Exposure to music and noise-induced hearing loss (NIHL) among professional pop/rock/jazz musicians

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Abstract
Noise-induced hearing loss (NIHL) has been extensively studied in industrial work environments. With the advent of new technologies, loud music has been increasingly affecting listeners outside of the industrial setting. Most research on the effects of music and hearing loss has focused on classical musicians. The purpose of the current study was to examine the relationship between the amount of experience a professional pop/rock/jazz musician has and objective and subjective variables of the musician’s hearing loss. This study also examined professional pop/rock/jazz musicians’ use of hearing protection devices in relation to the extent of their exposure to amplified music. Forty-four pop/rock/jazz musicians were interviewed using the Pop/Rock/Jazz Musician’s Questionnaire (PRJMQ) in order to obtain self-reported symptoms of tinnitus and hyperacusis. Forty-two of the subjects were also tested for air-conduction hearing thresholds in the frequency range of 1-8 kHz. Results show that the extent of professional pop/rock/jazz musicians’ exposure to amplified music was related to both objective and subjective variables of hearing loss: Greater musical experience was positively linked to higher hearing thresholds in the frequency range of 3-6 kHz and to the subjective symptom of tinnitus. Weekly hours playing were found to have a greater effect on hearing loss in comparison to years playing. Use of hearing protection was not linked to the extent of exposure to amplified music. It is recommended that further research be conducted with a larger sample, in order to gain a greater understanding of the detrimental effects of hours playing versus years playing.

Keywords: Hearing loss, hyperacusis, musicians, noise-induced hearing loss (NIHL), noise, tinnitus

Introduction
Exposure to noise, environmental or occupational, can bring on a wide array of effects, depending on factors such as level and characteristics of the hazardous noise, the duration of the exposure and individual susceptibility.[1]

The investigation of sensorineural, cochlear hearing loss relies upon audiometric data such as pure tone audiometry (behavioral audiometry) and otoacoustic emissions (OAE).[2]

Audiometric behavioral testing is also the main tool recommended by NIOSH in recordkeeping and assessing hearing decline at the work place (NIOSH, p. 54, 5.3 exposure assessment).[9]

Professional musicians are extensively exposed to sound levels that may be detrimental to their hearing. Research on continued exposure to loud music among musicians, has shown adverse effects on the auditory system.[4-13] These studies correlate professional hazards to hearing damage in accordance with criteria stemming from noise-induced hearing loss (NIHL).[14,15]

The use of criteria originating from industrial measures is common in research literature on exposure to music. Zhao et al.[16] states that excessive exposure to loud music causes various hearing symptoms such as tinnitus, and leads to a risk of permanent hearing damage, known as NIHL or noise-induced permanent threshold shift (NIPTS).[2] Puissant et al.[12] tested 8 college-aged trumpeters with a series of preliminary hearing tests prior to a one hour practice session and at several different stages after practice, using damage risk criteria for NIHL. Noise levels exceeded 85 dB for an average of 43.73 min per session. They concluded that trumpeters are at a significantly increased risk of hearing loss over that contributable to age alone. Phillips, Henrich and Mace[11] showed that overall prevalence of NIHL was 45%, with 78% of notches occurring at 6000 Hz among 329 student classical musicians aged 18-25 who played on a variety of
With controlled acoustics in a permanent rehearsal hall and permanent seating within a section, which allows for repeated exposure in steady conditions. In contrast, professional pop/rock/jazz musicians fluctuate between extremely busy periods of high demand and periods of unemployment. As a result, there is a relatively large body of research pertaining to classical musicians, whereas research on professional pop/rock/jazz musicians is sparse.

Although musicians have the power and ability to protect themselves from the risks of NIHL, they are not always consciously ready, socially willing or professionally able to reduce their harmful exposure to amplified music, due to the fact that the use of hearing protection can sometimes hinder the quality of performance. Huttunen et al. found ear plug use low among 15 classical musicians due to hampered listening to their own and to their colleagues’ playing. Musicians reported earplugs affecting their timbre and dynamics, and were found to be uncomfortable. It was reported that support and determination were required in order to become accustomed to hearing protectors. Killion discusses factors influencing use of hearing protection by trumpet players. Trumpet players reported lack of acclimatization time, shallow earmold seal leading to a large occlusion effect, and hearing loss of harmonic overtones. Thus, musicians often find themselves risking their health in order to achieve a better musical experience.

