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Hearing loss and tinnitus in rock musicians: A Norwegian survey

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Abstract

Our focus in this study was to assess hearing thresholds and the prevalence and characteristics of tinnitus in a large group of rock musicians based in Norway. A further objective was to assess related factors such as exposure, instrument category, and the preventive effect of hearing protection. The study was a cross-sectional survey of rock musicians selected at random from a defined cohort of musicians. A random control group was included for comparison. We recruited 111 active musicians from the Oslo region, and a control group of 40 nonmusicians from the student population at the University of TromsØ. The subjects were investigated using clinical examination, pure tone audiometry, tympanometry, and a questionnaire. We observed a hearing loss in 37.8% of the rock musicians. Significantly poorer hearing thresholds were seen at most pure-tone frequencies in musicians than controls, with the most pronounced threshold shift at 6 kHz. The use of hearing protection, in particular custom-fitted earplugs, has a preventive effect but a minority of rock musicians apply them consistently. The degree of musical performance exposure was inversely related to the degree of hearing loss in our sample. Bass and guitar players had higher hearing thresholds than vocalists. We observed a 20% prevalence of chronic tinnitus but none of the affected musicians had severe tinnitus symptomatology. There was no statistical association between permanent tinnitus and hearing loss in our sample. We observed an increased prevalence of hearing loss and tinnitus in our sample of Norwegian rock musicians but the causal relationship between musical exposure and hearing loss or tinnitus is ambiguous. We recommend the use of hearing protection in rock musicians.

Keywords: *Hearing loss, rock musicians, tinnitus*

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Introduction

Noise exposure can cause acute mechanical or metabolic damage to the inner ear, leading to subsequent accumulation of free oxygen radicals and outer hair cell death. [1] This acoustic injury can entail hearing loss, diplacusis, acoustic distortion, tinnitus, or hyperacusis. Hearing loss and hearing-related disorders that are caused by exposure to loud music have been the subject of increased epidemiological and audiological interest in later years. [2],[3],[4],[5],[6],[7] There are several studies that address the hearing of classical orchestra musicians, [8],[9],[10] but our knowledge about the audiological status of rock musicians is limited. [2] The loss of cochlear hair cells has been observed in animals that are exposed to loud pop music. [11] Sound levels in a classical music orchestra have a variance of 80-100 dB L_{pAeq} . [12] Sound levels at rock concerts have a variance of 100.8-115 dB L_{pAeq} with recorded peak values up to 148 dB LpCpeak [13] on the performer. Rock music is commonly performed at high sound levels and contains all audible frequencies, with an emphasis on the lower frequency spectra. Variations of sound levels during rock concerts are minor. [14]

In previous studies, hearing in rock musicians has commonly been studied by pure-tone audiometric assessment. The results are ambiguous, with the prevalence of hearing loss varying from 0% [4] to 41%. [13] The prevalence of hearing loss in those populations depends, however, on the audiometric criteria for hearing loss. In Kähäri's study from 2003, hearing loss was defined as ≥2 frequencies at ≥25 dB HL or one frequency ≥30 dB hearing level (HL) in ≥1 ear. [13] Axelsson and Lindgren (1977) defined hearing loss as a mean high frequency (3 kHz, 4 kHz, 6 kHz, and 8 kHz) ≥20 dB HL in ≥1 ear, which yielded a prevalence of hearing loss at 18.9%. A study of temporary threshold shift (TTS) after one rock concert recorded temporary hearing loss mainly in the low frequencies. [15] It has been demonstrated that the degree of TTS is proportional to sound level exposure. [16] Studies of permanent threshold shifts in rock musicians show a high frequency dip in the audiogram, which is most prominent at 6 kHz. [7],[13],[17],[18]

Several risk factors for the development of hearing disorders have been cited. A Swedish study concluded that age, years of playing, hours of playing per week, playing drums, previous military service, and leisure pop music listening were factors contributing to the risk of NIHL. [17] To some degree, the risk of cochlear injury is addressed by musicians by using hearing protection. A Swiss study found a significantly better mean hearing threshold of 2.4 dB in musicians using hearing protection at all times. [18] We also hypothesize that repeated use of insert material for hearing protection could lead to external ear canal or tympanic membrane problems in rock musicians.

