Research Article

Hearing Conservation Program for Marching Band Members: A Risk for Noise-Induced Hearing Loss?

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Purpose: To examine the risk for noise-induced hearing loss (NIHL) in university marching band members and to provide an overview of a hearing conservation program for a marching band.
Method: Sound levels during band rehearsals were recorded and audiometric hearing thresholds and transient otoacoustic emission were measured over a 3-year period. Musician's earplugs and information about hearing loss were provided to the students. The hearing thresholds of other college students were tested as a partial control.
Results: There were no significant differences in hearing thresholds between the two groups. During initial testing, more marching band members showed apparent high-frequency notches than control students. Follow-up hearing tests in a subsequent year for the marching band members showed that almost all notches disappeared. Persistent standard threshold shift (STS) across tests was not observed in the band members.
Conclusion: Band members showed no evidence of STS or persistent notched audiograms. Because accepted procedures for measuring hearing showed a lack of precision in reliably detecting early NIHL in marching band members, it is recommended that signs of NIHL be sought in repeated measurements compared to baseline audiograms rather than in a single measure (a single notch). A hearing conservation program for this population is still recommended because of lengthy rehearsal times with high sound-level exposure during rehearsals.

Key Words: hearing conservation, noise-induced hearing loss, high-frequency notch

Hearing loss from excessive noise exposure has been a well-known public health issue of the National Institute on Occupational Safety and Health (NIOSH). Noise-induced hearing loss (NIHL) in teenagers has become a particular concern since Niskar et al. (2001) published an analysis of survey data from the U.S. Centers for Disease Control and Prevention highlighting the risk. More recently, Shargorodsky, Curhan, Curhan, and Eavey (2010) suggested that 16%–20% of children ages 12–19 years may have some kind of hearing loss. Although they could not confirm it, these authors suggest that one factor that may contribute to this apparent increase in hearing loss at higher frequencies may be the regular exposure of teenagers to excessively loud music. Because the potential for noise exposure could be especially high among music students, particularly those participating in large instrumental ensembles, it has been suggested that a hearing conservation program needs to be implemented for groups of young musicians such as those in a marching band (e.g., Chesky, 2008)

The hazards of music exposure among musicians have been difficult to quantify because unlike most industrial noise, the intensity of music fluctuates widely over time. This intermittency in musical sounds can reduce the risk of hearing loss (Ward, 1991b). O'Brien, Wilson, and Bradley (2008) reported noise levels within a professional orchestra over 3 years in order to provide greater insight to the orchestral noise environment. Their findings indicated that players of particular instruments such as percussion, timpani, trumpets, and horns were at greatest risk of exposure to excessive sustained and peak noise levels (see Table II-V from O'Brien et al., 2008). In addition, other researchers have documented that sound levels recorded during rehearsal and performances sometimes meet or exceed Occupational Safety and Health Administration (OSHA) limits (Axelsson & Lindgren, 1981; Jansson & Karlsson, 1983; Royster, Royster, & Killion, 1991).

Although the importance of hearing protection for musicians has been acknowledged widely (Federman & Picou, 2009), there are a number of factors that make it difficult to establish a direct link between rehearsal sound exposure and hearing loss. First, audiometric thresholds as typically measured may lack the sensitivity needed for identifying early NIHL. Second, there is a great deal of variability in noise susceptibility among the general population (e.g., Ward, 1995): Sounds that may be damaging to

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some ears are not for others, and factors that predict susceptibility are unknown. Also, the high sound levels that are produced in band and orchestra rehearsals are intermittent as they are generally interspersed with teaching and coaching by directors, and rehearsals for university marching bands tend to be of relatively short duration, usually 90–120 min. Little is known about the negative effects of intermittent sound exposure, but we do suspect that intermittent sound is less damaging than continuous sound, even if the total exposures are equal (Ward, 1991a).

Despite the fact that actual exposure levels are challenging to measure, there are several reports that professional musicians have higher rates of hearing loss than nonmusicians (Royster et al., 1991; Sataloff & Sataloff, 1991). In a study of Chicago Symphony Orchestra musicians, Royster et al. (1991) noted that although the majority of the musicians had hearing thresholds within normal limits for their age, 52.5% of all ears showed a notched audiogram, suggesting NIHL. Interestingly, violinists and violists showed significant interaural hearing threshold differences due to the higher sound levels at the ear closest to their instrument. Royster et al. concluded that musicians with average susceptibility to noise are at risk for hearing loss due to orchestral sound levels. However, these studies focused on older musicians with a variety of noise histories. Because the musicians in their studies were largely middle age and had multiple potential causes of hearing loss, it is not clear whether exposure to music was the main contributing factor for the results. There was little information about whether any significant NIHL was a result of the orchestra alone, a combination of rehearsal plus other noise exposures or, perhaps, the general effects of aging.

In order to examine the effect of intense music on NIHL with little or no influence from aging, several studies have examined the hearing status of younger musicians. For example, Schmidt, Verschuure, and Brocaar (1994) studied 79 students at the Rotterdam conservatory ranging in age from 21 to 40 years (median = 25 years). They observed that 12 of 64 music students (19%) showed signs of a noise-related notched audiogram, whereas 5 of 47 nonmusician medical students (11%) showed signs of a noise-related notched audiogram. In another study, Phillips, Henrich, and Mace (2010) reported the prevalence of hearing loss among students in a music major (N = 329, ages 18–25 years). In this study, NIHL was defined by the presence of a notch that was 15 dB in depth at 4000 Hz or 6000 Hz relative to the best previous threshold. In order to prevent observing temporary threshold shifts (TTSs), students were asked to avoid practice and music exposure 12 hr before the hearing test. Phillips et al. found that the overall prevalence of NIHL in either ear was 45%. The large majority of notches (78%) were found at 6000 Hz, and the rest were at 40001Hz. The proportion of the total population with bilateral notching at any frequency was 11.5%, and that was mostly found at 6000 Hz. Similar characteristics of hearing loss were found by several other studies of classical musicians, suggesting that hearing loss due to music exposure occurs at an early age (Emmerich, Rudel, & Richter, 2008; Fearn, 1993; Jansen, Helleman, Dreschler, & de Laat, 2009; Ostri, Eller, Dahlin, & Skylv, 1989) and that such hearing losses were mostly observed at 6000 Hz (Backus, Clark, & Williamon, 2007; Fearn, 1993).