The purpose of the current study was to examine the relationship between the amount of experience a professional pop/rock/jazz musician has and subjective and objective variables of hearing loss. These were evaluated in two ways: Self-reporting by professional pop/rock/jazz musicians using a questionnaire based on Laitinen and Poulsen and an assessment of air-conduction thresholds at 1, 2, 3, 4, 6, and 8 kHz. The research hypotheses were:

1. Professional pop/rock/jazz musicians’ experience will positively predict hearing thresholds of 3-6 kHz.
2. Professional pop/rock/jazz musicians’ experience will positively predict self-reported symptoms (tinnitus and hyperacusis).
3. Professional pop/rock/jazz musicians’ experience will positively predict the use of hearing protection.
4. Self-reported symptoms (tinnitus and hyperacusis) will positively predict hearing thresholds of 3-6 kHz.

Methods

Subjects

44 professional pop/rock/jazz musicians aged 20-64 were sampled (mean age 37.45, S.D. = 9.7). Eight were female (18.2%) and 36 male (81.8%).

Participants played various instruments: Drums/percussion (22.7%), guitar (34.1%), bass (electric/upright) (9.1%),
Initially, professional musicians were approached. The response rate was 49.44%. 44 participants answered the questionnaire. 41 participants underwent a hearing threshold examination. Therefore, data pertaining to subjective symptoms includes 44 subjects and data pertaining to objective symptoms includes 41 subjects.

Procedure
A 1 h meeting was held with each participant, during which the questionnaire was completed in the presence of the examiner, to allow for clarifications and to ensure the participant completed all the questions. This was followed by an audiometric hearing threshold assessment of the frequency range of 1-8 kHz (by ascending intensity, up 5 dB down 10 dB), in the professional musician’s home or studio, using a portable audiometer, manufactured by Interacoustics, model AS208, with TDH39 headphones, manufactured by Telephonics. Hearing threshold evaluations were conducted after 12 hours of rest and with no immediate prior exposure to amplified music, according to the protocol of audiometric testing of occupational hazard.

Questionnaire
Laitinen and Poulsen used a questionnaire for orchestral musicians, comprised of several standardized questionnaires pertaining to subjective symptoms. The questionnaire, comprised of 91 questions was completed by 145 classical musicians from 3 orchestras in Finland. The questionnaire for the current study, the Pop/Rock/Jazz Musicians Questionnaire (PRJMQ), included 39 questions divided into the following sections: General information, health information regarding hearing disorders, working capacity and awareness of loudness of instruments, hearing protection, and general knowledge regarding musicians’ understanding of concepts of loudness as expressed by the dB scale. Most questions within the questionnaire began with a yes/no question (e.g. “Have you ever experienced hyperacusis?”), followed by a series of scale questions for those participants who replied “yes”. Scale questions required participants to rate the extent to which they experienced a subjective feeling (tinnitus, hyperacusis): Never, seldom, sometimes, often, or always within a certain musical setting (private lesson, rehearsal, performance, or musical concert attended), from one to five. All answers on a particular topic were averaged.

Based on guidelines from Kähäri, a professional pop/rock/jazz musician was considered according to the following criteria:

- Played an amplified musical instrument for at least 4 consecutive years and practiced/taught for a minimum of 5 h a week
- Gave a minimum of 3 performances a year
- Was financially compensated for playing the instrument.

Musical experience (ME) was calculated based on the number of years playing the instrument, multiplied by the number of weekly hours the musician played or was exposed to his/her musical instrument. Sixty-four percent of the participants achieved a minimal playing experience score of 0-500 units (years’ weekly hours). Our statistical analysis examined the effect of years and hours separately. All participants had a minimum of four years of experience playing their instrument with an average of 22.7 years (S.D. = 10.4). The average weekly exposure of participants to pop/rock/jazz was 23.55 h (S.D. = 17.7). A family history of hearing loss, acoustic trauma acquired prior to musical career, occupational exposure to noise (other than music), a history of chronic otitis media, prior ear surgery performed, known head trauma, and use of ototoxic medication were all criteria for exclusion from the study.

