Environmental Factors in Susceptibility to Noise-induced Hearing Loss in Student Musicians

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Abstract:

Hearing threshold and survey data collected over 3 years in a university school of music indicate that 52% of undergraduate music students show declines in high-frequency hearing at 6000 Hz consistent with acoustic overexposure. Declines at 4000 Hz have grown in number over the 3 years, from 2% the first year to 30% in the third year. These "noise notches" are seen in all instrument groups, including voice, and are seen more in the right ear than the left ear in all groups. Exposure to outside noise does not appear to be a determining factor in who develops these declines. It is concluded that genetic predisposition is a likely risk factor.

Keywords: noise-induced hearing loss | hearing threshold | musicians | genetic predisposition

Article:

When students of classical music enter college-level music programs, they are able, for the first time, to immerse themselves in an intensive program of study toward a professional career in music. Undergraduate music students spend more hours playing their instruments than was possible in high school, and many of these hours are spent in small practice rooms, where measured levels of sound exceed levels at which industry would be required to mandate a hearing conservation program.[1] As professional musicians, hearing health will be vital to their success. High-intensity levels in performance and practice can cause hearing loss that will threaten pitch, timing, and loudness perception.[2] It is crucial that students and instructors are aware of this threat and take measures to protect their hearing.

The incidence of hearing loss in professional classical musicians is 52%.[3] The loss of hearing brings with it problems with loudness, frequency, and temporal perception and often includes ringing in the ears, or tinnitus. These losses are critical to a musician who must correctly perceive and produce the accurate pitch, loudness, timbre, tempo, and style of a musical piece. While for nonmusicians the critical frequency range for speech perception is 250 to 4000 Hz, musicians must be able to discriminate specific frequencies over a much broader frequency range. The range for a piano is 16 to 8000 Hz, and the pipe organ, up to 16,744 Hz. Psychological issues related to hearing difficulties also may be present.[4-7]

Excessive exposure to high-intensity sound causes damage to the outer hair cells of the organ of Corti, in the cochlea. These cells are responsible for the enhancement of hearing sensitivity and tuning. The outer hair cells have a motor component that amplifies soft sounds at specific frequency points in the cochlea and are responsible for the sharpness of pitch perception as well as amplifying soft sounds.[8] Therefore, damage also causes a widening of the auditory filtering system, which reduces the accuracy of pitch perception.[9] This can occur with even a small amount of hearing loss.

Although it is assumed that amplified musical performances are loud, acoustic instruments and voices also reach high intensity levels. A soprano can sing at 115 dB SPL (sound pressure level), a tuba or violin reaches 110 dB SPL, and a trumpet, 111 dB SPL. Peak sound levels in student practice rooms have been measured at 110 dBA and higher.[1] Many factors contribute to the risk of hearing loss in musicians besides the frequency range and intensity level of the music. Reverberation within rehearsal rooms and rehearsal halls, placement within an ensemble, genetic predisposition, and duration of exposure each day, as well as accumulated years of exposure, are contributing factors.[9,10] It has also been shown that stress and whether or not the musician likes the piece of music both play a part in temporary shifts in hearing threshold.[11,12]

There is some controversy about the presence of hearing loss in musicians. In a study of the hearing acuity of professional musicians, Kahari et al.[7] found that noise notches occurred at 6000 Hz but were not outside normal limits. Permanent threshold shifts have been found in professional musicians by several investigators.[9,12-16] Karlsson et al.[14] suggested that the average threshold levels for symphony musicians were within the range expected for their age, and therefore concluded that performing with a symphony orchestra was not a risk to hearing. However, when Ostri et al.[15] compared their results with normative data collected by the International Standards Organization, they reported hearing loss in all age groups. The only study of hearing acuity of undergraduate music students is that of Fearn,[10] who reported that 33% of student orchestral musicians had elevated thresholds, 75% of which were at 6000 Hz and 50% in only one ear.

In 1999, the International Organization for Standardization reported that hearing loss due to excessive sound intensity increases faster in the first few years of exposure; this conclusion is supported by the research of Rosenhall, Pedersen, and Svanborg.[17] Since, at the college level, student musicians are able to practice longer hours and perform in more ensembles than in their precollege years, it is important to explore the possibility that this extended exposure is having a detrimental effect on the hearing of student musicians.