As awareness of the potential negative effect of music on hearing health increases, more professional musicians and music educators have been putting their effort to promote hearing conservation programs. For example, campaigns like Hearing Education and Awareness for Rockers have been facilitating hearing conservation for professional musicians over the past 2 decades (Federman & Picou, 2009). For students in music education, the Health Promotion in Schools of Music (HPSM) project recommends several strategic approaches to educating students about music-induced hearing loss and hearing conservation (Chesky, Pair, Yoshimura, & Landford, 2009). As part of the HPSM project, the College of Music at the University of Northern Texas launched a hearing conservation program for students and instructors who engaged in music ensembles each semester (Chesky, 2006). More recently, Federman and Picou (2009) suggested some tactical approaches to prevent NIHL among musicians. They suggested that musicians could be helped to protect their hearing by using more suitable musician's earplugs, increasing awareness of the signs of hearing loss, and reducing their exposure level by modifying the practice environment. However, many musicians are unwilling to wear hearing protection during practice due to discomfort, inability to communicate with others while wearing them, and reduced quality of music perception (Chasin & Chong, 1999; Chesky et al., 2009; Hsu, Chung-Cheng, Chin-Yo, & Chunn-Ming, 2004; Toppila, Laitinen, & Pyykkö, 2005). Some investigators did not even recommend earplugs as a primary method of hearing protection for musicians because of these challenges (Chesky et al., 2009).

Although it has been shown that intense music can have an adverse effect on hearing, and the incidence of NIHL among musicians may be higher than among nonmusicians, some investigators (Green, 2002; Schlauch & Carney 2007, 2011, 2012) have raised a concern that the typical method of measuring pure-tone hearing thresholds may not be specific enough to detect early NIHL in the general population. They suggested that the methods of Niskar et al. (2001) and others of reporting the presence of a high-frequency notch (HFN) can lead to a high false-positive rate due to measurement variability. This variability, which is inherent in threshold measurements, can result in an apparent notch in a person whose true audiogram has a flat configuration. Thresholds obtained at 6000 Hz and 8000 Hz—frequencies that are important for defining noise notches—have higher variability than do lower frequencies when they are measured with supra-aural earphones (Schlauch & Carney, 2011). Supra-aural earphones are also subject to a 5-dB calibration error at 6000 Hz, which is attributable to an interaction of a TDH-style earphone and its response in an NBS-9A coupler used to assess levels for calibration (Lutman & Qasem, 1998). This higher variability and the calibration error may have contributed to the finding of Phillips et al. (2010) that the majority of audiometric notches in their music-major study participants were observed at 6000 Hz. The possible influence of these factors, which can result in false-positive audiometric notches, appears in other studies, even ones obtained from young children with no risk factors for NIHL (Haapaniemi, 1996; Schlauch & Carney, 2011, 2012).

The purposes of the current study were to describe a hearing conservation program for marching band members at the University of Minnesota that was designed to examine the risk of NIHL and to report a preliminary analysis of the outcome measures done over 3 years. Further, we wished to determine whether routine hearing tests can identify early signs of NIHL in a group of students who may be at risk for NIHL. In addition to pure-tone audiometry, we used a physiological measure, transient otoacoustic emission (TEOAE), to examine the hearing status of marching band members. Because test–retest variability increases the possibility of a false notch, which might overestimate the risk of NIHL at 6000 Hz, we also conducted longitudinal hearing threshold and TEOAE measures for the marching band members. Analysis of thresholds measured at different times would provide an indication of test–retest reliability and any threshold change for the individual.

At the request of the University of Minnesota School of Music, the first two authors started a hearing conservation program to explore the possibility that exposure to high sound levels in the university's marching band might put some student members and staff at risk for NIHL. The program included sound-level measurements at marching band practices, regular hearing tests (pure-tone thresholds and TEOAE) for band members and staff, education about hearing loss, and dispensing of musician's earplugs that provide ~15-dB flat-frequency response attenuation. We asked the following questions:

- Do we observe noticeable NIHL in young healthy college students in the university's marching band? That is, are there more notched audiograms and reduced TEOAE among marching band members than among a control group?
- Are pure-tone hearing test procedures specific enough to accurately identify notched audiograms?
- Do hearing thresholds and TEOAE amplitudes of the marching band members change over time?
- Do we expect that our hearing conservation program, including regular education, regular testing, and the fitting of musician's earplugs, is adequate to prevent hearing loss in marching band members and staff?

Method

Participants

This study was conducted over 3 years. In each year, the marching band consisted of ~270 musicians, including ~25 percussionists and >200 woodwinds and brass. In Experiment 1, we tested two groups: Group 1 was made up of members of the University of Minnesota marching band (total *N* = 350 across the 3 years), and Group 2 was selected from a larger pool of young adults who represented a similar age and demographic sample as the marching band group (*N* = 348). Inclusion and exclusion criteria for subject selection are listed in Table 1.

Experimental Procedure

All participants in Group 1 (marching band, MB) received detailed audiological testing to measure their hearing status both in a pretest (baseline) and in a 3-to 4-month posttest (follow-up). They were subsequently tested annually during band camp. The baseline for band members was conducted before the band season, when members had not been exposed to MB noise for >5 months. The first MB follow-up test was conducted during the third or fourth month of regular band rehearsal and performance, but *before the end of band season* (i.e., while noise exposure was still occurring). The hearing status for Group 2 (control cohort, CC) was only measured once for each participant throughout a semester. Qualified personnel (a clinical fellow in audiology or a supervised graduate student in the audiology program) completed all testing in one of the sound-treated chambers located in the university's department of speech-language-hearing sciences. The standard test protocol took ~30 min and included the following measures:

- Otoscopy and screening tympanometry were used to rule out middle-ear dysfunction that might affect hearing thresholds or other measures. Tympanograms were classified as *within* or *outside* normal limits. Those participants with tympanograms outside normal limits were retested on another day. Data from the day of the abnormal tympanograms were not included in the database.
- Pure-tone air- and bone-conduction thresholds at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz were obtained with TDH-49 headphones using the modified Hughson-Westlake procedure. Thresholds were entered into the database for subsequent between-group (Group 1

Table 1. Study participants' characteristics for the marching band and the control cohort.

Subject group	Inclusion criteria	Exclusion criteria
Marching band (*N* = 350)	1. Current member of the marching band 2. Age ≤25 years	1. Documented hearing loss before pretest due to known factors such as genetics, disease 2. Hearing thresholds >45 dB HL
Control cohort (*N* = 348)	1. Age ≤25 years 2. Ambulatory/ healthy	1. Documented hearing loss before pretest due to known factors above 2. Exposure to regular marching band or orchestral practices and performances 3. Hearing thresholds >45 dB HL

vs. Group 2) and within-subject (pre- and posttest) comparisons for Group 1. Each response was analyzed for the presence of HFNs (as defined by Niskar et al., 2001). To determine the presence of threshold changes in Group 1, we used OSHA (1983) guidelines for standard threshold shift (STS) across tests.