As mentioned, drummers are more susceptible to NIHL. Ten drummers (23%) participated in the study. Drummers showed a range of 15-84 hours playing and a range of 17-47 years playing. Drummers showed an occurrence of 80% of tinnitus and 40% of hyperacusis. 70% of drummers reported using hearing protection, in relation to the rest of the participants of the study who reported 42.1% use of hearing protection.

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Right ear | Mean | S.D. | Left ear | Mean | S.D.
--- | --- | --- | --- | --- | ---
3000 Hz | 13.54 | 13.05 | 3000 Hz | 15.24 | 15.81
4000 Hz | 12.44 | 13.33 | 4000 Hz | 16.46 | 14.63
6000 Hz | 19.76 | 13.23 | 6000 Hz | 22.56 | 12.70
8000 Hz | 10.37 | 13.62 | 8000 Hz | 8.66 | 10.55

Data after accounting for age and gender affects

- 3000 Hz: 1.71, 11.81, 3000 Hz: 6.17, 14.27
- 4000 Hz: −4.02, 8.38, 4000 Hz: 3.14, 11.43
- 6000 Hz: −2.8, 11.46, 6000 Hz: 7.43, 11.57
- 8000 Hz: 1.7, 8.11, 8000 Hz: −8.64, 9.67

Appendix 1: Hearing thresholds: Raw data and data after accounting for age and gender effects (N = 42)

| Frequency (kHz) | Raw data | Data after accounting for age and gender affects |
| --- | --- | --- |
| 3000 Hz | 13.54 | −1.71 |
| 4000 Hz | 12.44 | −4.02 |
| 6000 Hz | 19.76 | −2.8 |
| 8000 Hz | 10.37 | 1.7 |

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piano/keyboard (13.6%), strings (cello/violin) (6.8%), wind instruments (recorders, flute, piccolo, harmonica, saxophone, electric wind instrument [EWI]) (6.8%), accordion (2.3%), voice (2.3%) and other (bouzouki, mandolin, kora [African harp]) (2.3%). 33 of the 44 musicians reported that in addition to their main instrument, they also play another musical instrument. Slightly more than half of all musicians (56.8%) reported using hearing protection at some time in their lives.
Thus, the answers of those participants who reported they had experienced hyperacusis were averaged into a value named mean hyperacusis. The same was done for questions on tinnitus. Use of hearing protection was measured based on a yes/no question (do you use hearing protection in both ears?). This binary question was followed by a series of more specific questions which were not statistically measurable and therefore were not analyzed in the current research.

**Results**

In order to examine our first hypothesis claiming that musicians’ experience (years playing X hours playing per week) will positively predict hearing thresholds of 3-6 kHz, a Pearson correlation test was conducted between ME and hearing tests of the right and left ears. Results indicated a significant positive correlation between ME and the hearing loss in both the left ($r_{39} = .46, p = .002$) and right ($r_{39} = .47, p = .002$) ears.

To better understand the effects of hours playing versus years playing we conducted four hierarchical regression analyses for the hearing thresholds PTA. In two regressions, the number of years playing was entered in the first step of the equation and hours playing per week was entered in the second step. In the two other regressions hours playing per week was entered in the first step of the equation and years playing was entered in the second step. Such regressions were done for each ear separately.

As can be seen from Table 1, hours playing per week significantly contributed to hearing loss of both the right and left ears after controlling for the musicians’ years playing. Specifically, hours playing per week contributed 11% of the explained variance of right ear hearing loss in addition to the contribution of years playing ($\beta = .34, p = .037$) and 12% of left ear hearing loss in addition to the contribution of years playing ($\beta = .36, p = .024$). The analysis shows that only hours playing per week was found to have the contribution to hearing loss for both left and right ears after controlling for the amount of years the musician played. Years playing did not contribute significantly to both left and right ears’ hearing loss after controlling for the contribution for hours playing per week [Table 1].

