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Predisposition

Noise-induced hearing loss (NIHL) is the most prevalent sensorineural hearing loss after presbycusis. Prevalence of NIHL increases with continued exposure and advancing age. The prevention of NIHL will require a better understanding of its prevalence in the population and contributing exposure factors.

NIHL can be caused by a single traumatic impulse sound but is more typically caused by repeated exposures to high intensity sound. According to NIOSH recommendations for the prevention of NIHL, high intensity sound exposure involves a time-intensity trade-off that begins with an allowable eight-hour exposure at 85 dBA, decreasing the time exposed by half for every three dB increase in intensity. Sound exposure measurements in music students and music teachers document exposure levels over 85 dBA (Behar et al, 2004; Mace & Phillips, 2008).

Another factor that can contribute to NIHL susceptibility and severity is chemical exposures (Rybak, 1992; Johnson & Nylen, 1995; Lataye & Campo, 1997; Morata & Campo, 2002; Fuente and McPherson, 2006) including ototoxic medications (Tan et al, 2001; Toppila et al, 2001), and smoking (Pouryaghoub et al, 2007). Medical conditions may also contribute to NIHL. These medical conditions include cardiovascular disease (Brant et al, 1996; Torre et al, 2005), diabetes (Frisina et al, 2006), kidney failure (Antonelli et al, 1990), immune function impairment (Iwai et al, 2003), and poor cholesterol readings (Gok et al, 2005).

Not all people exposed to high sound levels develop NIHL, suggesting that susceptibility to NIHL varies among individuals (Henderson et al, 1993; Lu et al, 2005). Researchers have associated several genetic variants with NIHL (Konnings et al, 2007; Sliwinski et al, 2008; Van Laer et al, 2006; Yang et al, 2006).

A drop in hearing sensitivity, often called a 'notch,' in the audiometric configuration between 3000–6000 Hz, characterizes NIHL.

Abstract

This study describes the prevalence and characteristics of noise-induced hearing loss (NIHL) in student musicians (N = 329) aged 18–25 years. Students completed a questionnaire regarding exposures before a hearing assessment. NIHL was defined by the presence of a notch 15 dB in depth at 4000 or 6000 Hz relative to the best preceding threshold. Overall prevalence of NIHL was 45%, with 78% of notches occurring at 6000 Hz. The proportion of the total population with bilateral notching at any frequency was 11.5%, mostly occurring at 6000 Hz. There was a significant increase in the frequency of notching in students who reported more than two hours per day of personal practice. There were no significant associations for instrument group or other noise exposures. The data suggest that susceptibility to NIHL among students of music is not uniform and cannot be ascribed solely to the instrument played and other exposures. Students with bilateral losses tend to have deeper notches and may represent a group that has an inherent predisposition to NIHL.

Sumario

Este estudio describe la prevalencia y las características de la hipoacusia inducida por ruido (NIHL) en estudiantes de música (N = 329) con edades entre 18 y 25 años. Los estudiantes completaron un cuestionario sobre exposición a ruido antes de la evaluación auditiva. Se definió NIHL como la presencia de una muesca de 15dB en 4000 o 6000Hz con relación al mejor umbral precedente. La prevalencia general de NIHL fue de 44%, con 78% de las muescas en 6,000 Hz. La proporción de la población total con muescas bilaterales en cualquier frecuencia fue de 11.5%, en su mayoría a 6,000 Hz. Hubo un incremento significativo en la frecuencia de las muescas en los estudiantes que reportaban más de dos horas al día de práctica profesional. No hubo una asociación significativa con grupos de instrumentos u otra exposición a ruido. Los datos sugieren que la susceptibilidad a NIHL entre los estudiantes de música no es uniforme y no puede atribuirse solamente al instrumento tocado o a otras exposiciones. Los estudiantes con pérdida bilateral tienden a tener muescas más profundas y pueden representar un grupo que tenga una predisposición inherente a la NIHL.

The loss is often asymmetric, usually with more loss in the left ear than the right ear (McBride & Williams, 2001; Nageris et al, 2007; Phillips et al, 2008). The operational definitions of NIHL reported in prevalence studies are variable. Studies reporting prevalence of NIHL in children have fairly consistently defined NIHL as a notch at 3000–6000 Hz which is 15 dB in depth relative to the thresholds at lower frequencies (Niskar et al, 2001; Renick et al, 2009). Studies of NIHL prevalence in adults have defined NIHL in terms of absolute thresholds at a level poorer than 20 dB HL (Agrawal et al, 2008).

There are a few examinations of NIHL in children and these have shown that the prevalence of NIHL increases steadily over childhood and adolescence. In 2001, Niskar et al reported data obtained from children aged 6–19 years during the National Health and Nutrition Examination Survey (NHANES), which included a medical examination. The overall prevalence of NIHL was 12.5%, with 1.8% of all subjects showing a bilateral loss. NIHL prevalence increased with age; 8.5% of 6–11 year-olds and 15.5% of 12–19 year-olds showed a notch. Haapanemi (2002) found the prevalence in Finnish children to be 8.3%; again, prevalence was lower in younger children (6.4%) than in older children (11.5%). Renick et al (2009) found a higher prevalence rate of 22.5% in Ohio farm children who were expected to have had high exposure levels, with 3.9% of tested subjects showing a bilateral loss. Again, the prevalence was lower for younger children (17.1%) than for older children (26.5%). In all the studies cited above, the frequency of greatest loss was 6000 Hz.

A comparison of reports of NIHL in young adults reflects the issue of notch definition. One the one hand, Agrawal and colleagues (2008) reported a prevalence of 8.5% in adults aged 20–29 years in the NHANES database. They used a definition of a high-frequency pure-tone average at 3000, 4000, and 6000 Hz of 25 dB HL or more. On

the other hand, using a criterion of only 10 dB notch depth, Lees et al (1985) found that 40% of the 60 students (aged 16–25 years) they tested had a notch of 10 dB depth, mainly at 6000 Hz. Consistency in use of a single definition of NIHL would benefit research in this area.

