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Key Words

Hearing in musicians
Hearing in rock/jazz musicians
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Tinnitus
Hyperacusis
Distortion
Diplacusis

Assessment of hearing and hearing disorders in rock/jazz musicians

Evaluación de la audición y de los problemas auditivos en músicos de rock y jazz

Abstract

The aim of this study was to assess hearing and hearing disorders among rock/jazz musicians. One hundred and thirty-nine (43 women and 96 men) musicians participated. The results are based on pure-tone audiometry and questionnaire responses. According to our definition of hearing loss, tinnitus, hyperacusis, distortion and/ or diplacusis as hearing disorders, we found disorders in 74% of the rock/jazz musicians studied. Hearing loss, tinnitus and hyperacusis were most common, and the latter two were found significantly more frequently than in different reference populations. The women showed bilateral, significantly better hearing thresholds at 3–6 kHz than the men. Hyperacusis, and the combination of both hyperacusis and tinnitus, were found to be significantly more frequent among women than among men. Hearing loss and tinnitus were significantly more common among men than among women. It is important to evaluate all kinds of hearing problems (other than hearing loss) in musicians, since they represent an occupational group especially dependent on optimal, functional hearing. On the basis of our results, we suggest that hearing problems such as tinnitus, hyperacusis, distortion and/ or diplacusis should, in addition to hearing loss, be defined as hearing disorders.

Sumario

El objetivo de este estudio fue evaluar la audición y los problemas auditivos entre músicos de rock y jazz. Participaron ciento treinta y nueve músicos (43 mujeres y 96 hombres). Los resultados se basan en una audiometría tonal y las respuestas a un cuestionario. De acuerdo con nuestra definición de hipoacusia, acúfeno, hiperacusia, distorsión y/o diploacusia, encontramos problemas en un 74% de los músicos de rock y jazz estudiados. Las entidades más comunes fueron la hipoacusia, el acúfeno y la hiperacusia y éstas últimas dos, se hallaron más frecuentes que en diferentes poblaciones de referencia. Se encontró que la audición en 3–6kHz fue significativamente mejor en mujeres que en hombres. Así mismo se encontró que la hiperacusia y la combinación de hiperacusia y acúfeno, son significativamente más frecuentes entre las mujeres que entre los hombres. En los hombres fue más común la hipoacusia y el acúfeno. Es importante evaluar todo tipo de problema auditivo (además de la hipoacusia) en los músicos, puesto que se trata de un grupo especialmente dependiente del óptimo funcionamiento de la audición. Con base en nuestros resultados, sugerimos que además de la hipoacusia, se considere que el acúfeno, la hiperacusia, la distorsión y/o la diploacusia deben ser definidos como problemas auditivos.

Introduction

There is ongoing debate concerning a correlation between high sound levels and hearing disorders. The most commonly assumed causes of hearing disorders that affect musicians are the high sound levels to which they are exposed (Hart et al, 1987; Drake-Lee, 1992; Early & Horstmann, 1996). These hearing disorders can manifest themselves in several ways, and can represent a great burden for those affected.

In previous studies in classical musicians, five different hearing disorders, assumed to be caused or elicited by high sound levels resulting from music, were found: *measured hearing loss*, *tinnitus* (acoustical sensation of sounds), *hyperacusis* (hypersensitivity to low or moderate sound levels), *distortion* (music sounds out of tune), and/or *diplacusis* (pathological matching of frequency and pitch) (Kähäri et al, 2001a).

These hearing disorders may all appear singly or in different combinations. They may further imply multiple auditory disabilities in music perception and cognition, such as detection and analysis of loudness, pitch and timbre, which make it very difficult for those affected to continue working or practising

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music (Axelsson et al, 1995; Behroozi & Luz, 1997; Anari et al, 1999).

Previous studies in rock/jazz musicians have provided contrasting results. Many reports show nearly unaffected hearing in a surprisingly high number of cases, in spite of high sound levels and long exposure times. A review of previous studies done by Axelsson & Lindgren (1978) showed a prevalence of permanent hearing loss caused by music of 0–8% (an average of 5%). In their own material, they found that 22% of 83 musicians had a sensorineural hearing loss of >20 dB HL at one frequency after correction for age, occupational noise, and heredity (Axelsson & Lindgren, 1978).

The aims of this study

The primary aim of this study was to assess hearing and the incidence of hearing disorders in rock/jazz musicians. Further aims were:

1. To correlate the high-frequency pure-tone average (HFPTA) values with a reference population (International Organization for Standardization, 2000), taking age and sex into consideration.
2. To assess the incidence of other hearing disorders, such as tinnitus, hyperacusis, distortion and diplacusis, in rock/jazz musicians, and make comparisons with age-appropriate reference populations (Coles, 1984; Axelsson & Ringdahl, 1989; Fabijanska et al, 1999).
3. To assess the influence of low and high levels of weekly exposure to sound on pure-tone hearing thresholds in rock/jazz musicians.
4. To report sound level measurements made on a random selection of musical performances.

Hypothesis

On the basis of previous reports, our hypothesis is that rock/jazz musicians do not suffer from a higher incidence of hearing disorders than reference populations (non-musicians).

Materials and methods

The study was descriptive and cross-sectional. It described the actual state of the survey group at the time of the study, and was based on voluntary subjects.

It is difficult, if not impossible, to obtain an exact figure for the number of active musicians in Sweden today. After consulting the two major Swedish musicians' and artists' unions, we estimated that 21000 people try to support themselves by playing or working with music, including about 7000 music teachers. This leaves about 14000 people of different ages spread all over Sweden who work actively with music in various forms, either as songwriters, musicians in different music genres, singers, disc jockeys, or sound technicians.

