ABSTRACT

THE EFFECTS OF MUSIC ON EXTENDED HIGH FREQUENCY HEARING

By Patricia M. Deatherage

The importance of hearing acuity for musicians cannot be overstated. Unfortunately, the levels of exposure during practice, rehearsal and performance are capable of damaging the hearing mechanism. The extended high frequency hearing of 66 subjects, aged 18-27 years was measured. Subjects were assigned to the musician group (n=33) or the nonmusician group (n=33). Comparisons between the extended high frequency thresholds (EHF), conventional pure tone thresholds and \( \text{VO}_2 \text{ max} \) measurements between musicians and nonmusicians were made. Though expected, due to the differing amounts of noise exposures between groups, no statistically significant differences were found. However, a slight trend in the EHF was noted with musicians thresholds improving as frequency increased. The results illustrated slightly better thresholds among the musicians than nonmusicians in the EHF, though not statistically significant.
Effects of Music on Extended High Frequency Hearing

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CHAPTER I

Introduction

Noise induced hearing loss (NIHL) is a continuing problem in our society. Fortunately, awareness of the damaging effects of hearing loss has increased over the last several decades and hearing conservation has emerged as an important precept. Approximately 28 million people in the U.S. suffer from hearing loss and 10 million have hearing loss caused at least in part by noise exposure (Einhorn, 1999). Musicians are especially vulnerable to the effects of high noise levels due to their continual exposure in practice and performance (Early & Horstman, 1996). Though their exposure is intermittent, musicians still are at risk for suffering from the devastating affects of NIHL because of the sound pressure levels attained by instruments (Table 1). Hearing is crucial for musicians to continue performing at a standard, which is expected, and accustomed. Therefore monitoring the effects of noise on musicians’ hearing is imperative.

Extended high frequency (EHF) audiometry, also known as ultra high frequency (UHF) audiometry, consists of testing hearing acuity from 9000 Hz through 20,000 Hz. EHF is a means by which the effects of ototoxicity can be monitored among individuals needing such strong medications (Kopke et al., 1999). EHF audiometry could also be used to monitor the effects of noise damage among musicians; EHF assesses the integrity of the hair cells in the most basal region of the cochlea where noise damage may initially appear (Borchgrevink, Hallmo & Mair, 1996). Musicians may have characteristic patterns of hearing loss in the extended high frequencies (10, 000 –20,000 Hz) due to noise damage. EHF may be useful in monitoring the effects of noise and possibly be used as an early warning sign of damage to hair cell function.
A healthy cardiovascular fitness level improves hearing acuity. Individuals in poorer cardiovascular condition are more susceptible to hearing loss attributed to noise exposure (Hutchinson et al., 2000). Since musicians are exposed to tremendous amounts of noise, level of physical fitness may contribute to the result of exposure to high noise levels.

Traditional air conduction thresholds from 500-8000 Hz will also be tested to compare with the EHF results. Also, correlations between fitness level, traditional air conduction threshold and EHF threshold levels among musicians versus nonmusicians will be attempted. The physical fitness of an individual may influence the consequences of exposure to damaging noise (Manson, Alessio, Cristell & Hutchinson, 1994).
Noise Induced Hearing Loss

Approximately twenty-eight million people suffer from hearing loss in the United States. Within those twenty-eight million people one-third have a NIHL etiology for at least a portion of the hearing loss. There are no age restrictions for NIHL. The end results of noise exposure can be a mild to profound hearing loss and can be accompanied by tinnitus (Campbell, 2001).

Noise can be defined as a perceptible auditory stimulus that is undesirable because of the negative side effects. Psychological effects of noise can be bothersome and the physiological effects have repercussions that are noticeable for a lifetime. Noise of a sufficient magnitude elicits damage to the cochlea, specifically to the hair cells. As sound travels through the outer and middle ear to reach the inner ear, the frequency of the sound is the most substantial factor for determining the reaction of the cochlea. Specific frequencies cause vibrations at different locations along the basilar membrane in the cochlea. The cochlea contains inner and outer hair cells that are tonotopically arranged throughout the two and one-half turns of the cochlea along the basilar membrane. The higher frequency sounds stimulate the basal end of the cochlea, which is nearest the oval window between the middle and inner ear. Meanwhile lower frequencies cause vibrations in the portion of basilar membrane nearest the apex of the cochlea (Kryter, 1994). Subsequent to noise exposure, hair cells in the cochlea may split or the stereocilia may bind together producing distortion. It is also possible for stereocilia to become incapable of relaying information efficiently to the hair cells. (Feuerstein, 2001)
Current research now shows that the same harmful stimuli that cause damage to the vestibulo-cochlear nerve also causes a change in the effectiveness of basilar membrane vibration (Ruggero, Rich, Robles & Recio, 1996).