- Other measures were also obtained at each test session:
    - TEOAEs were measured using ILO 88 equipment and standard protocol. TEOAE amplitude and signal-to-noise ratio in the 2- to 6-kHz region were obtained to identify high-frequency changes in the outer hair cell function (e.g., Marshall & Heller, 1998).
    - Case history and a noise exposure self-report were assessed in all participants. We used a noise exposure questionnaire listing 15 common noise sources to interview each participant about potential effects. Each potential noise risk factor (e.g., motorcycle use, hunting gunshots, factory noise, rock band, etc.) and hearing protection usage were rated for time units such as *never*, *rarely*, *some*, *often*, and *daily*. Then, each rating was converted to a numeric unit for later analysis (e.g., *never* = 0 and *daily* = 4). On the second part of the questionnaire, participants identified their estimated noise exposure from occupational, recreational, and other sources. The questionnaire is shown in the Appendix.
    - Ear protection compliance and hours of rehearsal were also assessed for all MB members by self-report.
- Sound levels were measured during an indoor MB practice session, in cooperation with the University of Minnesota safety officials. Estimates were obtained using a Quest Type I sound-level meter held at students' ear level at several locations throughout the ensemble. We measured sound levels using a dBC scale for 30-s periods in each location. Results are reported in the Results section.
- During the baseline hearing test session, a noncustom musician's earplug, ER 20 (Etymotic Research), was given to each MB member. We chose this type of earplug because they are far less expensive than customized earplugs and provide relatively flat attenuation that can minimize distorted music perception (Niquette, 2007; Santucci, 1990). MB members were provided with instructions for handling, cleaning, and inserting the earplugs. At the end of each hearing test, individual counseling was provided to both MB members and CC students in order to educate them about the potential harm to hearing of exposure to intense sound, signs of NIHL, long-term consequences of hearing loss, proper use of earplugs, and ways to minimize overall noise exposure level. For the returning MB members, we specifically asked whether they actually used the earplugs; if so, how often they wore them, and what the reasons not to wear them during practice were. It was re-emphasized that wearing the earplugs and reducing recreational noise exposure could protect participants' hearing. MB members were also encouraged to ask questions or express concerns about their general hearing health.

Results

Sound Levels During Rehearsals

We measured sound levels on two occasions: first at a small ensemble rehearsal and later at an early indoor MB practice, at which 270 members were present and were sight-reading new music. We measured sound levels at various places for different instruments using a Quest precision sound-level meter (C-weighted/slow and peak), which allowed us to estimate levels of continuous and very brief, transient sounds. Sound-level measurements for the full ensemble are shown in Table 2. The sound levels were measured in dBC, which can be considered only as a guide to estimating hearing loss risk. We also noted that sound exposure during a 60- to 90-min band rehearsal is intermittent rather than continuous. Nevertheless, we observed that these sound levels were high enough that they might potentially pose a risk of NIHL to MB members.

Questionnaire

All participants were asked to provide information about their music history, noise exposure, and medical history (see the Appendix for the questionnaire). We were able to collect and analyze 254 questionnaires from the MB and 258 from the CC. For the noise exposure rating, we asked participants to rate their exposure to 14 noise factors and assigned numeric ratings (from *never* = 0 to *daily* = 4.) A one-way analysis of variance (ANOVA) with between-subject variables showed that there was no group difference in the noise exposure rating, $F(1, 510) = 0.0062$, $p > 0.05$. The average rating was 14.9 ($SD = 6.4$) for the MB and 14.8 ($SD = 5.7$) for the CC. For the MB members, the estimated rehearsal hours per week varied substantially across members, ranging from 1 to 2 hr to >40 hr. Band members reported having ensemble practice between 2 and 10 hr per week on average, depending on the season. Drum line participants indicated that they practiced more frequently (up to 20 hr per week) during competition seasons. More than 50% of the MB reported that they never used earplugs

Table 2. Measurements of full-ensemble sound levels at various locations in the band organization.

Location	Average levels (dB C slow)	Peak levels (dB C peak)
Director	104–107	115–122
Percussion	110–120	132–134
Saxophones	105–106	115–117
Brass	106–109	120
Snare/crash cymbals	105–110	125–131
Clarinets, trumpets	98–105	112–117
Trombones, toms	107	127–133

Table 3. The percentage of the marching band (MB) members who completed the noise exposure questionnaire for the number of rehearsal hours, hearing protection (HP) usage, and years of practice with their instruments.

Rehearsal hr/week	% of MB	HP usage	% of MB	Years of practice	% of MB
1–10	32	Never	55	1–3	2
11–20	50	Rarely	15	4–6	4
21–30	11	Some	8	7–9	41
31–40	2	Often	9	10–13	45
> 40	6	Daily	13	14–18	8

during rehearsals. Personal conversations with the MB members revealed that the main complaints about using earplugs were a dislike of the earplugs, discomfort, inability to hear the director, change to the sound of the music, and inconvenience. The students who were in percussion tended to use the earplugs more often than the rest of the MB. A brief summary of the questionnaire results is provided in Table 3.

Pure-Tone Hearing Threshold Results

To address the question of the presence of signs of early NIHL observable in a single test, we first looked at the basic findings from both groups. Figure 1 shows box plots of hearing thresholds for first-time testing of MB members (N = 350), and Figure 2 shows the results from the CC (N = 348). Figures 1 and 2 show that most hearing thresholds from both groups were completely within normal limits, with median thresholds between 0 and 5 dB HL for both groups. No apparent elevation in threshold was seen at 3.0 or 4.0 kHz, which are frequencies where the impact of noise would be likely to be evident. However, thresholds at 6.0 kHz were slightly elevated compared to those at lower frequencies. Although this could be an early indicator of NIHL, the possibility of a 5-dB calibration error attributable to an interaction of a TDH-style earphone and its response in an NBS-9A coupler used to assess levels for calibration (Lutman & Qasem, 1998) cannot be ruled out.

Figure 3 shows the same data broken down by sex: 176 males and 174 females in Group 1 and 56 males and 292 females in Group 2. No apparent threshold difference was observed between sexes in either group. Table 4 shows the means and standard deviations for first-time testing for the MB and CC groups. A repeated measures ANOVA with group designation (MB vs. CC) as the between-subject factor found no significant difference between the two groups, $F(2, 735) = 2.936$, $p = 0.054$. Even though there was no statistical difference between groups, when the average thresholds of the same ear were compared between groups, hearing thresholds of the CC group were slightly lower (~3 dB or less) than those of the MB group at 1.0, 2.0, 3.0, and 4.0 kHz. However, no difference was noted at higher frequencies (6 and 8 kHz).

Figure 1. Box plots showing the distributions of threshold data for the first-time testing of band members under the age of 26. The dark center line represents the median value; the triangle represents the mean threshold; the bottom and top of the rectangle represent the 25th and 75th percentile, respectively; and the "whiskers" represent an extreme value that is derived from the size of the rectangle. Values beyond the end of the whiskers are considered extreme values and are represented using circles. Data represented by circles have been "jittered" with a small random number for clarity.