Artist agencies and music production companies supplied us with the addresses of 300 supposedly active musicians in southwestern Sweden. Personal invitations were sent out, explaining the study and the inclusion criteria. The criteria were age of at least 25 years and a history of a minimum of 5 years as a professional musician. The subjects should primarily be working with rock/jazz music in live performances, and not as studio musicians/technicians, who are mainly exposed to sound via earphones. The subjects were to have no other obvious reason for a supposed hearing disorder than high musical sound levels. Finally, the invitation made it clear that the subjects had to be prepared to participate in one to three examinations (2–5 h) without financial compensation.

Thirty of the 300 musicians who were invited did not meet the inclusion criteria, and were therefore excluded. After making phone calls and reaching 40 musicians who did not answer our mailed invitation, we found that the reasons for not participating were not meeting the inclusion criteria, too long a distance to travel, or professional engagements. Four of the invited musicians stated that they were not interested in participating in this kind of study, and another 87 were not reachable by either phone or mail.

In all, 139/230 (60%) entered and completed the study (43 women and 96 men). The median age was 35 years (range 26–47 years) for women and 37 years (range 26–51 years) for men.

Pure-tone audiometry

Pure-tone audiometry was done using an Interacoustic AC3 audiometer with earphones (TDH 39 with MX-41-AR cushions) (International Organization for Standardization, 1989). The audiometer was calibrated according to ISO 389-1 (International Organization for Standardization, 1991) and ISO 389-3 (International Organization for Standardization, 1994), and all hearing measurements took place in a 140×140 cm soundproof booth (Tegnér T-room) that fulfilled standard acoustical requirements. The test order of the left and right ears was pseudo-randomized. The test frequencies were 0.25, 0.5, 1, 1.5, 2, 3, 4, 6 and 8 kHz. An ascending measurement technique was used, and threshold values were established three times at each test frequency. To avoid temporary threshold shifts, all musicians were tested on their day off or after a hearing rest (≥8 h without music exposure). If a hearing loss (for criteria, see below) was detected, a bone conduction hearing test was done and a tympanometry test conducted using a Grason Stadler GSI33, in order to exclude conductive hearing loss.

The criterion for normal hearing was defined in the same manner as in previous studies of classical musicians, using a pure-tone threshold at ≤20 dB HL at the frequencies tested (0.25–8 kHz). Our criterion for hearing loss was ≥2 frequencies at ≥25 dB HL or one frequency at ≥30 dB HL in ≥1 ear, measured with pure-tone audiometry (Kähäri et al, 2001a,b).

Questionnaire

All 139 musicians completed a questionnaire (250 questions) partly based on questions used in a previous study (Kähäri et al, 2001a,b) and a tinnitus form used at Sahlgrenska University Hospital in Göteborg (Socialstyrelsen, 2000). The latter is a Swedish version of 'Tinnitus severity gradings; cross sectional studies' (Coles et al, 1991). The presence of tinnitus, hyperacusis, distortion or diplacusis was established by the questionnaire. Separate sections for each of these hearing disorders comprised 14 primary and four sub-questions each, to establish the occurrence, elicitation factor, duration, location and severity of each hearing disorder.

Tinnitus was defined as a spontaneous or evoked sensation of sounds, e.g. ringing or buzzing, often combined with pure tones

that occur in the absence of an external sound source. The different sounds could be uni- or bilaterally located in the ears, or experienced and located somewhere in the head.

Hyperacusis was defined as hypersensitivity to the loudness of sounds, including a decreased pure tone, and uncomfortable loudness level of specific sounds normally not experienced as loud, uncomfortable or annoying.

Distortion was defined as frequencies, overtones and/or harmonics that were not experienced in their true original form but as distorted, unclear, fuzzy and out of tune.

Diplacusis was defined as a pathological matching of frequency and pitch that may involve dissonance or a sudden change of pitch when a change in loudness occurs.

On the basis of results of pure-tone audiometry that determined hearing loss, and on the basis of reported questionnaire results establishing the presence of tinnitus, hyperacusis, distortion, and diplacusis, we divided the musicians into groups: those with no hearing disorders (unaffected), and those with hearing disorders (affected). The group with hearing disorders (affected) was further divided into musicians with one discrete hearing disorder (hearing loss, tinnitus, hyperacusis, distortion, or diplacusis), and into subgroups with >1 hearing disorder (=1+1–4 hearing disorders). The musicians could belong to several subgroups, since it was demonstrated that several of them were affected by more than one hearing disorder.

The influence of low and high levels of weekly exposure to music on hearing thresholds

In analysing the questionnaire, we identified and defined two groups of musicians who reported either a low or a high degree of weekly exposure to music. A third group of musicians was identified and defined as medium exposed. The definitions were based on their reported number of workdays per week, hours of music exposure per workday, and standard work time/week in Sweden, which is set to 40 h/week (100%).

Our definitions were as follows.

Musicians exposed for 3 days or less per week and for 4.5 h or less per working day were considered as *low exposed* (n=39/139, 15 women and 24 men).

Musicians exposed for 3.5–7 days per week and for at least 5 h per working day were considered as *high exposed* (n=51/139, 19 women and 32 men).

Musicians who fell into the low- or high-exposure groups regarding workdays per week but not according to hours per working day (or vice versa) were defined as *medium exposed* (n=49/139, 9 women and 40 men). This medium group was excluded from further analysis; only hearing thresholds in the low- and high-exposure groups were analysed.