The results of exposure to sound of a damaging level may result in a temporary threshold shift (TTS) or a permanent threshold shift (PTS). A TTS is a reduction in hearing sensitivity in at least one and perhaps more of the common test frequencies, is transitory in nature, and can be a precursor of PTS. The relationship between TTS and PTS is not well defined but it can be assumed that if a TTS does not occur, PTS also will not occur. Following an event such as a concert, a day in a noisy factory, or activity involving power tools, hearing acuity may not seem as sharp and tinnitus may be present. TTS will usually disappear within 16-18 hours after exposure. Restoration of hearing is dependent upon the intensity of the stimulus and the length of exposure time (Behar, Chasin & Cheesman, 2000).

The National Institute for Occupational Safety and Health (NIOSH) states that sound measured below 75 dBA does not produce permanent hearing impairment. Any sound measure above 85 dBA has the potential to be dangerous for the human hearing mechanism. In industry, daily exposure of at least eight hours to noise levels of 85 dBA and higher places an individual at serious risk for NIHL. Increasing the intensity by 5 dB decreases the amount of safe exposure time in half. (NIH, 1990)

There are several variables to consider when determining the amount of damage, which occurs due to extreme noise exposure. Duration of exposure and intensity of the sound have been mentioned. Other factors include whether the stimulus is intermittent, the level of quiet during the intermittent periods and the spectrum in which the signal
occurs. The spectrum of the signal is significant because research indicates that noise damage from a broadband noise occurs at one octave band higher than noise. The Occupational Safety and Health Administration (OSHA) established guidelines for assessing the initial levels hearing damage may develop (Feuerstein, 2002). Other factors responsible for the difficulty of estimation of noise damage include errant reports of noise levels, inaccurate hearing threshold assessment, and inconsistencies in the type of hearing protection used. Also, individual variations in sound transmission through the outer ear, middle ear, and stapedial reflex must be considered. Individual differences in inner ear structures such as the hair cells and basilar membrane, differences in inner ear blood flow, chemistry of the inner ear and efferent information from the brain are other factors to consider. Additional variables may include genetic factors, age, and environmental factors such as temperature, amount of physical labor, vibration, and exposure to toxins (Behar, Chasin & Cheesman, 2000).

Musicians and Hearing Loss

Musicians are a select group of individuals whose vocation is dependent upon hearing acuity. Accuracy in pitch perception and dynamics separates mediocre musicians from professionals who excel in the field. The risks of NIHL for musicians must not be disregarded due to observed reluctance of musicians to accept hearing protection as a viable necessity. Unfortunately, the standard at which industrial hearing conservation is governed usually does not apply to the music industry. (Hall & Santucci, 1995)

Permanent sensorineural hearing loss, tinnitus, loudness summation and diplacusis may characterize music induced hearing loss (MIHL) (Chasin, 1996). Diplacusis is a difficulty with perception of pitch or pitch distortion. A musician’s career
could be devastated by such a result of MIHL, especially if they are a violinist or a conductor. Sensorineural loss in the higher frequencies may cause a musician to play too loud which would have disastrous consequences on their quality of performance (Sataloff, 1991). The audiometric configuration of MIHL is similar to NIHL by the characteristic noise notch at 3-6 KHz. However, MIHL audiometric configuration may be more asymmetric due to specific instrument played, seating arrangement in orchestras or bands, and intermittent exposure. Also an instrumentalist playing a higher pitched instrument may manifest MIHL visible at 8K Hz (Chasin, 1996).

Many studies have focused on hearing loss among musicians. McBride et.al. (1992) confirmed that noise levels for classical musicians are not only considered uncomfortable but exceed permissible occupational noise level standards. Another study revealed that after exposure to unamplified music 31% of young musicians had a TTS of 15-20 dB. Approximately 50% of the subjects who had been exposed to amplified music had a TTS of 15-20 dB. Usually the TTS was measured at 6K Hz and the sources of the highest noise levels were percussion, brass and loud speakers (Fearn, 1993).

