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Comparison of hearing levels of college music and non-music majors: Does rehearsal noise affect hearing health?

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COMPARISON OF HEARING LEVELS OF COLLEGE MUSIC AND NON-MUSIC MAJORS: DOES REHEARSAL NOISE AFFECT HEARING HEALTH?

by

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Abstract.* *Noise exposure was assessed in college students using dosimeters. Hearing sensitivity was measured using pure-tone thresholds and distortion product otoacoustic emissions. Results indicate music majors are exposed to higher levels of noise due to rehearsal compared to their non-music major peers.

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Did I learn and did I love well?

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Abbreviations

DPOAE	Distortion Product Otoacoustic Emission
L_{eq}	Equivalent-Continuous Sound Level
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PTA	Pure-Tone Average
SLM	Sound Level Meter
TWA	Equivalent Time Weighted Average

INTRODUCTION

Musicians represent a unique population for hearing loss. They are habitually exposed to high levels of sound due to the product rather than consequence of their work (Backus, Clark, & Williamson, 2007). Exposure typically begins at a young age when the individual is learning his/her instrument. As concluded by Rosenhall, Pedersen, and Svanborg (1990), hearing loss from excessive sound intensity will increase faster during the first few years of exposure before plateauing. For professional musicians, their first years of formal training most often begins post high school in college or a conservatory. At the collegiate level, musicians refine their performance skills to a professional standard through efficient practicing and performance in ensembles. There is a possibility that this habitual, high-intensity exposure experienced in personal practice sessions and ensemble performance may have a detrimental effect on the hearing health of student musicians who aspire to be professional musicians. As professional musicians, hearing health will be vital to their success and hearing loss can disrupt pitch, timing, and loudness perception. Literature documenting the effects of noise exposure in student musicians is limited, focusing instead on the hearing health of professional musicians. Hearing assessment in young musicians, however, has the potential to predict susceptibility for Noise-Induced Hearing Loss (NIHL) with little or no influence from aging (Phillips, Shoemaker, Mace, & Hodges, 2008). Early assessment also allows health professionals to document hearing loss that may precede a young musician's professional career.

One of the first reports of NIHL in university music majors stated that 33% of college orchestral musicians presented with a notch at 6.0 kHz on the audiogram (Fearn, 1993). NIHL is characterized by a notch, or dip, in the audiometric configuration between 3.0-6.0 kHz (Phillips, Henrich, & Mace, 2010). Several years later, Phillips and Mace (2008) conducted a three-year longitudinal study of university music students and found that 52% of undergraduate music students demonstrated similar declines in high frequency hearing at 6.0 kHz. Phillips et al. (2010) revisited the 2008 study, incorporating a well-defined criteria for determining NIHL among musicians, specifically looking at the depth (in dB HL) of the 6.0 kHz notch. They calculated notch depth as the difference between the poorest threshold at 3.0, 4.0, or 6.0 kHz and the best hearing threshold at 1.0, 2.0, 3.0, or 4.0 kHz in a contiguous progression (Phillips, Henrich, & Mace, 2010). A significant noise notch was defined as a depth greater than or equal to 15 dB HL. Using this criteria, Phillips et al. (2010) found that overall, 45% of undergraduate music students showed declines in high frequency hearing at 6.0 kHz with a depth in notch of 15 dB HL or greater in at least one ear. It is reasonable to expect that an undergraduate music major, subjected to daily sounds of sufficient intensity both inside and outside of rehearsal, and considering personal propensity and time dedicated, is likely to develop acoustic trauma and present with characteristic NIHL on the audiogram (Morais, Benito, & Almaraz, 2007). Despite their findings, Phillips et al. (2010) and Fearn (1993) concluded that susceptibility to NIHL among students of music is not uniform. Nearly one-half of music students have NIHL and the remainder do not. Other studies report musicians' hearing threshold levels do not significantly differ from those of non-exposed populations (e.g. Obeling & Poulsen, 1999; Johnson, Sherman, Aldridge, & Lorraine, 1985).

Distortion Product Otoacoustic Emissions (DPOAEs) have been proposed as a more objective and sensitive test for assessing the effects of noise exposure compared to pure-tone audiometry. Compared to pure-tone thresholds, DPOAEs may be an attractive method for assessing NIHL in musicians at an early stage (Jansson & Karlsson, 1983). DPOAEs measure the response of outer hair cells (OHCs) to sound. OHCs react mechanically to stimulation and this electro-motile action provides objective confirmation of cochlear dysfunction (Jansson & Karlsson, 1983). Gorga and colleagues (1997) determined that DPOAEs provide early and reliable warning signs of cochlear dysfunction due to noise exposure before the problem is evident on the audiogram.

Although hearing sensitivity may or may not differ between musicians and non-musicians, differences are prevalent in sound level measurements between the groups. Emmerich, Rudel, and Richter (2008) made dosimeter measurements at various positions throughout the orchestra. The peak sound pressure level measured was 92.9 dB A, which exceeds the standard of 85 dB A that is regulated by OSHA. Emmerich et al. (2008) also observed peaks higher than 100 dB A during a two-hour orchestral performance. Axelsson and Lindgren (1981) recorded sound pressure levels during two orchestral performances and determined that the true equivalent sound level measured over time (L_{eq}) for both performances was between potentially harmful levels of 85 and 90 dB A. Miller et al. (2007) monitored 27-student musicians with a dosimeter during their practice times using the Occupational Safety and Health Administration (OHSA) (1983) and National Institute for Occupational Safety and Health (NIOSH) (1998) measurement criteria. OSHA specifies an 80 dB threshold, a 90 dB criterion level, and a 5 dB exchange rate. NIOSH (1998) specifies an 80 dB threshold, an 85 dB criterion, and a 3 dB doubling rate. They found that compared to both measurement criteria, the noise level experienced by student musicians yielded values that exceeded a 100% daily noise dose for all subjects, thus supporting the need for hearing conservation programs to educate student musicians.

While there is a method for determining NIHL in musicians, the issue of increased risk for NIHL in musicians has been the subject of extensive debate. There are a number of factors that make it difficult to establish a direct link between rehearsal sound exposure, practice sound exposure, and hearing loss. Unlike occupational noise, music is highly variable. The duration, frequency, and intensity change on a daily, and oftentimes hourly, basis depending on the instrument played, position in the ensemble, type of music, and proximity to surrounding instruments (Miller, Stewart, & Lehman, 2007). As evident in the aforementioned studies, sound levels during performances are highly variable as is the duration of music. Despite the apparent harmful exposure, the duration is relatively short—a musician typically performs in ensembles for periods of up to two hours, which consists of short peaks of excessive sound separated by quieter intervals allowing the ear time to recover (Schmidt, Verschuure, & Brocaar, 1994). In addition, musicians do not typically perform year round nor are they exposed to the same noise levels while performing different pieces of music (Behar, MacDonald, Lee, Cui, Kunov, &Wong, 2004).

Literature suggests a risk for NIHL is ostensible in student musicians, however, due to inconsistent findings in the field, very few hearing conservation programs exist in music schools and conservatories. No available evidence confirms increased risk of NIHL with increasing exposures for music majors compared to their non-music major peers. Young adults in general do not believe potentially damaging levels of noise experienced through various leisure activities will increase their risk for developing NIHL (Zhao, French, Manchaiah, Liang, & Price, 2012; Wickham, Anderson, & Greenburg, 2008). Leisure activities include: listening to personal music players (PMPs), attending concerts and sporting events, and occupying bars and loud restaurants. PMPs in particular are the most accessible and are becoming increasingly dangerous in terms of noise exposure. Reported outputs from PMPs can reach up to 110 dB A, with the average sound level exceeding 85 dB A for an average duration of exposure between two and three hours per day (Zhao et al., 2010). In 2009, the lawsuits that followed after the introduction of Apple iPods brought public attention to the hazards loud music imposes on young people's hearing (Morata, 2007). However, this attention and public scrutiny relates only one of many ways in which young adults may be over-exposed to loud music. Rock concerts, for example, have increased in attendance over the last several decades. Sound levels recorded at rock concerts are on average 100-115 dB A for up to three hours (Tan, Tsan, & Wang, 1990). Bars and nightclubs report noise intensities ranging from 90 to 98 dB A with peak levels approaching 116 dB A (Gunderson, Moline, & Catalano, 1997; Sadhra, Jackson, Ryder, & Brown, 2002). The patrons that attended those clubs were generally exposed on average 3.1 hours for 1.5 occasions per week (Sadhra et al., 2002). Compared to several musician studies, the level and duration of nightclub noise exposure exceeds the amount and length of exposure of high levels of music during rehearsal.

Fearn and Hanson (1984) found that overall, student musicians demonstrate no statistically significant difference in their hearing thresholds compared to a control group of non-musicians. Schmidt, Vershuure, and Brocaar (1994) also looked at the hearing thresholds of college-age musicians and medical students and found no statistically significant differences between the groups. Major technological advancements have occurred, especially in PMPs, and such devices are far more accessible and popular today than they were in 1994, supporting the hypothesis that the prevalence of NIHL hearing loss has increased. Rabinowitz, Slade, Galusha, Dixon-Ernst, and Cullen (2006) performed a longitudinal study that looked at the hearing status of young adults and found that the prevalence of hearing loss among the group of participants had not significantly increased over the span of two decades. Several theories exist as to why apparent results are absent. Rabinowitz et al. (2006) proposed that it might be too early to detect the effects of emerging technology. Schmidt et al. (1994) suggest that wanted sound is less harmful than unwanted sound and supposedly musicians have a built in tolerance for loud sounds. Similarly, Fleisher and Muller (2005) suggest that repeat exposures may result in a toughening protective effect from the cochlea. Green (2002) and Schlauch and Carney (2007, 2011) found that audiograms, as typically measured, might lack the sensitivity for identifying early NIHL and therefore the difference is not evident. Taking into account these theories, it is difficult to attribute one particular reason as to why hearing sensitivity of student musicians do not differ from their non-musician peers.