To identify whether differences in weekly sound exposure influenced hearing thresholds, pure-tone hearing thresholds, in the left and right ears, were tested for significance. The difference between the two groups with respect to sex was also tested for significance, i.e. in women with low exposure versus women with high exposure, and the same for men.

Sound levels

Sound level measurements of a random selection of musical performances were done, for both musicians (four measurements) and listeners (eight measurements). The measurements were made with a Larson and Davis 706 dose meter attached to the collar of the shirt near the subject's ear.

Sweden currently has two different ways of viewing recommended safety limits regarding noise at work and musical activities.

FOR MUSICIANS

The Swedish Occupational Safety and Health Administration has regulations and recommendations for calculated noise-induced hearing loss risk based on 85 dB $L_{Aeq\ 8h}$, with 115 dB(A) and 140 dB(C, peak) as maximum levels (Occupational Safety and Health Administration, 1992).

FOR LISTENERS

The recommendation of the Swedish National Board of Health and Welfare is set at 100 dB L_{Aeq}, with 115 dB(A) as the maximum value during a musical performance (no maximum peak level is given). This higher value is based on research using the hypothesis that 'musical noise' is not as injurious as conventional noise, e.g. industrial noise. The Swedish National Board of Health and Welfare has therefore added 5 dB to the 85 dB L_{Aeq} limit given by the Swedish Occupational Safety and Health Administration. They calculate 100 dB L_{Aeq} to be a safe limit for a duration of 1 h/day (or 5 h/week), on the assumption that other exposure to sound does not exceed 85 dB L_{Aeq} during the rest of the week (National Board of Health and Welfare, 1996).

High-frequency pure-tone average hearing threshold values

We compared the HFPTAs of the musicians with those of ISO 7029, which takes into account age and sex for otologically normal persons (International Organization for Standardization, 2000). Calculations were made of HFPTAs for the left and right ears. Calculated HFPTAs were average values based on 3, 4, 6 and 8 kHz. To compare the incidence of tinnitus and hyperacusis, Coles (1984), Axelsson & Ringdahl (1989) and Fabijanska et al (1999) were used as age-appropriate reference materials. No reference populations were found for distortion and diplacusis.

Statistics

Statistical analyses were done with SPSS 10.0 using the Mann–Whitney U-test to assess any significant differences between the sexes and different hearing disorders. The Wilcoxon signed rank test and Students' t-test (two-tailed) (MS Excel 5.0) were used to assess any significant differences between ears and different hearing disorders within sexes. The significance level was set at ≤ 0.05.

Results

Questionnaire

The musicians played primarily in settings with four to six musicians, and in all cases with amplified music. The mean duration of professional musical activities was 19 years (range: 5–40 years). The mean durations of musical activities per week and day were 4 days/week (range: 1–7 days) and 5 h/day (range: 2–12 h.).

Pure-tone audiometry: all subjects

The results of pure-tone median audiograms for women and men are shown in Figures 1 and 2. The women showed bilaterally significantly better hearing threshold values at 3, 4 and 6 kHz compared to men, who also showed a broader distribution within the 10–90th percentiles. No significant hearing threshold difference between the left and right ears was found among the women (Figure 1). Men showed slightly, but significantly, worse hearing thresholds in the left ear at 0.25, 1.5, 2, 3 and 4 kHz than in the right ear, and a poorer hearing threshold at 1 kHz in the right ear as compared to the left (Figure 2).

Number of affected musicians

Table 1 shows the numbers of affected and unaffected women and men with one discrete hearing disorder, with >1 hearing disorder, and in the major groups of combined hearing disorders.

Hearing thresholds for musicians with one, discrete hearing disorder compared to unaffected musicians

Ten men were found to have hearing loss; five had tinnitus and five hyperacusis. We found no significant difference (except for a poorer hearing threshold at 2 kHz in the right ear among those with hyperacusis) when we compared pure-tone hearing thresholds for the two groups. However, significantly *better* hearing thresholds were found in the men with tinnitus at 1.5 and 2 kHz in the right ear and at 4 kHz in the left ear in a comparison of the five men with discrete tinnitus with the unaffected men. When the men with hyperacusis were compared with unaffected men, we found significantly worse hearing thresholds for the men with hyperacusis at 0.25, 0.5, 1, 2 and 3 kHz in the right ear, and at 0.25 and 6 kHz in the left ear. Hearing thresholds were distributed well within the normal range for both groups, with a maximum value at 6 kHz (16 dB HL) for the left ear in the hyperacusis group.

Hearing thresholds for women with >1 hearing disorder, compared to unaffected women

Significantly worse pure-tone hearing thresholds were found at 0.25, 0.5, 4 and 6 kHz in the right ear and at 0.25 and 0.5 kHz in the left ear in a comparison of women with hearing loss with female musicians who were unaffected. Women with tinnitus and hyperacusis showed significantly worse hearing thresholds at 4 kHz in the right ear, and those with diplacusis at 6 kHz in the left ear, as compared to unaffected women.

Hearing thresholds for men with >1 hearing disorder, compared to unaffected men

Bilaterally significantly poorer hearing thresholds at 2, 3, 4, 6 and 8 kHz were found in men with hearing loss compared to male musicians who were unaffected (Figure 3). The same was true among men with tinnitus (except for 2 kHz in the left ear) and hyperacusis as compared to unaffected men. The distortion group was found to have significantly poorer pure-tone hearing threshold values at 3 and 4 kHz in the right ear (but not in the left) as compared to unaffected men. Poorer hearing thresholds were found in the left ear, with a maximum at 4 kHz in all groups of men with >1 hearing disorder, except for those with hyperacusis, where values in the left and right ears merged at 4 and 6 kHz, well within the normal range (<20 dB HL).