The purpose of the current study was to begin a multi-year examination of hearing acuity in undergraduate music students. In each of 3 years starting with the 2003-04 academic year, an audiogram was created for each volunteering student. In addition, a brief questionnaire was administered to obtain information on class level, instrument played, use of hearing protection, exposure to amplified sound, experience of tinnitus, and history of middle ear disorders. In the third year, questions were added regarding family history of hearing loss and other types of loud sound exposure.

METHODS

Participants

The first year of the study included 110 undergraduate music students in a large state university school of music (University of North Carolina at Greensboro). In year 2, an additional 50 students volunteered to participate, and in year 3, another 178 participants were tested (total n = 338). All participants were recruited from the student body after a presentation about the project in convocation, which all music students are required to attend. In year 3, freshmen and sophomores also were recruited from their classes, which resulted in a large proportion of each class participating. Freshmen and sophomores were tested in the fall semester, and juniors and seniors were tested in the spring semester. All students signed an informed consent form prior to participating in the study. Table 1 shows the composition of each year's participants in terms of class and gender. Table 2 shows the composition of each year's participants by instrument group.

TABLE 1. Numbers of Participants by Class and Gender

	Year 1		Year 2		Year 3		
	F	M	F	M	F	M	Totals
Freshman	10	18	4	9	55	52	148
Sophomore	18	15	6	12	25	25	101
Junior	10	9	3	5	6	7	40
Senior	14	16	5	6	4	4	49
TOTALS	52	58	18	32	90	88	338

TABLE 2. Number of Students by Instrument and Year

	Year 1	Year 2	Year 3
Voice	28	12	45
Percussion	20	9	25
Brass	24	11	44
Wind	19	12	36
Strings	17	6	28

The freshman class is always the largest class in the school, as can be seen in the tables. Carry-over of students volunteering in multiple years was low, which may in part reflect the loss of many members of the freshman class. In year 2, 25 students who had participated in year 1 volunteered to participate again; 2 of these volunteered in year 3 (also in year 3 one student volunteered who had last participated in year 1). In year 3, 13 students who had participated in year 2 but not year 1 volunteered.

Procedures

Audiometric thresholds for the frequencies 250 to 8000 Hz were obtained with a GS 17 audiometer (Grason-Stadler, Mitford, NH) in sound-treated rooms in the School of Music following standards set out in the Occupational Noise Exposure Revised Criteria (NIOSH, 1998).[18] Because this is a university population and not an industrial population, aspects of the NIOSH recommendations could not be met. Whereas hearing examinations can be mandated for an employee, student participation in the study has been voluntary, as required by the Institutional Review Board.

Measurements were made in the morning in an attempt to have 12 hrs of nonexposure prior to testing. Nevertheless, student practice does not follow an 8-hr workday, and many students reported practicing their instrument in the evening before the hearing test. Recommendations for a full audiological evaluation were made to students with thresholds outside normal limits, but this could not be mandated. Sound levels of test rooms were measured with a sound level meter (Quest 1700; Quest Technologies, Oconomowoc, WI) to determine that ambient noise levels met the standards for hearing testing under the Occupational Safety Health Act, which is used when testing at industrial sites.[19]

A noise-induced hearing loss is characterized by a sharp drop in hearing sensitivity at 4000 or 6000 Hz, called a *noise notch*. Notches were conservatively defined (from a clinical standpoint) as at least a 10-dB drop in threshold from 1000, 2000, or 3000 Hz to 4000 Hz or from 1000, 2000, 3000, or 4000 Hz to 6000 Hz, with at least a 5-dB recovery at 8000 Hz. This is slightly more conservative than the criteria used by Niskar et al.[19] in their study of school-aged children, in which they used a 15-dB drop from the preceding frequencies back to 1000 Hz.

Sound exposure measurements were made on a subset of 21 students participating in the study. Students wore a Cirrus-Research doseBadge (Cirrus Research, Hunmanby, UK) pinned to one shoulder under the ear for an entire day. Measurements collected included average sound level (in dBA), maximum sound levels (in dBA), and sound dose incurred per NIOSH recommendations (1998).[18] *Sound dose* represents the amount of exposure based on a time/intensity trade-off. NIOSH recommendations state that exposure to 85 dBA for 8 hrs is 100% of the allowed dose of exposure. Allowable exposure is halved for every increase of 3 dB in the exposure levels, so that an 8-hr exposure to 88 dBA would be a 200% dose.