Due to the limited current research in noise exposure levels for student musicians this research focused on undergraduate student music majors at Washington University in St. Louis and their age-matched peers. In this descriptive study the author addressed the question of whether undergraduate music majors are exposed to more noise compared to undergraduate non-music majors and whether additional noise exposure could result in increased risk for hearing loss. The authors performed dosimetric measurements during orchestra rehearsal, interviewed all participants with a specially designed questionnaire adapted from the Julia M. Davis Speech-Language-Hearing Center Hearing Conservation Client Questionnaire and measured pure-tone thresholds and DPOAEs in both the music and non-music majors. The first aim of this study is to assess the hearing sensitivity of student music majors and their age-matched peers using conventional pure-tone audiometry and DPOAEs. Pure-tone thresholds will be compared between groups and with the age-adjusted thresholds found in the new Annex B, National Health and Nutrition Examination Survey, 1999-2004 (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). DPOAEs are more sensitive to minute changes in cochlear function compared to conventional audiometry and may be able to demonstrate slight differences between musicians and non-musicians. The second aim of this study is to use dosimeters to compare the average level of exposure experienced by music majors and their age-matched peers during an average 12-hour day. Dosimeter measurements will be used to estimate the average noise exposure experienced by each group. The third aim of this study is to determine patterns of noise exposure and attitude towards noise levels and hearing loss in both experimental groups. A questionnaire will be used to provide subjective data on the type of sound exposure experienced by student musicians and the controls as well as attitudes towards hearing protection.

The overall goal of this study is to identify susceptible individuals and high-risk exposures that may be encountered by student musicians. The null hypothesis states that compared to the non-musician control group, student musicians ages 18-25 years will have no statistically significant differences in their hearing thresholds; student musicians will have no statistically significant differences in overall average noise exposure levels compared to their age-matched peers; and student musicians will have no significant differences in attitude towards noise exposure and hearing loss. The results from this study may help collegiate music programs understand the need for preventative measures and increase awareness of hearing loss in young musicians.

METHODS

Participants

Participant Recruitment

The Human Research Protection Office at Washington University School of Medicine approved this research (201302002). Participants were recruited from Washington University in St. Louis' Department of Music and undergraduate Danforth campus by flyers. All participants were at least 18 years of age and informed consent was obtained from each individual prior to beginning the study. Ten music majors and ten non-music majors ranging in age from 18 to 21 participated in this study (mean= 19.7, SD = 1.08). Undergraduate music majors are defined as those who are enrolled in the Bachelor's of Arts in Music or Bachelor's in Music degree program at Washington University in St. Louis. As a requirement for the degree, all music majors must be enrolled in an ensemble. Control participants are defined as undergraduate, non-music majors from Washington University in St. Louis. Music majors and non-music majors were paired randomly according to their gender and age. Testing took place inside a sound proof booth located in the Program in Audiology student laboratory. All participants had normal outer and middle ear function, as confirmed by otoscopy and otologic history, and all participants were native English speakers.

Experimental Procedures

Otoscopy

Visual examination of the ear canal and tympanic membrane was conducted to ensure normal anatomy and no presence of debris. All participants passed the otoscopic examination.

Pure-tone Audiometry

Audiometric measurements were made on a subset of 10 out of the 20 students (5 music, 5 non-music majors) who participated in this study. Pure-tone thresholds were assessed at the end of a typical school day for each participant. All pure-tone threshold measurements were conducted using a GSI 61 diagnostic audiometer with insert earphones in a sound-treated test booth meeting ANSI/ASA S3.1-1999 (R2008) specifications for audiometric test rooms. The GSI 61 clinical audiometer was professionally calibrated annually according to ANSI 3.6 1996, and checked biologically each day. Pure-tone air conduction thresholds were obtained using a modified Hughson-Westlake procedure for test frequencies of 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz (Hughson & Westlake, 1944). Initial descent towards threshold was accomplished in 10 dB steps. Presentation level was raised in 5 dB steps for no response. Threshold was defined as the lowest level at which two responses were obtained out of three presentations on an ascending run. Figures 4 and 5 depict the average thresholds obtained from the music and non-music major groups. Figure 6 illustrates the average pure-tone thresholds between both groups. Figure 7 illustrates the ISO 1999 Annex B average comparison of 50th percentile males and females ages 24-35.

Distortion Product Otoacoustic Emissions

Distortion Product Otoacoustic Emissions (DPOAEs) were obtained using the Biologic SCOUT Sport System. Boys Town National Hospital normative values were used for comparison. DPOAEs were assessed consecutively with the pure-tone thresholds at the end of a typical school day. Results are plotted as a DPgram shown in Figures 8, 9, and 10. DPOAEs were replicated for both ears. If symmetrical, the right ear was chosen for analysis. If asymmetrical, the ear with the least amount of artifact was chosen. Absent emissions were not included in the averaged data.

DPOAEs were evoked using tone pairs, f1 and f2, with particular intensity and frequency relations (f1:f2 ratio). The evoked response from these stimuli occurs at a third frequency, the distortion product frequency fdp, which is calculated as fdp= 2X f1-f2. Stimulus intensity level for DPOAEs is set at an L1/L2 stimulus paradigm of 66/55 dB SPL for DPOAEs and is plotted as a function of frequency. The frequency ratio of f2/f1 was 1.22. DPOAEs were measured at the frequency 2f1-f2 for 27 f2 frequencies ranging from 1500 to 10301 Hz and plotted relative to f2. DPOAEs minus the noise floor must be greater than or equal to 6 dB SPL in order to be considered present.

Dosimetry

Noise exposure levels were monitored using the 706, 705+, and 703+ Type 2, A-weighted sound level meters (Larson-Davis Spark Instruments) (Figure 11) set to measure noise levels using the OSHA (1983) and NIOSH (1998) measurement criteria. A dosimeter is an integrating sound level meter that has the capability of measuring the equivalent sound level of the environment. Personal dosimeters are the most common method for assessing the risk of noise exposure. A-weighted meters are used to more closely represent the sensitivity of the human ear to different frequency ranges. The 706, 705+ and 703+ were calibrated to 114 dB (+/-2 dB) before every use and pre-programmed in the Blaze software to simultaneously integrate sound level measurements under two difference measurement criteria: OSHA and NIOSH. The specifications for each can be found in Table 2. The sound intensity of each one-third octave band was recorded once per second during the duration of the monitoring period to determine what types of sound were contributing to the overall sound pressure level. A new set of AA alkaline batteries were inserted before each use. The 3/8th inch diameter microphone was worn on each participant's right shirt-collar. The user was instructed on proper handling. All participants were given a dosimeter to wear from 8:30 A.M. until 9:00 P.M. on a Monday. Testing took place from March 11th until April 8nd during the rehearsal of Howard Hanson's *Symphony No. 1*, Aaron Copland's *Orchestral Variations*, and Leonard Bernstein's *West Side Story*. No technical difficulties were encountered.

Questionnaire

Ten participants (5 music and 5 non-music majors) completed a questionnaire that consisted of 15 relevant questions related to ear and hearing problems, noise exposure, and questions about attitude towards hearing protection. The questionnaire is located in Appendix B. Participants completed the questionnaire after the informed consent was read and signed. Participants were not required to answer all questions and could refrain from answering without any penalty. Music majors answered additional questions about number of practice hours, rehearsal attendance, and music background. Each risk factor (e.g., motorcycle use, hunting gunshots, factory noise, etc.) and hearing health (e.g., ringing in the ears, dizziness, ear pain, etc.) question were rated for time units, such as never, rarely, some, often, and daily. Then, each rating was converted to numeric unit for later analysis (for example, never = 0 and daily = 4).

Data Analysis

The sound level measurements were analyzed using *Blaze*© software and exported to Excel spreadsheets (Microsoft Inc, Redmond, Washington). Table 2 displays the NIOSH and OSHA formulas used to calculate the noise dose values and percentages.

Statistical analyses

All statistical analyses were performed using IBM SPSS V. 20.0 software. Results were considered per participant. The significance level used for all the tests and the correlations was p= 0.05 or smaller. P values lower than 0.05 were considered statically significant. The author employed comparative and descriptive methods. The focus was on the following results:

- The L_{eq} averages obtained during a 12.5-hour day with rehearsal, without rehearsal, and the L_{10}, $_{25}$, $_{50}$, $_{75}$, and $_{90}$ percentages.
- OSHA and NIOSH noise dose levels and percentages in each group.
- DPOAEs in music and non-music majors.
- Pure-tone thresholds in music and non-music majors.
- Subjective answers to the questionnaire.

RESULTS

Participant Demographics

Table 1 displays each participant's gender, age, and whether or not he/she is a music major (MM).

Pure-tone Audiometry

Ten (five music and five non-music majors) of the 20 participants completed an audiological assessment, which consisted of testing pure-tone thresholds and DPOAEs. Because the dosimeter microphone was worn on the participant's right shoulder, the right ear was considered for analysis. If the ears were asymmetrical, the better ear was considered. Figures 4 and 5 display group mean audiometric thresholds of the music and non-music majors, respectively. A Student's t-Test showed a small, but significant correlation between groups at 2000 Hz ($t(8)= 2.68$, $p= 0.027$). No significant difference was found between groups at the remaining frequencies. Compared to age and gender norms, the hearing thresholds from both groups are within normal limits with median pure-tone average (PTA) thresholds 7.5 dB HL (SD= 4.66) in the non-music major group and 8.6 dB HL (SD= 4.78) in the music major group. The mean thresholds of the music and non-music majors were compared to ISO 1999 Annex B (1990), a document produced by the International Organization of Standardization to explore the prevalence of occupational noise induced hearing loss by duration and intensity of noise exposure in the workweek. ISO 1999 Annex B (1990) shows hearing threshold levels associated with unscreened population of an industrialized country. The ISO 1999 data is not representative of hearing threshold levels for young adults in their 20s, but to obtain a general comparison, data from the present study was compared to the 50th percentile in the 30 year age group. Results were subjectively compared at 0.25, 0.50, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz.