Prevalence figures for NIHL by exposure type have been reported for both industrial populations and for professional musicians. Reports of the prevalence of NIHL in industrial populations varies by industry (electrical workers, sand and gravel workers, and construction workers) between 37–59.7% (McBride & Williams, 2001; Landen et al, 2004; Dement et al, 2005; Rachiotis et al, 2006). A global prevalence of NIHL was estimated to be 29% for 20–29 year-olds in a review of 17 studies worldwide (Nelson et al, 2005). Prevalence studies on industrial workers typically report the notch to be at 4000 Hz.

The reported adult prevalence figures for professional musicians (38–50%) are similar, with notches mainly at 6000 Hz (Emmerich et al, 2007; Kahari et al, 2004; Jansen et al, 2008). Jansen et al also reported that hearing thresholds of musicians were generally better than the average population by ISO standards except at 6000 Hz, where they were worse. Studies suggest that the prevalence of NIHL increases with age among musicians: Emmerich et al reported that the prevalence of NIHL in student musicians aged 11–18 years is 11%. Fearn (1993) reported the frequency of NIHL among college-age student orchestral musicians at 33%, with 6000 Hz as the most prevalent notch frequency.

The examination of hearing in college-age classical music students (aged 18–25), with well-defined criteria for NIHL, described in the current study is particularly useful for examining the prevalence and characteristics of NIHL. As noted, the acuity of music students is better than non-musicians, except at 6000 Hz (Jansen et al, 2008). Such students are likely to have few of the chronic medical disorders associated with advancing age, such as high blood pressure and diabetes, that have been associated with hearing loss. They are also unlikely to show the complicating effects of high frequency hearing loss associated with advancing age. Student musicians practice both individually and in ensembles, but usually do not experience the eight-hour days of exposure to industrial noise which is reported to be more harmful than music exposure (Strasser et al, 2003). Nevertheless, their exposure levels are high enough to put their hearing at risk (Phillips & Mace, 2008). Among three earlier studies of young musicians, the only other study to focus solely on college music students reported that 45% played only in amplified groups, and 24% in orchestras and amplified groups (Fearn, 1993). The students in the current study are classical musicians. In addition to pure-tone threshold tests, this report also includes a detailed survey of exposure information to ascertain possible factors contributing to NIHL such as instrument played, hours of practice, ensemble membership, and other noise or chemical exposures. The current study also denotes and analyses the relative prevalence and severity of unilateral and bilateral NIHL, which may provide insights into susceptibility to NIHL.

Materials and Methods

Study population

The current investigation involved 329 university students of classical music, aged 18–32 years (though only eight were over the age of 22 years), and consisted of 176 males and 153 females. The population included 130 first-year, 73 second-year, 50 third-year, and 76 fourth-year students at the School of Music. As students

often changed instruments or had gaps in their years playing an instrument, it was not possible to categorize them by years playing an instrument. There were 96 vocalists, 75 brass players, 71 wind instrument players, 40 string players, 27 keyboard players, and 20 percussionists. Most of the participants were students of classical music, though 19 were jazz students. The majority reported no use of hearing protection (282/329). Of the 47 who reported use of hearing protection the majority employed it less than half the time. Students affected by cold and allergy symptoms were requested to reschedule their hearing examination. The UNCG IRB Board approved all protocols utilized in the study.

The UNCG School of Music had instituted a hearing conservation policy for the year in question, and all students are now required to have their hearing tested annually. First year students participated in the fall semester in order to have the test as early as possible. Fourth year students also participated in the fall, as many would be unavailable in the spring of their senior year due to student teaching requirements. Second and third year students participated during the spring semester.

Questionnaire

Students completed a questionnaire prior to having their hearing tested. Items on the questionnaire included information about music exposure (i.e. year in school, instrument played, ensemble participation, hours of individual practice per day), medical history (i.e. otologic history and personal as well as family history of high blood pressure, diabetes, cancer, autoimmune disease, heart disease, kidney disease, and hearing loss). Family history of hearing loss was specified as parents, siblings, and grandparents. In addition, students reported exposure from outside noise sources (music and non-music). Reported environmental information, outside of school, included loud music (stereo or personal media player, concerts, and clubs), exposure to other loud sources of sound related to work or recreation, and exposure to chemical substances such as cigarette smoking. These factors can cause hearing loss or exacerbate hearing loss due to acoustic overexposure. Chemical exposure data was collected for the following chemicals: toluene (paint and paint thinners, adhesives, and lacquers), styrene (insulation, carpet backing, fiberglass, automobile parts, plastics, and synthetic rubber), acrylonitrile (plastics, acrylic fibers, nylons, fumigants, and synthetic rubbers), and carbon monoxide (smoking, car exhaust). Chemical exposure was defined as 'extended exposure of one month or more of regular exposure since you started playing your instrument.' Collected exposure information for non-music sound included power tools, gunfire, all-terrain vehicles, and cell phones. Students completed the questionnaires prior to audiometric testing. Students signed informed consent forms for the use of their audiometric data and questionnaire results.

Procedures

Pure-tone thresholds were obtained with a modified Hughson-Westlake procedure for the frequencies 1000, 2000, 3000, 4000, 6000, and 8000 Hz with a GSI-17 audiometer (Milford, NH) in a sound-treated room which met ANSI standards for ambient noise from 1000–8000 Hz. Sound levels of test rooms were measured with a sound level meter (Quest 1700, Oconomowoc, WI). Graduate research assistants who conducted evaluations were trained by a skilled audiologist, who then reviewed results for interpretive accuracy. All tests occurred in the morning in an attempt to have 12 hours of non-exposure prior to testing, and students had been requested

to refrain from practicing within 12 hours of the test. The formula for calculating notch depth was $ND = PT - BT$ where ND is notch depth; PT is poorest threshold at 3000, 4000, or 6000 Hz followed by recovery ≥ 5 dB; and BT is best threshold at 4000, 3000, 2000, or 1000 Hz in a contiguous progression.