At the time of testing, student participants were also asked to fill out a short questionnaire. In years 1 and 2, the questionnaire included questions about instrument played and in what ensembles and simple yes/no questions about history of ear disease, experience of tinnitus, use of earplugs, and exposure to amplified sound. In year 3 the questionnaire was expanded to ask for detailed responses from choice boxes on type of tinnitus (never, occasionally for a few seconds, after practice, after other noise), exposure to noise (firearms, power tools, recreational vehicle, loud stereo music), and family history of musical ability and of hearing loss (specific to which family members).

All statistical analyses were run using SPSS for Windows 14.0.

RESULTS

The proportion of 6000 Hz notches in the student population remained stable through the 3 years, whereas the number of students with a notch at 4000 Hz grew. In year 1, 54% (n = 110) of the students tested had a notch at 6000 Hz in at least one ear, with only 2 students showing notches at 4000 Hz. In year 2 (n = 50), 6000-Hz notches were found in 50% of the students tested, with 14% showing notches at 4000 Hz. In year 3 (n = 178), 52% of the students had notches at 6000 Hz and 30% had notches at 4000 Hz. When students reporting recent exposure (i.e., exposure within the previous 12 hrs) were removed from the analyses, results were the same.

In year 1, there were more notches at 6000 Hz in the right ear (n = 42) than the left ear (n = 29), and 15 of these were bilateral. In year 2, the right/left numbers were balanced at 15/16, with 9 of these bilateral. In year 3, there were again larger numbers of notches in the right ear (n = 65) than the left ear (n = 49), with 24 bilateral losses. When the students reporting recent exposure were removed and the data were examined as a 3-year aggregate, right ear and left ear notch presence was similar (49 in the right ear, 41 in the left ear). The depth of these 6000-Hz notches was similar in both cases (Table 3).

TABLE 3. Numbers of Participants Showing 6000 Hz Notches by Depth, Ear and Year

Notch Depth (dB)	Year 1 (n = 110)		Year 2 (n = 50)		Year 3 (n = 178)	
	R	L	R	L	R	L
10	11	8	2	3	15	18
15	16	11	7	8	19	14
20	10	4	3	2	16	9
25	1	2	3	2	7	4
30	2	3		1	5	2
35	2				2	2
40						
Total	42	28	15	16	65	49

The two 4000-Hz notches in year 1 were unilateral, one in each ear for 2 students. Of the 8 students with 4000-Hz notches in the small cohort for year 2, 2 were bilateral, with 4 more right ear notches and 2 more left ear notches. For year 3, there were 15 4000-Hz notches in the right ear and 20 in the left ear, with 4 of these bilateral. After students with recent exposure were removed, 14 over the 3 years had notches at 4000 Hz in at least one ear, 3 of which were bilateral.

There were not many repeat volunteers from year to year in the study. In year 2, 25 students were tested who had been tested in year 1; of those 25 students, 12 had notches. Of the 12 students with notches, 6 were found to have deeper notches at 6000 Hz in year 2 by 10 to 20 dB, and 3 of them also had drops at 4000 Hz. Three students who had not shown a notch in year 1 had a notch in year 2. In year 3, 13 students were tested who had been tested in year 2, 8 of whom had notches. Three of the 8 students with notches were recorded with a 15- to 20-dB drop in sensitivity at 6000 Hz, and 1 percussionist with an original notch at 6000 Hz had a 10-dB drop at 4000 Hz bilaterally. Of the 13 students who experienced drops in sensitivity, 9 were males, 6 had exposed themselves to amplified sound, 4 were percussionists, 4 were brass players, 3 were wind players, and 1 each wind and voice.