Three men were affected by all five different disorders. Each of these men had a history of working with music for an average 22 years. Their current sound exposure was 5 days/week and 9 h/day. All three played drums, and two also played the saxophone. Two of the three used customized earplugs during all rehearsals and performances.

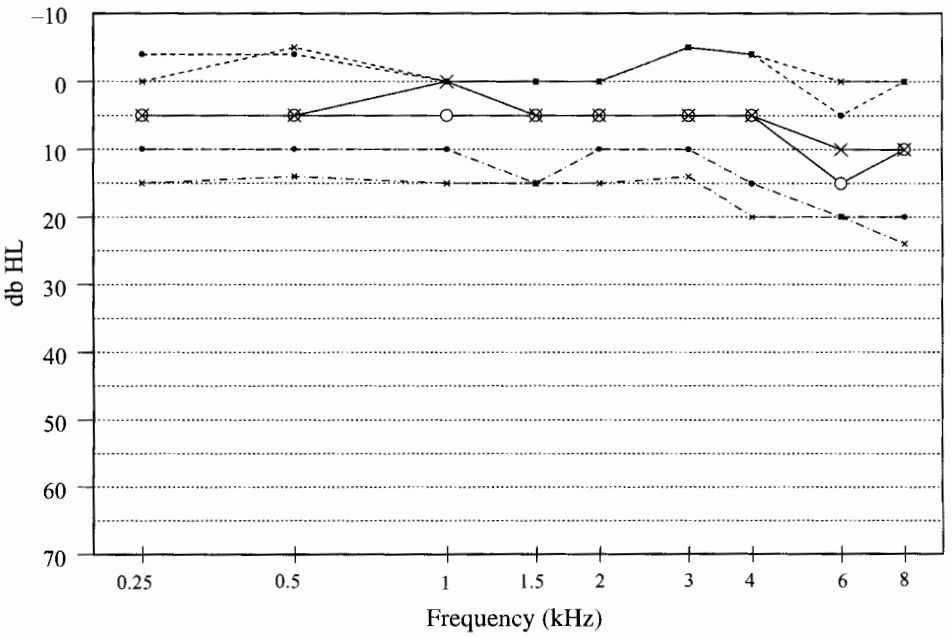

Figure 1. Pure-tone hearing thresholds for all 43 women. Solid lines: 50th percentile; x, left ear; o, right ear. Dotted lines: 10th percentile; x, left ear; o, right ear. Dashed lines: 90th percentile; x, left ear; o, right ear.

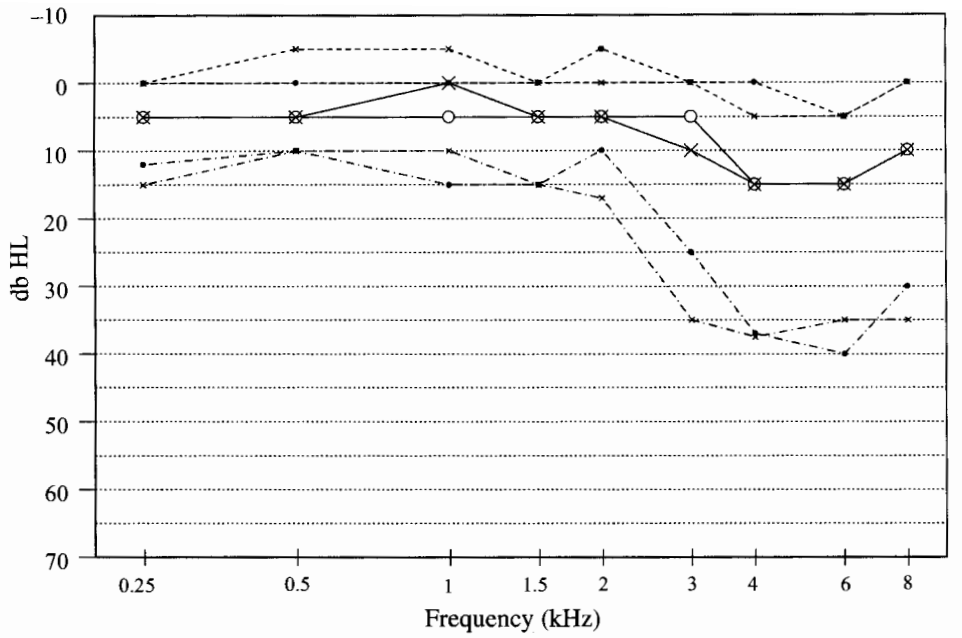

Figure 2. Pure-tone hearing thresholds for all 96 men. Solid lines: 50th percentile; x, left ear; o, right ear. Dotted lines: 10th percentile; x, left ear; o, right ear. Dashed lines: 90th percentile; x, left ear; o, right ear.

Table 1. The numbers of unaffected and affected musicians, musicians with one discrete hearing disorder, subgroups of 1+1–4 (>1) hearing disorders, and numbers of musicians in major groups of combined hearing disorders.