Figure 7 shows the average thresholds of the undergraduate music and non-music majors in their early twenties (mean= 19.7, SD= 1.08) and the average thresholds found in the ISO 1999 data. Statistical analysis was not calculated.

Distortion Product Otoacoustic Emissions

Figure 8 displays the Distortion Product Otoacoustic Emissions (DPOAE) responses obtained from 10 participants (5 music majors and 5 non-music majors). Non-music majors show statistically larger amplitude DPOAEs than music majors, especially in the mid- to high frequency regions. Statistically significant differences were found at 2953 Hz ($t(8)= -2.70$, $p= 0.03$), 4172 Hz ($t(8)= -3.92$, $p= 0.004$), and 4969 ($t(8)= -3.08$, $p= 0.02$). The overall group average relation between DPOAE responses and pure-tone thresholds was weak with a small, but insignificant difference found at 2000 Hz ($t(8)= .793$, $p= 0.45$).

Dosimeter Measurements

Dosimeter measurements were collected from 20 participants (10 music and 10 non-music majors). A music and non-music major were both age and gender matched for analysis. Twelve-hour measurements occurred on Mondays between March 11th and April 8th from 8:30 A.M. until 9:00 P.M. This was done in order to keep data collection consistent between participants with regards to orchestra repertoire. Figure 1 summarizes the sound pressure level (SPL) on a dB A-weighted scale for measurements obtained during a 12.5-hour period on Monday. Thirty minute average levels were calculated from 1-second interval recordings across the entire duration. A Student's t-Test was performed and revealed statistically significant differences ($p \geq 0.05$) between participants 1 ($t(48) = -2.39$, $p= 0.02$), 5 ($t(48) = -1.94$, $p= 0.05$), and 9 ($t(48)= -2.64$, $p= 0.01$). According to the 12.5-hour L_{eq} (Equivalent Continuous Noise Level), music majors on average experienced more exposure to high intensity noise compared to their non-music major peers during that particular day. Figure 2 summarizes the SPL on a dB A-weighted scale for measurements obtained on Monday minus the rehearsal time period (7:00-9:00 PM) for the 20 participants. No significant differences were found between groups in regards to the amount of noise exposure (in dB A) without the rehearsal time period.

Figure 3 displays the L_{10}, L_{25}, L_{50}, L_{75}, and L_{90} values. The n-percent exceeded level, L_n, is the sound pressure level exceeded for n percent of the time in a given interval. In other words, for n percent of the time, the fluctuating sound pressure levels are higher than the L_n level. According to these results, music majors experienced significantly higher L_{10} (t(18) = -7.35, p= .000) and L_{25} (t(18)= -10.5, p= .000) values compared to the non-music majors. No significant differences were found at L_{50}, L_{75}, and L_{90}.

There are two commonly recognized sound level measurement criteria used to measure daily occupational noise exposure: OSHA and NIOSH. Table 2 summarizes the mean daily noise dose values for the music and non-music majors obtained during the 12.5-hour day using OSHA and NIOSH criteria, respectively. The NIOSH dose recorded in music majors (n=10) was 88.8 dB A compared to 76.2 dB A recorded in non-music majors (n=10). The daily noise dose values using the NIOSH criteria was 340% in music majors and 19% in non-music majors. The 8-hour time-weighted averages (TWA) and daily noise doses were significantly higher using the NIOSH measurement criteria than the OSHA measurement criteria. The significantly higher noise dose values obtained using the NIOSH criteria were expected due to the different criterion levels and exchange rates used by both methods. The OSHA dose recorded in music majors (n=10) was 85.7 dB A compared to 73.4 dB A recorded in non-music majors (n=10). The daily noise dose values using the OSHA criteria was 85% in music majors and 15% in non-music majors.

Table 3 displays the 8-hour time-weighted averages (TWA) broken down into three-hour and five-hour exposure times. The music majors experienced 90.8 dB A in three of the eight-hour exposure periods and 80.1 dB A in five of the eight-hour exposure periods. The non-music majors experienced 74.7 dB A in three of the eight-hour exposure periods and 70.5 dB A in five of the eight-hour exposure periods.

Questionnaire

A total of 10 participants (5 music and 5 non-music majors) provided ancillary information about their history of noise exposure and attitude towards noise exposure. Twenty percent of participants reported playing their instrument over 10 hrs/wk, while 80% reported playing their instrument less than 10 hrs/wk. For the music majors, the estimated rehearsal hours per week ranged from 1-3 hours, which varies depending on the season (i.e. rehearsals for the university orchestra are terminated during the summer). All music major participants (n=5) reported that they never use earplugs during rehearsal or practice time. One participant reported that she saw an audiologist for custom earplugs, but was dissatisfied with their performance and no longer uses them. Phillips et al. (2008) also found that hearing protection is not commonly used in student musicians. They determined that hearing protection is not used because it may be accompanied by the loss of subtle effects that are necessary to play music and interact with fellow musicians (Phillips et al., 2008). The most exposure for each group of participants occurs from headphones (90%) followed by concert attendance (65%).

When asked about their interest in a hearing conservation 3-hr credit course, 40% of the participants (n=10) expressed interest. All of the non-music majors (n=5) were disinterested in a hearing conservation course providing reasons such as, “sounds boring” and “not worth the time." Four out of five music major participants showed interest in a hearing conservation course providing responses such as, "I've never heard of this topic and would like to learn more."

The desire for a hearing conservation course and the participant's rate of loud music exposure were compared using the Wilcoxon-Mann-Whitney two sample rank-sum test. According to the results the amount of time spent listening to loud music has no influence on whether or not one is in favor of a hearing conservation course ($U= 2.5$, $p < 0.05$). Mann-Whitney test was also used to assess the undergraduate music and non-music major's use of hearing protection. It was hypothesized that musicians protect their hearing more than non-musicians because they depend on it for their career. According to the results of this test, there was no relationship between participant group and use of hearing protection ($U= 5.5$, $p < 0.05$).

DISCUSSION

Music majors from Washington University in St. Louis' Department of Music and non-music majors from the undergraduate Danforth campus were recruited on a voluntary basis. This could have produced a selection bias, likely towards acquaintances with the author. Washington University in St. Louis' Department of Music is very small with an estimated size of 25 music majors. The undergraduate Danforth campus consists of an estimated 6,000 individuals. Gender effects were not examined in this study due to the small number of participants.

Dosimetry

There is an inherent weakness in working with a population of university students. Undergraduate students in general work in highly variable sound environments and have exposure schedules that are almost impossible to predict. Determining the noise exposure levels of university students, for the purpose of estimating the risk of hearing loss is challenging; many variables are involved and their influence is difficult to assess. For example, there are variations between the noise levels depending on the piece of music being played. Jazz music differs in intensity and duration compared to classical music, and some composers, such as Wagner or Brahms, are more notorious than others for creating excessive sound levels. Additionally, changes in sound level measurements can occur from surrounding instruments and seating arrangement in the ensemble.

Sound level measurements occurred on Mondays between March 11th and April 8th from 8:30 A.M. until 9:00 P.M. in order to consistently monitor rehearsal noise from the same repertoire. It is important to note that the assessment of noise exposure in musicians is an almost impossible task. It was beyond the author's control to monitor the type of music the musician practiced during their personal practice sessions and any lessons that took place on Mondays, therefore, personal practice sessions and lessons were not monitored in this study. In addition, the author did not deem it necessary to examine sound exposure during practice sessions because Phillips et al. (2008) determined that orchestral musicians experience similar sound exposure in the practice room as they do during rehearsals.

Participants were asked to wear a dosimeter during the entire 12.5-hour period on Monday. It is evident in all music major participants that rehearsal time in particular adds significantly to a music major's daily recommended noise exposure compared to the controls. Since this study looked only at 12.5-hour exposures on Monday, future studies might track daylong exposures Monday thru Friday. Hearing loss is the result of long-term exposure to high noise levels; therefore, the measured exposure levels should be normalized over a longer time period.

Pure-tone Threshold

There are several reports that professional musicians have higher rates of hearing loss than non-musicians (Royster, Royster, & Killion, 1991; Sataloff, 1998). Other studies report musicians' hearing threshold levels do not significantly differ from those of non-exposed populations (e.g. Ubeling & Poulsen, 1999; Johnson et al., 1985). This study looked at student musicians and hypothesized that music majors who are exposed to more noise on average compared to their age-matched peers would have poorer hearing. While there is sufficient exposure to high-level sound on a regular basis for student musicians, as evidenced in the sound level measurements, there is no immediate evidence of noise trauma compared to their peers. The results from this study demonstrated that both music and non-music majors in this sample population had similar hearing thresholds. A significant difference was noted at 2000 Hz, but 2000 Hz is not typically a threshold affected by noise exposure and could be the effect of standing waves due to poor insert earphone placement (McBride & Williams, 2001). More participants are needed to determine whether or not this difference at 2000 Hz is significant or not. Hearing is known to be most sensitive and thus also most vulnerable to noise around 4.0 kHz (McBride & Williams, 2001).