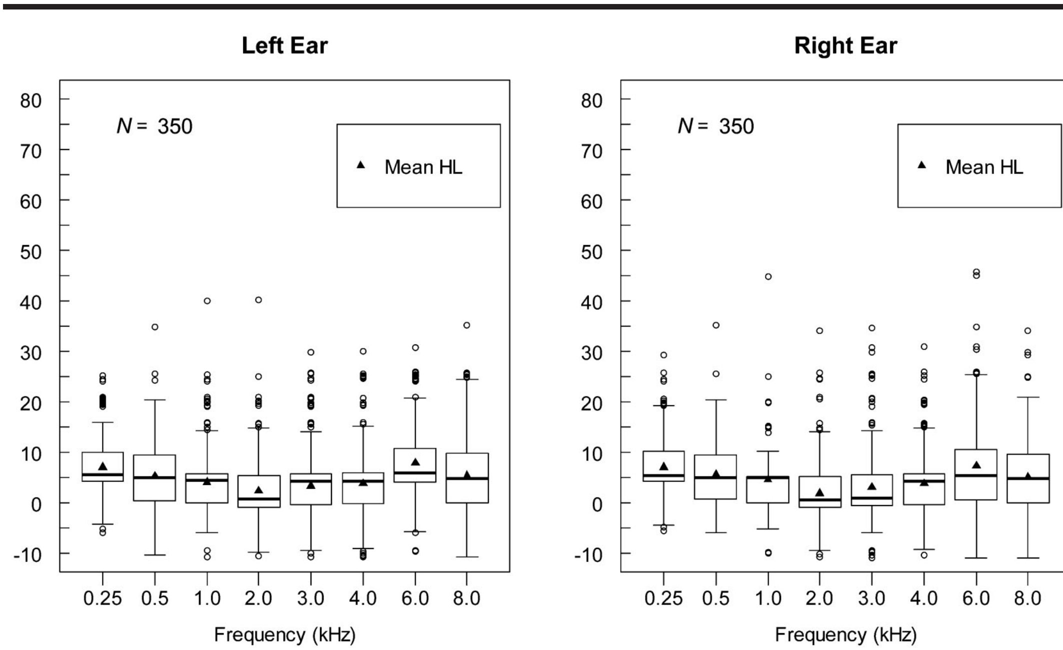


Figure 2. Box plots showing the distributions of threshold data testing of control group members under the age of 26. The data are displayed as in Figure 1.

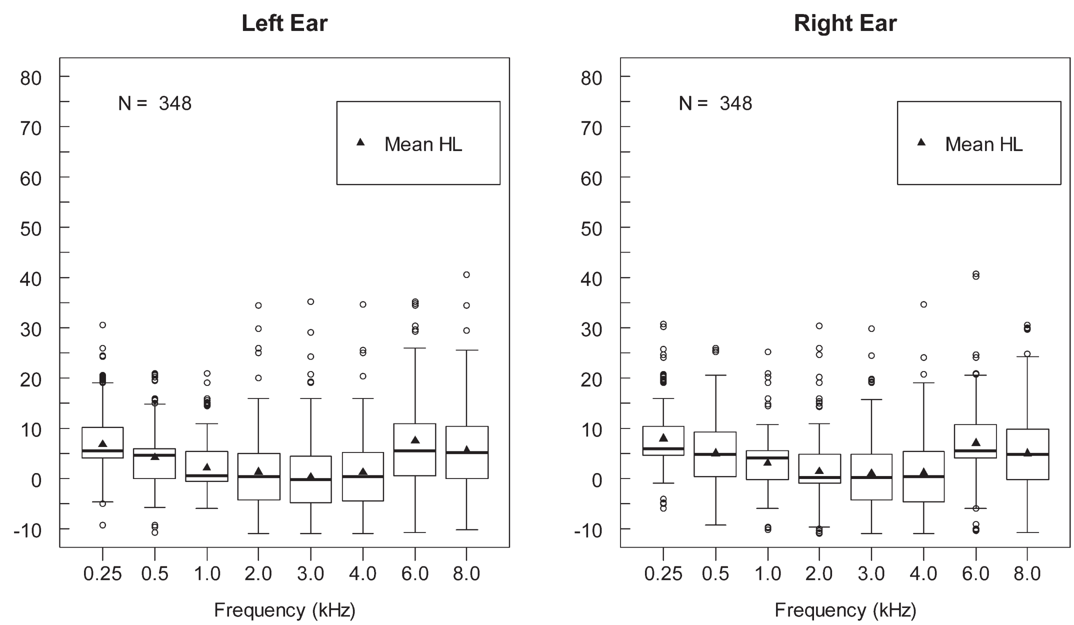


Figure 3. Box plots showing the distribution of threshold data for first-time testing of band members and for the control group, broken down by male (M) and female (F) for the right ear (RE) and left ear (LE). The data are displayed as in Figure 1.