Cochlear injury can lead to inadequate signal transmission in the hearing pathways followed by hyperacusis and tinnitus. [19] The known prevalence of chronic tinnitus in rock musicians has a range of 17-43%. [13],[20]

The main aim of this study has been to assess the cochlear status in a large sample of rock musicians, with a focus on pure-tone hearing thresholds, and to elucidate the occurrence of tinnitus in rock musicians. We recognize the need for expansion of our knowledge base on these issues with a large, controlled study in a randomly selected sample. A further goal has been to study the relationships between hearing problems and influencing factors such as exposure, type of instrument, and protective measures in rock musicians. In addition, ear canal and tympanic membrane problems have been addressed in this study.

Methods

Subjects

Rock musicians

Our working definition of a rock musician is a performing musician who classifies himself/herself as operating within the rock music category. Several of our participants reported that they were also performing in other musical genres (pop, jazz, electro, hip-hop, country, and others). To simplify our analyses, all were pooled into the rock musician category. The sample of musicians was recruited in two sessions. We collaborated with Norsk Musikkråd (Norwegian Music Council) for the use of its BandOrg database for active rock musicians in the Oslo region. This database included 330 subscribing members. All were invited via electronic mail (e-mail). Twenty responded initially via e-mail and a further 26 responded to a follow-up telephone inviting them to participate, yielding a total of 46 participants from the BandOrg sample. This part of the musician sample was not recruited in a random procedure.

We had access to a comprehensive list of musicians performing at the Øya festival (major Norwegian rock music festival) in 2011-12. The list contained 110 bands, consisting of 3-5 members. Using the rand between function in Microsoft Excel (Microsoft Corp., Redmond, Washington, USA), 25 bands were drawn from this sample. A total of 102 musicians were invited by e-mail or phone, out of whom 71 musicians were included in our study. Among nonparticipants, the most common reason for not participating was conflicting time schedules.

In total, 117 rock musicians were included in our study-102 males and 15 females. Statistical analysis was performed after data collection to ensure that there were no demographic differences or significant differences in the distribution of our variables of interest between the Øya and BandOrg subsamples. Hence, we pooled the two groups together in our rock musician sample.

During the data sampling phase, 6 of the 117 musicians were excluded from the study (for cerumen occlusion, failure to answer the questionnaire, or failure to attend the clinical examination). Hence, the total number of subjects in the musician group that was included in our study was *n* = 111 [Table 1].

	Rock musicians	Controls
Total	111	40
Males (%)	97 (87.4)	32 (80)
Females (%)	14 (12.6)	8 (20)
Age, yrs., median (range)	30 (16-52)	26 (19-39)

Table 1: Age and gender distribution of rock musicians and controls

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In the musician sample, the distribution of instruments was as follows: vocals −6.3%, guitar −27.9%, bass −15.3%, and drums −20.7%. If the musician was a singer and played another instrument, he/she was allocated to the relevant instrument group under the assumption that the exposure would be that of the instrument he/she played in addition to singing. In the sample, 25.2% declared that they played several instruments. Regarding genre categories, 13.5% declared that they played rock, 9% punk/hardcore, 9.9% metal, 6.3% pop, and 29.7% several of the aforementioned genres. Meanwhile, 20.7% did not disclose their genre.

Control group

For our control group, we invited an age- and gender-matched sample of students at the University of TromsØ by informing about the project and asking students to participate. We aimed to recruit a random sample, which was possible only among female students. Our students were from Economics, Law, Health, and Computer Science faculties. In total, 40 students were recruited for our control sample −32 males and 8 females [Table 1].

Clinical examinations were performed at the offices of Norsk Musikkråd in Oslo, Norway (musicians) and the Ear, Nose, and Throat (ENT) Department of the University Hospital of Northern Norway (controls). The staff and technical equipment were identical in both locations.