Protecting the hearing of musicians is a difficult task, which requires flexibility on the part of the musician and the hearing care professional. Musicians may be subjected to intense noise during rehearsals, recording, performing or listening to music themselves. The type of noise exposure may depend on the instrument they play and what instruments surround them during a performance. Vocalists may not want to use ear protection because they may feel they will be incapable of judging the sound quality of their own voice. A musician may also have some type of high frequency MIHL and so they may request the sound engineer increase the level of high frequency sounds either through
earphones or monitors. Additionally, the Occupation Safety and Health Administration (OSHA) regulations do not exist for exposure to music as those found in industrial settings (Hall & Santucci, 1995). Musicians are exposed to damaging noise levels in a various environments, whether performing in an auditorium or a recording studio. Every environment has to be accounted for in terms of hearing protection because different hearing protection is needed based on instrument and acoustic environment. The same musician may perform different types of music that varies in intensity. These variances in intensity require different amounts of signal reduction for protection. A third important reason protecting the hearing of musicians is difficult is hearing protection may not be a priority for the musician. A musician may see the importance of attenuating intense sounds for protection of hearing but the desire to please audiences may take precedence (Hall & Santucci, 1995).

Even though monitoring the effects of MIHL on musicians can be difficult, several researchers have endeavored to prove the importance of protection of musicians’ hearing. A classic study by Axelsson and Lindgren (1978) sought to discover if pop musicians exhibit MIHL. Findings indicated that 13-30% of pop musicians had sensorineural hearing loss, which is surprisingly low considering the amount of noise exposure these musicians face (see Table 1). Explanations for the low incidence of hearing loss among musicians cited by Axelsson and Lindgren were that pop music is usually low frequency in nature and low frequency noise is not as harmful to the hair cells of the cochlea. Another cited reason was the intermittent nature of pop music, which allows some recovery from TTS. Finally, upon discovery of a hearing loss, pop musicians retire from playing to conserve their hearing (Axelsson & Lindgren, 1978).
Despite a lack of evidence to support the idea that musicians are at great risk for hearing loss, Axelsson and Lindgren completed a follow-up study in 1981. They felt the research was not uncovering the truth regarding noise exposure among musicians. The follow-up study seemed to unearth more questions than answers by finding again only 13% of musicians with a hearing loss from 3-8K Hz and these losses were usually highly correlated with military service, age and a long duration of exposure to noise. Their findings did indicate that drummers are at a greater risk for hearing loss. Other factors increasing the risk of hearing loss were described as the larger number of hours exposed per week, the higher amount of years spent consistently performing as a musician, older age and military service. In addition, TTS measures were taken after noise exposure for audience members and the musicians. There was no apparent relationship between the exposure and time and the amount of TTS, which was not an anticipated finding. Another interesting finding was that female music listeners were less susceptible to NIHL than male music listeners. The pop musicians usually had higher thresholds than the audience and because of that had less TTS than the members of the audience (Axelsson & Lindgren, 1981).

A study to determine levels of hearing loss in music students at a conservatory versus a control group of medical students was conducted. No significant difference in hearing thresholds among musicians versus the medical students was found. Each group had similar incidences of sensorineural hearing loss in the 3-6K Hz region, attributed to noise exposure. Also, there was not a consistent relationship between hearing thresholds from 250-8K Hz and the extended high frequency thresholds. Their findings did not indicate increased thresholds in the extended high frequency regions when a loss was
present in the 250-8K Hz range. Therefore, Schmidt et al. (1994) felt that extended high frequency hearing acuity couldn’t be used as an early indicator of MIHL (Schmidt, Verschuure & Brocaar, 1994).

Sataloff (1991) reviewed several studies regarding musicians and hearing loss and found additional research is needed. McBride et al. (1992) examined the noise exposures of classical musicians and found that musicians are at risk for noise damage but other research has not been able to support this theory. Due to the conflicting nature of research, examining noise exposures and protective strategies for musicians must be employed.

**Extended High Frequency Audiometry (EHF)**

At one time EHF was not considered a viable option diagnostically. Several factors inhibited the success of EHF: the source of the signal, where the signal was placed in relation to the external auditory meatus, and the physical characteristics of the pinna and external auditory meatus. These factors were successful in dominating the success of EHF diagnostically because of the excessive directionality of sound in the extended high frequencies. These problems attributed to the lack of acceptable and dependable procedures for the acquisition of EHF thresholds. Normative data has also been difficult to procure because of the inconsistency of methods adopted by various research facilities (Borchgrevink, Hallmo & Mair, 1996).