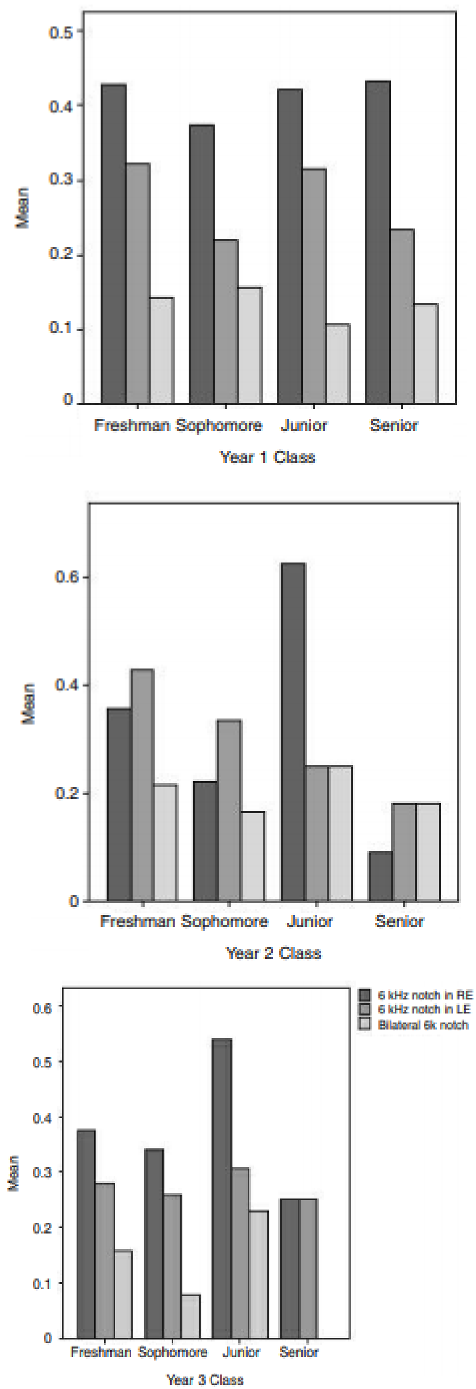

FIGURE 1. Proportion of participants showing a noise notch at 6000 Hz by class.

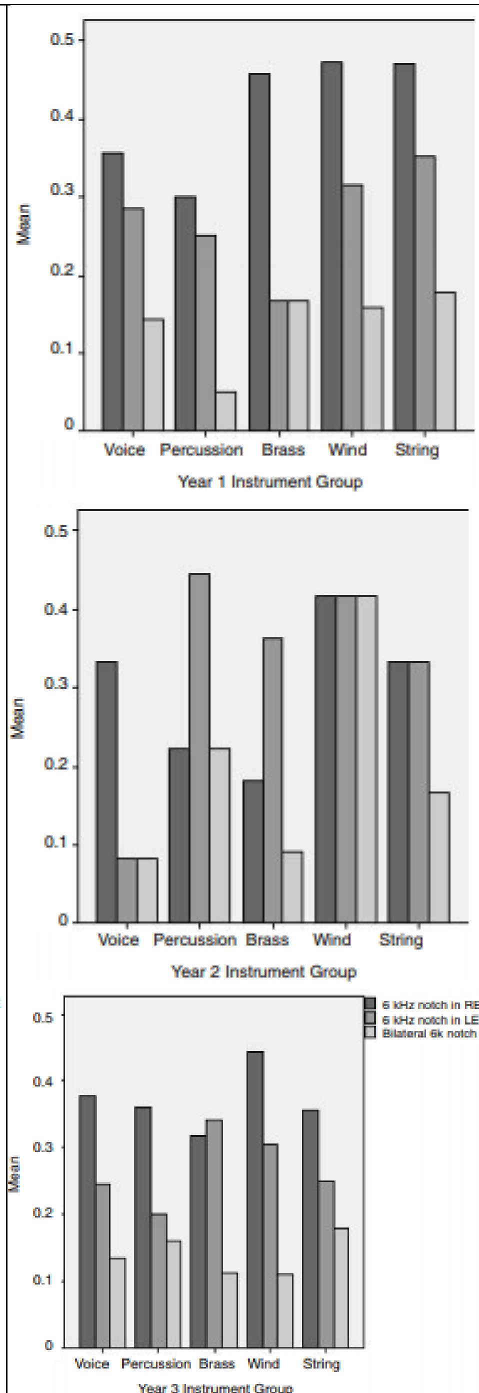

FIGURE 2. Proportion of participants showing a noise notch by instrument group.