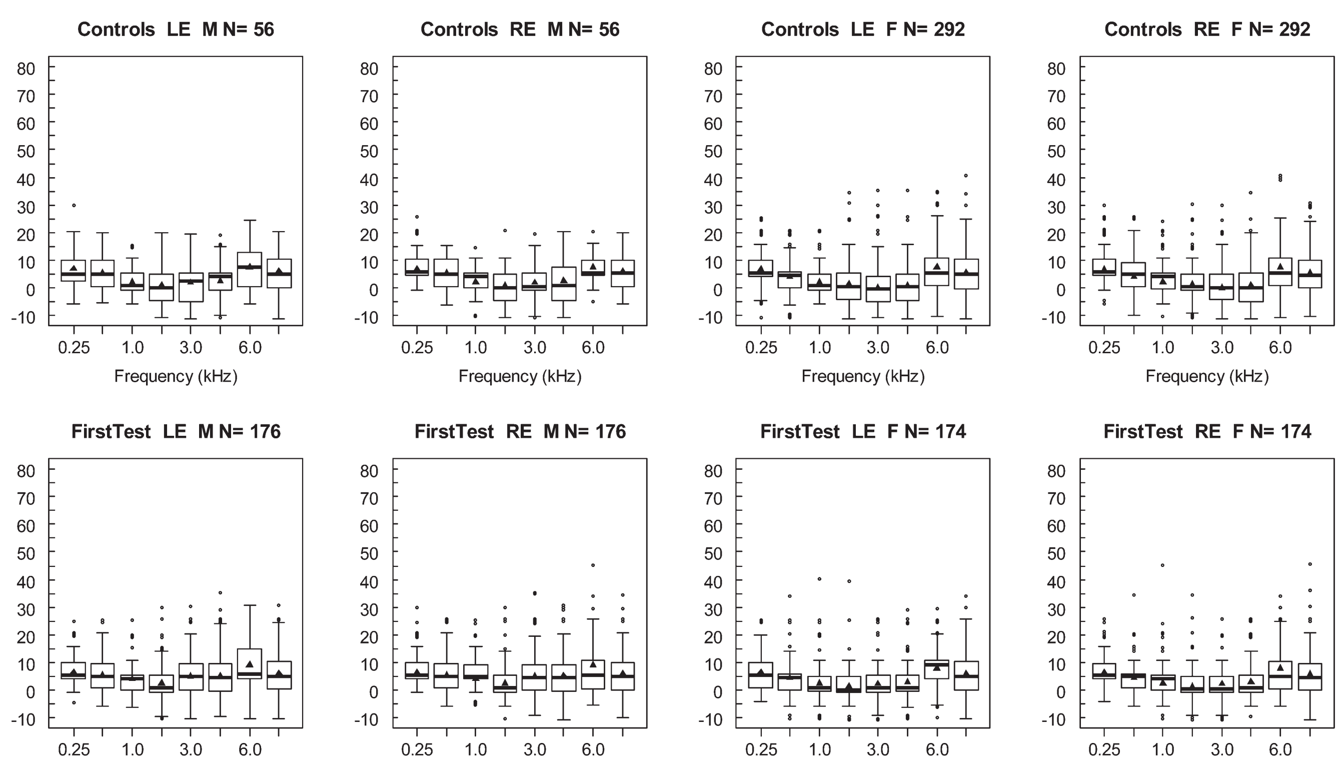


Table 4. Means and standard deviations for first-time testing for MB members and for controls.

		Frequency															
		250		500		1000		2000		3000		4000		6000		8000	
Group	Ear	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Band	Left	7.09	5.61	5.25	5.75	4.07	5.93	2.35	6.07	3.34	6.26	3.81	6.66	7.95	7.72	5.39	7.26
N = 350	Right	7.05	5.7	5.59	5.45	4.58	5.73	1.85	5.86	3.03	6.07	3.86	6.42	7.29	8.25	5.17	7.15
Control	Left	6.80	5.97	4.17	5.53	2.16	5.07	1.32	6.47	0.33	6.70	1.22	6.64	7.47	7.97	5.57	7.99
N = 348	Right	7.97	5.98	5.03	5.50	3.13	4.93	1.36	5.90	1.09	6.11	1.14	6.89	7.07	7.54	5.06	7.30

Examination of Notched Audiograms and TEOAEs

To address the original question, we sought to determine if there were more notched audiograms (indicative of a possible NIHL) among the MB members than among the CC students. In order to do that, we had to define *notched audiograms* according to a fixed set of criteria. Schlauch and Carney (2011) reviewed various methods for determining the presence of a notched audiogram. Based on their findings, we chose the notch criteria developed by Niskar et al (2001). These criteria require that an audiogram meet all of these conditions: (a) thresholds at both 0.5 and 1.0 kHz of 15 dB HL or better; (b) the poorest threshold at 3.0, 4.0, or 6.0 kHz at least 15 dB higher (poorer) than the poorer threshold at 0.5 kHz and 1.0 kHz; and (c) a threshold at 8.0 kHz at least 10 dB lower (better) than the poorest threshold at 3.0, 4.0, or 6.0 kHz.

Based on these criteria, the audiograms from both groups (350 first-time MB and 348 CC) were evaluated for the presence of a notch. Table 5 shows that 12.4% of the participants in the MB showed a notch in one or the other ear or both ears, whereas 8.6% of the participants in the CC showed a notch. These findings are consistent with the estimated prevalence of 8.5% and 15.5% notched audiograms for younger children (6–11 years) and older children (12–19 years), respectively (Niskar et al., 2001).

Schlauch and Carney (2011) performed computer simulations that modeled the precision of pure-tone audiometry, and their results support the idea that 10% of audiograms in teens showing notches could be false positives. It is possible, therefore, that many of the notches found in a single test session are not indicators of true NIHL. The simulations accounted for most, but not necessarily all, of the notches observed in Niskar et al. (2001) and the present study. Thus, the possibility remains that some of these apparent notches could reflect real hearing loss.

Table 5. Number of notched audiograms observed, evaluated using the Niskar et al. (2001) criteria, in the first-time testing of MB members and in the control group. The percentage of persons in each group that each number represents is shown in parentheses.

	Bilateral	Unilateral left ear	Unilateral right ear	Total
Band (*N* = 350)	10 (2.8%)	17 (4.8%)	17 (4.8%)	12.4%
Control (*N* = 348)	6 (1.7%)	13 (3.7%)	11 (3.2%)	8.6%

In addition to pure-tone audiometry, we analyzed the TEOAE amplitude of the ears of MB members with and without notches. Several studies have reported a significant correlation between a reduction in TEOAE amplitude and the presence of NIHL (Hall & Lutman, 1999; Jansen et al., 2009). Furthermore, Lapsley-Miller, Marshall, Heller, and Hughes (2006) found decreased group average OAE amplitudes after several months of noise exposure, whereas the average audiometric thresholds did not show any change. In the current study, it was hypothesized that if the apparent notches were a result of TTS, then possible changes in TEOAE amplitude might accompany the notch, as suggested by Helleman, Jansen, and Dreschler (2010).