To examine the second hypothesis stating that professional musicians’ experience (years playing X hours played per week) will positively predict self-reported symptoms (tinnitus and hyperacusis), a Pearson correlation test was conducted between the two variables. As stated earlier, none of the participants reported having distortion or diplacusis. Results showed a significant positive correlation between ME and mean sporadic tinnitus ($t_{42} = .30, p = .05$) and between ME and mean hyperacusis ($t_{42} = .31, p = .04$), confirming a significant positive correlation between musical experience and the reported subjective variables.

| Measures | 3-6 kHz left ear | 3-6 kHz right ear |
|----------|------------------|-------------------|
| **Step 1** | | |
| Years playing | .23 | .17 |
| R² Change | .05 | .03 |
| **Step 2** | | |
| Years playing | .15 | .09 |
| Hours per week | .36 | .34 |
| R² Change | .12 | .11 |

To examine the third hypothesis stating that musicians’ experience will positively predict the use of hearing protection, three logistic regressions were conducted (one for each measurement: Years playing, hours per week, and years playing X hours per week) on the use of hearing protection as the dependent variable. Results indicated that none of the measurements of experience predicted the use of hearing protection.

To examine the fourth hypothesis asserting that self-reported symptoms (tinnitus and hyperacusis) will positively predict hearing thresholds of 3-6 kHz, a Pearson correlation test was conducted between the two variables for each ear. The results indicated a significant correlation between tinnitus and hearing thresholds only for the left ear ($r_{39} = .34, p = .03$; $r_{39} = .18, p = .25$). The results also indicated no significant correlation between hyperacusis and hearing thresholds for both ears ($r_{39} = .17, p = .28$; $r_{39} = .026, p = .87$).

In order to examine whether there will be a difference in hearing thresholds in the left and right ears between drummers and non-drummers, we conducted a mixed model repeated measures analysis of variance (ANOVA). The model showed significant results regarding different hearing thresholds between the right and left ears ($F (1,39) = 5.41, p = .025, \eta^2 = .12$) and significant results regarding the comparison between drummer musicians than non-drummers musicians ($F (1,39) = 7.53, p = .009, \eta^2 = .16$). There was no significant interaction between being a drummer and hearing thresholds ($F (1,39) = 1.11, p = .30, \eta^2 = .028$). Specifically, there was greater damage for the left (M = 5.41, S.D. = 10.42) than right (M = 2.90, S.D. = 8.80) ear. Moreover, drummers had greater hearing damage (M = 10.33, S.D. = 11.48) than non-drummers (M = 2.16, S.D. = 8.15).
Table 2 presents the means and S.D. of tested PTA at 3-6 kHz before and after age and gender adjustments. As will be further discussed, Table 2 shows that both right and left ear thresholds are affected by an average 2.80-5 dB decline that cannot be explained by age or gender.

Finally, in order to examine whether the hearing threshold is significantly different from zero, each score after age and gender correction was compared to zero (representing intact hearing) using a one-sample t-test. Results regarding both left and right ears were found to be significant (t_{left\text{ ear40}} = 3.32, p = 0.002; t_{right\text{ ear40}} = 2.11, p = 0.041), thus proving that there is significant damage to both left and right ears, among participating professional pop/rock/jazz musicians, when compared with norms.

Discussion

The current research tested the hearing thresholds of professional pop/rock/jazz musicians and their subjective reports of tinnitus and hyperacusis, in relation to their musical experience and extent of exposure to amplified music. The study found a positive correlation between the extent of exposure to amplified music and hearing thresholds of 3-6 kHz. The more experience professional pop/rock/jazz musicians had (i.e., the more exposure to amplified music), the poorer their hearing thresholds. Hours per week was found to have a greater effect in predicting hearing loss in both ears in addition to the contribution of years playing. However, years playing had no significant contribution in predicting hearing loss for both ears in addition to the contribution of hours per week.