EHF is beginning to be appreciated as a viable diagnostic tool for monitoring the effects of NIHL, ototoxicity and hearing loss subsequent to surgery. Findings suggest that higher frequencies are more sensitive to exposure to noise and strong ototoxic medication than the frequencies below 9K Hz. Thresholds of normal hearing individuals
in EHF show greater deviation than in the conventional audiometric frequencies. Aging does negatively affect high frequency hearing sensitivity, which could impact the usefulness of EHF among an older adult population (Harrell, 2001). Research by Osterhammel (1979) indicated no differentiation between EHF thresholds of individuals with steady state industrial noise exposure and subjects without noise exposure; he concluded that EHF is not a reliable early indicator of NIHL. Further research by Laukli and Mair (1985) concurred with the findings of Osterhammel finding that young adult subjects with history of steady state noise exposure had normal EHF thresholds despite exposure to noise in an industrial setting. In contrast, Morton and Reynolds (1991) found that noise exposure as well as age combined to make the EHF thresholds more susceptible to damage and therefore a decrease in hearing acuity would become apparent in the EHF thresholds first (Ahmed, Dennis, Badran, Ismail, Ballal, Ashoor & Jerwood, 2001).

In the late sixties and early seventies the usefulness of EHF audiometry began to be understood. Jacobson et al. (1969) discovered that the hearing loss caused by ototoxic medications could be detected in the higher frequencies at least two months before the damage was present in the frequencies usually utilized in conventional audiometric testing (500-8000 Hz). Another important example of research exemplifying the usefulness of EHF was completed by Corliss et al. (1969); researchers found that in some situations, damage caused by NIHL is detectable in frequencies above 8000 Hz before the hearing loss is detectable at below 8000 Hz (Northern, Downs, Rusmose, Glorig & Fletcher, 1971).
Early research by Flottorp (1973) indicated that frequencies above 5000 Hz are adversely influenced by acoustic trauma such as noise. He performed pure tone testing on 288 young adults from 125 Hz through 12,000 Hz. The results demonstrated the sensitivity of the upper frequencies to noise damage. Flottorp also suggested three possible reasons for the decrease in hearing acuity in the higher frequencies after noise exposure. The first reason is most hearing protection, at that time, emphasized protection in the 2000-4000 Hz areas rather than above 5000 Hz. Other reasons include the individual variations in the shape of the ear canal, which creates differences in resonance of sounds, head baffle effect, and pressure in the middle ear. Finally, Flottorp hypothesized that weak blood supply to the base of the Organ of Corti or an immaturity develop stria vascularis may be involved (Flottorp, 1973).

Fausti et al. (1979) found evidence to support suggestions that frequencies above 8000 Hz reflect noise damage earlier than frequencies below 8000 Hz. Through histological studies, the base of the cochlea is susceptible to deterioration by early adulthood. Fausti realized the importance of testing subjects of a young age to distinguish the effects of noise versus presbycusis. He selected 100 young adults with normal hearing from 250-8000 Hz and without current otologic pathologies. A detailed case history regarding noise exposure was taken describing the duration of noise exposure whether a steady-state exposure or impulse exposure. Damage from impulse exposures may be more restricted in the mechanical damage to the Organ of Corti whereas steady exposure over an extended period of time may produce metabolic changes in the inner ear. Subjects with exposure to noise had a decline in hearing acuity above 8000 Hz that worsened as the frequencies increased. Those with steady-state
exposure and impulse exposure demonstrated the greatest amount of hearing loss above 12,000 Hz. Subjects exposed to impulse noise often had irregular, asymmetrical high frequency hearing loss but subjects exposed to noise steadily often had even, symmetrical high frequency hearing loss. Fausti identified individuals with audiometric configurations that did not follow this pattern but the general trend suggests that the type of noise exposure may elicit a specific area of damage or type of damage to the cochlea. (Fausti, 1979).

Johnson et al. (1986) examined the hearing acuity among orchestral musicians compared to nonmusicians. Using conventional audiometry (250-8K Hz) and EHF (9-20K Hz) obtained thresholds were examined comparing musician versus nonmusician, age and gender in comparison to previous research. The premise for using a population of musicians was prompted by the theory that musicians have superior hearing acuity or perception as suggested by their musical ability. Johnson et al. endeavored to more clearly define the EHF hearing of the normal population by comparing their results to musicians. The outcome of the study disclosed several notable conclusions. Similar hearing acuity among the musicians and nonmusicians was found and a consistent decrease in hearing acuity as the frequency increased (approximately 7.6 dB for each frequency above 9K Hz for both groups). Other important findings included the fact there was no prominent hearing threshold decline due to consistent noise exposure among musicians as well as no apparent gender or interaural differences (Johnson, Sherman, Aldridge, & Lorraine, 1986).
Fitness Level and Hearing Acuity

As NIHL becomes more prominent in society, there is a need to identify contributing predisposing factors. A possible contributing factor is level of physical fitness of an individual in relation to how noise exposure affects the hearing mechanism. The basic premise of the theory is encompasses cardiovascular health and the adequacy of blood flow to the cochlea (Manson, Alessio, Cristell, & Hutchinson, 1994). The adequacy of blood supply to the cochlea determines the efficacy of the mechanism to perform and recover from trauma (Miller, Ren, Dengerink, & Nuttall, 1996). The stria vascularis is thought to be particularly vulnerable in poor blood circulation in the cochlea (Hutchinson et al., 2000).