Phillips et al. (2008) collected hearing threshold data in student musicians and the results showed that over a three-year period, the risk for noise-induced hearing loss, indicted by a notch in high frequency hearing thresholds, could be seen in about half of the student musician participants. No notches were observed between 3.0 and 6.0 kHz in the 10 music majors tested in this current study. Phillips et al. (2008) concluded that the methods for identifying signs of early NIHL in student musicians is imprecise and that searching for notched audiograms proved to be an ineffective method for identifying risk of NIHL. No evidence of persistent notched audiograms in the pure-tone thresholds occurred in either group. Perhaps these young and healthy individuals might have more tolerance to high sound levels. It is evident in Table 3 and Figure 3 that music majors and their peers have more intermittent sound exposure, which can significantly reduce overall noise dose. According to Chasim and Chong (1999), the effects of music exposure are highly influenced by multiple extraneous variables, such as the intensity and duration of exposure and individual propensity to noise damage. Not all people exposed to high sound levels develop NIHL, suggesting that susceptibility to NIHL varies among individuals (Henderson, Subramanian, & Boettcher, 1993; Lu, Cheng, Li, Zeng, & Zhao, 2005). Evidence exists that some people are more sensitive to noise damage than others (Ellermeier, Eigenstetter, & Zimmer, 2001; Weinstein, 1978).

Distortion Product Otoacoustic Emissions

Audiometric thresholds as typically measured may lack the sensitivity for identifying early NIHL (McBride & Williams, 2001). Some investigators (Green, 2002; Schlauch & Carney, 2007, 2011) have raised a concern that audiometric thresholds as typically measured may lack the sensitivity for identifying NIHL. DPOAE measurement has been proposed to be a more objective and more sensitive test for assessing the effects of noise exposure than the pure-tone threshold average PTA (Janessen & Kafisson, 1983). The OHCs are part of the auditory system that is considered the most vulnerable to loud sounds (Reuter & Hammershoi, 2007). Therefore, OAEs have greater sensitivity to detect small noise-induced changes in the auditory system compared to pure-tone thresholds (Reuter & Hammershoi, 2007). Lapsley-Miller, Marshall, and Heller (2004) found decreased average DPOAE amplitudes after six months of noise exposure, while the average audiometric threshold did not (yet) change. They found no significant correlation between changes in audiometric threshold and changes in OAEs, which supports the hypothesis that OAEs indicate noise-induced changes in the inner ear, still undetected by pure-tone audiometry (Lapsley-Miller et al., 2004). In this study, noise exposure from rehearsal did not create differences in pure-tone thresholds between groups, however, it did result in slight differences among several of the music majors' DPOAEs. Music majors in the present study experienced more exposure to high intensity sound on average compared to their non-music major peers. Although there was minimal difference in pure-tone threshold levels between groups, significant differences in DPOAEs were noted when compared to the controls. Despite the slight significant difference between groups, Kujawa and Liberman (2009) suggest we cannot rule out the possibility that physiological damage might happen in the auditory system without noticeable changes in hearing thresholds or otoacoustic emissions.

When confirmed by further experimental evidence, the measurement of OAEs could be an attractive method to assess NIHL in musicians in an early stage (Reuter & Hammershoi, 2007). Excessive noise exposure can lead to metabolic and/or mechanical effects resulting in damage to the organ of Corti (Keppler et al., 2010). The primary damage is concentrated on the outer hair cells, which are more vulnerable to acoustic overstimulation than inner hair cells. Otoacoustic emissions (OAEs) are thought to reflect the nonlinear active processes of the cochlea based on the motile activity of the outer hair cells (Keppler et al., 2010). The OAEs can be used to assess existing subclinical outer hair cell change and preclinical frequency-specific hearing loss (Gorga et al., 1997). OAEs, however, cannot make exact prediction of degree or configuration of hearing loss. DPOAE calibration errors and maintaining a constant ear probe position for subsequent measurements was an issue in this study and thus may account for absent or abnormal DPOAE responses.

Dosimetry

L_n can be obtained by analyzing a given noise by statistical means. L_{10} is the level exceeded for 10% of the time, meaning for 10% of the time, the sound or noise has a sound pressure level above L_{10}. For the remainder of the time, the sound or noise has a sound pressure level at or below L_{10}. These higher sound pressure levels are observed at L_{10} probably due to sporadic or intermittent events. The author observed that the L_{10} sound levels were high enough that they might potentially pose a risk of NIHL to music major participants. L_{50} is the level exceeded for 50% of the time. It is statistically the mid-point of the noise readings and represents the median of the fluctuating noise levels. L_{90} is the level exceeded for 90% of the time. For 90% of the time, the noise level is above this level. It is generally considered to be representing the background or ambient level of a noise environment. Music majors spend considerably more time in louder environments compared to their non-music major peers.

Equivalent Continuous Sound Level (L_{eq}), which is a simple average of the measured sound level, does not represent the real risk for NIHL because it is biased towards the more intense sounds in the orchestra. Resulting noise exposures of musicians are never high enough to present a hazard to their hearing because of the limited duration of rehearsals and performances (Behar et al., 2006). Exposure levels in the orchestra fluctuate slowly and are maintained at high levels for prolonged periods (Behar et al., 2006). Further investigations should address this issue to provide a more realistic estimate of an orchestral musician’s risk for hearing loss (Opperman, Reifman, Schlauch, & Levine, 2006). It would be interesting to examine the daily measured dose data on a subset of participants as compared with notch depth to determine whether some music students with a high dose have no hearing loss, and others with a low dose have a substantial notch.

Music majors on average experience a 12.6 dB difference in exposure compared to their age-matched peers using NIOSH standards and a 12.3 dB difference in exposure using OSHA standards. Music majors are exposed to more than 100% of the safe dose for noise-hazard safety using both OSHA and NIOSH criteria. Compared to occupational standards, use of hearing protection and a hearing conservation program would be mandated. Music however differs in temporal pattern, intensity, duration, and spectrum compared to noise. For example, a worker in a factory will be exposed to a constant level of noise for almost the entire working day while a musician usually only plays for a couple of hours with short peaks of excessive sound. Between these periods there are usually quieter intervals, as evident in Figure 1, in which the ear can recover (Schmidt el al., 1994). Significant differences between industrial noise and music raise questions about the application of industrial norms to musicians, which means that research into this subject is needed (Schmidt et al., 1994).

In addition to the intensity of music, its spectrum is also important to consider. The spectrum is not the same for music and for factory noise: in music the lower frequencies dominate and they are less damaging to the ear because the stapedius muscle attenuates the low frequencies more effectively (Schmidt et al., 1994). Instruments radiate sound differently and thus also contribute towards the acoustical spectrum. Woodwind and brass high frequency notes are directional, for example, and may have more effect on the musician sitting in front of them than on the player (Phillips et al., 2008).

Questionnaire

A small number of participants (n=10) answered the questionnaire, therefore statistical calculations are less meaningful. The questionnaire served the purpose of assessing musical background of music majors, types of noise exposure experienced by all participants, and attitude towards NIHL.

Hours spent practicing varied greatly among student musicians depending on their personal goals, ensemble demands, and private lessons. The majority of noise exposure occurs from loud music experienced through personal music players. It was surprising to find that most individuals would not use hearing protection if it were free and available at a loud venue. The author suspected that music majors in particular would be interested in a hearing conservation program, but only one of the five music-major respondents expressed interest. There is an apparent lack of concern towards NIHL in the undergraduate population.

CONCLUSION

The primary objective of this study was to determine whether music majors are at an increased risk of exposure to loud noise compared to their age-matched peers. Results suggest (1) music majors experience 12 dB more exposure on average compared to their non-music major peers; (2) pure-tone thresholds amongst the groups have no significant difference; and (3) a slight difference in DPOAEs was found, however, more participants are needed to determine whether or not this finding is statistically significant.

This study sought to determine whether routine hearing tests, such as pure-tone audiometry and DPOAEs can identify early signs of NIHL in a group of music major students compared to their non-music major peers. The goal of the study was identify susceptible individuals and high-risk exposure to target for preventative measures. No final conclusion can be drawn from the results collected in this study. Due to the small population size it is unclear as to whether or not there is a distinct physiological correlation between pure-tone thresholds and DPOAEs between the groups. The author found a small, yet not statistically significant difference in thresholds at mid-frequencies between the musicians and control group. When evaluating data from all subjects, there was no distinct and consistent correlation between amount of noise exposure and hearing loss. A firm statement on this issue can only be made on the basis of a longitudinal study. The pure-tone audiogram should remain the gold standard for the assessment of NIHL, however, DPOAEs are proven to be more sensitive to changes in hearing (Jansson & Karlsson, 1983). Although we did not see evidence of hearing loss, we nevertheless recommend monitoring and adherence to OSHA or the more conservative, NIOSH, recommendations for musicians (Owens, 2008).

Overall, music majors appear to be at a higher risk for permanent NIHL according to the average sound levels experienced during a 12.5-hour period. In congruence with the results found by Phillips et al. (2008), the results from this study support the need for on-going hearing conservation programs in music schools to educate student musicians about the dangers of excessive exposure to loud music. Hearing conservation programs should include monitoring with conventional pure-tone audiometry and DPOAEs on an annual basis. In conclusion, a hearing protection policy, annual assessment of hearing, regular education, and consistent use of earplugs are important for this population. This study might be considered as a first step to encourage self-awareness of hearing health and the consequences of hearing loss.

