment in orchestral musicians. *Scand Audiol*. (1989) 18:243–9. doi: 10.3109/01050398909042202

78. Schmuziger N, Patscheke J, Probst R. Hearing in nonprofessional pop/rock musicians. *Ear Hear*. (2006) 27:321–30. doi: 10.1097/01.aud.0000224737.34907.5e

79. Maghiar MJ, Lawrence BJ, Mulders WH, Moyle TC, Livings I, Jayakody DMP. Hearing loss and mental health issues in amateur and professional musicians. *Psychol Music*. (2023) 51:1584–97. doi: 10.1177/03057356231155970

80. Størmer CCL, Laukli E, Høydal EH, Stenklev NC. Hearing loss and tinnitus in rock musicians: a Norwegian survey. *Noise Health*. (2015) 17:411–21. doi: 10.4103/1463-1741.169708

81. Speaks C, Nelson D, Ward WD. Hearing loss in rock-and-roll musicians. *J Occup Med*. (1970) 12:216–9. doi: 10.1097/00043764-197006000-00004

82. Juman S, Karmody CS, Simeon D. Hearing loss in steelband musicians. *Otolaryngol Head Neck Surg*. (2004) 131:461–5. doi: 10.1016/j.otohns.2003.12.023

83. Murray N, Lepage E, Mikl K. Inner ear damage in an opera theatre orchestra as detected by otoacoustic emissions, pure tone audiometry and sound levels. *Aust J Audiol*. (1998) 2:67–78. Available at: https://www.researchgate.net/publication/294587738_Inner_ear_damage_in_an_opera_theatre_orchestra_as_detected_by_otoacoustic_emissions_pure_tone_audiometry_and_sound_levels

84. Couth S, Prendergast G, Guest H, Munro KJ, Moore DR, Plack CJ, et al. Investigating the effects of noise exposure on self-report, behavioral and electrophysiological indices of hearing damage in musicians with normal audiometric thresholds. *Hear Res*. (2020) 395:108021. doi: 10.1016/j.heares.2020.108021

85. Emmerich E, Rudel L, Richter F. Is the audiologic status of professional musicians a reflection of the noise exposure in classical orchestral music? *Eur Arch Otorhinolaryngol*. (2008) 265:753–8. doi: 10.1007/s00405-007-0538-z

86. Lüders D, Gonçalves CGO, Lacerda ABM, Ribas Â, De Conto J. Music students: conventional hearing thresholds and at high frequencies. *Braz J Otorhinolaryngol*. (2014) 80:296–304. doi: 10.1016/j.bjorl.2014.05.010

87. McBride D, Gill F, Proops D, Harrington M, Gardiner K, Attwell C. Noise and the classical musician. *Br Med J*. (1992) 305:1561–3. doi: 10.1136/bmj.305.6868.1561

88. Setiawan EP, Riska MM. Noise effect of gamelan jegog to the risk of hearing loss among jegog players in Sangkaragung village, Negara, Jembrana. *Biomed Pharmacol J*. (2018) 11:2169–74. doi: 10.13005/bpj/1598

89. Müller R, Schneider J. Noise exposure and auditory thresholds of military musicians: a follow up study. *J Occup Med Toxicol*. (2018) 13:14–8. doi: 10.1186/s12995-018-0196-7

90. Behar A, Chasin M, Mosher S, Abdoli-Eramaki M, Russo FA. Noise exposure and hearing loss in classical orchestra musicians: a five-year follow-up. *Noise Health*. (2018) 20:42–6. doi: 10.4103/nah.NAH_39_17

91. Myers E. Noise exposure and hearing protection in marching band students. Rehabilitation, Human Resources and Communication Disorders University of Arkansas (2021) Available at: https://scholarworks.uark.edu/rhrcuht/71/ (Accessed January 28, 2025).

92. Westmore GA, Eversden ID. Noise-induced hearing loss and orchestral musicians. *Arch Otolaryngol*. (1981) 107:761–4. doi: 10.1001/archotol.1981.00790480037010

93. Pawlaczyk-Łuszczyncska M, Zamojkska M, Dudarewicz A, Zaborowski K. Noise-induced hearing loss in professional orchestral musicians. *Arch Acoust*. (2013) 38:223–34. doi: 10.2478/aoa-2013-0027

94. Reddell RC, Lebo CP. Ototraumatic effects of hard rock music. *Calif Med*. (1972) 116:1–4. Available at: https://pubmed.ncbi.nlm.nih.gov/5008499

95. Ramma L. Patterns of noise exposure and prevalence of hearing loss amongst Cape Town minstrel carnival musicians. *S Afr J Commun Disord*. (2021) 68:e1–6. doi: 10.4102/sajcd.v68i1.789

96. Gebel E, Jones SM, Honaker JA. Perception of hearing loss in orchestral musicians. College of Education and Human Sciences: Dissertations, theses, and Student Research University of Nebraska Lincoln (2017). 285 p Available at: https://digitalcommons.unl.edu/cehsdiss/285/ (Accessed January 28, 2025).