Axelsson et al.\textsuperscript{41} conducted a longitudinal study of 40 pop/rock musicians, engineers and managers, whose hearing was initially tested at the average age of 26, and then retested after 16 years at the average age of 41. They found a statistically significant, more advanced hearing loss over time among those musicians who showed hearing loss in the initial study, the greatest hearing loss suffered by drummers. Over 20% of participants also showed other types of notches (beyond 4-6 kHz) in one or more frequencies in one or both ears. This data is further supported by Poissant et al.\textsuperscript{12} who showed that even 1 h of exposure per day could create an apparent increased risk among trumpet players. This research suggests that 60-year-old male and female musicians exposed to trumpet noise for 4 h per day for forty years would be 85% and 300%, respectively, more likely to have hearing loss than their peers with negative or reduced noise exposure histories.

The validity of these outcomes is strengthened by the fact that many professional pop/rock/jazz musicians in the current study reported playing an additional instrument, which put them at an even greater risk of NIHL not accounted for in the statistical analysis of the current study. Other studies on pop/rock/jazz musicians found hearing decline similar if not worse than the hearing decline found in the current study.\textsuperscript{4,8} Axelsson et al.\textsuperscript{41} found a hearing decline of 2-3 dB in both right and left ears. Kähäri\textsuperscript{8} found an average hearing decline of 8 dB in both ears. Thus, greater emphasis should be given to the fact that even a short exposure to amplified music can cause long lasting damage to hearing and as such the importance of using hearing protection.

The study also found a significant positive correlation between professional pop/rock/jazz musicians’ experience/extent of exposure and subjectively-reported variables of tinnitus and hyperacusis: The greater the exposure to music, the more frequent the subjectively-reported symptoms. These outcomes are further supported by Juman et al.\textsuperscript{6} whose research showed that tinnitus and hypersensitivity are related to extent of exposure among nonprofessional steelband musicians.

This study hypothesized that there would be a significant positive correlation between self-reported symptoms (tinnitus and hyperacusis) and the hearing thresholds of 3-6 kHz.

Our results showed a connection only between left ear PTA thresholds and sporadic tinnitus. Our study showed a prevalence of 31.8% of tinnitus. Similar results are reported by Kähäri\textsuperscript{7} (43%) and Schmuziger et al.\textsuperscript{13} (17%). This prevalence is higher than the estimate among the normal hearing population (15%).\textsuperscript{7} Kähäri\textsuperscript{7} stated that the high percentage of permanent tinnitus could be the product of excessive sound levels (p. 48).

The current study found a positive correlation between left ear PTA thresholds and sporadic tinnitus. A high prevalence of tinnitus has been found in musicians with hearing loss.\textsuperscript{6,13} This study’s correlation between tinnitus and hearing loss was found for the left ear only. This finding supports various studies that have indicated a small hearing asymmetry between right and left hearing thresholds, related to exposure to noise.\textsuperscript{5,7,8} Previous studies show a slightly higher susceptibility to several kinds of hearing damage in the peripheral hearing mechanism of the left ear, related to NIHL. Khalfa et al.\textsuperscript{21} found that nerve fibers within the efferent nerve system attenuate outer hair cell (OHC) motility more strongly in middle frequencies of the left ear, compared with those of the right ear. Where the left ear OHCs are less functional, fibers within the medial olivary complex (MOC) compensate, and may become more functional, especially in mid-range frequencies. Khalfa et al.\textsuperscript{21} claimed that this phenomenon, which increases with human development and affects middle frequencies of the left ear only, results in the left ear being more susceptible to noise damage and tinnitus.

| Ear    | Tested PTA average 3-6kHz (SD) | PTA average after age-and gender-matching to otologically normal reference population (SD) |
|--------|-------------------------------|-------------------------------------------------------------------------------------------------|
| Right  | 14.02 (10.64)                 | 2.90 (8.80)                                                                                   |
| Left   | 15.73 (11.17)                 | 5.41 (10.42)                                                                                  |
As mentioned in the method, 10 professional drummers participated in the current study and were found to have significantly higher hearing thresholds compared to other musicians within the study. Hoffman et al. indicated that 315 percussionists aged 18-75 had poorer mean hearing thresholds at all frequencies, compared with a reference population. Axelsson et al. found 10 percussionists to have the poorest hearing thresholds in a longitudinal study across 16 years among a group of 40 musicians, sound engineers, and managers. Juman et al. showed significant auditory threshold deterioration among 29 steelband musicians, compared with a control group of 30 non-musicians. However, further statistical analysis found that being a professional drummer did not add a significant variance for explaining hearing loss for both left and right ears. A larger sample of drummers is required in order to establish the etiology. Professional drummers’ hearing decline in our study might have been a result of being more experienced than other participants in the study (having more hours per week of practice).