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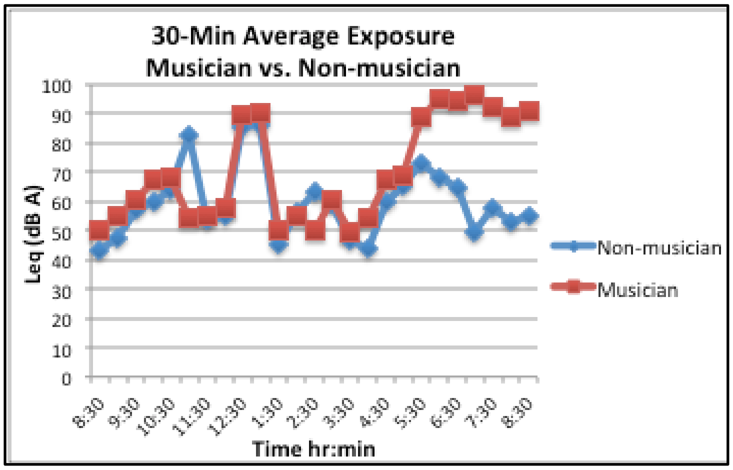
Appendix A



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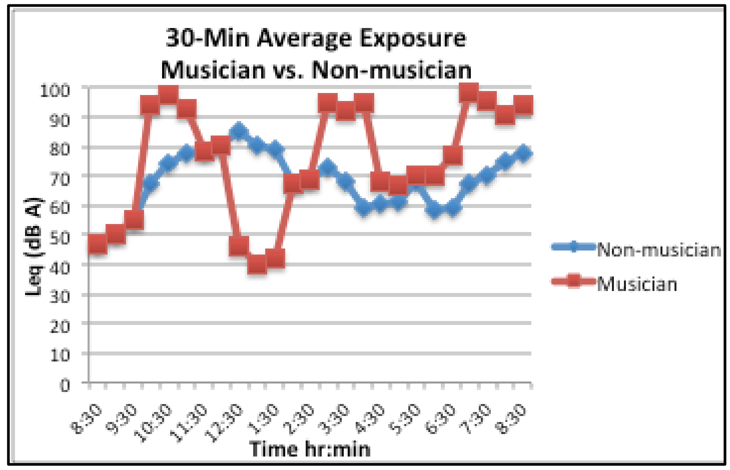

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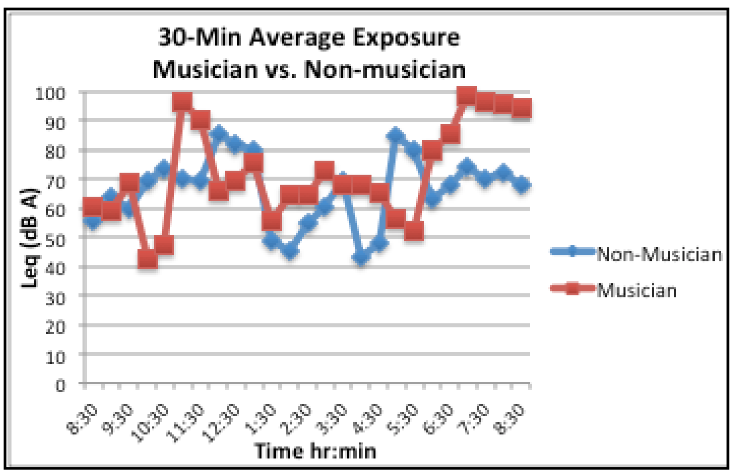

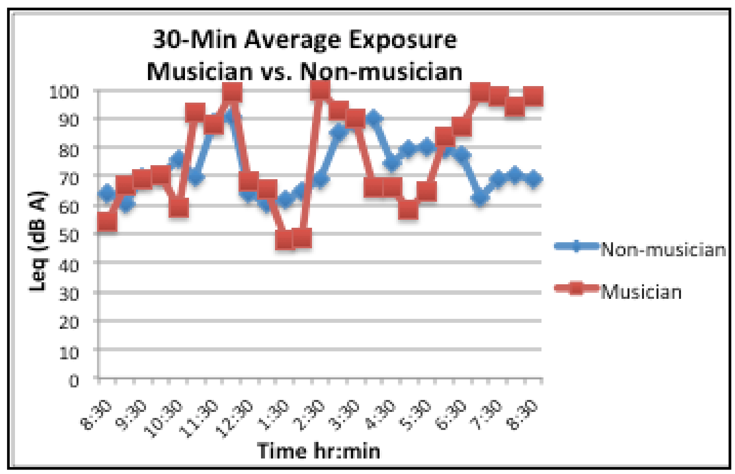

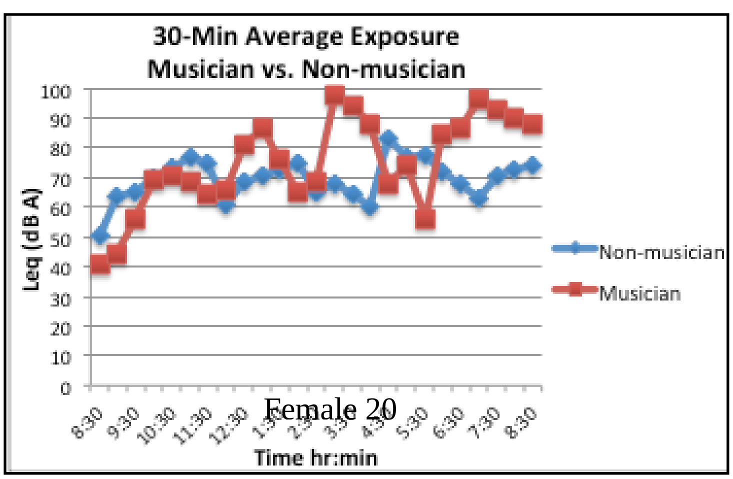

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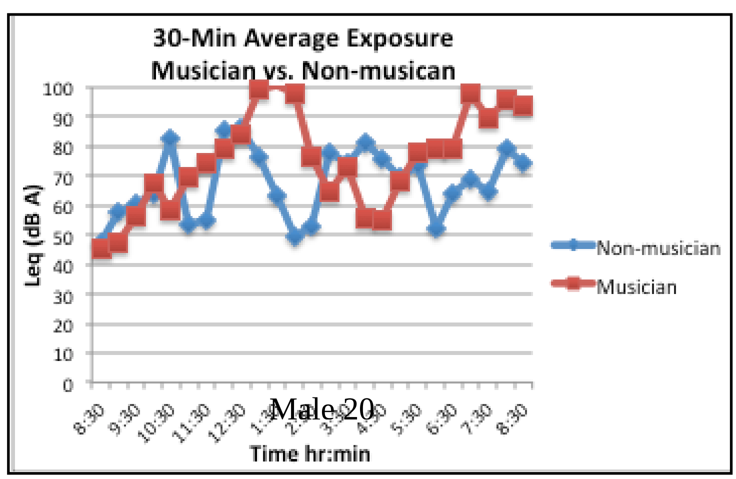

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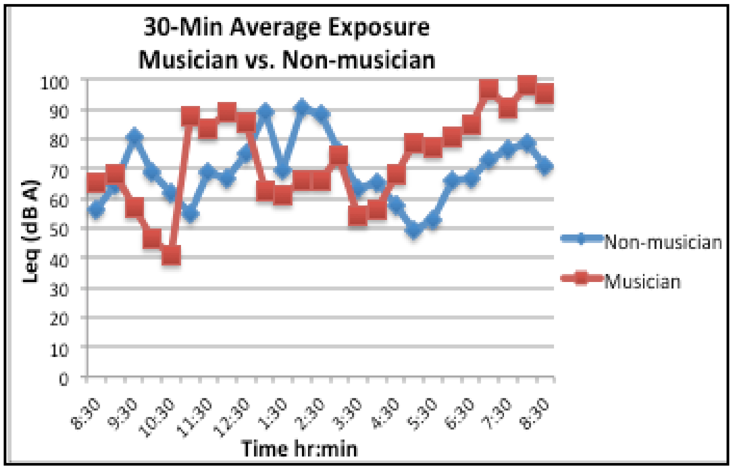

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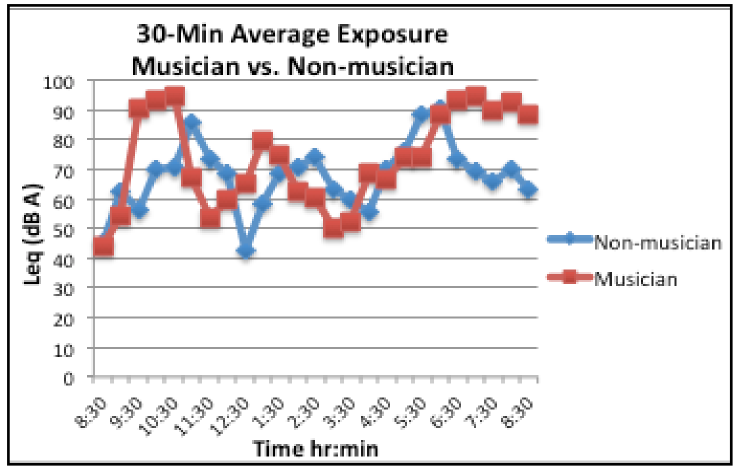

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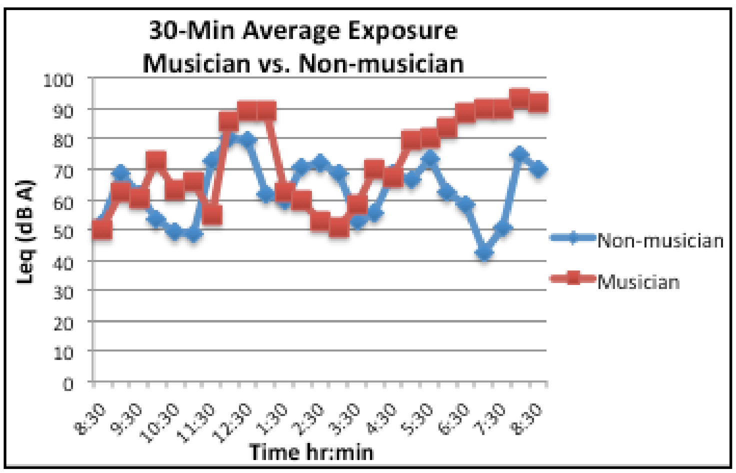