The determination of the depth of a notch is illustrated in Table 1 as follows: For the right ear, the poorest threshold is at 6000 Hz. The best threshold at a lower frequency in a continuing progression is 5 dB HL at 1000 Hz; the threshold at 8000 Hz is better than the poorest threshold by 10 dB. This meets the criterion for the presence of a notch that is 15 dB in depth. For the left ear, the poorest threshold is again at 6000 Hz with an 8000 Hz threshold that is 10 dB better. The best threshold at a preceding frequency in a continuing progression in this case is at 3000 Hz, which is 5 dB HL, rather than the 0 dB HL at 1000 Hz, which has an intervening poorer threshold of 10 dB HL at 2000 Hz. Recommendations for a full audiological evaluation were made to students with thresholds outside of normal limits, but this could not be mandated.

All statistical analyses were performed using SPSS 15.0; results were examined with a significance level used for all tests of $p = 0.05$ or smaller. The analyses examined the prevalence of unilateral or bilateral NIHL at 4000 and 6000 Hz as compared with the general population. Continuous variables such as depth of notches and number of hours of individual practice were examined using a t-test or one-way ANOVA. Chi-square analyses were used to examine the prevalence of notches by categories such as instrument group, ensemble participation and class ranking.

Results

Audiologic/otologic descriptors

Overall threshold data indicated that 148/329, or 45% of students for the most recent year ($N = 329$) had a notch at 4000 or 6000 Hz in at least one ear with a depth of 15 dB or greater. Table 1 shows the frequency of 4000 and 6000 Hz notches in the total population of 329 students. The mean thresholds from 1000–8000 Hz for students who had no NIHL are shown in Figure 1 (a); those with a 4000 Hz notch in Figure 1 (b); and with a 6000 Hz notch in Figure 1 (c), respectively. Of these 148 students, 112 (78%) had notches at 6000 Hz, 32 (22%) at 4000 Hz, and 4 at 3000 Hz. Ten of these 148 students had a 4000 Hz notch in one ear and a 6000 Hz notch in the other ear. Of the 112 students with 6000 Hz notches, 25 were bilateral, while 3 of the 32 students had bilateral 4000 Hz notches. Bilateral NIHL, therefore, was found in 11.5% of the music student population. Unilateral 6000 Hz notches were more prevalent in the left ear (63%, $N = 55$) than the right ear (37%, $N = 32$). In addition, 28 students had a unilateral sloping high frequency hearing loss and two students had a bilateral high frequency hearing loss in that category. Most were categorized as mild; two were moderate. These

students were included in the analyses as having no NIHL. Three students had substantial hearing loss: one flat mild unilateral loss, one flat mild bilateral loss, and one had a flat loss that was moderate in one ear and severe in the other. These students were not included in analyses of unilateral and bilateral NIHL.

The proportion of the tested population that had bilateral notching at 4000 and/or 6000 Hz was 11.5%, representing 26% of the subjects showing NIHL. Nine of the 25 students with bilateral notches had been tested in a previous year, and five of them had already shown a bilateral notch on the previous test date. Three had unilateral notches at the previous test date and one had no loss previously. In no case did a student who had previously shown bilateral notching later have a unilateral notch or normal hearing. On the other hand, 13 of 38 students with repeat tests, who had shown a unilateral notch in the previous year, showed no notch in the current year. Seven of these 13 notches were presumed to represent temporary threshold shifts, while four became bilateral notches and two had threshold drops at adjacent frequencies that resulted in a decrease in notch depth such that they no longer met our criteria for inclusion in the NIHL category.

A one-way ANOVA comparing notch depth between bilateral and unilateral notches revealed that a significantly higher proportion of bilateral notches occurred at a depth of 25 dB or more in right [$F(1) = 29.394$], and left ears [$F(1) = 22.474$, $p < .0001$], respectively. Figure 2 shows the proportion of total notches at each of three depth categories (15 dB, 20 dB, and 25 dB or more) for unilateral and bilateral right (RE) and left (LE) ears. For students with unilateral notches, 58% were at a 20-dB depth or more, while 21% of unilateral notches were > 25 dB. Bilateral notch depths for the 6000 Hz notches ranged from 15–35 dB, with 85% showing a notch that was 20 dB or more in depth in at least one ear, and 48% with a notch of 25 dB or more in depth in at least one ear. In other words, individuals with bilateral notches more often also had more severe notching than those showing a unilateral notch. Absolute thresholds at 6000 Hz were significantly poorer in students who reported a family history of hearing loss [$F(1) = 3.783$, $p < .05$].

There was no significant difference in the prevalence of NIHL between males and females. The reported incidence of otologic disorders was not significantly different between students with notching and those with normal hearing. Eighteen percent of the students with notches reported tinnitus after practice ($N = 26/144$) or other noise exposure, as did 17.1% of those with normal hearing ($N = 31/181$). The percentage did not vary by the frequency of the notch, and were not significantly different from each other. No students reported constant tinnitus.

Music-related exposure data

When comparing the presence of NIHL by class standing, fourth-year students (23% of participants) were found to have significantly

Table 1. Notch depth decisions: The poorest threshold level at 3000, 4000, or 6000 Hz was determined. If the threshold at the higher frequencies improved by at least 5 dB, the notch depth was calculated as the difference between the poorest threshold and the best hearing threshold at a lower frequency in a contiguous progression.