Early research connecting cardiovascular health with hearing loss suggested that hearing loss might be an indicator of genetic predisposition to heart disease. A study comprised of sixty-four adults aged twenty-three to sixty-two were placed on an eight-month exercise program. After the eight-month period the exercise program had no effect on the pure tone thresholds of the subjects. In contrast, the results displayed a faster recovery time from TTS after the exercise program than before (Ismail, Corrigan, MacLeod, Anderson, Kasten, & Elliot, 1973).

Colletti et al. (1991) sought to determine if exercise had any impact on the stapedial reflex, which in turn changed the amount of TTS incurred. Findings indicated that the stapedial reflex was attenuated in amplitude and a modest elevation in threshold was evidenced due to physical exercise. A depressed stapedial reflex would theoretically provide less protection from noise trauma. The stapedius muscle is attached to the stapes in the middle ear and contracts when high intensity sounds occur. The reflex actually
decreases the intensity of low and mid-frequency sounds thereby protecting the ear (Chasin, 1996). Colletti et al. also felt their findings corroborated with Lindgren & Axelsson (1988) findings that physical exercise enhances NIHL. However, whether the stapedial reflex influences the amount of TTS accrued during exercise could not be verified through their results (Colletti, Fiorino, Verlato, & Montresor, 1991).

Manson et al. (1994) studied the effects of exercise during exposure to noise and how exercise affected the amount of hearing loss based on cardiovascular health. Noise in isolation was not found to influence the cardiovascular system but there were variations among the subject groups after exercise with noise. The individuals who were in the best cardiovascular condition had the least amount of threshold shift at 2000 Hz. The same pattern ensued as the medium cardiovascular fit group had the next lowest amount of threshold shift at 2000 Hz, followed by the most threshold shift at 2000 Hz for the group considered to be the low cardiovascular fit group. These threshold changes occurred whether the individuals were exposed both to noise and to noise and exercise. No hearing loss occurred in any group when exercise was completed without noise. Therefore, exercise does not appear to exacerbate the effect of noise damage regardless of cardiovascular fitness level (Manson et al. 1994).

Kolkhorst et al. (1997) also researched the effects of cardiovascular fitness on individual sensitivity to hearing loss incurred via noise exposure. Findings indicated cardiovascular health, recent physical exercise and small percentage of body fat were all related to lower susceptibility to TTS due to noise exposure. Increasing fitness level to lower body fat accompanied by hearing protection could possibly improve the amount of TTS incurred when exposed to noise. A feasible rationale for enhanced protection from
noise due to these variables could be attributed to ability of fit individuals being able to tolerate stress more readily than less fit individuals.

Hutchinson et al. (2000) examined cardiovascular fitness and muscle strength in relation to hearing acuity. The combined effects of cardiovascular health and muscle strength were studied to determine if muscle tone decreased or enhanced the effect of good cardiovascular health on hearing sensitivity. The subjects were divided into groups according to high or low cardiovascular health and high or low muscle strength. Findings indicated that cardiovascular health is the most significant variable in terms of hearing acuity but that high muscle strength only enhanced the positive effects of good cardiovascular health.

Two studies examined the effects of noise and exercise on Distortion Product Otoacoustic emissions (DPOAE). The initial study by Engdahl (1996) revealed an increase in TTS, a change in pure-tone threshold and a change in DPOAE amplitude during physical exercise with noise. Physical exercise was not found to cause any significant changes in pure-tone threshold or DPOAE amplitude without noise. Hooks-Horton et al. also conducted a study examining DPOAE and exercise (2001). These findings revealed no effect of noise and exercise combined, as opposed to noise alone, upon DPOAE amplitude or pure-tone threshold levels. In addition, no difference in gender or specific ear was reported.

Purpose

Musicians are consistently exposed to high levels of noise due to their vocation. A system for early identification of MIHL would be valuable in preserving the hearing of these individuals. The effectiveness of EHF audiometry for monitoring ototoxicity has
been well documented. EHF audiometry may also be determined to be a useful technique for monitoring the effects of MIHL due to the sensitivity of frequencies about 8000 Hz to noise damage. Co-existing effects of fitness level on MIHL will also be studied.