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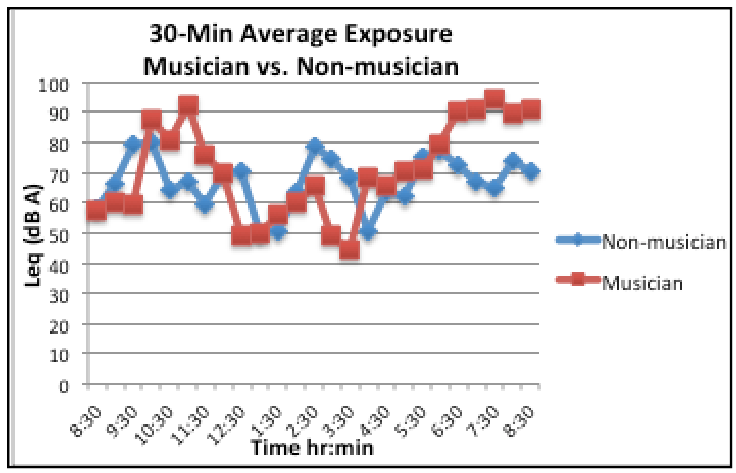

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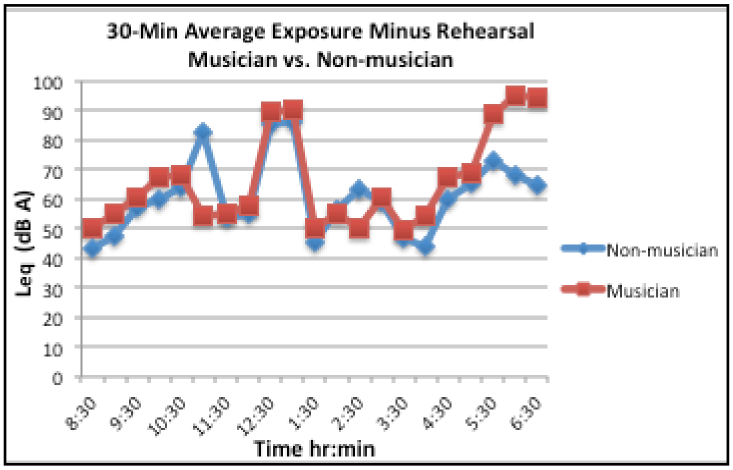
Figure 1: 30-minute average weighted exposure for a 12.5-hour period for musicians and non-musicians, age and gender matched accordingly and displayed at the bottom of each graph.



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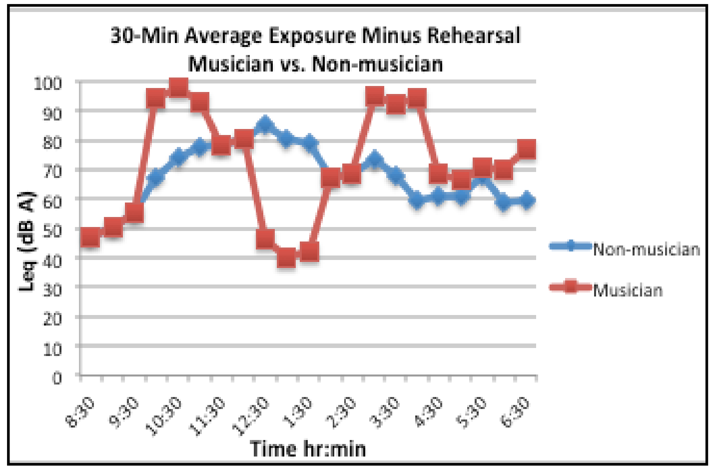

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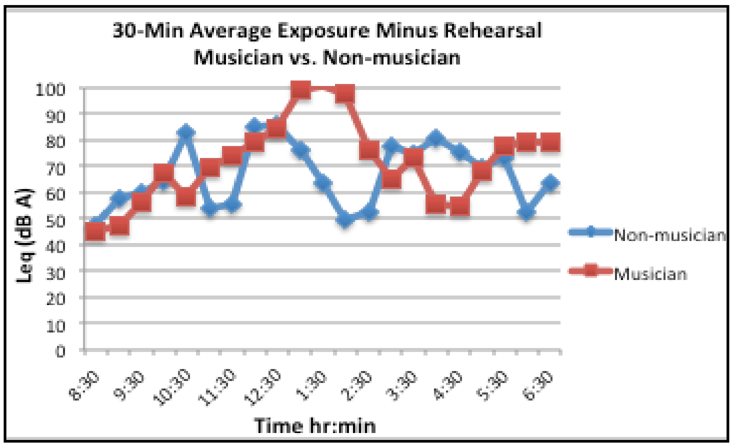

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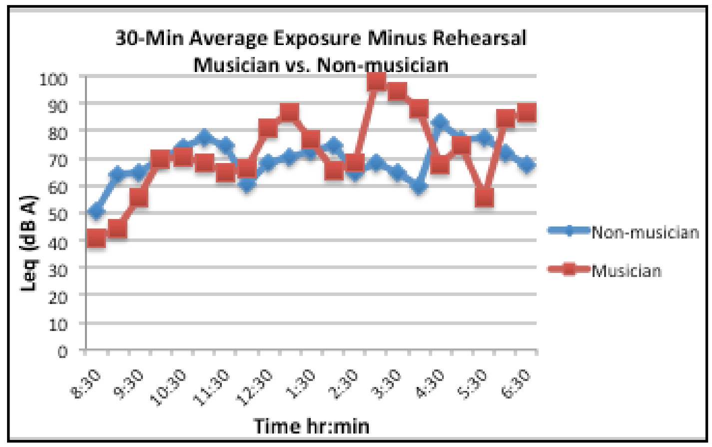

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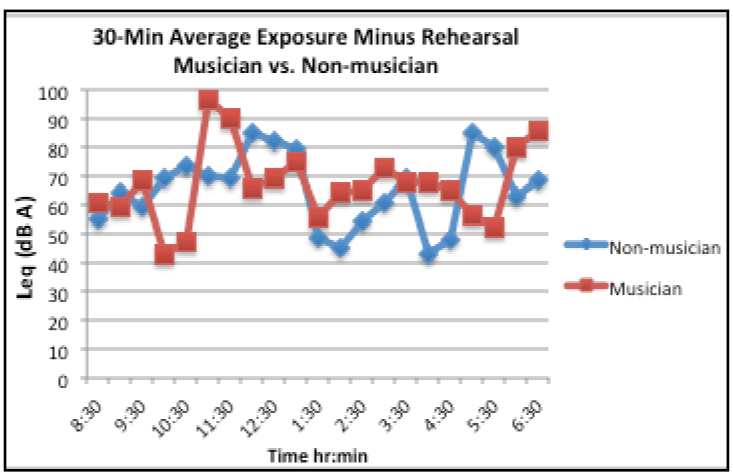

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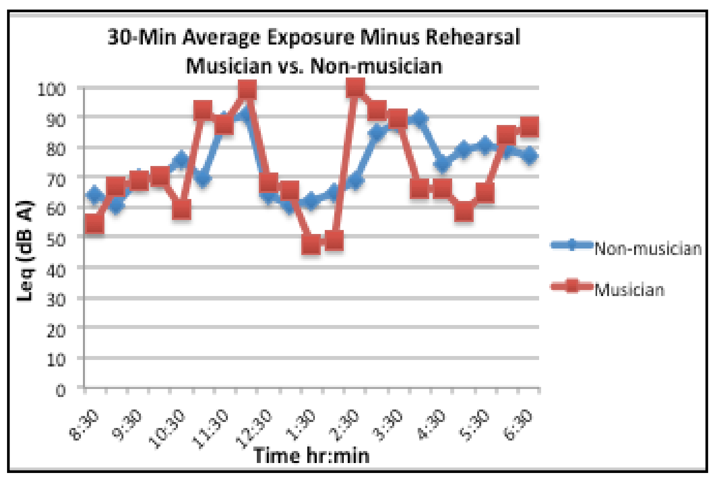

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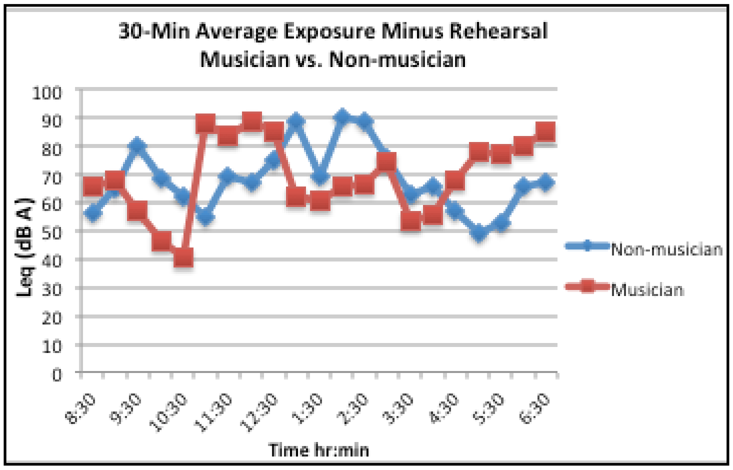

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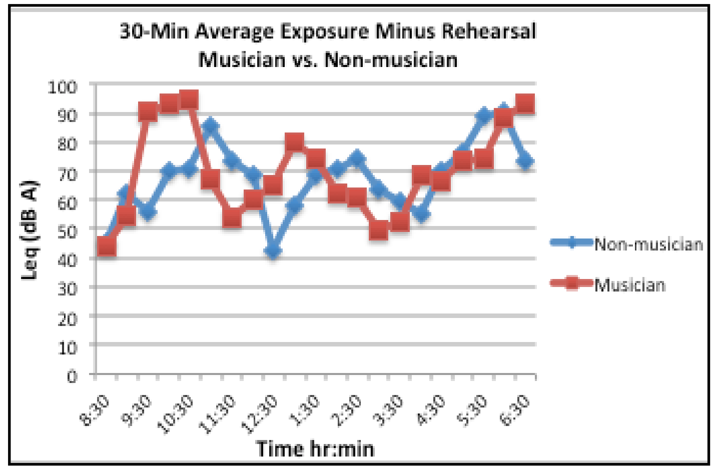