Methods

All participants responded to a web-based questionnaire with 85 items [Appendix 1 [Additional file 1]], distributed electronically via Norwegian Social Science Data Services (NSD). The questionnaire included questions about audiological symptoms including the presence, duration, and degree of tinnitus, noise exposure, musical instrument type, music-related activities, and the use of hearing protection. The questionnaire included one item from The Brief Illness Perception Questionnaire [21] and risk factors cited in a Swedish study. [22] The questionnaire response rate was 97.3% in the musician sample and 100% in the control sample. From our questionnaire, the following items were addressed in this work: presence, duration and degree of tinnitus, frequency and duration of musical practice including performances, gender, age, genre, instrument, use of hearing protection, and frequency of leisure musical exposure.

All were examined by a medical doctor with bilateral otomicroscopy before performing the hearing tests, and the cerumen was removed where necessary. Tuning fork tests including the Weber and Rinne tests were performed at 512 Hz. Pure-tone audiometry was performed in both ears using a Madsen Itera II audiometer with TDH-39 earphones in an IAC Mini 250 audiometric booth, complying fully with International Organization for Standardization (ISO)-8253-1. For the control group, measurements were taken at the University hospital of Northern Norway in a sound-attenuating room, meeting the ISO criteria for background noise (ISO-8253-1, 2010). Audiometry was performed using the ascending method (ISO 8253-1, 2010) with a random first ear by an experienced audiologist. Pure-tone audiometric results were presented as hearing threshold levels for individual frequencies, and for some of our analyses, as the mean threshold levels of the frequencies 3 kHz, 4 kHz, and 6 kHz (dB HL). This variable is referred to as the mean high frequency (MHF). For this study, our criterion for the presence of hearing loss was ≥2 frequencies ≥25 dB HL in ≥1 ear or one frequency ≥30 dB HL in ≥1 ear, as measured by pure-tone audiometry. [13]

Tympanometry was performed on all subjects using a handheld Titan IMP440 from Interacoustics (Middelfart. Fyn, Denmark), Denmark. Ear canal volume (ECV), compliance, and pressure were registered.

All audiometric equipment that were used in our study had been calibrated according to ISO standards within 6 months of data collection.

The results were entered into a computer database and analyzed using the Statistical Package for the Social Sciences (SPSS) version 22 IBM (Armonk, New York, USA), according to common standards for medical statistics. The distributions of all parameters were assessed using normal plots. The statistical tests that we used were Student's *t*-test, Pearson's chi-square test, paired-samples *t*-test, and linear regression. For statistical significance, a cutoff at $P \leq 0.05$ was chosen. Informed consent was obtained from all the participants. The protocol was approved by the regional ethics committee (2012/127/REK Nord). Where pathological findings were encountered at the clinical examination, subjects were advised to contact their general practitioner for consultation.

Results

Otomicroscopy

The results of the otomicroscopic examination are presented in [Table 2]. No statistically significant differences between the musician sample and control group were identified using the Pearson's chi-square test.

Table 2: Otomicroscopic fi ndings in both ears for the rock musician (*n* = 111) and control (*n* = 40) samples

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Tympanometry

No significant differences in ECV, compliance, or pressure were found between the musician and control samples using the Student's *t*-test ($P > 0.05$). In musicians, the mean pressure was negative in both the ears [right: −8 daPa, standard deviation (SD) 28.5, left: −5 daPa, SD 35.0], this was attributable to a few outliers.

Hearing threshold levels

An overview of pure-tone audiometric findings in the rock musician and control groups is presented in [Table 3]. The prevalence of hearing loss in the musician sample ($n = 111$) was 37.8% [95% confidence interval (CI): 28.8-46.8%]. Among the male musicians, 36.1% (26.5-45.7%) had hearing loss and among the female musicians, 50% (23.8-76.2%) had hearing loss. In the control group, 2.5% (0-7.3%) had hearing loss according to our criteria [males: 3.1% (0-9.1%) and females: 0%]. The distribution of instruments in the hearing loss group was as follows: Vocals −7%, guitar −21%, bass −19%, drums −24%, and multiple instruments −22%. No significant association between an instrument group and hearing loss was uncovered using the Pearson's chi-square test. [Table 4] represents a cross-tabulation of different high-frequency hearing loss categories according to relevant definitions across the prevalence of chronic tinnitus.