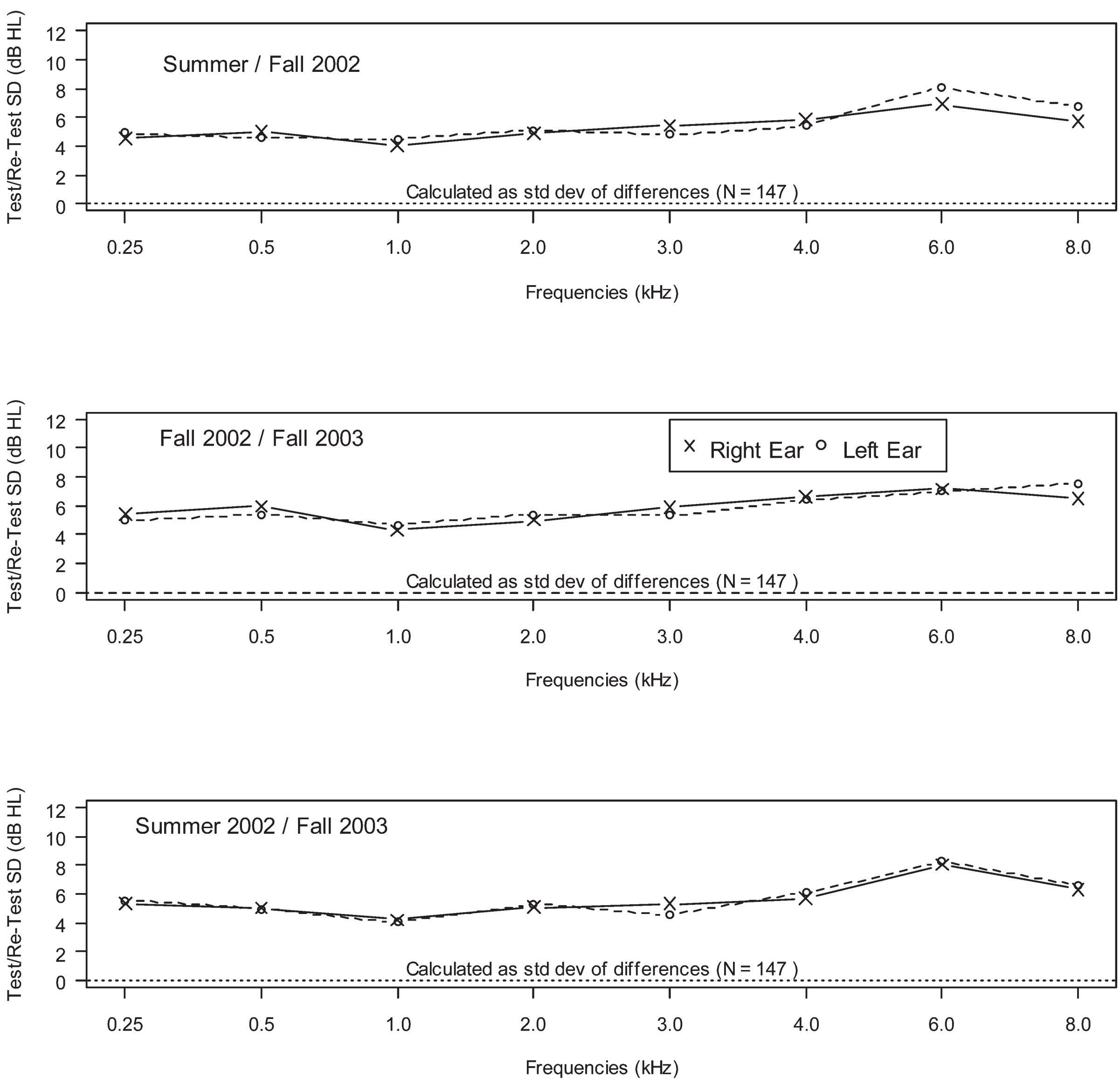
We assessed data during the fall of Year 1, when the largest number of ears with notches were noted ($n = 44$). TEOAE amplitudes at 2800 Hz and 4000 Hz were selected as likely the best potential indicators of high-frequency TTS (Jansen et al., 2009). No differences in TEOAE amplitude were observed between groups of the ears (those with notches, $n = 44$; those without notches, $n = 280$.). TEOAE amplitude was 17.3 dB ($SD = 6.7$) and 14.3 dB ($SD = 7.2$) for the ‘notch'' ears at 2800 Hz and 4000 Hz. For the ‘‘no-notch'' ears, the amplitudes were nearly identical at both frequencies: 17.3 ($SD = 6.0$) and 14.4 dB ($SD = 6.6$), respectively. In addition, for those MB members who showed a notch at least once during the test periods, we examined TEOAE amplitudes within those participants for times when they had a loss and times when they did not. For example, out of 44 MB members who showed a notch in the fall of Year 1, 25 of them did not have a notch in the summer of Year 1 and the fall of Year 2.

We analyzed the TEOAE data using a repeated measures ANOVA with the within-subject factors being the TEOAE values for frequencies 2.8 kHz and 4 kHz and the two tests. Test 1 is the result from a test, given in Summer Year 1, in which a notch was observed; Test 2 is the first test in which the notch disappeared (either in Fall Year 1 or Fall Year 2). If a participant had bilateral notches, each ear was considered separately. The frequency factor was not significant, $F(1, 24) = 1.36$, $p = 0.225$, nor was the test factor, $F(1, 24) = 3.22$, $p = 0.085$. We cannot rule out the possibility that a larger sample of TEOAE amplitude differences might produce statistically significant results, but this sample did not produce a significant reduction in TEOAE amplitude at the times when notched audiograms are observed.

Schlauch and Carney (2011) suggested that measurement variability could play a large role in the percentage of notches observed. Measurement variability is defined by the *SD* of test–retest differences (*SDD*s) from audiograms obtained at separate times, which for our purposes always included removing and replacing the earphones. The *SDD* generally increases as the time between successive tests increases. Figure 4 shows that the *SDD*s for our study are ~5 dB for the lower frequencies and 6–8 dB for 6000 Hz and 8000 Hz. These *SDD*s are on the low side of the range for those observed in prior studies and are about the same as the values used for simulating the precision of audiometry in Schlauch and Carney. Note that the variability was about the same regardless of the test–retest comparison interval.

To assess the false-positive rates that might be expected in this study, we conducted computer simulations using the variability noted in Figure 4 (the three *SDD*s calculated between each pair of testing occasions were averaged across ears at each frequency and divided by $\sqrt{2}$ to obtain the *SD*). The simulations used a procedure identical to that described in Schlauch and Carney (2011). We simulated both ears for 147 out of 350 members who stayed in the MB throughout the testing periods. The procedure assumes that each of the 147 "listeners" has a flat audiogram, with 5 dB added to the

Figure 4. Test/retest standard deviations for all combinations of testing sessions. This value is calculated as the standard deviation of the differences in threshold between sessions (the earlier session being subtracted from the later one).



value for 6000 Hz to simulate the potential calibration error noted earlier. The obtained simulated audiograms vary because of deviations above and below the "actual" threshold. Some of these simulated audiograms that incorporate this measurement variability will, by chance, have significant notches that meet the criteria described by Niskar et al. (2001). Those that meet the Niskar et al. criteria may be considered false positives. In our simulation of a sample corresponding to the MB, the average false-positive rate was 11.56%, with a 95% confidence interval of 6.8% to 17.0%. The percentage of notches observed in the first and third measurement of the MB (N = 147) and in the larger CC (N = 348) both fell within this interval. The simulation also predicted bilateral notches in 2.5% of persons, which is a finding similar to that observed in the MB and CC groups.

Table 6 shows the results for retesting of a subset of the MB members (N = 147). The number of notches showed variability across time. Unilateral notches showed an increase from Test 1 to Test 2 and a decrease on the final test. Bilateral notches showed a decrease throughout, which is a further indication that the observation of notches was caused by variability rather than permanent changes in hearing.

We completed an additional analysis of repeated thresholds to track persons in the MB who showed a notch on the first test through the second and third tests. These data are shown in Table 7. Each subsequent test showed a reduction in the percentage of participants who had repeatable notches. This pattern was observed despite the fact that the total percentage of ears with notches increased from 15.1% to 26.7% from Test 1 to Test 2 (as seen in Table 6). These data provide a further indication that the notches in many persons are transitory and are likely the result of the variability inherent in audiometry.

Table 6. Number of notched audiograms observed, evaluated using the Niskar et al. (2001) criteria, in the first and subsequent testing of 147 MB members.