97. Axelsson A, Lindgren F. Pop music and hearing. *Ear Hear*. (1981) 2:64–9. doi: 10.1097/00003446-198103000-00002

98. Santoni CB, Fiorini AC. Pop-rock musicians: assessment of their satisfaction provided by hearing protectors. *Braz J Otorhinolaryngol*. (2010) 76:454–61. doi: 10.1590/S1808-86942010000400009

99. Comeau G, Koravand A, Swirp M. Prevalence of hearing loss among university music students. *Can Acoust*. (2018) 46:37–51. Available at: https://jcaa.caa-aca.ca/index.php/jcaa/article/view/3042

100. Ramrattan H, Gurevich N. Prevalence of noise-induced hearing loss in middle and high school band members: a preliminary study. *Folia Phoniatr Logop*. (2020) 72:302–8. doi: 10.1159/000501154

101. Phillips SL, Henrich VC, Mace ST. Prevalence of noise-induced hearing loss in student musicians. *Int J Audiol*. (2010) 49:309–16. doi: 10.3109/14992020903470809

102. Laraqui S, Manar N, Laraqui O, Laraqui F, Laraqui Hossini CEH. Screening and prevalence of hearing loss in professional musicians. *Saf Health Work*. (2022) 13:S279. doi: 10.1016/j.shaw.2021.12.1625

103. Lüders D, Da Silva Martins KRR, De Lacerda ABM, de Oliveira Gonçalves CG, Heupa AB. Sound exposure and audiometric profile of military police band musicians. *Int Arch Otorhinolaryngol*. (2017) 21:S89.

104. Maia JRF, Russo ICP. Study of the hearing of rock and roll musicians. *Pro Fono*. (2008) 20:49–54. doi: 10.1590/s0104-56872008000100009

105. Jerger J, Jerger S. Temporary threshold shift in rock-and-roll musicians. *J Speech Hear Res*. (1970) 13:221–4. doi: 10.1044/jshr.1301.221

106. Gündüz B, Yıldırım Gökay N, Orhan E, Yılmaz M. The comprehensive audiological evaluation in young violinists: the medial olivocochlear system, high frequency thresholds, and the auditory figure ground test. *Eur Arch Otorhinolaryngol*. (2022) 279:3837–45. doi: 10.1007/s00405-021-07122-8

107. Karlsson K, Lundquist PG, Olaussen T. The hearing of symphony orchestra musicians. *Scand Audiol*. (1983) 12:257–64. doi: 10.3109/01050398309044429

108. Widuri A, Gartiwa G, Pujiyanto E. The influence of sound exposure onset and duration to the hearing loss prevalence in musicians. Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, December 20-21, 2022 (2022). Available at: https://ieomsociety.org/proceedings/2022australia/29.pdf (Accessed January 28, 2025).

109. Høydal EH, Lein Størmer CC, Laukli E, Stenklev NC. Transient evoked otoacoustic emissions in rock musicians. *Int J Audiol*. (2017) 56:685–91. doi: 10.1080/14992027.2017.1321788

110. Pouryaghoub G, Mehrdad R, Pourhosein S. Noise-induced hearing loss among professional musicians. *J Occup Health*. (2017) 59:33–7. doi: 10.1539/joh.16-0217-OA

111. Couth S, Prendergast G, Guest H, Munro KJ, Moore DR, Plack CJ, et al. A longitudinal study investigating the effects of noise exposure on behavioural, electrophysiological and self-report measures of hearing in musicians with normal audiometric thresholds. *Hear Res*. (2024) 451:109077. doi: 10.1016/j.heares.2024.109077

112. Zhao F, Manchaiah VKC, French D, Price SM. Music exposure and hearing disorders: an overview. *Int J Audiol*. (2010) 49:54–64. doi: 10.3109/14992020903202520

113. Wang Q, Qian M, Yang L, Shi J, Hong Y, Han K, et al. Audiometric phenotypes of noise-induced hearing loss by data-driven cluster analysis and their relevant characteristics. *Front Med*. (2021) 8:662045. doi: 10.3389/fmed.2021.662045

114. Moore BCJ, Lowe DA, Cox G. Guidelines for diagnosing and quantifying noise-induced hearing loss. *Trends Hear*. (2022) 26:23312165221093156. doi: 10.1177/23312165221093156

115. Tambs K, Hoffman HJ, Borchgrevink HM, Holmen J, Engdahl B. Hearing loss induced by occupational and impulse noise: results on threshold shifts by frequencies, age and gender from the Nord-Trøndelag hearing loss study. *Int J Audiol*. (2006) 45:309–17. doi: 10.1080/14992020600582166

116. Hoffman HJ, Dobie RA, Losonczy KG, Themann CL, Flamme GA. Declining prevalence of hearing loss in US adults aged 20 to 69 years. *JAMA Otolaryngol Head Neck Surg*. (2017) 143:274–85. doi: 10.1001/jamaoto.2016.3527

117. Ramage-Morin PL, Banks R, Pineault D, Atrach M. Unperceived hearing loss among Canadians aged 40 to 79. *Health Rep*. (2019) 30:11–20. doi: 10.25318/82-003-x201900800002-eng