Pure-tone audiometric threshold levels						
Frekvency kHz	Right ear (dB HL)			Left ear (dB HL)		
	Rock musicians dB HL (SD)	Controls dB HL (SD)	*P*	Rock musicians dB HL (SD)	Controls dB HL (SD)	*P*
0.125	6.9 (4.6)	6.0 (4.1)	.306	7.3 (5.0)	5.1 (5.1)	.097
0.25	5.4 (5.4)	3.3 (4.3)	.027	5.7 (4.8)	3.0 (4.4)	.002
0.5	5.2 (5.2)	2.8 (4.1)	.006	5.2 (5.2)	2.4 (3.9)	.001
1	4.1 (4.5)	2.0 (3.5)	.011	5.0 (4.7)	0.9 (3.4)	.000
2	3.4 (7.9)	1.6 (4.4)	.090	5.5 (8.0)	1.9 (6.0)	.011
3	6.4 (11.2)	2.1 (6.1)	.023	7.6 (9.8)	3.5 (6.4)	.016
4	9.0 (14.0)	4.1 (6.2)	.037	9.9 (11.5)	5.9 (6.7)	.041
6	21.3 (11.5)	11.5 (7.1)	.000	22.4 (11.3)	10.8 (7.6)	.000
8	8.7 (10.0)	5.0 (5.5)	.030	8.6 (10.8)	7.3 (7.2)	.477

Table 3: Mean pure-tone audiometric threshold levels (db HL) for rock musicians (*n* = 111) and controls (*n* = 40), right and left ears with standard deviations and *P* values

Click here to view

Table 4 Hearing in rock musicians and controls with med ian age and presence of tinnitus

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Hearing threshold levels in male and female musicians were significantly different only at 0.25 kHz in the left ear, and in the control group at 0.125 kHz and 0.25 kHz in the left ear. The mean threshold levels for the two genders are pooled together in [Table 3]. There were significant differences between the musicians and controls at 0.25 kHz (both ears), 0.5 kHz (both ears), 1 kHz (both ears), 2 kHz (left ear), 3 kHz (both ears), 4 kHz (both ears), 6 kHz (both ears), and 8 kHz (right ear) ($P < 0.05$). The most pronounced differences in mean thresholds were found at 6 kHz (left ear 11.6 dB HL, right ear 9.8 dB HL). [Figure 1] presents the mean hearing threshold levels for the worst ear of both musicians and controls, with significant differences found at frequencies 0.25 kHz, 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz ($P < 0.05$) using both Student's *t*-test and analysis of variance (ANOVA). Intraear comparisons uncovered a significantly poorer hearing at 1 (mean difference 0.9 dB HL) and 2 kHz (mean difference 1.6 dB HL) in the left ear of musicians, and at 1 kHz (mean difference 1.1 dB HL) in the right ear of controls ($P < 0.05$). The male musicians had a significantly poorer hearing in the left ear at 2 kHz and female musicians had higher thresholds in the left ear at 1 kHz, 2 kHz, and 3 kHz ($P < 0.05$).

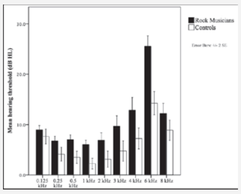
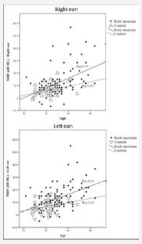


Figure 1: Mean hearing thresholds (worst ear) in rock musicians (*n* = 111) and controls (*n* = 40)

Click here to view

After performing a linear regression analysis with all the individual frequencies as dependent variables, and age, gender, and group (rock musicians versus controls) as independent variables, we found that age was a significantly contributing factor at the frequencies 0.125 kHz (right ear), 3 kHz, 4 kHz, 6 kHz, and 8 kHz in both ears. The hearing thresholds of rock musicians remained significantly higher than the control group at 0.25 kHz (left ear), 0.5 kHz (bilaterally), 1 kHz (left ear), and 6 kHz (bilaterally) regardless of the contribution of age. MHF thresholds were significantly higher in the musician group (right ear: 6.3 dB HL, left ear: 6.6 dB HL, $P < 0.05$) than in the control group. However, at the linear regression with MHF as dependent variable, and age and group as independent variables, the difference between rock musicians and controls was significant only in the left ear ($P < 0.05$). A scatterplot serves to illustrate MHF as a function of age for both musicians and controls [Figure 2].