	Total, 139 *n (%)*	*Females, 43* *n (%)*	*Males, 96* *n (%)*	*p-value*
Number of unaffected and affected musicians				
Unaffected hearing	36 (26)	16 (37)*	20 (21)	0.00
Affected hearing	103 (74)	27 (63)	76 (79)*	0.00
Number of musicians with one discrete hearing disorder				
Hearing loss (measured)	11 (8)	1 (2)	10 (10)*	0.00
Tinnitus (reported)	7 (5)	2 (5)	5 (5)	0.14
Hyperacusis (reported)	9 (6)	4 (9)	5 (5)	0.20
Distortion (reported)	1 (0)	0 (0)	1 (0)	–
Diplacusis (reported)	0 (0)	0 (0)	0 (0)	–
Number of musicians with >1 (1+1–4) hearing disorders				
Hearing loss (measured)	57 (41)	7 (16)	50 (52)*	0.00
Tinnitus (reported)	60 (43)	17 (40)	43 (45)*	0.00
Hyperacusis (reported)	54 (39)	24 (56)*	30 (31)	0.00
Distortion (reported)	24 (17)	6 (14)	18 (19)*	0.00
Diplacusis (reported)	4 (3)	0 (0)	4 (4)	–
Number of musicians in the three major groups of combined, hearing disorders				
Hearing loss+tinnitus	30 (22)	4 (9)	26 (27)*	0.00
Hearing loss+tinnitus +hyperacusis	15 (11)	3 (7)	12 (12)*	0.05
Tinnitus+hyperacusis	19 (14)	11(26)*	8 (8)	0.02

Significant difference ($p \leq 0.05$) in number between sexes and highest values.

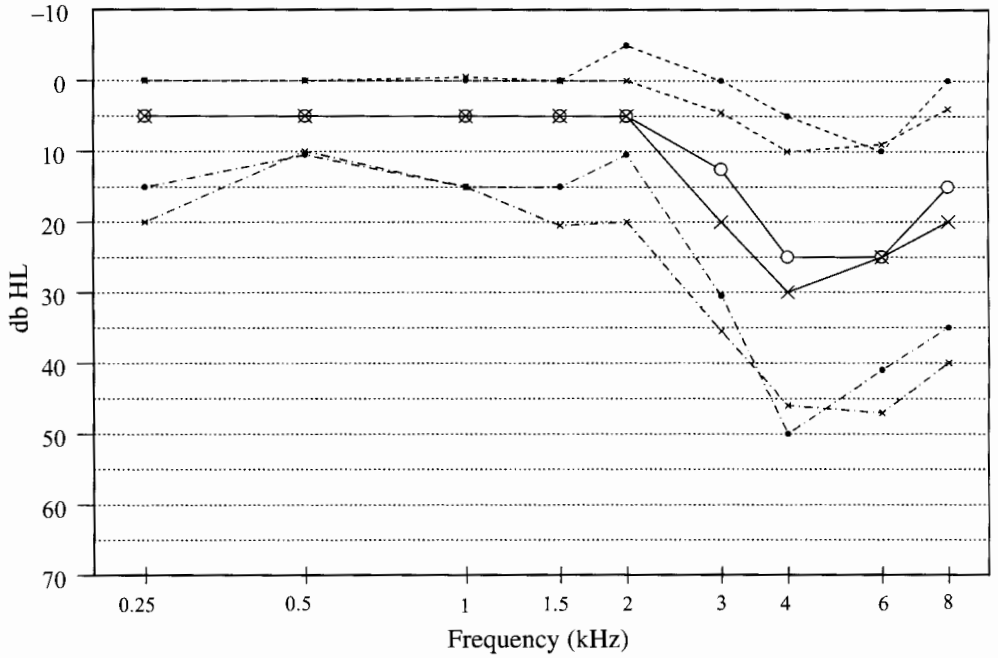

Figure 3. Pure-tone hearing thresholds for 50 men with hearing loss. Solid lines: 50th percentile; x, left ear; o, right ear. Dotted lines: 10th percentile; x, left ear; o, right ear. Dashed lines: 90th percentile; x, left ear; o, right ear.

The influence of low and high degree of weekly sound exposure on hearing thresholds

The musicians in the low-exposure group worked an average of 1.5 days/week (range: 0–3 days) and 2 h/workday (range: 0–4.5 h), which is an average of 3 h/week (range: 0–13.5 h). The high-exposure group reported working an average of 5 days/week (range: 3.5–7 days) and 6.5 h/workday (range: 5–12 h), which is an average of 32.5 h/week (range: 17.5–84 h), and significantly more than the value for the low-exposure group. This assessment represented only the current situation, and did not take history of sound exposure into account. The two groups had similar histories of working with music, however, with an average of 19 years (the range in the low-exposure group was 5–36 years, and that in the high-exposure group was 8–37 years).

The low-exposure group included 28 (72%) musicians with >1 hearing disorder, 10 women and 18 men. The high-exposure group included 34 (67%) musicians with >1 hearing disorder, 12 women and 18 men. There was no significant difference in severity in terms of the number of different hearing disorders between the two groups (average 1.2/1.5 disorders and range 0–5 in the two groups).

Significantly poorer hearing threshold values (for both women and men) were found at 4 kHz in the right ear in the low-exposure group than in the high-exposure group. Pure-tone hearing thresholds were distributed well within 20 dB HL for both groups, except at 6 kHz in the low-exposure group, where the left ear reached 20 dB HL.

A comparison of pure-tone hearing thresholds in women with low exposure and women with high exposure showed no significant difference. We found significantly poorer hearing thresholds in men with low exposure (but within 15 dB HL) at 3 and 4 kHz in the right ear than in men with a high weekly sound exposure.

Sound level measurements

Sound level measurements made close to the musicians' ears showed that four of four measurements exceeded acceptable values. Measurements made at the listeners' position showed acceptable values in seven of eight measurements with respect to the sound level recommendations, although the dB(C) levels were exceeded in four of eight measurements. All quiet pauses were excluded (Table 2).