	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
Right ear threshold (in dB HL)	5	10	10	10	20	10
Left ear threshold (in dB HL)	0	10	5	10	20	10

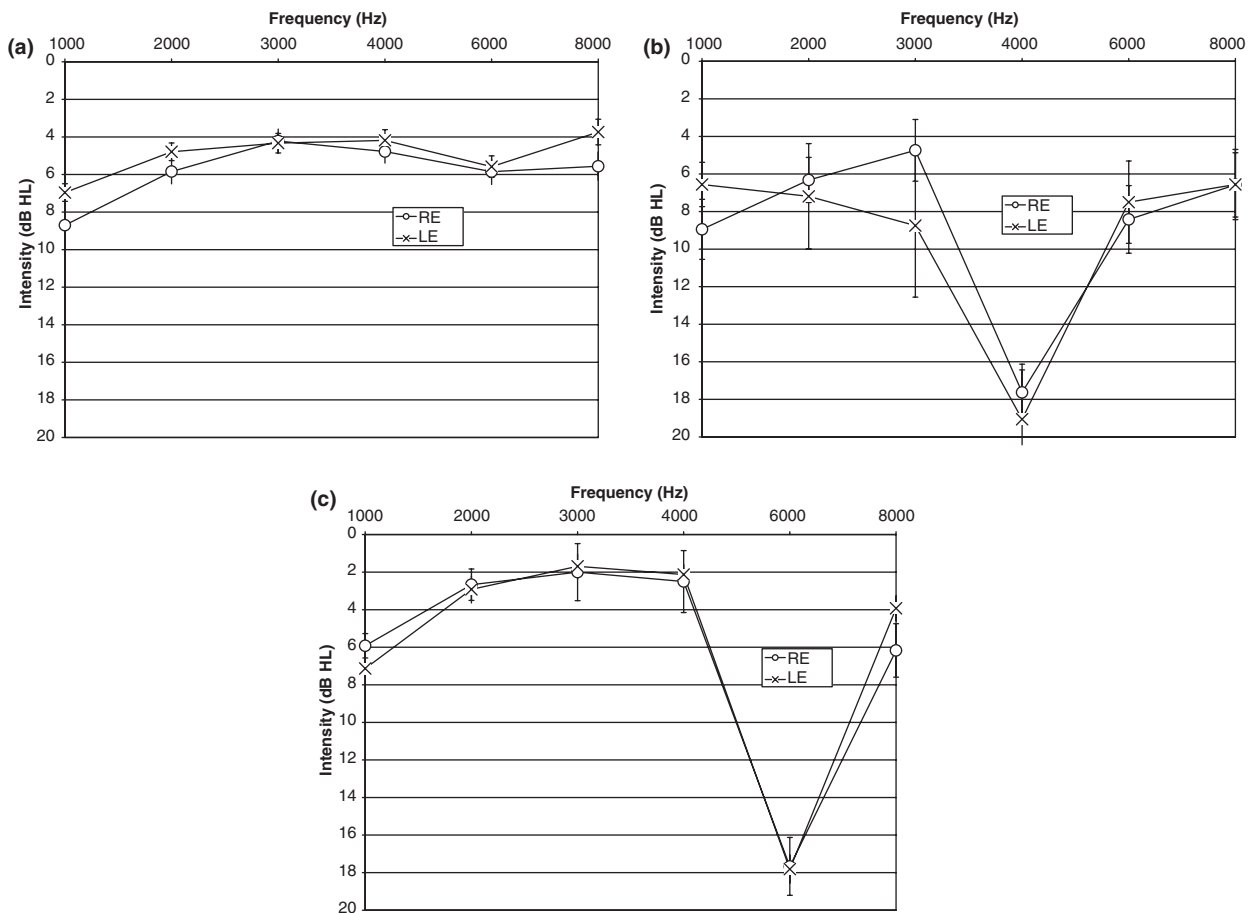


Figure 1. Mean hearing threshold and standard error of the mean (SEM) for students over the range of 1000–8000 Hz. (a) Students showing no notches, N = 185; (b) students showing a notch at 4000 Hz, N = 22; (c) students showing a notch at 6000 Hz, N = 112 (RE = right ear, LE = left ear).

more bilateral notches than other classes ($\chi^2(4) = 14.492, p = .006$). Neither ensemble participation nor instrument group (voice, percussion, brass, wind, string, keyboard) was a significant factor in the presence of NIHL (see Table 2). Although pianists can be classified as percussionists, the authors have created a separate classification for them, as their music is more sustained compared with other percussion instruments. Figure 3 presents the instrument group information as the proportion of the total students with NIHL who

have bilateral and unilateral losses. In this figure, it can be seen that the proportion of bilateral notching is not significantly higher for louder instruments (e.g. brass), and indeed is similar across all of the instrument groups.

Of the students with a 4000 Hz notch, 48.4% reported exposure to amplified music, while fewer (35%) students with a 6000 Hz notch (N/6000 Hz notch) reported such exposure. However, 54% of students reporting exposure to amplified sound had no notches at all. A Pearson chi-square analysis of the frequency of notches at 6000 Hz by ensemble participation revealed that the percussion ensemble had a significant proportion of their members (5/6) with unilateral notches ($\chi^2(1) = 3.818, p = .05$).

Analysis of ensemble participation produced unexpected results. Two of the seven members of a small group of chamber singers (40%) had bilateral notching at 6000 Hz ($\chi^2(1) = 4.326, p < .05$). The number of bilateral notches was also significant for the chorale, where six out of 34 singers had bilateral notches ($\chi^2(1) = 5.185, p < .05$). This represents an 18% incidence rate, which is somewhat higher than that in the general student population. Differences between ensembles for the proportion of notches at 4000 Hz were not significant.