Figure 2: MHF in relation to age in rock musicians (*N* = 111) and controls. (*N* = 40)



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Hearing threshold levels, musical exposure, and instrument

Based on the questionnaire, we recategorized the musicians into exposure groups (low, medium, and high) as related to frequency of performance (low < every third month (*n* = 11), high > once every 2 weeks (*n* = 45)), weekly amount of practice [low < 2 h a week (*n* = 4), high >10 h/week (*n* = 25)], and duration of activity as a musician [low < 1 year (*n* = 5), high >5 years (*n* = 23)]. In [Figure 3], we present the worst ear mean pure-tone hearing thresholds for the low, medium, and high performance exposure groups. Using ANOVA, we found significantly poorer hearing thresholds in the low performance exposure group in the worst ear at 6 kHz [32.3 dB HL (SD 17.1)] as compared to 26.0 dB HL (SD 10.7) in the medium exposure group and 23.3 dB HL (SD 8.5) in the high exposure group and 8 kHz [17.7 dB HL (SD 12.1)] versus 13.5 dB HL (SD 11.33) in the medium exposure group as compared to 9.3 dB HL (SD 8.4) in the high exposure group (*P* > 0.05). For practice exposure, no significant differences were observed. For length of activity, a significant difference at 250 Hz was found but there were no significant differences in higher frequencies.

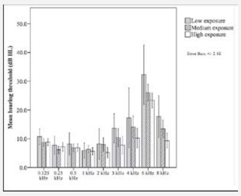

Figure 3: Pure-tone hearing thresholds in the worst ear related to performance exposure in rock musicians (low exposure group *n* = 11, medium exposure group *n* = 55, and high exposure group *n* = 45)

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When musicians were stratified into categories according to the instrument they played, guitarists (*n* = 31) had 4.1 dB HL higher hearing thresholds than vocalists (*n* = 7) at 1 kHz in the right ear (*P* < 0.05), bass players (*n* = 17) had 3.9 dB poorer hearing than vocalists at 1 kHz in the right ear (*P* < 0.05), bass players had 7.8 dB HL poorer hearing at 3 kHz and 9.5 dB HL poorer hearing at 4 kHz than guitar players in the right ear (*P* < 0.05). When drummers (*n* = 23) were compared to all categories of nonpercussive instrumentalists, there were no significant differences. Comparisons of instrument categories were made using the Student's *t*-test. When using ANOVA to study differences in the entire spectrum of instruments, no significant differences in the worst ears were observed.

Hearing threshold levels and hearing protection

Among the musicians, 21.6% never used hearing protection. Meanwhile, 47.7% used hearing protection during performances, 64.9% during practice, and 64.9% when attending performances by other musicians. Musicians were categorized into one group that never or infrequently used hearing protection (*n* = 63) and another group that always used hearing protection during practice and performances (*n* = 48). Using the Student's *t*-test, nonuser hearing thresholds were significantly higher at 0.125 kHz (both ears), 0.25 kHz (left ear), 0.5 kHz (left ear), 1 kHz (left ear), 3 kHz (both ears), 4 kHz (left ear), 6 kHz (right ear), and 8 kHz (left ear) (*P* < 0.5). The 6-kHz mean threshold difference in the right ear was 5 dB HL. In [Figure 4], the worst ear pure-tone hearing thresholds of hearing protection users and nonusers are presented.