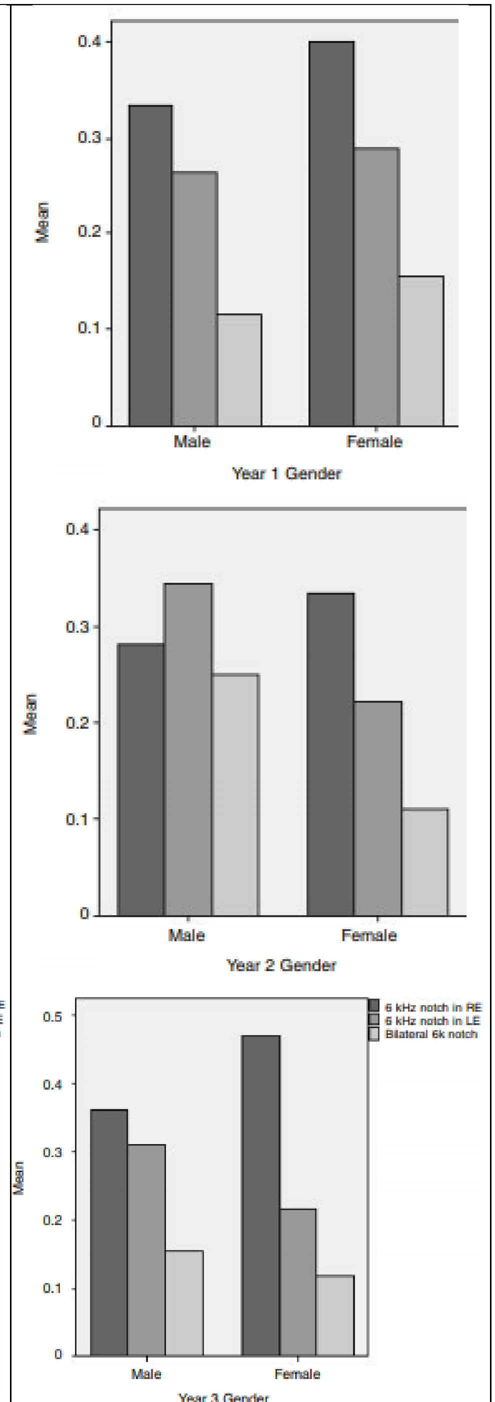

FIGURE 3. Proportion of participants with a noise notch at 6000 Hz by gender.

Music-related Environmental Factors

Data were merged for all 3 years, using the most recent thresholds when multiple years were available. Mean threshold data for notch frequencies for all students were subjected to a repeated measures ANOVA, with class and instrument as between-subjects variables and the multiple frequencies as the repeated measure. A main effect for threshold differences was seen for frequency [$F(3) = 32.932$, $p < 0.001$], but not for class or instrument group. This was also true when students with recent reported exposure were removed from the analysis [$F(3) = 12.942$, $p < 0.001$]. Thresholds at 4000 Hz were significantly different from those at 6000 Hz for each ear ($p < 0.001$). Chi-squared analyses were significant for right/left ear differences at 4000 Hz ($p = 0.001$) and 6000 Hz ($p = 0.003$). Notches at 4000 Hz were more prevalent in the left ear (n = 28) than right ear (n = 19). Notches at 6000 Hz were more prevalent in the right ear (n = 114) than left ear (n = 80).

There were no significant class or instrument group differences on the presence of a notch at 6000 Hz. Gender differences were significant at 4000 Hz for both ears and at 6000 Hz for the left ear, but means were 2 to 4 dB and hence not clinically significant. However, because the tendencies are informational to musicians who wish to protect their hearing, the proportions of students exhibiting a noise notch by class, instrument group, and gender are seen in Figures 1 to 3.

Mean thresholds by instrument group for students with a 6000-Hz noise notch can be seen in Table 4. Table 5 shows the mean thresholds of students with a 6000-Hz noise notch by class. Paired-samples t-tests performed on student data in whom a noise notch was present in either ear found significant differences between the thresholds at 3000 to 6000 Hz, 4000 to 6000 Hz, and 6000 to 8000 Hz for both ears ($p < 0.001$). Mean thresholds for students without a noise notch were equivalent across the frequency range (5 to 7 dB at 6000 Hz).

TABLE 4. Mean Thresholds by Instrument Group for Students with a Noise Notch at 6 kHz (in dB HL)

	Left Ear (*n* = 80)						Right Ear (*n* = 114)					
	1k	2k	3k	4k	6k	8k	1k	2k	3k	4k	6k	8k
Voice	4.5	2.6	0.8	-1.1	15.8	4.2	7.1	2.7	-1.3	0.5	15.2	4.6
Percussion	10.6	10.0	7.5	8.8	21.9	10.0	11.6	4.6	3.1	3.1	17.7	4.2
Brass	6.5	6.0	4.3	4.0	17.3	5.5	6.9	3.2	2.8	5.0	16.1	4.4
Wind	6.6	5.8	2.1	5.8	15.5	5.0	9.1	5.7	2.0	4.7	16.3	5.6
String	6.8	2.5	2.5	3.9	17.9	5.4	8.9	4.3	1.6	3.3	16.5	5.2

TABLE 5. Mean Thresholds by Class for Students with a Noise Notch at 6 kHz (in dB HL)