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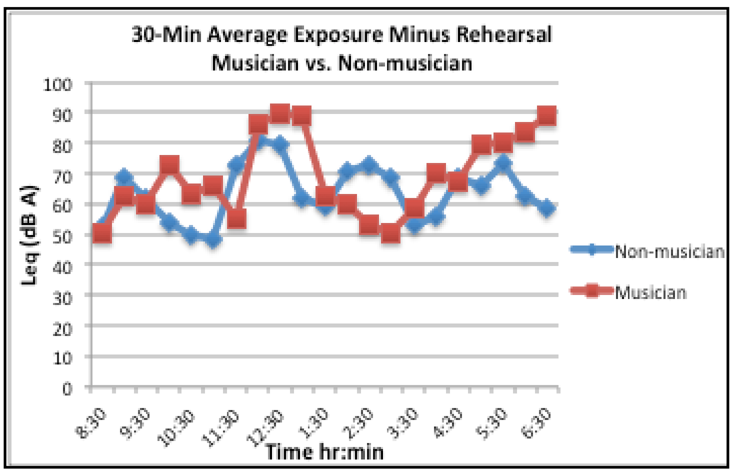

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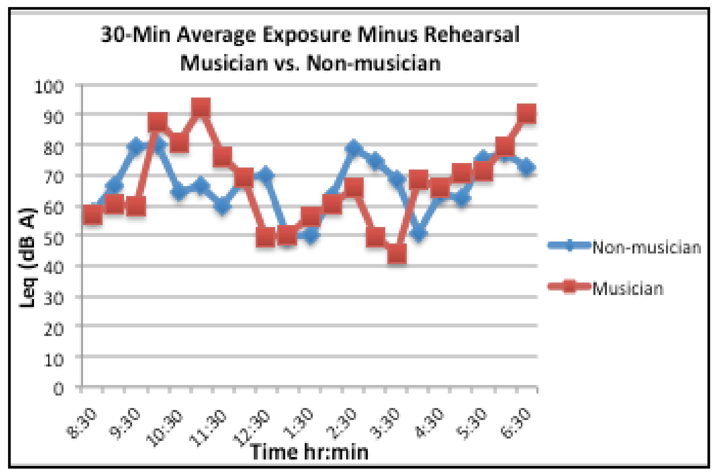

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Figure 2: 30-minute average weighted exposure minus rehearsal time for musicians and non-musicians, age and gender matched accordingly and displayed at the bottom of the graph.

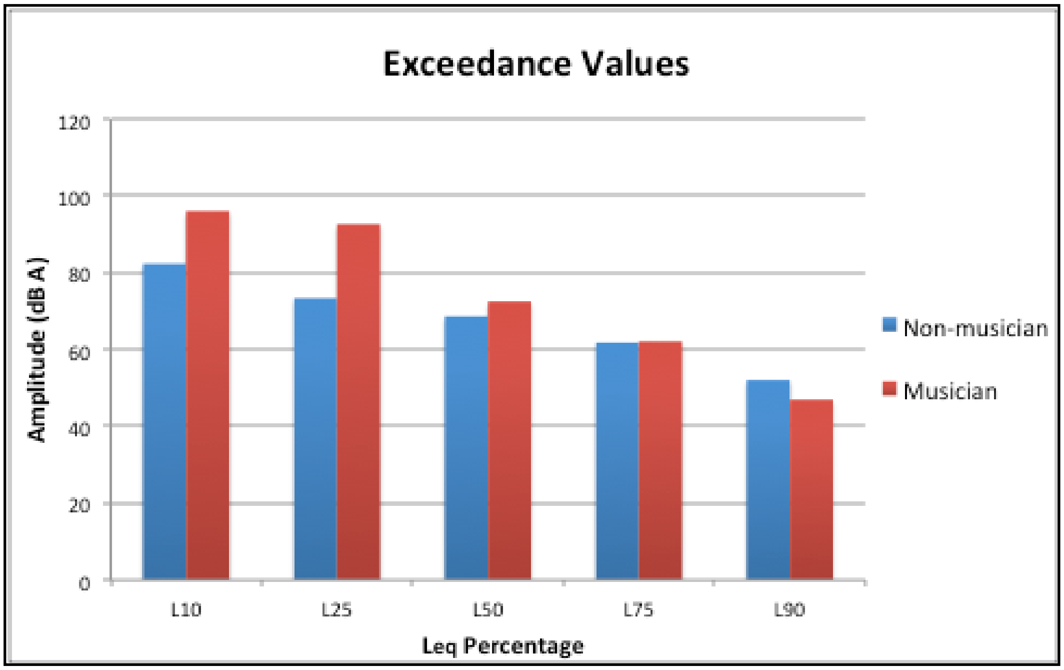

Figure 3: L_{eq} exceedance values compared between musicians and non-musicians at L_{10}, L_{25}, L_{50}, L_{75}, and L_{90}.

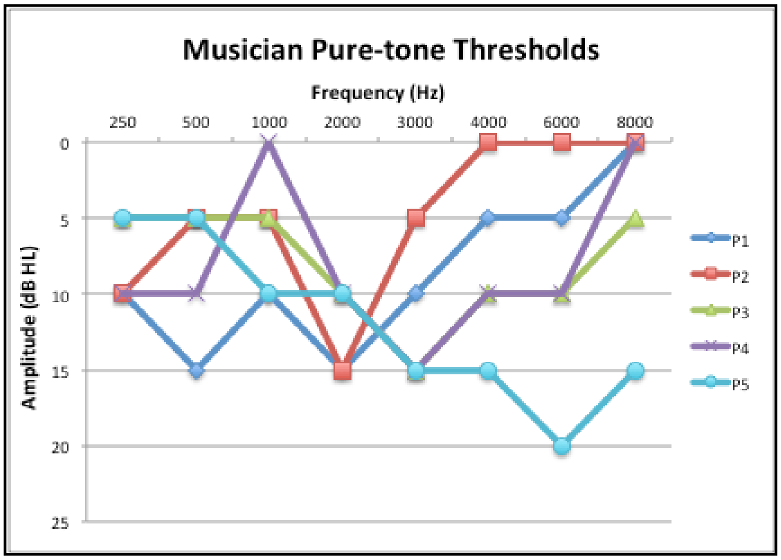

Figure 4: Musician (n=5) pure-tone thresholds assessed from 0.25- 8.0 kHz.

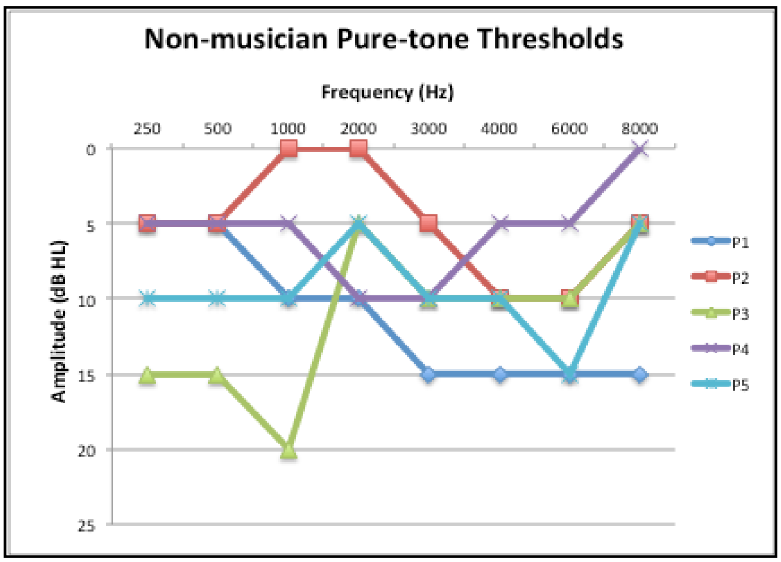

Figure 5: Non-musician (n= 5) pure tone thresholds assessed from 0.25-8.0 kHz.

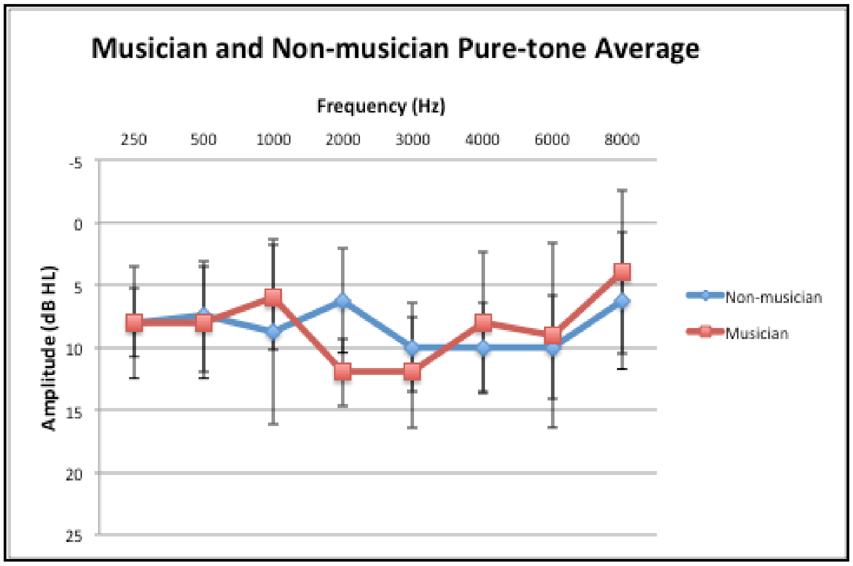

Figure 6: Musician and non-musician pure-tone threshold averages from 0.25-8.0 kHz. Error bars display standard deviation.