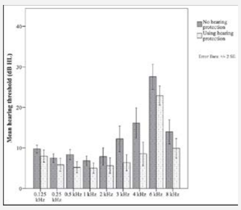

Figure 4: Pure-tone hearing thresholds in rock musicians (worst ear) who always used hearing protection during concerts and practice (*n* = 48), and rock musicians who never or occasionally used hearing protection (*n* = 63)

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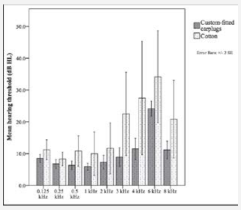
Hearing thresholds were compared between musicians using custom-fitted earplugs (*n* = 60), premolded earplugs (*n* = 41) and musicians using cotton (*n* = 6). Here, it is referred to custom-fitted earplugs known as high-fidelity earplugs that provide equal sound reduction across the frequency spectrum. Our data did not include information about the type of sound filter that each individual musician was using. Premolded earplugs refer to noncustomized earplugs made out of silicone, plastic, or rubber, and which do not offer an equally efficient sound attenuation. Significantly higher hearing threshold levels at 0.125 kHz (right ear), 3 kHz (right ear) and 6 kHz (both ears), most pronounced at 6 kHz (11.8 dB HL in the left ear, 11.1 db HL in the right ear) were observed in those using cotton for protection (Student's *t*-test: *P* < 0.05). A graphic representation of hearing thresholds in the worst ear for the two categories is supplied in [Figure 5]. No significant hearing threshold differences were found between those with custom-fitted (*n* = 60) and pre-molded (*n* = 41) earplugs using the Student's *t*-test (*P* > 0.05).

Figure 5: Pure-tone hearing thresholds in rock musicians (worst ear) using custom-fi tted earplugs (*n* = 60) and cotton (*n* = 6)



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Hearing threshold levels and tinnitus

The prevalence of chronic tinnitus in our musician sample was assessed using item 1 in our questionnaire, and was found to be 19.8%. None of our control group subjects reported chronic tinnitus. The occurrence of tinnitus in the musician sample across increasing categories of severity is represented in [Figure 6]. The instrument distribution within the chronic tinnitus group was as follows: guitar −36.4%, bass −13.6%, drums −27.3%, others −9.1%, and multiple instruments −13.6%. [Table 5] shows the responses to various relevant questionnaire items in both the chronic tinnitus and hearing loss subsamples.

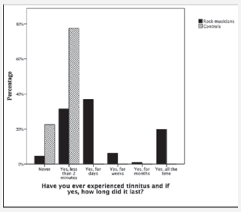

Figure 6: Prevalence in categories according to duration of tinnitus in rock musicians (n = 111) and controls (n = 40)

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	Tinnitus-group % (95% CI)	Hearing loss-group % (95% CI)
Do you use hearing protection?		
Yes, when I play concerts	68.2 (48.4-87.6)	47.6 (32.5-62.7)
Yes, when I practice	81.8 (65.7-97.9)	61.9 (47.2-76.6)
Yes, when I attend other concerts	68.2 (48.4-87.6)	57.1 (42.1-72.1)
No, never	4.5 (-5.1-13.2)	23.8 (10.1-36.7)
Do you consider hearing disorders related to playing music a problem? (yes)	13.6 (0.7-27.9)	9.5 (0.6-18.4)
Have you considered quitting playing music due to hearing disorders? (yes)	22.7 (5.2-40.2)	4.8 (-1.7-11.3)
Have you consulted a doctor about your hearing disorders/ ear symptoms? (yes)	40.9 (20.4-61.4)	19 (7.1-30.9)
Have you ever sought professional help for psychological problems? (yes)	18.2 (2.1-34.3)	11.9 (2.1-21.7)

Table 5: Tinnitus-group (n = 22) and hearing-loss group (n = 42): Responses to relevant items in the questionnaire

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The chronic tinnitus group (n = 22) was compared with other musicians, and there were no significant differences in hearing thresholds at any frequency between the two categories when analyzed with the Student's t-test ($P > 0.05$).

Six of the musicians declared that they had considered terminating their career due to hearing problems. When they were compared with the remaining musicians, there were no significant threshold differences at 6 kHz in either ear (Student's t-test: $P > 0.05$). When we compared those (n = 8) who found hearing-related symptoms to be a problem when performing with musicians that did not report this issue, we found no significant differences in hearing thresholds using the Student's t-test ($P > 0.05$). Using Pearson's chi-square test, we observed no significant difference between musicians with constant tinnitus (n = 22) and the remaining musicians (n = 89) when we asked them about whether hearing problems were an obstacle to performance ($P < 0.05$).