The amount of time spent in individual practice mattered more broadly, with the number of reported hours of practice per day

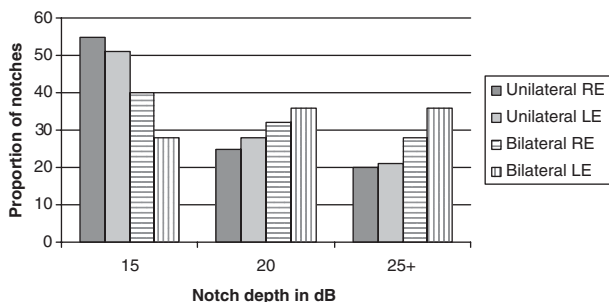


Figure 2. Percentage of notches over depth range for students with unilateral and bilateral notches. Total combined percentage for each ear-related category is 100% (RE = right ear, LE = left ear).

Table 2. Proportion (number) of total students who have unilateral and bilateral notches of 15 dB or more at 4000 and/or 6000 Hz. (N=329).

	4 kHz	6 kHz	4 & 6 kHz (bilaterals)	Overall frequency
Unilateral RE	.024 (8)	.1 (33)	–	.13 (41)
Unilateral LE	.03 (11)	.17 (54)	–	.20 (65)
Bilateral	.01 (3)	.08 (25)	.03 (10)	.12 (38)

ranging from 0 to 7.5 hours. Students who reported two or more hours of practice each day (40% of the 239 who answered this question) were more likely to exhibit a notch at some frequency ($t=2.07$, $p < .05$). There were no significant differences in number of hours practiced for the students with 4000 vs. 6000 Hz, or unilateral vs. bilateral notches.

Exposure data outside of school

Although the majority of students (52%, total N=182) reported multiple types of exposure to music outside of school, students with notches do not report more external sources of acoustic over-exposure to music than students with no notches (see Table 3). In fact, while a slightly lower proportion of students with bilateral 6000 Hz notches report exposure to loud stereos, concerts, portable music players, and amplified sound when compared with students with unilateral notches, the differences were not significant. This was also true for absolute thresholds, which were not lower for students using personal media players.

Eighty percent of respondents (253/316) reported exposure to loud music outside of their classical music studies (stereos, clubs, amplified bands, and concerts). The majority of the 316 (53%) reported exposure to multiple sources. The differences in proportions of students with notches and those without who report these exposures were not statistically significant. A t-test of the effects of the use of personal media players (217 students) or a cell phone (320

students) on the presence of notches at 4000 or 6000 Hz revealed no significant differences.

The reported use of power tools was correlated with the elevated occurrence of a notch at 4000 Hz, for which 10 notches were found out of 53 students reporting such exposure ($\chi^2(2)=6.672$, $p < .05$). Other exposure included firearms practice, hunting, power tools, and all terrain vehicles. These students tended to have exposures to multiple noise sources. There were no significant gender effects. Of those who reported non-music noise exposure (N=71), 11 (15%) had a notch at 4000 Hz, compared with 9% in the general music student population, and 23 (32%) had a notch at 6000 Hz, compared with 37% in the general music student population. The proportion of students with a notch and non-music exposure was 48% (34/71), which is slightly higher than the percentage of students with a notch in the general student population, though the difference is not statistically significant. More losses were found in the left ear compared with the right ear as would be expected for the use of rifles and power tools if most of the users are right-handed (Stewart et al, 2001). Absolute thresholds at 3000 Hz [$F(1)=5.229$, $p < .03$], and 4000 Hz [$F(1)=6.36$, $p < .02$] were significantly higher in students who reported the use of firearms. This was also true at 4000 Hz for exposure to power tools [$F(1)=6.14$, $p < .02$]. Absolute thresholds were also significantly poorer at 2000 Hz [$F(1)=8.661$, $p < .01$], 3000 Hz [$F(1)=5.788$, $p < .02$], and 4000 Hz [$F(1)=5.724$, $p < .02$].

Very few students reported exposure to chemicals. An exception was carbon monoxide (55/317), though no significant associations were found with NIHL. Smoking (N=16) was significantly associated with the elevated occurrence of a unilateral 6000 Hz notch (N=6) ($\chi^2(2)=4.317$, $p < .05$), but not with bilateral notches (N=3). Certain reported chemical exposures were associated with a higher incidence of notching than in the general music student population. As an example, five of the six students reporting exposure to toluene, a chemical found in paint and paint thinners, adhesives and lacquers, had notching, predominantly at 6000 Hz, and one of these students had bilateral notches. Medication use in 15 categories was reported, with the most common being birth control (N=33), allergy medications (N=26) and antidepressants (N=15). Fewer than 10 students reported the use of any other type of medication. There were no significant associations between the frequency of notching and any medications.

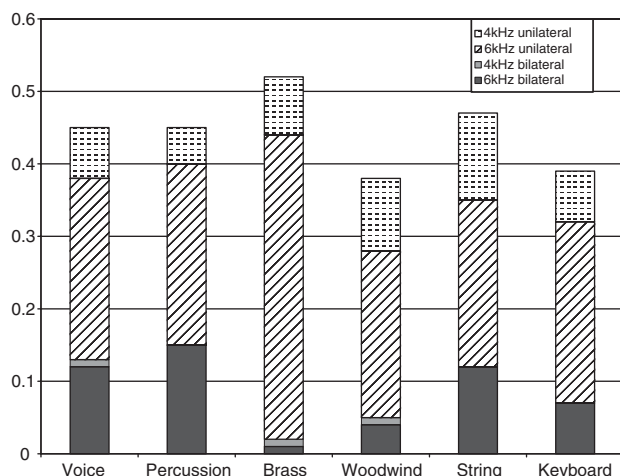


Figure 3. The proportion of students with a notch by instrument group who have bilateral and unilateral notches by instrument group.