	Left Ear (*n* = 80)						Right Ear (*n* = 114)					
	1k	2k	3k	4k	6k	8k	1k	2k	3k	4k	6k	8k
Freshman	8.4	5.8	4.6	4.9	18.1	7.2	7.8	3.8	1.6	3.9	16.4	4.5
Sophomore	5.8	4.8	1.3	2.8	15.4	3.3	10.5	5.3	1.6	2.1	18.2	8.1
Junior	4.5	5.0	1.5	2.5	16.0	7.0	5.4	4.2	1.7	3.3	17.1	2.9
Senior	2.8	1.7	2.2	0	18.3	2.8	7.7	4.3	1.7	3.7	13.0	3.7

Mean thresholds at 4000 Hz for students with a 4000-Hz noise notch were not as deep relative to the surrounding frequencies, with the deepest mean thresholds for the right ear at 20 dB HL (hearing level) and 18 dB HL for the percussionists and brass players, respectively, while the other instrument groups were in the 10- to 12-dB HL range. Mean thresholds at 4000 Hz for the left ear were highest for percussion (15 dB HL) and wind players (17 dB HL), while the other instrumental groups fell between 8 to 10 dB HL. Though the greatest threshold shifts in this group were at 4000 Hz, significant differences between percussion and string groups were found at 6000 Hz ($p = 0.04$) and at 8000 Hz between percussion and both wind and voice groups ($p < 0.001$).

Paired-samples t-tests revealed significant differences in thresholds between both 2000 and 3000 paired with 4000 Hz and between 4000 paired with both 6000 and 8000 Hz ($p < 0.001$). For students without recent exposure, significant differences were found between 2000 and 3000 Hz, 4000 and 6000 Hz, and 6000 and 8000 Hz for the right ear and between 3000 and 4000 Hz, 4000 and 6000 Hz, and 6000 and 8000 Hz for the left ear ($p < 0.05$).

Daily measured dose data on a subset of students participating in the study are compared with notch depth in Figure 4. These data show that some students with a high dose have no hearing loss, and others with a low dose have a substantial notch. Of the students whose data are included in Figure 4, only four have a bilateral noise notch. Those four include notches of 45 dB depth in the right ear and 10 dB left (40% dose); 20 dB right and 10 dB left (58% dose); 30 dB right and 35 dB left (65% dose), all found along the y axis; and 35 dB right and 20 dB left (3109% dose). The alarmingly high sound dosages were measured during pep band.

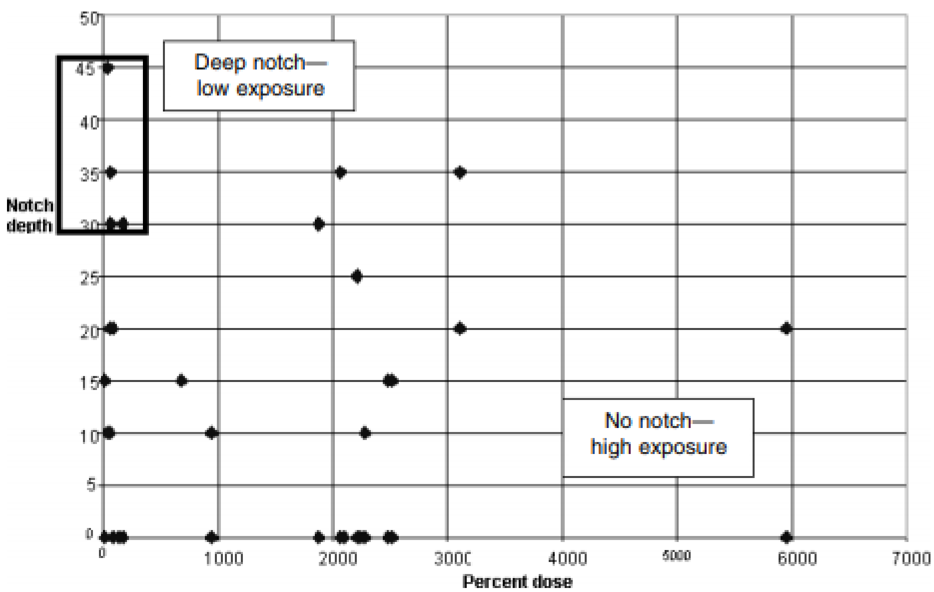

FIGURE 4. Percentage of daily allowed sound dose by depth of noise-induced hearing loss notch at 6000 Hz.