[Table 6] presents the degree of performance, practice, and career duration exposure (low, medium, and high) within the chronic tinnitus sample (n = 22). When analyzed by the Pearson's chi-square test, no statistically significant associations were found between those variables ($P > 0.05$).

	Performance exposure	
Low	Medium	High
1 (4.5%)	10 (45.5%)	11 (50%)
	Practice exposure	
Low	Medium	High
5 (22.7%)	15 (68.2%)	2 (9.1%)
	Lenght of activity exposure	
Low	Medium	High
0 (0%)	3 (13.6%)	19 (86.4%)

Table 6: Prevalence of chronic tinnitus in musicians across degree of musical exposure (n = 22)

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Cofactors in our analyses

Randomized versus nonrandomized musician subsamples

Our musician sample consisted of two subgroups - a nonrandomized population (n = 43) and a randomized population (n = 68). Between these two samples, there were no statistically significant differences in any of the parameters that have been addressed in this study.

Discussion

Our study represents the largest controlled study of hearing issues in rock musicians to date. By our criteria, 37.8% of our rock musician sample had a hearing loss. The prevalence of hearing loss was 2.5% in the control group. If we exchange our criteria for the presence of hearing loss according to previous studies, and use the mean of 3 kHz, 5 kHz, 6 kHz, and 8 kHz ≥20 dB HL in ≥1 ear, the hearing loss prevalence in our musician group would be 18.9%, or using the criterion of 1 ear ≥20 dB HL, the prevalence would be 84.7%. Although significantly poorer hearing thresholds were observed at almost all frequencies in rock musicians, the most pronounced threshold shift was found at 6 kHz. This finding corroborates previous work. [6],[7],[13],[17],[20] The 6-kHz threshold shift could be attributable to the known musical noise exposure in the rock musician sample. It is noteworthy that the control sample, too, had an incipient hearing threshold elevation bilaterally at 6 kHz [Figure 1]. This could be interpreted as a latent noise-induced hearing loss in the young adult general population. In another study submitted by the authors of this paper, we did not observe any significant differences in exposure from leisure musical noise between musicians and controls. A 1996 study demonstrated that a statistically significant increase of average hearing thresholds could be observed in young people using a personal cassette player for more than 7 h/week (n = 54). [23]

Intraear comparisons indicated minor interaural differences in musicians where hearing thresholds were elevated at 1 kHz and 2 kHz in the left versus right ears. Previous work indicates poorer hearing at most frequencies in professional musicians' left ears, [13],[20] which is attributed to findings in classical musicians [24] where string players hold their instrument close to their left ear. In rock music, however, sound is always amplified and multidirectional, which could explain the minor interaural differences in our rock musician sample.

Interestingly, we observed poorer hearing in the low exposure subgroup in comparison to the high exposure subgroup for performance. We acknowledge the need to interpret these results with care, as the true accumulated exposure of each musician will vary based on several other factors (such as length of activity, practice exposure, and correspondent sound levels) but this finding corroborates Axelsson and Lindgren (1977) who found elevated thresholds when comparing short- with long-sessioning musicians. Kähäri *et al*. (2003) found that hearing threshold levels at 4 kHz in the right ear were significantly lower in the high exposure group in comparison to the low exposure group. In a follow-up study, it was observed that a group of musicians had almost unchanged hearing levels after 16 years of musical activity. [16] The only significant deterioration was observed at 4 kHz and 8 kHz (left ear) and 4 kHz (right ear) while the median hearing levels were still within normal limits at the age of 41 years. Several hypotheses have been proposed to explain this phenomenon, among which one is the protective effect of a continuous contraction of the stapedius muscle, [25] or a training effect in individuals who are routinely exposed to noise. Such an effect has been identified in hamsters; [26] it has been proposed that an increase of contractile proteins in the outer hair cells occurs in chronically noise-exposed individuals, which leads to an increased resistance to acoustic trauma. According to previous work, musicians have greater resistance to TTS after musical noise exposure than audiences. [17]