Discussion

The music student population characterized in the present study was chosen to examine the prevalence of NIHL in a young adult population exposed to high sound levels on a regular basis. The prevalence of NIHL in at least one ear in the student musicians was 45%. This is within the range of 33–50% found by other studies of classical musicians, though most report data from older populations than the current study, which would suggest that music-induced notches occur at an early age (Emmerich et al, 2008; Fearn, 1993; Jansen et al, 2009; Ostri et al, 1989). Variability between studies is likely to result partially from differences in the definition of NIHL described previously. Most of the notches (78%) seen in this study were at 6000 Hz and were unilateral; this percentage is similar to that found in college music students by others (Backus et al, 2007; Fearn, 1993). Emmerich and colleagues also found that the deepest notches were at 6000 Hz, as have other reported studies (Jansen et al, 2008).

Table 3. Number and proportion of students in each instrument group and non-musicians who have notches

	No notch	4 kHz one ear only	6 kHz one ear only	Total one ear only	4 kHz bilateral	6 kHz bilateral	4/6kHz bilateral	Total bilateral
Voice (N=94)	52 (.55)	7 (.07)	23 (.25)	30 (.32)	1 (.01)	11 (.12)	1 (.01)	13 (.13)
Percussion (N=20)	11 (55%)	1 (.05)	5 (.25)	6 (.30)	0	3 (.15)	0	3 (.15)
Brass (N=74)	36 (48)	6 (.08)	31 (.42)	37 (.50)	1 (.01)	1 (.01)	2 (.03)	4 (.05)
Wind (N=70)	44 (.63)	7 (.10)	16 (.23)	23 (.33)	1 (.01)	3 (.04)	1 (.01)	5 (.07)
String (N=42)	18 (.43)	5 (.12)	14 (.33)	19 (.45)	0	5 (.12)	4 (.10)	9 (.21)
Keyboard (N=28)	17 (.61)	2 (.07)	7 (.25)	9 (.32)	0	2 (.07)	2 (.07)	4 (.14)

The total frequency of NIHL in student musicians is higher than in the general population as reported above and is similar to the frequency range (44–50%) of NIHL found in industrial workers (McBride & Williams, 2001; Rachiotis et al, 2006). However, notches in students of music were at 6000 Hz, while those reported in industrial workers are typically reported at 4000 Hz (Rachiotis et al, 2006; Landen et al, 2004). Rachiotis and colleagues reported that the majority of notches were found at 4000 Hz in a population of electro-production workers. McBride and colleagues found that notches at 4000 Hz were significantly associated with the noise exposure of electrical transmission workers and firearms exposure, while those at 6000 Hz were not. They did not include exposure to loud music in their analyses.

As noted through the survey, these young musicians did not show hearing problems that could be associated with chemical exposures, or industrial-type noise exposure, though there was a significant association between smoking and notching. Whether this represents a causal relationship or whether smoking is associated with other exposures (such as club music) was not determined.

These results are also consistent with the increase in the frequency of NIHL at 6000 Hz with age reported by other studies. As noted earlier, the prevalence of NIHL ranges from as low as 6.4% at age 6–11, to as high as 15.5% by the age of 18 (Haapanemi, 2002; Niskar et al, 2001); and is even higher among young people working on farms (17.5% to 26.5%; Renick et al, 2009). The advantage of comparing these studies with the current work follows from the similarity in the definition of NIHL that was applied. Two of these studies also reported that the prevalence of bilateral NIHL was 1.8% among all children and 3.9% in the farm youth, though these numbers were not reported by age range.

The report by Agrawal et al (2008) on the NHANES data provides the only NIHL prevalence numbers on adults, and applies a more stringent definition of NIHL as a 25 dB high-frequency pure-tone

average from 3000–6000 Hz. This resulted in a much lower reported frequency of NIHL in a population aged 20–29 years at 8.5%, which is slightly lower than that reported by Niskar et al for 12–18 year-olds. However, Agrawal et al reported a 2.8% frequency of bilateral NIHL in 20–29 year-olds (33% of those with NIHL), which is higher than the prevalence reported for teenagers. This might suggest that people with bilateral NIHL have deeper notches, which is in agreement with the findings in the current student music population.

The frequency of bilateral NIHL can be analysed with respect to the total proportion of NIHL cases. Simplistically, if bilateral NIHL results primarily from continuing exposure, it would be expected that the proportion of those with bilateral NIHL would increase at the same rate as the proportion of unilateral NIHL. By contrast, if bilateral NIHL is primarily derived from an inherent susceptibility, then the proportion of bilateral NIHL among all subjects showing a notch would be expected to remain relatively steady. In student musicians, bilateral notches were found in about 11% of all tested students and in 26% of students with NIHL. This is similar to the 25% of bilateral notches reported in electrical transmission workers (McBride & Williams, 2001) and the 28% reported in the general population by Agrawal et al (2008). The steady state level of bilateral notching among those showing NIHL implies that it does not typically result from the progression of unilateral NIHL to bilateral NIHL through continuous sound exposure, but rather represents a trait that is discernible in most subjects by early adulthood. In the report of children (Niskar et al, 2001), bilateral losses represent 14.4% of the total cases of NIHL. In the children of farm families, bilateral losses represent 17% of the cases of NIHL (Renick et al, 2009), further suggesting that bilateral notching begins to occur during childhood development and is presumably exacerbated by excessive sound exposure in young people.