Band member	Test 1 Summer Year 1	Test 2 Fall Year 1	Test 3 Fall Year 2
Unilateral	17 (11.6%)	36 (24.5%)	15 (10.2%)
Both ears	6 (4.1%)	4 (2.7%)	3 (2.0%)
Both ears all three tests	1	1	1
Total	23 (15.1%)	40 (26.7%)	18 (12.3%)

Table 7. Number of notched audiograms observed in subsequent tests by only the individuals who showed notched audiograms in the first test. By the third test, the majority of the notches, both unilateral and bilateral, had disappeared.

Band member	Test 1	Test 2	Test 3
Unilateral notch on initial test	17 (11.6%)	8 (5.4%)	2 (1.4%)
Bilateral notch on the initial test	6 (4.1%)	3 (2.0%)	1 (0.7%)

Threshold Shift

Because multiple measurements of thresholds were obtained from the MB, we also explored changes in threshold over time. In order to investigate threshold shift, we used the definition of standard threshold shift as defined in the Code of Federal Regulations (OSHA standards). STS is defined as "a change in hearing threshold of an average of 10 decibels (dB) or more at 2000, 3000, and 4000 Hertz (Hz) in one or both ears." (Recording and reporting occupational injuries and illness, 2004). Based on predictions from a multinomial analysis, as outlined in Schlauch and Carney (2007), we expected that the criteria for an STS would yield a low false-positive rate when the *SDD*s for those individual frequencies were 5 dB, as observed in this study.

No bilateral STSs were observed. Eight participants (8 of 147) showed an apparent unilateral threshold shift from Summer Year 1 to Fall Year 1, but only one shift persisted in a re-test. This one MB member showed threshold shifts over the course of the hearing test sessions done for this project. His shift was a gently sloping (not notched) change in high-frequency thresholds for one ear only. Follow-up showed a family history of hearing loss, and the student was referred for otological evaluation after the second test. No further information is known about the etiology of the progressive loss, but it is unlikely that it was related to high noise exposure levels.

Discussion

The original purpose of this study was to identify as early as possible the MB members who might be at risk of NIHL caused by high music levels in the university's MB. Based on our estimates and on previous studies (Chesky et al., 2009; Federman & Picou, 2009), we assumed that this group of students might be at risk of exposure to high sound levels. In order to detect early signs of NIHL in the students, we carefully examined two typical signs of NIHL resulting from exposure to loud music: notched audiogram and threshold shifts. As we analyzed the results, we determined that the methods of identifying signs of early NIHL were imprecise. Searching for notched audiograms proved to be an ineffective method of identifying risk for NIHL. Audiograms from both the MB and CC groups were evaluated for the presence of notched audiograms, as defined by Niskar et al. (2001). The MB appeared to show a higher percentage of notches than the CC; however, in repeat tests of MB members, almost all of the notches disappeared. Thus, a secondary purpose of this study was to evaluate the measures used to identify early signs of NIHL. Computer simulations supported the idea that the metric for estimating ears with notched audiograms was likely contaminated by false positives. Computer simulations of flat audiograms yielded a wide range of expected false-positive responses (6.8%–17.0% presumed notched audiograms), similar to that seen in our actual measurements. Further, the simulations yielded a small percentage of bilateral notches, as was also observed in MB members. Most causes of NIHL are expected to yield bilateral losses (Green, 2002; Schlauch &

Carney, 2011). The simulation results suggest that the apparent notched audiograms were not early signs of NIHL.

Repeated threshold measurements of the MB revealed that many of the notches were, in fact, transitory. For example, as seen in Table 6, 15% of the MB group (23 persons) showed a notch on the first test. By the third test, only three of these original 23 persons showed a notch on all three tests (Table 7). It is notable that during one test session (Fall Year 1), the number of unilateral notched audiograms for the MB rose steeply. At that time, 36 apparent unilateral notches were observed in the MB group (24% of persons tested showed a notch in at least one ear). Upon retest, the majority of those unilateral notches resolved. We cannot rule out the possibility that TTS may have contributed to the high number of notches observed, but we have no reason to expect high levels of exposure during that testing period. Further, no concurrent reduction in TEOAE amplitude was seen, supporting the hypothesis that TTS was not the primary factor.

Overall, only one person showed a reliable and persistent notched audiogram in both ears. That individual showed a notched audiogram at the time of the first test, and the audiogram did not change over time. Based on these one-time measures (notched audiograms and TEOAEs), we have no evidence that involvement in the MB produced higher thresholds, more notched audiograms, or lower TEOAE amplitudes than those experienced by the CC.

Other studies that have found a significant percentage of musicians having noise notches could have been influenced by false-positive responses. For example, Schmidt et al. (1994) reported a similar percentage of notched audiograms to the MB in the current study from both students in conservatory (16%) and a control group (14%). The age range of the participants was older (21–48) than in the current study, but, more importantly, the notch criteria were not as strict as those defined by Niskar et al. (2001). Schmidt et al. used a criterion of hearing loss in one or both ears of 20 dB or more at 3, 4, and 6 kHz, with the threshold at the frequencies adjacent to the notch at least 5 dB better. The high incidence of notched audiograms from both groups could come from three possible sources: measurement error, calibration, and actual noise-shifted thresholds. First, in audiometric testing, a 5-dB difference in threshold at the same frequency or an adjacent frequency (assuming both "true" thresholds are equal) is quite common based on measurement variability (Schlauch & Carney, 2007). If so, that 5-dB lower threshold at the frequencies adjacent to the dip might disappear if the same person were retested. Second, calibration error and high variability at higher frequencies for TDH-type headphones might have caused a high false-positive rate to be observed in their study (Hoffman, Dobie, Ko, Themann, & Murphy, 2010; Lutman & Qasem, 1998; Schlauch & Carney, 2011). Third, many of the threshold shifts could be real. Unfortunately, the problems of measurement variability and a potential calibration error make the observance of a notched audiogram from a single measurement of hearing threshold an imprecise indicator of NIHL.

In addition to the notch measures, we saw no signs of significant threshold shifts in the MB group. We examined changes in threshold over time in MB members by applying the OSHA (1983) guidelines on STS. Except for one student with significant otologic history, there was no consistent STS observed across three tests. The STS observed from several members was inconsistent and could have been a result of testing variability. As is the case for detecting notches in audiograms, threshold shifts might be subject to test–retest variability. In order to avoid inherent measurement variability, when STS is suspected, it is part of OSHA and NIOSH protocols to repeat testing and recalculate STS.

As Schlauch and Carney (2011) suggested, several methods can be implemented to improve the precision of pure-tone audiometry for identifying incipient NIHL. One of these is to make repeated estimates of threshold and average the results. Schlauch and Carney simulated several methods for repeating thresholds and averaging the results: (a) retest all persons, (b) retest the frequencies 6 kHz and 8 kHz and calculate the average threshold, and (c) retest complete audiograms for those participants in whom a notch was observed. These approaches require different time commitments and costs: The more thresholds that are repeated, the more expensive the method is to implement. These approaches were done for the three pairs of test occasions in the present study, and the results are shown in Table 8. It seems clear from these results that all of the methods reduced the observed notches. The least expensive method (retest only the ears that meet Niskar et al., 2001 criteria) performed better than either of the other methods for reducing false positives, but the implications for false negatives for any of these approaches is unknown.