Hypotheses

Null Hypothesis ($H_0$): There is no association between music induced hearing loss and extended high frequency hearing thresholds of musicians.

Alternate Hypothesis ($H_1$): There is an association between music induced hearing loss and extended high frequency hearing thresholds of musicians.
CHAPTER III

Method

Subjects

Males and females ranging from 18 to 27 years were chosen to participate and were divided into two groups determined by musician or non-musician status. One group contained 33 musicians and the other group contained 33 non-musicians. The musicians involved in the study were either instrumentalists or vocalists and were involved in performing or practicing.

Inclusion Criteria

All subjects participating in the study were between the ages 18-27 years with hearing thresholds of 25 dB HL or better between 250-8000 Hz and normal middle ear function. Normal middle ear function was defined as: Type A tympanogram with pressure <110 daPa, equivalent volume of <1.5 cm³, and static compliance of >0.30 mmho (Hunter & Margolis, 1992). Musicians were defined as those who participated in practicing or performing music vocally or with an instrument at least two hours per week. Non-musicians were selected from a pool of volunteers who did not perform vocally or use a musical instrument for practice or performance and had fewer than two hours of exposure to loud music per week.

Exclusion Criteria

Individuals with hearing thresholds greater than 25 dB HL, middle ear pathology or abnormality, and those not in the 18-27 year old age range were discarded from the subject pool.
Subject Consent

All subjects were required to sign written consent forms, which described the study and were notified of the right to withdraw from the study at any time. Also to protect the confidentiality of the subjects, a number system for coding data for each subject was utilized. The number system was determined and applied only by the student researcher and faculty advisor. An example of the consent form can be found in Appendix 1.

Procedure

The research study was comprised of five components: 1) hearing health and music questionnaire; 2) tympanometry; 3) traditional pure-tone thresholds from 500-8000 Hz; 4) EHF thresholds from 10,000-20,000 Hz; 5) fitness evaluation.

A questionnaire was necessary to reveal pertinent case history information. For musicians, information sought included length of time per week exposed to loud music during practice or performance, instrument played and seating arrangement in relation to other musical instruments in the orchestra or band. For nonmusicians, history of noise exposure was evaluated. For both subject groups the presence of tinnitus, problems with hearing acuity in noise and history of temporary threshold shift was documented. TTS is defined as a reduction in hearing sensitivity in at least one and perhaps more of the common test frequencies, and is transitory in nature. An example of the questionnaire can be found in Appendix 2.

Tympanometry using the Welch Allyn GSI 33 Middle Ear Analyzer was employed to assess the integrity of the middle ear. The pure-tone hearing test was performed on a GSI-61 audiometer with standard insert earphones for frequencies from
250-8000 Hz with the criteria of 25 dB HL or better. All subjects in the study were
required to have normal hearing thresholds. EHF thresholds were obtained from 10,000-
20,000 Hz with Sennheiser HAD 200 circumaural headphones designed specifically for
EHF audiometry with the GSI-61 audiometer.

The fitness evaluation contained several components: measurement of height and
weight, measurement of body fat, and calculation of VO₂ max measured using a heart
monitor while subject rode a stationary bicycle. A projected VO₂ max was derived from
height and weight and the actual results were compared to the projected information
(Kolkhorst, et.al., 1997; Ross & Jackson, 1990).

Experimental Design

The experimental design was an experimental, predictive study comparing
variables within subject and between subjects groups.

Statistical Analyses

The EHF thresholds between musicians and nonmusicians were compared using a
multivariate analysis of variance (MANOVA) with the left and right ears tested
simultaneously. Alternate multivariate analyses were utilized to decrease the influence of
missing values for the EHF at 18,000 and 20,000 Hz. The multivariate analysis was
duplicated in light of the missing values. One analysis was administered without the
18,000 and 20,000 Hz frequencies and one analysis included these values. The
conventional pure tone thresholds were analyzed using a multivariate analysis of variance
for a difference in means of pure tone thresholds between musicians and nonmusicians.
The MANOVA was replicated within the musician group to discern any disparity
between subjects based on type of instrument played. The predicted and actual VO₂ max
measurements were analyzed using a Pearson correlation coefficient and graphical techniques.
CHAPTER IV

Results

Sixty-six subjects participated in the study. Data regarding gender and age was obtained for each subject. Participating in the study were 36 males and 30 females (Figure 1). The musician groups contained 22 males and 11 females (Figure 2). The nonmusicians group had 14 males and 19 females (Figure 3). The subjects had an age range of 18 to 27 years old (Figure 4). The mean age among musicians was 21.21 years of age and the median was 21. Among nonmusicians, the mean age was 22.21 and the median was 22. The entire subject group had a mean age of 21.71 and a median age of 21.5 (Table 2).