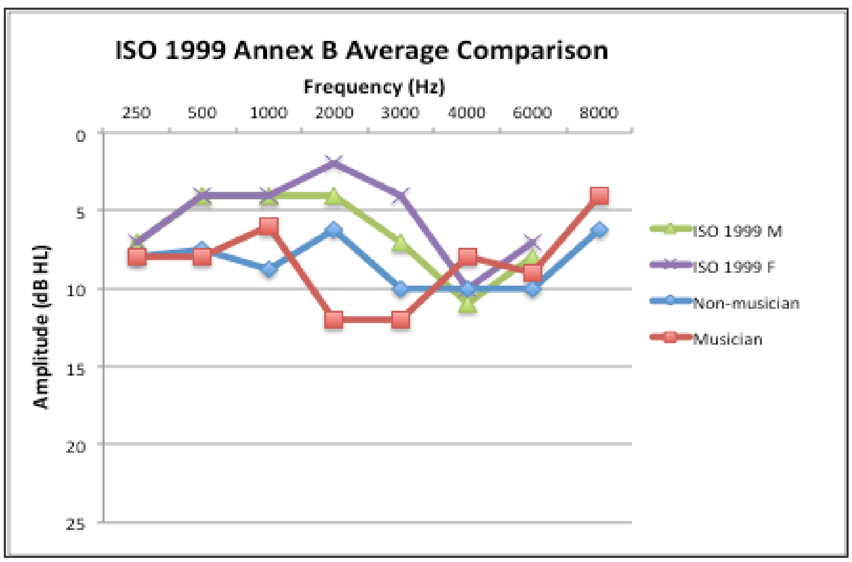

Figure 7: ISO 1999 Annex B Average Comparison of 50th percentile males and females ages 24-35 as compared to the musician and non-musician's average pure tone thresholds

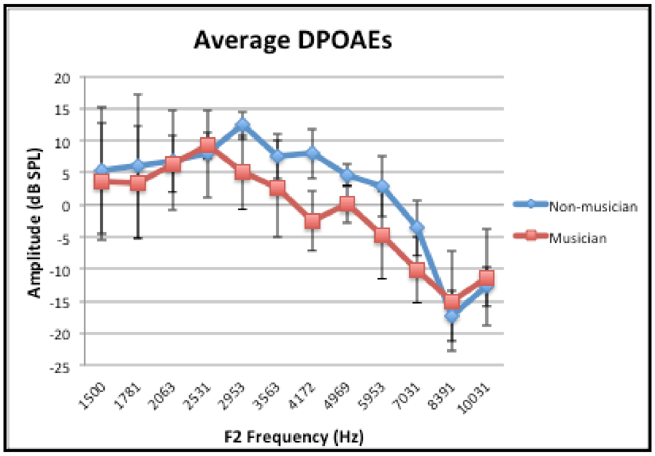

Figure 8: Average DPOAEs between musicians and non-musicians from 1500-10031 Hz. Error bar represents ± one SD.

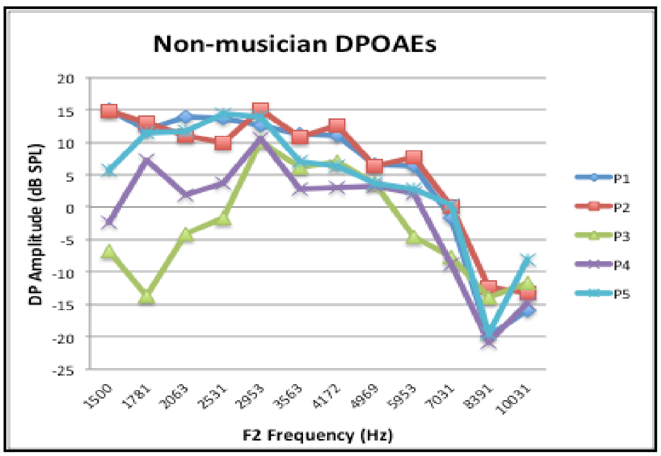

Figure 9: Non-musician (n= 5) DPOAEs from 1500-10031 Hz.

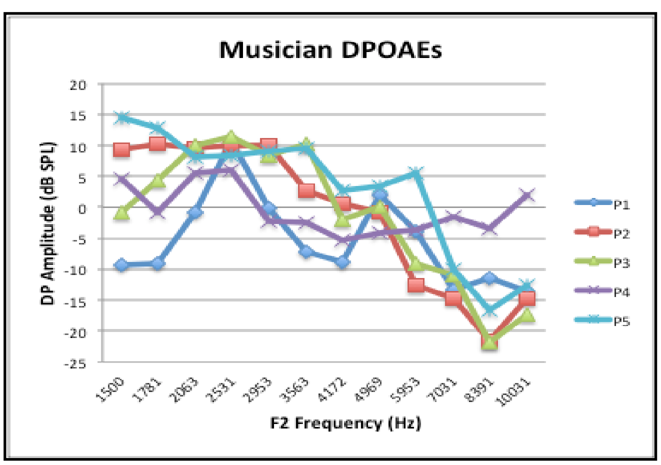

Figure 10: Musician (n=5) DPOAEs from 1500-10031 Hz.

Figure 11: Larson-Davis 706, 705+ and 703+ dosimeters used for recording the sound level.

Participants	Gender	Age
MM1	F	19
MM2	F	19
MM3	F	20
MM4	F	21
MM5	F	19
MM6	F	19
MM7	M	20
MM8	M	18
MM9	M	21
MM10	M	21
NM1	F	21
NM2	F	21
NM3	F	18
NM4	F	19
NM5	F	19
NM6	F	20
NM7	M	20
NM8	M	18
NM9	M	20
NM10	M	21
Mean		19.7
SD		1.08

Table 1: Participant demographics. MM=Music major. NM= Non-music Major. M=Male. F=Female.

	OSHA	NIOSH
Exchange	5 dB	3 dB
Threshold	80 dB	80 dB
Criterion	90 dB	85 dB
Duration	8 sec	8 sec

Table 2: OSHA and NIOSH noise exposure standards utilized in this study.

	Non-musician Average (dB A)	Musician Average (dB A)
	85.81	97.11
	83.88	95.96
	82.06	94.66
	78.55	93.6
	76.57	92.43
3hr	74.7	90.77
	74.01	89
	72.81	86.47
	71.42	84.75
5hr	70.49	80.05
	69.67	76.82
	68.13	74.69
	67.27	72.1
	66.18	68.51
	65.68	67.45
	64.37	65.78
	63.71	64.55
	61.66	63.86
	60.28	62.15
	58.51	59.55
	57.08	56.71
	55.31	53.77
	53.41	52.27
	50.72	47.69
	47.67	44.62

Table 3: TWA (dB A) for musicians and non-musicians. Three-hour and five-hour TWA is highlighted.

Appendix B

Date: ____________
ID #:_____________

The following assessment was adapted with permission from the Julia M. Davis Speech-Language Hearing Center Hearing Conservation Client Questionnaire, University of Minnesota, 2013. Please read each question carefully and mark your appropriate answer.

1) Are you an undergraduate music major?

__________YES __________NO

1a.) If **yes**, please specify instrument(s): ___________________________________

2) Do you have relatives (parents/siblings) with hearing loss?

__________YES __________NO

2a.) If **yes**, please expand: ____

3) Have you had a hearing assessment before?

__________ YES __________NO\

3a.) If yes, please expand: ____

4) Please circle the following accordingly:

Ringing in your ears:	never	rarely	sometimes	often	daily
Pressure in your ears:	never	rarely	sometimes	often	daily
Ear pain:	never	rarely	sometimes	often	daily
Dizziness/loss of balance	never	rarely	sometimes	often	daily
Sensitive to loud sounds in the right ear:	never	rarely	sometimes	often	daily
Sensitive to loud sounds in the left ear:	never	rarely	sometimes	often	daily
Do you wear hearing protection?	never	rarely	sometimes	often	daily

5) In what settings do you/would you wear hearing protection?

6) If bars/concerts/sport venues offered hearing protection for no additional charge, would you accept it?

_________YES _________NO

6a.) If NO, please explain?

7) Do you have a history of noise exposure?

__________YES _________NO

8) Do you play a musical instrument (and are not a music major)?

__________YES ________NO _______(N/A)

8a.) How many hours a week do you practice your musical instrument? ___________

9) Please circle the following according to your exposure:

Loud machinery/power tools	never	rarely	sometimes	often	daily
Farming/landscaping/factory equipment	never	rarely	sometimes	often	daily
Motorcycles/boats/airplanes	never	rarely	sometimes	often	daily
Music through earphones	never	rarely	sometimes	often	daily
Live concerts	never	rarely	sometimes	often	daily
Hunting guns	never	rarely	sometimes	often	daily
Loud music	never	rarely	sometimes	often	daily

For Music Major Participants Only

1) If a 3-credit hearing conservation course was offered to undergraduate music majors only, would you consider taking the course?

__________YES _________NO _________N/A (select if a non-music major)

1a.) If YES, how would you benefit from the course?

____

____

2) How many hours of band rehearsal have you attended this week? _______________________

2a.) Did you wear ear protection during those rehearsals (circle below)

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

3) How many hours a week do you practice your instrument outside of band rehearsals? _______

4) How many years have you been practicing an instrument? ______

5) How many years have you been involved in an ensemble? ______

6) Are you a member of another musical ensemble not affiliated with the university? _________

6a.) How many hours a week do you practice with that ensemble? _________