Results from this study and others further suggest that even at high levels of exposure, not all exposed individuals develop NIHL,

Table 4. Proportion (number) of students reporting exposure to music outside university studies

	No notch (N=183)	4 kHz notch (N=29)	4 kHz bilateral (N=3)	6 kHz notch (N=97)	6 kHz bilateral (N=25)
None	.09 (17)	.10 (3)	0	.18 (17)	.16 (4)
Portable music player	.52 (95)	.65 (19)	1.0 (3)	.82 (80)	.72 (18)
Stereo music	.57 (105)	.72 (21)	.33 (1)	.70 (68)	.48 (12)
Concerts	.36 (66)	.59 (17)	1.0 (3)	.51 (49)	.32 (8)
Amplified sound	.34 (62)	.48 (14)	.66 (2)	.42 (41)	.32 (8)
Clubs	.13 (23)	.14 (4)	0	.20 (19)	.16 (4)

and they may be relatively resistant to NIHL. Studies have shown an association between the presence of specific genetic variants and the prevalence and severity of NIHL among industrial workers (Konnings et al, 2007; Sliwiska-Kowalska et al, 2008; Van Laer et al, 2006; Yang et al, 2006) though it remains to be seen whether other variants in these genes or other genes confer some resilience to NIHL.

What would a genetically-based predisposition to NIHL look like? We propose that such a predisposition is likely to be systemic, affecting both ears as a result, and would begin to present as a bilateral notch at a relatively early age. Several other observations made during the course of this study are consistent with the possibility that bilateral notching is at least partly rooted in genetic predispositions. For instance, the proportion of notches greater than 25 dB at 6000 Hz was significantly higher ($P \leq 0.0001$) among subjects with a notch in both ears compared to unilateral notches. In other words, the notches seen in subjects with bilateral NIHL tend to be more severe than their unilateral counterparts, as might be expected for those who are unusually susceptible to NIHL. As noted, the appearance and severity of bilateral loss was not connected in this study with any unusual exposure, instrument group, or practice regimen.

A few anomalous subgroups of the student musician population (small vocal group) have unusually high numbers of musicians with bilateral NIHL. It may be that the sound exposures for these groups are low enough that those musicians who sustain a loss in these groups tend to be those who are predisposed; and hence they tend to show a bilateral loss. On the other hand, percussionists and brass players, whose exposure levels are known to be high (Phillips & Mace, 2008), have a high proportion of unilateral NIHL, which could mean that their losses are more related to exposure. Based on the inferences derived from these studies, therefore, bilateral notching may prove to be an early indication of vulnerability to NIHL that is not particularly dependent upon excessive noise exposure, but which could be exacerbated by continued exposure, as indicated by the relative severity of notches in college age students with bilateral NIHL who were seen in this study.

An examination of the audiologic status of family members for students with bilateral vs. unilateral NIHL is currently under way. A direct genetic association study is also needed, examining several genetic variants that recently have been associated with NIHL. Future research is also needed that provides detailed analyses of sound exposure in student musicians: durations at specific sound levels for individuals, peak levels by instrument and ensemble, and long-term measurements of individual exposure. The goal is to be able to identify susceptible individuals and high risk exposures to target for preventive measures.

As data on sound levels in practice rooms and hearing loss in student musicians came to light in our early investigations, it was apparent that a hearing protection policy was in the best interests of the students in the School of Music. A policy was drafted, and presented to the faculty. Faculty approval of the proposal resulted in the implementation of the Hearing Conservation Policy, which is the institution of mandatory yearly hearing evaluations, as well as a yearly assembly dedicated to hearing protection education. For further information, please use the following web address: <http://www.uncg.edu/mus/mri/hearing.html#conservation>.

In summary, the prevalence of NIHL in a college population of music students was 44%, with 6000 Hz as the prevailing notch frequency. Bilateral NIHL was observed in 11.5% of all tested subjects, and may reflect a genetic predisposition.

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References

- Agrawal Y., Platz E.A. & Niparko J.A. 2008. Prevalence of hearing loss and differences by demographic characteristics among US adults: Data from the National Health and Nutrition Examination Survey, 1999–2004. *Arch Intl Med*, 168, 1522–1530.
- Backus B., Clark T. & Williamson A. 2007. Noise exposure and hearing thresholds among orchestral musicians. In: A Williamson & D Coimbra (eds.), *Proceedings of the International Symposium on Performance Science 2007*. European Association of Conservatoires (AEC), pp. 23–28. (See www.performancescience.org to download.)
- Backus B.C., Clark T. & Williamson A. 2007. Noise exposure and hearing thresholds among orchestral musicians. Presented at the International Symposium on Performance Science. Retrieved 2/10/2008 at <http://www.performancescience.org>.
- Behar A., MacDonald E., Lee J., Cui J., Kunov H. et al. 2004. Noise exposure of music teachers. *J Occup Environ Hyg*, 1(4), 342–347.
- Dement J., Ringen K., Welch L., Bingham E. & Quinn P. 2005. Surveillance of hearing loss among older construction and trade workers at Department of Energy nuclear sites. *Am J Ind Med*, 48(5), 348–358.
- Emmerich E., Rudel L. & Richter F. 2008. Is the audiologic status of professional musicians a reflection of the noise exposure in classical orchestral music? *Eur Arch Otorhinolaryngology*, 265, 753–758.
- Fearn R.W. 1993. Hearing loss in musicians. *J Sound Vibration*, 163(2), 372–378.
- Fuente A. & McPherson B. 2006. Organic solvents and hearing loss: The challenge for audiology. *Int J Audiol*, 45, 367–381.
- Gok U., Halifeoglu I. & Yildiz M. 2005. Levels of paraoxonase and serum lipid parameters in patients with noise-induced hearing loss. *FU Saglik Bil Dergisi*, 19, 257–261.
- Haapaniemi J. 1995. The 6-kHz acoustic dip in school-aged children in Finland. *Eur Arch Otolaryngol*, 252, 391–394.
- Henderson D., Subramaniam M. & Boettcher F.A. 1993. Individual susceptibility to noise induced hearing loss: an old topic revisited. *Ear Hear*, 14(3), 152–168.
- Jansen E.J.M., Helleman H.W., Dreschler W.A. & de Laat J.A. 2009. Noise induced hearing loss and other hearing complaints among musicians of symphony orchestras. *Int Arc Occup Environ Health*, 82, 153–164.
- Johnson A.C. & Nysten P.R. 1995. Effects of industrial solvents on hearing. *Occup Med*, 10, 623–640.
- Kahari K.R., Axelsson A., Hellstrom P. & Zachau G. 2001. Hearing development in classical orchestral musicians. A follow-up study. *Scand Audiol*, 30, 141–149.
- Konnings A, Van Laer L., Carlsson P., Bondeson M., Rajkowska E. et al. 2007. Association between variations in CAT and noise-induced hearing loss in two independent noise-exposed populations. *Hum Mol Genet*, 16, 1872–1883.
- Laitinen H. 2005. Factors affecting the use of hearing protectors among classical music players. *Noise & Health*, 7(26), 21–29.
- Landen D., Wilkins S., Stephenson M. & McWilliams L. 2004. Noise exposure and hearing loss among sand and gravel workers. *J Occup Environ Hyg*, 1(8), 532–541.
- Lataye R. & Campo P. 1997. Combined effects of simultaneous exposure to noise and toluene on hearing function. *Neurotoxicol Teratol*, 19, 373–382.
- Lees R., Roberts H. & Wald Z. 1985. Noise-induced hearing loss and leisure activities of young people: A pilot study. *Can J Public Health*, 76, 171–173.
- Lu J., Cheng X., Li Y., Zeng L. & Zhao Y. 2005. Evaluation of individual susceptibility to noise-induced hearing loss in textile workers in China. *Arch of Environ Occup Health*, 60(6), 287–294.