Subjects were required to have a pure tone threshold of no greater than 25 dB HL at 500-8K Hz. Three different mean pure tone averages were calculated for each group: 1) 500, 1000, and 2000 Hz; 2) 1000, 2000, 3) 4000 Hz; 4000, 6000, 8000 Hz. Overall, the musicians had poorer pure tone averages than the nonmusicians, which is consistent with the effects of noise exposure. However, given the large variability within each group, there was much overlap. Means and standard deviations are reported in Tables 3 for musicians and Table 4 for nonmusicians.

Extended high frequency thresholds from 10,000 to 20,000 Hz revealed the musicians had increasingly better thresholds than the nonmusicians as frequency increased. Means and standard deviations are reported in Table 5 for musicians and Table 6 for nonmusicians. A limitation of the study was the measurement of EHF. The extended high frequency thresholds of several subjects were tested while the audiometer was not calibrated correctly. Ten subjects were retested and correction factors were
developed for adjustment of the thresholds in error. For increased reliability in hearing assessment, audiometric calibration should be verified prior to testing.

The mean predicted VO\textsubscript{2} max measurements for the musician group was 42.01 (standard deviation of 9.25) and 41.61 (standard deviation of 6.75) for the nonmusician group. The predicted values were calculated from the formulas provided on the Houston Nonmusician Exercise Test (Ross & Jackson, 1990). An example of the exercise test can be found in Appendix 3. The limited amount of actual VO\textsubscript{2} max measurements obtained prevented use of these values in statistical analysis. A Pearson correlation of -.451 was found between the actual and predicted values. There was no significant difference between the musicians and nonmusicians regarding the predicted VO\textsubscript{2} max measurements. The means and standard deviations of predicted VO\textsubscript{2} max values for musicians and nonmusicians are reported in Table 7.

The study contained musicians playing 13 different instruments. Brass, woodwind, strings, percussion, piano, and vocalists were among the group (Figure 5). The average length of time the musicians have been playing or performing was 11.12 years. The musicians group only had six individuals out of 33 who reported they smoked. The nonmusicians had five individuals out of 33 who reported they smoked. Within each group of smokers, there was much variability in amount of use. Five nonmusician subjects reported heavy smoking (≥ 1 pack/day). Two musician subjects reported heavy smoking. Reports of tinnitus were frequent in both groups. Twenty-three musicians and 17 nonmusicians reported the occasional presence of tinnitus. Only four out of 33 musicians reported wearing hearing protection and of the 15 nonmusicians reporting noise exposure, only one stated they wore hearing protection.
Table 1

*Noise levels of Musical Instruments and Environments*

<table>
<thead>
<tr>
<th>Musical Instrument or Environment</th>
<th>Decibel Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Piano Practice</td>
<td>60-70</td>
</tr>
<tr>
<td>Fortissimo Singer – 3 feet away</td>
<td>70</td>
</tr>
<tr>
<td>Chamber Music in a small auditorium</td>
<td>75-85</td>
</tr>
<tr>
<td>Regular sustained exposure capable of damage</td>
<td>90-95</td>
</tr>
<tr>
<td>Piano – fortissimo</td>
<td>92-95</td>
</tr>
<tr>
<td>Violin</td>
<td>84-103</td>
</tr>
<tr>
<td>Cello</td>
<td>82-92</td>
</tr>
<tr>
<td>Oboe</td>
<td>90-94</td>
</tr>
<tr>
<td>Flute</td>
<td>85-111</td>
</tr>
<tr>
<td>Piccolo</td>
<td>95-112</td>
</tr>
<tr>
<td>Clarinet</td>
<td>92-103</td>
</tr>
<tr>
<td>French Horn</td>
<td>90-106</td>
</tr>
<tr>
<td>Trombone</td>
<td>85-114</td>
</tr>
<tr>
<td>Tympani and bass drum rolls</td>
<td>106</td>
</tr>
<tr>
<td>Average Walkman on 5/10 setting</td>
<td>94</td>
</tr>
<tr>
<td>Symphonic music peak</td>
<td>120-137</td>
</tr>
<tr>
<td>Amplified rock music peak</td>
<td>120</td>
</tr>
<tr>
<td>Rock music peak</td>
<td>150</td>
</tr>
</tbody>
</table>