Another method to improve the precision of pure-tone audiometry is to use an earphone that yields lower

Table 8. Number of persons whose audiograms met Niskar et al. (2001) criteria when audiograms from two test sessions were averaged in each of three ways: (a) average of all audiograms (All), (b) average of 6 and 8 kHz thresholds for all audiograms (6–8), and (c) average audiograms for ears in which a notch was observed (Notch).

Band member (*N* = 147)	Summer Year 1 to Fall Year 1			Fall Year 1 to Fall Year 2			Summer Year 1 to Fall Year 2		
	All	6–8	Notch	All	6–8	Notch	All	6–8	Notch
Total notches for first test	23	23	23	40	40	40	23	23	23
Total notches averaged audiograms	19	20	16	10	21	8	9	12	8

variability at 6.0 kHz and 8.0 kHz (Schlauch & Carney, 2011). These two frequencies are critical for the evaluation of noise-induced notches. 6.0 kHz might be particularly important for musicians because the spectrum of music, depending on the instrument played, might have a higher frequency emphasis (Chasin, 2006) than that of typical industrial noise.

Data suggest that insert earphones and circumaural earphones yield smaller *SDD*s for thresholds at 6.0 and 8.0 kHz than do supra-aural earphones. If supra-aural earphones were used, it would be better to calibrate them by using a real ear coupler rather than an NBS-9a coupler for calibration of supra-aural earphones (ANSI, 2010) in order to minimize possible error at 6.0 kHz (Hoffman et al., 2010; Lutman & Qasem, 1998). Although this correction does not reduce threshold variability, it eliminates the error that makes thresholds in persons with flat audiograms have roughly 5-dB poorer thresholds at 6.0 kHz. This presents a bias that favors observation of more notched audiograms.

It is essential that testers establish a good baseline audiogram for future comparison. Based on our observations, we recommend that baseline audiograms be based on more than one estimate of each audiogram, because they are so critical. Averaging of two or more audiograms reduces false positives for the presence of a notch. Schlauch and Carney demonstrated this reduction in false positives through computer simulations (Schlauch & Carney, 2011) and by averaging serial audiograms obtained from children following a short delay between successive tests (Schlauch & Carney, 2012).

Although there is exposure to high-level sound on a regular basis in the MB members, we saw no immediate evidence of noise trauma compared to their peers. We have no evidence of threshold shift or persistent notched audiograms in the pure-tone thresholds of the MB group. This might be due to the following possible reasons. Perhaps these young and healthy individuals might have more tolerance to high sound levels. Second, their practices were frequently located in an open field, which can dissipate the amplitude of sound faster and more efficiently compared to closed locations. Third, they might have more intermittent sound exposure that can significantly reduce overall noise dose.

Although we did not see evidence of hearing loss in the MB members we studied, we nevertheless recommend careful monitoring and adherence to NIOSH recommendations for musicians (Owens, 2008). In fact, we found small, yet not statistically significant, differences in thresholds at mid frequencies between the MB and CC groups. In addition, as Kujawa and Liberman (2009) suggested, we cannot rule out the possibility that physiological damage might happen in the auditory system without noticeable changes in hearing thresholds or otoacoustic emissions. Some of the MB members, especially those in the percussion section, reported rehearsing >40 hr per week. Importantly, more than half of the band members reported that they never use hearing protection. Furthermore, many of these students choose to become professional musicians—a group that has been shown to be at great risk of NIHL (Royster et al., 1991; Sataloff & Sataloff, 1991).

Due to the preliminary nature of the current project, it is not easy to determine whether or not the hearing conservation methods implemented here were fully effective for the university MB members. However, this project might be considered as a first step to encourage self-awareness of hearing and the consequences of hearing loss.

Other model educational programs have been developed for professional musicians and students in music majors in order to promote hearing conservation (Chesky et al., 2009; Federman & Picou, 2009). Although the students' attitudes toward the earplugs were not always positive, as previously suggested by Chasin and Chong (1999) and Chesky et al. (2009), most of the MB members reported that they were willing to use the earplugs as much as they could. A few of them who were considering professional careers in music purchased custom earplugs for more frequent use. We conclude that regular education, monitoring hearing status, and fitting musician's earplugs remain important for this population.

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Appendix (p. 1 of 2)

Julia M. Davis Speech-Language-Hearing Center Hearing Conservation Client Questionnaire

Name: ______________________________ Date: ____________________________

Please rate your exposure to the following:

Loud machinery	never	rarely	some	often	daily
Power tools	never	rarely	some	often	daily
Factory equipment	never	rarely	some	often	daily
Woodworking tools (saws, etc.)	never	rarely	some	often	daily
Hunting guns or artillery	never	rarely	some	often	daily
Farm equipment	never	rarely	some	often	daily
Landscaping equipment	never	rarely	some	often	daily
Personal watercraft	never	rarely	some	often	daily
Power/speed boats	never	rarely	some	often	daily
Small airplanes	never	rarely	some	often	daily
Motorcycles	never	rarely	some	often	daily
Loud music	never	rarely	some	often	daily
Music through earphones	never	rarely	some	often	daily
Live concerts	never	rarely	some	often	daily

Others? ____

Do you ever feel:

Ringing in your ears	never	rarely	some	often	daily
Pressure / fullness in your ears	never	rarely	some	often	daily
Ear pain	never	rarely	some	often	daily
Excessive wax	never	rarely	some	often	daily
Dizzy/out of balance	never	rarely	some	often	daily
Do you use hearing protection?	never	rarely	some	often	daily

In what settings?

____

What type?

____

Appendix (p. 2 of 2)

Julia M. Davis Speech-Language-Hearing Center Hearing Conservation Client Questionnaire

Do you have a history of noise exposure during any of the following:

Noisy job? Explain.

____

Noisy recreational activities (hunting, snowmobiling, etc.)? Explain.

____

Other____

Do you have any significant history of illness:

General health____

Significant illness, high fever: ____________________________________

Medications____

Do you have a history of any of the following:

Hearing problems/Tinnitus____

Vestibular problems____

Other ear, nose, throat problems____________________________________

Family History of Hearing Loss_____________________________________

Last hearing test conducted: ________________Where__________________

How many hours of band rehearsal have you attended this week? ________________

Did you wear ear protection during those rehearsals? (Circle one below)

All of them Most of them Some of them None of them

How many hours of band rehearsal have you attended today? __________________

Did you wear ear protection during those rehearsals? (Circle one below)

All of them Most of them Some of them None of them

How many hours a week do you practice your instrument outside of band rehearsals? ______

How many years have you been in an instrumental music organization? _____________

How many years have you been practicing an instrument? ______________________

Are you a member of another musical organization besides the university band? _______