Comparison of HFPTAs and incidence of hearing disorders with reference populations

When each individual's bilateral HFPTAs were plotted together with the ISO 7929 values, it was found that women were distributed at or just below the ISO 7029 median according to their age (Figure 4). This was also the case in the majority of the men, although 22/96 (23%) fell outside the 90th percentile (Figure 5). Of the 22 men who were distributed outside the 90th percentile, 11 were mainly string players, four were disc jockeys, three were percussionists, one was a sound technician, one was a wind player, one was a keyboard player, and one was a vocalist. The HFPTAs of the right ear were distributed outside the 90th percentile in five cases, and those of the left ear in eight cases. A bilateral distribution outside of the 90th percentile was found in nine cases. The following significant differences were found in comparing the incidence of hearing disorders (musicians with >1 hearing disorder, women and men) with age-appropriate reference populations. Tinnitus was found in 43% of the musicians as compared to 6–20% (Coles, 1984; Axelsson &

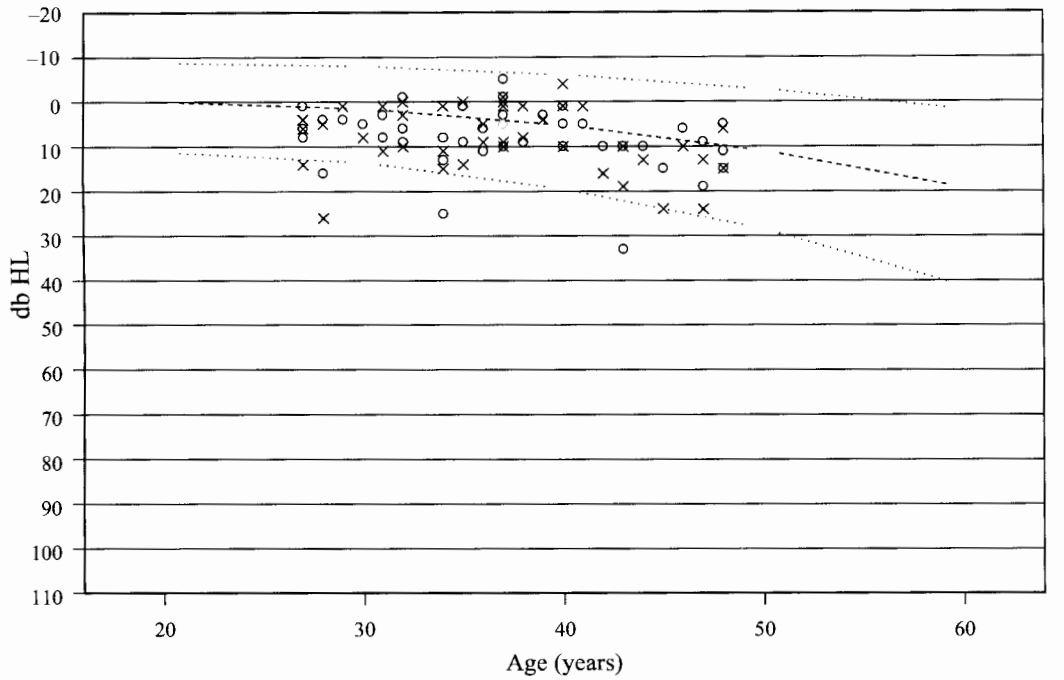

Figure 4. The high-frequency pure-tone average (HFPTA) values (3, 4, 6 and 8 kHz) for 43 women, according to age. x, left ear; o, right ear. The figure includes the 10th, 50th and 90th percentiles for ISO 7029 HFPTAs.

Table 2. Results of random sound level measurements.

Musical style and type of premise	*No. of members in setting*	*Position of dose meter microphone*	*Measurement time*	L_{Aeq}	*dB(A) max. (fast)*	*db(C) (peak)*
Rock/medium sized discotheque	4	On listener 6 m from stage	50 min	***104.3***	***117.6***	***150.1***
Folk music/restaurant with small stage	1	On listener 1.5 m from loud speaker	1 h 56 min including pause)	90.8	108.8	129.7
			1 h 38 min (excluding pause)	91.4	108.8	129.7
Rock/large stage and discotheque	5	On listener 10 m from loudspeaker, 25 m from stage	1 h 55 min	93.8	114.8	***>140***
Jazz/jazz club (two measurements)	11	On listener 5 m from stage to the left and the right side	2h 59 min	91.2	111.7	136.9
				94.8	***117.2***	***145.8***
Blues/jazz club (2 measurements)	4	On listener 5 m from stage to the left and the right side	2 h 5min	97.4	***122.2***	***153.3***
				98.5	113.8	130.8
Punk jazz/jazz club	3	On drummer	1 h 5min	***108.9***	***124***	***148.9***
Jazz+theatre/Jazz–theatre club	3	On drummer	1 h 55min	***100.8***	***123.9***	***141.4***
Rock/small stage in small-sized discotheque	4	On basist	50 min	***115***	***129.4***	***142.8***
Rock/large stage and discotheque	5	On basist	1 h 30 min	***106***	***120***	133.5

Bold italics indicate exceeded values according to current Swedish regulations.