Nonmusic Environmental Factors

Of the 301 students, 82 (27%) reported a history of ear infections. Chi-squares statistics were not significant for an association of otologic history with a notch at either 4000 or 6000 Hz. The numbers of students using hearing protection regularly went up each year, from 1 in the first year to 12 in the second and 29 in the third, and was not a significant factor in these analyses. Percussionists, brass, and wind players reported using hearing protection more than any other instrument group, with no clear gender bias.

Chi-squared analyses revealed a gender bias in exposure to amplified sound ($p \geq 0.003$). In year 3, acoustic overexposure was broken down into categories that included firearms, power tools, recreational vehicles, and loud music. In that year, 27 males and 41 females denied any overexposure to loud sounds outside the music building. Loud stereo music was the most common overexposure, with 29 males and 35 females reporting such exposure. All other categories were low in incidence and pertained mostly to male students. Total numbers for outside noise exposure for males and females were similar. The proportion of students reporting exposure to loud music was similar for the 6000-Hz notch group (48%) and the no notch group (51%). Although the proportions for 4000-Hz notches are somewhat different, with only 44% of students with a notch reporting exposure to loud music compared with 53% of those without a notch, the difference was not significant.

Students reporting tinnitus constituted 41.4% of the male participants and 48% of the female participants in the first years. However, when this question was expanded from a yes/no format to a more detailed format in year 3, the incidence of reported tinnitus dropped dramatically. The majority of students (164/178) in year 3 claimed to experience tinnitus only occasionally for a few seconds or not at all. None reported constant tinnitus, 21 reported experiencing tinnitus after exposure to loud noise, and 3 after instrumental practice.

DISCUSSION

These data, collected over 3 years of a study of hearing in university student musicians, indicated that a risk for noise-induced hearing loss, indicated by a notch in high-frequency hearing thresholds, could be seen in over half of the music students participating in this study. The largest proportion of these noise notches were found at 6000 Hz, with a much lower number at 4000 Hz. This finding is similar to the 58% of orchestral musicians found to have a hearing loss as reported by Ostri et al.[15] and the 53% of orchestral musicians found to have a hearing loss reported by Royster et al.[16] This percentage is higher than that reported by Fearn,[10] whose study included 16- to 30-year-olds at the Leeds College of Music. Fearn's 220 participants included 45% who reported playing only with amplified groups, 26% who played in loud big bands, 24% who played with both orchestras and amplified groups, and 29% who played only with orchestras. He found that 33% of orchestral musicians and 50% of those playing in amplified groups had an absolute threshold of 15 to 20 dB HL at 6000 Hz.

Another study of 50 college students aged 18 to 30 years old who reported at least 1 hr/day of exposure to personal listening systems was done by Moustafapour et al.,[23] who found that 18% had a 6000-Hz notch > 10 dB. In the present study. 39% of the music students had a notch > 10 dB at 6000 Hz. Studies of industrial populations have generally found that the greatest threshold shift from noise exposure was at 4000 Hz[21,22] In a study of shipyard workers, Mori[24] found that those who also reported listening to loud music had their greatest threshold shift at 6000 Hz.

It is possible that some of the students with a notch in this study were exhibiting temporary threshold shifts, since they had been playing their instruments the evening before their morning hearing evaluation. The largest proportion of students was tested at 8:00 or 9:00 AM, the first class of the day for those tested at this time. Therefore, it is likely that they had at least 8 hrs of quiet prior to testing. This is a weakness in working with a population of university music students, but it is preferable to ignoring this threat to their future livelihood and enjoyment of their music.

There has been some concern raised that the current audiometric threshold standards for 6000 Hz are not accurate, based on currently seen thresholds in young people.[24,25] However, in this study not all students tested had a shift in their threshold at 6000 Hz, which would suggest that the problem does not lie with audiometric standards. Bauer et al.[21] also found a drop in many young people at 6000 Hz and reviewed the possible reasons, favoring the hypothesis that it is caused by societal noise.

Nevertheless, not all students with similar exposures demonstrated a threshold shift as a result. It is likely that individual susceptibility to noise damage is a factor. Animal studies demonstrate a genetic susceptibility to noise damage to the inner ear,[26,27] and the search for the genetic bases of noise-induced hearing loss has begun.[28,29] It may be that environmental factors can be used to determine subsets among the susceptible students who may exhibit allelic differences related to mechanical damage vs. systemic damage due to oxidative stress. The differences between the current results and those of Mostafapour et al.[23] would suggest that some nonmusic students who are predisposed to noise-induced hearing loss do not experience a sufficient exposure to elicit damage, or that some music students who do not have a genetic predisposition are exposed to sound loud enough to cause damage anyway. It is likely that the differences in the music and nonmusic students suggests that a greater proportion of vulnerable students show a notch in the music student population.