Only 47.7% of the musicians reported that they were using hearing protection during performances. The prevalence of hearing protection was higher for musical practice (64.9%). A possible explanation for this finding could be that hearing protection lowers the musician's ability to perceive all tonal nuances, which is considered important by many musicians when performing. Difficulties of hearing their own and other instruments, and interference with their own performance when using hearing protection have been reported in classical musicians. [27] Autophonia, pressure in the ears, interference on high frequency perception, [6] and affected timber and/or dynamics [28] when using hearing protection have also been reported. The percentage of hearing protection users (during practice and performance) was higher in the tinnitus group (59.1%) than both the musician groups as a whole (43.2%) and the hearing loss group (42.9%). It is conceivable that tinnitus sufferers to a larger extent focus on the necessity of hearing protection, whereas general rock musicians rarely consider hearing protection in the absence of symptoms. [27] We found a significantly poorer hearing at 6 kHz in musicians who did not use hearing protection (right: 5 dB HL, left: 4.6 dB HL). This corroborates the significant MHF difference of 2.4 dB HL that was observed in a previous study of users and nonusers of hearing protection. [20] There were no significant differences in hearing thresholds between those using custom fitted earplugs and premolded earplugs at 6 kHz but those using custom-fitted plugs had significantly better hearing (right: 11 dB HL, left 11.8 dB HL) than those using cotton for protection. We would not recommend the use of cotton for hearing protection unless it is the only alternative.

Contrary to prior results, [22] drummers did not have poorer hearing thresholds than nonpercussive instrumentalists but guitarists and bassists had worse hearing than other instrumentalists at 1 kHz in the right ear, and guitarists had poorer hearing than bassists at 3 kHz and 4 kHz (right ear), with the most pronounced difference in the 4 kHz frequency (9.5 dB HL).

From our results, we conclude that 12.4-27.2% (95% CI) of young adult rock musicians have chronic tinnitus. This is a contrast to our control sample where none of the healthy students reported chronic tinnitus. A Swedish study of rock/jazz musicians [13] found tinnitus in combination with more than one other hearing disorder in 43% of their rock/jazz musician sample. The prevalence of tinnitus in an unscreened population is 8-15%. [29],[30],[31] The median age in our musician sample was 30 years. Shargorodsky *et al.* reported in their 2010 study a prevalence of frequent tinnitus of 2.6% in the age group of 30-39 years. Hence, our data indicate a tenfold increase in the prevalence of tinnitus in rock musicians when compared to the general population. Within the tinnitus group, none of the affected musicians reported severe symptoms, and few considered their symptoms to be an impediment when performing. Among those with a hearing loss, there were even fewer individuals who considered their symptoms to be of a severe nature. The use of hearing protection was more prevalent in the tinnitus group than in the hearing loss group, which is conceivably related to a heightened awareness of hearing in tinnitus sufferers. It is also noteworthy that there were no significant differences in hearing threshold levels between the musicians with chronic tinnitus and those without tinnitus. This finding could be attributed to the known central nervous contribution to tinnitus symptomatology.

Conclusion

According to us, the prevalence of hearing loss in Norwegian young adult rock musicians is 37.8%. A moderate hearing threshold elevation at 0.25 kHz, 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz with the most prominent hearing loss at 6 kHz was observed in our rock musician sample. The most performance-exposed musicians had lower hearing thresholds at 6 kHz than the least performance-exposed musicians. Bassists and guitarists had higher hearing thresholds than vocalists. Habitual users of hearing protection had lower hearing thresholds than nonusers. Around 20% of young adult rock musicians have chronic tinnitus but no statistically significant relationship between perceived chronic tinnitus and pure-tone audiometric hearing thresholds was observed in our study. None of the musicians with chronic tinnitus reported severe symptoms, and few considered it to be an impediment to performance.

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Conflicts of interest

The authors report no conflicts of interest.

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Figures

[Figure 1], [Figure 2], [Figure 3], [Figure 4], [Figure 5], [Figure 6]

Tables

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