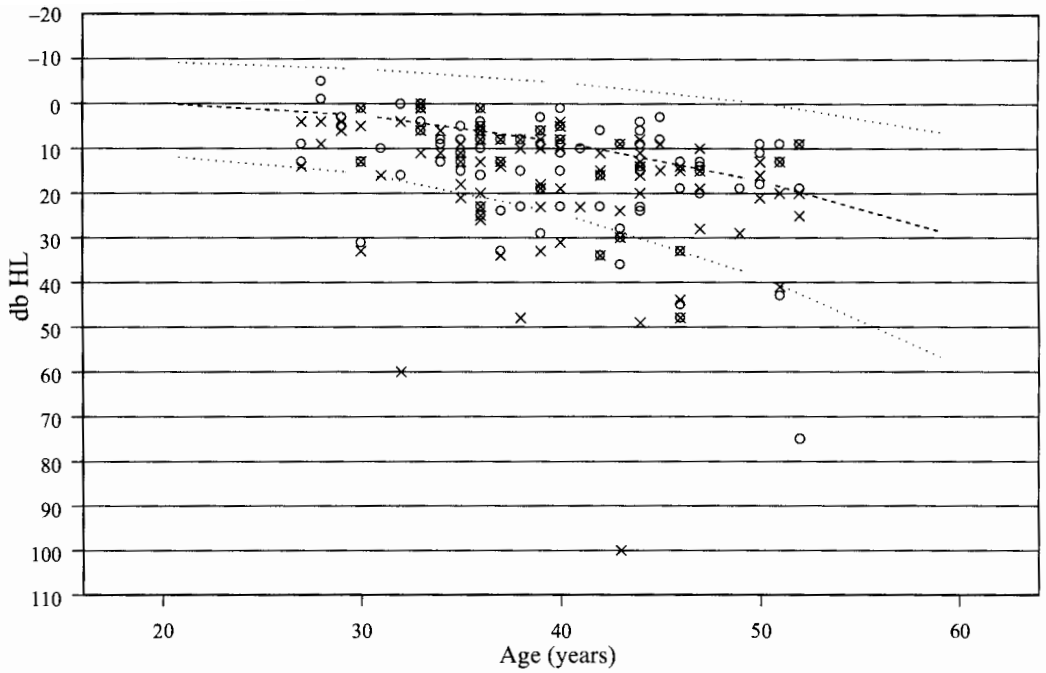

Figure 5. The high-frequency pure-tone average (HFPTA) values (3, 4, 6 and 8 kHz) for 96 men, according to age. x, left ear; o, right ear. The figure includes the 10th, 50th and 90th percentiles for ISO 7029 HFPTAs.

Ringdahl, 1989; Fabijanska et al, 1999), and hyperacusis in 39% as compared to 15% (Fabijanska et al, 1999).

Discussion

The subjects, whom we consider to be representative of Swedish rock/jazz musicians, were all volunteers, and the participation rate of 60% can be considered good. Among Swedish musicians, the distribution of women and men who are members of the Swedish Musicians' Union is 10% women and 90% men (G. Ivarsson, personal communication). Since one of our aims was to study any possible sex differences, it was necessary to include a larger percentage of females. The proportions were 30% women and 70% men in our study.

The questionnaire and the questions used in this study were sufficient for our needs, since our aim was to assess the occurrence, elicitation factor, duration, location and severity of different hearing disorders, not primarily the degree of severity. The pure-tone audiometry test method followed standard procedures. Our audiological criteria, to some extent, take into account the risk of a bias effect resulting from the test method (Arlinger, 1985). Since the subjective hearing tests involve several risks because of the test method, it should be borne in mind that mathematically statistically significant differences are not always equivalent to important medical differences, especially in measurements of rather small differences in hearing thresholds made on a single occasion.

With our definition of hearing disorder, the rate of disorders among rock/jazz musicians was much higher than we anticipated (74%). A previous study of rock musicians showed a lower incidence of hearing loss (Axelsson & Lindgren, 1977, 1978). The authors suggested 'that there might be a difference in inner ear circulation on a hormonal basis if high sound levels are experienced as *beautiful music* or *terrible noise*' as an explanation of the low incidence (13%) of hearing loss that they found. In a follow-up study 16 years later, a 'slight to moderate' high-frequency hearing loss was found in 22% of those who were still active musicians. The authors considered this a low degree of hearing loss, and offered the same hypothesis as above (Axelsson et al, 1995). However, when hearing loss, tinnitus and hyperacusis were considered, the actual frequency of hearing disorders was 68%, a rate not significantly different from that found in the present study.

It has been shown in large epidemiological studies that women have better hearing thresholds than men (International Organization for Standardization, 2000). This was also true in the present study for 3, 4 and 6 kHz, bilaterally. In our study, the women had a significantly higher proportion of hyperacusis and combined tinnitus and hyperacusis than the men. On the other hand, men showed a significantly greater proportion of hearing loss and combination of hearing loss and tinnitus than women. There may possibly be psychosocial or genetic and/or hormonal factors behind these findings, but further research is needed to evaluate them. There could also be a difference in pathology between hearing loss and tinnitus, hyperacusis, distortion, and diplacusis. This could in part explain why relatively mild hearing losses were found, indicating intact hair cells but an abundance of other hearing disorders that may have their origin in other parts of the auditory system than the cochlea. When comparing the hearing thresholds of the five men with discrete tinnitus and the five men with discrete hyperacusis with those of unaffected men, we found interesting differences. In spite of normal hearing thresholds, we found that those affected by tinnitus had three significantly better pure-tone hearing thresholds than the unaffected men. In contrast, men with hyperacusis had seven pure-tone hearing thresholds that were poorer than those of unaffected

men. This may indicate a different origin, higher up in the auditory system than the cochlea, in those with tinnitus compared to those musicians suffering from hyperacusis. However, the samples were small, and this could increase the risk that they were non-representative. Hyperacusis is probably the hearing disorder that causes the greatest suffering among musicians. This is indeed distressing, especially for musicians whose work depends on a finely tuned hearing ability. Hyperacusis makes it difficult for the musicians to perform, and is often accompanied by fear and sometimes depression, which has been shown in tinnitus cases (Hart et al, 1987; Zöger et al, 2001).