Within the environmental factors related to the students' music studies, instrument group would seem to be a viable factor, yet the only significant differences in thresholds were found to be between percussionists and string players at 6000 Hz and between percussionists and voice and wind players at 8000 Hz when the percussionists' notches were at 4000 Hz. This difference would indicate that all instrumental groups are at risk, though brass players, wind players, and percussionists were most strongly represented in the small group of repeat participants who experienced a drop in hearing sensitivity. When we look at the entire study population in cross-section, however, the proportion of students with a 6000-Hz noise notch does not increase with years of matriculation. Since the proportion of freshmen with notches at 6000 Hz is similar to the proportion in other years, the freshmen seem to be arriving at school with this early damage having already occurred. However, there were individual students (13 out of 38 students with repeated tests) whose thresholds worsened from one year to the next, with drops from 10 to 20 dB at 4000 or 6000 Hz. This finding is consistent with the hypothesis that some students are more susceptible to acoustic overexposure than others. The proportion of students with a 4000-Hz noise notch was seen to increase dramatically during the 3 years of this study, from two students (1.8%) in the first year, to 14% in year 2, and 30% in year 3. It may be that this increase is due to the increased use of both cell phones and digital music players among students.

There may be mitigating factors that help to prevent further hearing loss in student musicians. It has been shown in chinchillas that moderate levels of sound can condition the ear by causing the production of antioxidants, which might lessen the effects of oxidative stress on the inner ear.[30] This may mean that moderately loud passages of music prepare the inner ear for more intense passages. Actually, it seems that any mild stressor can have the same effect, so it may be that the stressful environment of school in general and preparation for adjudicated performances each semester have a beneficial effect on hearing protection.[31] Music has been found to be less deleterious to hearing than comparable levels of industrial noise, so the progress of the hearing loss may not follow the same course.[32]

The finding of more right-ear notches than left-ear notches at 6000 Hz would seem to be related to instrument played or position in ensemble playing. Instruments such as the flute and piccolo are normally played on the right and may produce more exposure in that ear when playing alone during practice, but they may cause overexposure to the left ear of a neighboring player during rehearsal. The French horn and tuba are also normally played so that the sound exits the instrument on the right, but the bell of the instrument is directed away from the player. In a small practice room with hard walls, this arrangement could still affect the right ear more than the left due to reverberation, and it also again might affect the left ear of a neighboring musician. However, there are more right-ear notches at 6000 Hz for all instrument groups, including vocalists.

It should also be noted that there are many sources of loud sounds other than those experienced as a result of being a music major, of which listening to loud music is reportedly the largest contributor in the current study. Of the students in year 3, 48% reported listening to loud music outside school. There was a distinct gender bias in listening to amplified sound, with males giving themselves more exposure, but a repeated measures ANOVA did not find an interaction between frequency thresholds and exposure to amplification.

Beyond acoustic overexposure, no single music or nonmusic variable examined in this study was shown to be a significant factor in the susceptibility to noise-induced hearing loss among student musicians. This may mean that genetic susceptibility is the greatest factor related to noise-induced hearing loss among music students.

The authors have found sound levels in student practice rooms that warrant a hearing conservation program.[1] The current results on hearing sensitivity in the student musicians also support that conclusion; substantial numbers of music students are risking their hearing and their future livelihoods. In fact, such a hearing conservation policy has been approved at this university school of music, and an implementation policy is under construction. It will include mandatory annual hearing tests for all students.

As Fearn[10] noted, carefully monitored audiometric results will point to rehearsal and performance areas that require sound level measurements. In turn, these measurements may lead to environmental modifications that will reduce exposure. It will be important to account for the individual musician's placement while rehearsing and performing with various ensembles. Instruments radiate sound differently. Woodwind and brass high frequency notes are directional, for example, and may have more effect on the musician sitting in front of them than on the player.

In summary, over half of classically trained student musicians in this college setting exhibited damaged hearing, most frequently at 6000 Hz and in the right ear. All instrument groups are affected equally, and it therefore seems likely that individual susceptibility or resistance to acoustic overexposure is the most crucial variable to the acquisition of a noise-induced hearing loss in student musicians. Students entering a concentrated music program should obtain a baseline audiogram and be monitored and educated about hearing conservation throughout their undergraduate years.

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