- McBride D.I. & Williams S. 2001. Audiometric notch as a sign of noise induced hearing loss. *Occup Environ Med*, 58, 46–51.
- Morata T.C. & Campo P. 2002. Ototoxic effects of styrene alone or in concert with other agents: A review. *Noise Health*, 4, 15–24.
- Mendes M.H., Morata T.C. & Marques J.M. 2007. Acceptance of hearing protection aids in members of an instrumental and voice music band. *Braz J Otorhinolaryngol*, 73(8), 1124–1131.
- Mori T. 1985. Effects of record music on hearing loss among young workers in a shipyard. *Int Arch Occup Environ Health*, 56, 91–97.
- Nageris B.I., Raveh E., Zilberberg M. & Attias J. 2007. Asymmetry in noise-induced hearing loss: Relevance of acoustic reflex and left or right handedness. *Otol Neurotol*, 28, 434–437.
- NIOSH: Preventing occupational hearing loss: A practical guide. U.S. Dept. of Health and Human Services Publication No. 96–110, 1998.
- Nelson D.I., Nelson R.Y., Concha-Barrientos M. & Fingerhut M. 2005. The global burden of occupational hearing loss. *Am J Ind Med*, 38, 446–458.
- Niskar A.S., Kieszak S.M., Holmes A., Esteban E., Rubin C. et al. 1998. Prevalence of hearing loss among children 6–19 years of age: The 3rd National Health & Nutrition Survey. *JAMA*, 279, 1071–1075.
- Niskar A.S., Kieszak S.M., Holmes A., Esteban E., Rubin C. et al. 2001. Estimated Prevalence of Noise-Induced Hearing Threshold Shifts Among Children 6 to 19 Years of Age: The Third National Health and Nutrition Examination Survey, 1988–1994, United States. *Pediatrics*, 108, 40–43.
- Ostri B., Eller N., Dahlin E. & Skyly G. 1989. Hearing impairment in orchestral musicians. *Scand Audiol*, 18, 243–249.
- Phillips S.L. & Mace S.T. 2008. Sound level measurements in music practice rooms. *Music Performance Res*, 2, 36–47.
- Phillips S.L., Shoemaker J., Mace S.T. & Hodges D.A. 2008. Environmental factors in susceptibility to noise-induced hearing loss in student musicians. *Med Prob Performing Artists*, 23, 20–28.
- Rachiotis G., Alexopoulos C. & Drivas S. 2006. Occupational exposure to noise, and hearing function among electro production workers. *Auris Nasus Larynx*, 33, 381–385.
- Renick K.M., Crawford J.M. & Wilkins J.R. 2009. Hearing loss among Ohio farm youth: A comparison to a national sample. *Am J Ind Med*, 52, 233–239.
- Rybak L.P. 1992. Hearing: The effects of chemicals. *Arch Otolaryngol Head Neck Surg*, 106, 677–686.
- Sliwiska-Kowalska M., Noben-Trauth K., Pawelczyk M. & Kowalski T.J. 2008. Single nucleotide polymorphisms in the Cadherin 23 (CDH23) gene in Polish workers exposed to industrial noise. *Am J of Hum Biol*, 20, 481–483.
- Strasser H., Irle H. & Legler R. 2003. Temporary hearing threshold shifts and restitution after energy-equivalent exposures to industrial noise and classical music. *Noise & Health*, 5, 78–84.
- Tan C., Hsu C., Lee S.Y., Liu S.H. & Lin-Shiau S.Y. 2001. Potentiation of noise-induced hearing loss by amikacin in guinea pigs. *Hear Res*, 161, 72–80.
- Toppila E., Pyykkö I. & Starck J. 2001. Age and noise-induced hearing loss. *Scand Audiol*, 30, 236–244.
- Van Laer L., Carlsson P.I., Ottschytch N., Bondeson M.L., Konings A. et al. 2006. The contribution of genes involved in potassium-recycling in the inner ear to noise-induced hearing loss. *Hum Mutat*, 27, 786–795.
- Yang M., Tan H., Yang Q., Wang F., Yao H. et al. 2006. Association of hsp70 polymorphisms with risk of noise-induced hearing loss in Chinese automobile workers. *Cell Stress Chaperones*, 11(3), 233–239.