Significantly poorer hearing thresholds (except for 1 kHz) were found in the left ear than in the right ear among male musicians. While this cannot easily be seen visually in Figure 2, the statistically significant differences observed were related to the lack of symmetrical distribution of hearing thresholds between the ears. These small left–right ear differences are, however, consistent with previous findings in classical musicians (Kähäri et al, 2001a,b). It is often suggested that left- and right-ear differences in musicians are caused by instruments being held close to the left ear, consequently exposing the left side to higher sound levels than the right (Chasin, 1996). The sound environment of rock/jazz musicians is mostly an amplified one, however, and sounds are reflected from many angles by monitors and loudspeakers, and the musicians often move about on the stage, which, of course, would in part contradict this hypothesis.

The low- and high-exposure groups showed the same number of hearing disorders, despite differences in sound exposure, which was somewhat surprising. While both groups had worked with music for an average of 19 years, we found no major significant differences in comparisons of pure-tone hearing thresholds between the two groups. Even more surprisingly, the differences we did find showed poorer hearing thresholds in the low-exposure group. However, the lack of any greater difference between the two groups may reflect a bias effect, since the exposure time that they reported at the time of the study gives little indication of their exposure in the past.

The sound levels measured in the musicians' position were high. The safe exposure time was exceeded after 1–45 min in the different measurements. Furthermore, all dB(A) maximum and all (except one) dB(C) values were exceeded, which indicates a pronounced risk of damage to the inner ear. Measurements carried out in the listeners' position were not as high, but dB(A) maximum and dB(C) levels were exceeded in four of eight measurements. Considering that our subjects were experienced musicians with a long history of excessive sound exposure, and on the basis of findings in other studies and our random sound level measurements, we would not have been surprised to find even more profound hearing losses. There may be several reasons for the hearing losses not being as severe as might be expected. Perhaps there is a positive effect of musical sound exposure which stimulates and activates the stapedial muscle, and also induces a toughening effect (Colletti & Sittoni, 1986; Canlon et al, 1992; Miyakita et al, 1992). There is also a possibility that listeners and musicians have varying susceptibilities to noise-induced hearing disorders, possibly resulting from genetic factors (Cremers, 1996).

There is, unfortunately, a lack of age-appropriate reference populations in which such hearing disorders as hyperacusis, distortion and diplacusis have been investigated. Our results showed a significantly higher proportion of hearing disorders among the rock/jazz musicians we studied than among the reference populations available. Using the musicians' HFPTAs together with ISO 7029 HFPTA values is one way to assess high-frequency hearing in terms of a summarized picture of the whole group. However, there is also a possibility of misleading information, because the average values for 3, 4, 6 and 8 kHz may hide notches in the audiogram at discrete frequencies. It should also be noted that the ISO 7029 values were averaged for practical reasons. Consequently, these results can be considered to be informative but should be treated with care. In our study, the majority of the HFPTAs of women and men were distributed between the 50th and 90th percentiles, which was comparable to the findings of earlier studies in classical musicians (Kähäri et al, 2001a,b). Twenty-two men showed highly elevated HFPTAs worse than the 90th percentile, however, which must be considered alarming. Instruments played by these men differed, and no typical instrument exposure was noted, except that four of them also worked as disc jockeys, and during these occasions used earphones.

When calculating hearing disorders among classical musicians in the same manner as in the present study, we found hearing disorders in 68% (Kähäri et al, 2001a). This proportion is not significantly different from the findings in the present study. We found differences in the occurrence of different hearing disorders and differences in hearing threshold configuration, however. Male rock/jazz musicians with hearing losses showed a notch indicating a noise-induced hearing loss with maximum loss at 4 kHz, whereas the classical musicians showed a notch at 6 kHz. Several differences in work conditions, environment and music between the two types of musicians exist, and it would be interesting to study this further.

The pure-tone audiogram gives us a first image of a hearing loss, and is a basic tool in the diagnosis of congenital or acquired hearing losses. However, pure-tone audiometry has been stated in previous studies not to be a sufficiently sensitive test alone to detect the early stages of hearing disorders and to allow a full assessment of hearing (Chasin, 1996; Kähäri et al, 2001a). We strongly recommend that a thorough hearing assessment include extended measurements such as speech in noise, uncomfortable loudness level in the case of pure tones, and otoacoustic emission tests, along with assessment of other hearing disorders. These extended measurements, which were made in our main study, will be analysed and presented in later reports.

Summary and conclusion

Hearing disorders were found in 74% of 139 rock/jazz musicians. Hearing loss, tinnitus and hyperacusis were the most common hearing disorders, and occurred significantly more often among rock/jazz musicians than in different reference populations. Hyperacusis and a combination of tinnitus and hyperacusis were significantly more common among women than among men, and hearing loss and the combination of hearing loss and tinnitus were significantly more common among men than among women. Men displayed slightly but significantly elevated hearing thresholds in the left ear as compared to the right.

The sound level measurements made on a random sample of musical performances showed excessively high sound levels. These indications of high sound levels are alarming, and action

should be taken on the basis of extended measurements in order to secure a safe sound environment for musicians and listeners.

Our initial hypothesis that rock/jazz musicians do not have a higher proportion of hearing disorders than non-musicians must be rejected. A high proportion of the rock/jazz musicians (74%) studied here do have hearing disorders, and more than 50% of the musicians had very distressing combinations of hearing disorders.

Musicians, as an occupational group, are especially dependent on optimal and functional hearing, and we thus consider further research in this field to be of great importance. On the basis of results presented in this article, we suggest that hearing problems such as tinnitus, hyperacusis, distortion and/or diplacusis, in addition to hearing loss, should be defined as hearing disorders, and in the future should be reported together with hearing losses.

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