Finally, our study did not find a correlation between the extent of exposure to amplified music and the use of hearing protection or between self reported symptoms and use of hearing protection. Although in our study, 56% of the professional pop/rock/jazz musicians reported use of hearing protection, Juman et al. showed that the use of personal hearing-protective devices (PHPD) in the form of earplugs and earmuffs is not reported as a common habit. Laitinen and Poulsen found that most classical musicians do not use hearing protectors regularly in both ears, but tend to use them more frequently in one ear.

Many professional pop/rock/jazz musicians reported that the use of hearing protection affected the quality of sound and was uncomfortable. This means that while musicians do use hearing protection devices, they do not use them everywhere or all the time. The tradeoff between the protection and comfort/quality of sound may be too big a price to pay, even for professional musicians who are highly exposed to loud music and who suffer hearing deterioration. Schmuizger et al. found that tinnitus and hyperacusis were reported by subjects as having minimal impact on their lives. It is possible that the degree of self-reported symptoms was not sufficiently bothersome for the professional musicians to try to treat them or protect against them.

High frequency hearing loss is a telling sign of NIHL. Although all our subjects did not report any active ear-nose-throat (ENT) pathologies, it would be interesting to study possible effects of noise/music on low frequency thresholds. Since all studies dealing with pop/rock/jazz musicians focused on hearing thresholds and questionnaires, future research is needed in larger samples, and with additional objective tools. Research hypotheses related to use of hearing protection were not confirmed. Therefore, it is suggested that future research focus on other factors affecting use of hearing protection, such as social conventions, type of PHPD and awareness to the dangers of extended exposure to amplified music. Hours and years served as a reference to the amount of exposure within the current research. Further research might attempt to consider other relevant contributing factors, such as periods of more or less musical activity within a musician’s professional career, or the extent of attendance to musical concerts. Future research should focus on reducing heterogeneity. This can be done by focusing on particular musical genres or on certain musical instruments. Beyond quantifying hearing thresholds and subjective variables such as tinnitus and hyperacusis, further research is warranted on other subjectively reported variables and on musician’s professional and personal quality of life and wellbeing, following hearing decline. Our finding that the left ear of our subjects was more susceptible to noise, supported by earlier findings concerning music as well as regular noise, emphasizes the importance of further research of the mechanisms that play a role in this phenomenon.

Damage risk criteria (DRC) regulations draw on the approach of noise of equal energy, giving identical magnitude to noise intensity and duration of exposure. Thus, rules of intensity versus exposure in hours can predict the extent of auditory damage. The current research has shown that the effects of practice (measured in hours) are more hazardous than the effects of years playing. Future research is warranted in order to better define factors influencing professional musicians’ exposure to noise.

Our findings of the high prediction-power of professional pop/rock/jazz musicians’ hours/week exposure to amplified music and hearing loss as well as the non-correlation between hours exposure per week and the use of hearing protection highlights the dramatic importance of education towards awareness among musicians. Awareness to the implications of subjective symptoms of hearing loss will make the possible long-lasting damage to professional musicians’ hearing more salient among the population in general and particularly among those exposed to amplified music. Furthermore, educating on this matter will promote musicians’ awareness to the need to use hearing protection at all times, as the damage to their hearing happens even after a short exposure.

**Conclusions**

The current study has shown that professional pop/rock/jazz musicians exposed to loud, amplified music, do suffer from symptoms of NIHL. Professional pop/rock/jazz musicians’ extent of exposure to amplified loud music are related to hearing loss and other subjective effects related to hearing damage such as tinnitus and hyperacusis. In addition the current results have shown, that professional pop/rock/jazz musicians’ exposure to amplified music per week predicts...
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objective hearing loss after controlling for age, gender, and years of experience.

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How to cite this article: 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.

Source of Support: Nil, Conflict of Interest: None declared.