Table 2

*Age of Musicians and Nonmusicians*

<table>
<thead>
<tr>
<th></th>
<th>MUSICIANS</th>
<th>NONMUSICIANS</th>
<th>ALL SUBJECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>21.21</td>
<td>22.21</td>
<td>21.71</td>
</tr>
<tr>
<td>Median</td>
<td>21</td>
<td>22</td>
<td>21.5</td>
</tr>
</tbody>
</table>

Table 3

*Musician’s Pure Tone Average for Right and Left ear*

<table>
<thead>
<tr>
<th>Hz</th>
<th>Right Ear (dB HL)</th>
<th>Left Ear (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500, 1000, 2000</td>
<td>8.61</td>
<td>8.46</td>
</tr>
<tr>
<td>1000, 2000, 4000</td>
<td>7.35</td>
<td>9.51</td>
</tr>
<tr>
<td>4000, 6000, 8000</td>
<td>6.01</td>
<td>5.42</td>
</tr>
</tbody>
</table>
Table 4

Nonmusicians Pure Tone Averages for Right and Left Ear

<table>
<thead>
<tr>
<th>Hz</th>
<th>Right Ear (dB HL)</th>
<th>Left Ear (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500, 1000, 2000</td>
<td>6.24 5.99</td>
<td>7.25 6.11</td>
</tr>
<tr>
<td>1000, 2000, 4000</td>
<td>5.18 5.79</td>
<td>6.85 6.85</td>
</tr>
<tr>
<td>4000, 6000, 8000</td>
<td>3.59 6.45</td>
<td>5.32 6.43</td>
</tr>
</tbody>
</table>

Table 5

Musicians Extended High Frequency Thresholds for Right and Left Ear

<table>
<thead>
<tr>
<th>(Hz)</th>
<th>Right Ear (dB SPL)</th>
<th>Left Ear (dB SPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>15.63 10.48</td>
<td>19.36 9.24</td>
</tr>
<tr>
<td>12,500</td>
<td>30.35 13.59</td>
<td>28.61 11.25</td>
</tr>
<tr>
<td>14,000</td>
<td>30.82 15.57</td>
<td>26.72 11.90</td>
</tr>
<tr>
<td>16,000</td>
<td>54.41 17.58</td>
<td>57.65 18.79</td>
</tr>
<tr>
<td>18,000</td>
<td>79.01 24.87</td>
<td>82.03 25.73</td>
</tr>
<tr>
<td>20,000</td>
<td>92.52 31.66</td>
<td>93.52 31.01</td>
</tr>
</tbody>
</table>

Table 6

Nonmusicians Extended High Frequency Thresholds for Right and Left Ear

<table>
<thead>
<tr>
<th>(Hz)</th>
<th>Right Ear (dB SPL)</th>
<th>Left Ear (dB SPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>15.91 10.35</td>
<td>20.91 10.58</td>
</tr>
<tr>
<td>12,500</td>
<td>30.94 13.28</td>
<td>30.67 12.96</td>
</tr>
<tr>
<td>14,000</td>
<td>30.79 15.60</td>
<td>27.85 14.17</td>
</tr>
<tr>
<td>16,000</td>
<td>55.45 16.72</td>
<td>60.15 18.51</td>
</tr>
<tr>
<td>18,000</td>
<td>85.56 13.57</td>
<td>88.89 13.41</td>
</tr>
<tr>
<td>20,000</td>
<td>102.50 2.67</td>
<td>103.13 7.04</td>
</tr>
</tbody>
</table>

Table 7

Predicted VO₂ max Measurements for Musicians and Nonmusicians

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musicians</td>
<td>42.01</td>
<td>9.25</td>
</tr>
<tr>
<td>Nonmusicians</td>
<td>41.61</td>
<td>6.75</td>
</tr>
</tbody>
</table>
Figure 1 Gender Distribution of Musicians and Nonmusicians

Gender

Male 55%
Female 45%
Figure 2  *Gender Distribution of Musicians*

![Gender Distribution of Musicians](image)

- Male: 67%
- Female: 33%

Male 67%
Female 33%
Figure 3 *Gender Distribution of Nonmusicians*

Gender of Nonmusicians

- Male: 42%
- Female: 58%
Figure 4  *Age Distribution of Musicians and Nonmusicians*
Figure 5 *Instrument Distribution of Musicians*

### Instrument Distribution

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Number of Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuba</td>
<td>4</td>
</tr>
<tr>
<td>Trombone</td>
<td>3</td>
</tr>
<tr>
<td>Vocalist</td>
<td>3</td>
</tr>
<tr>
<td>Cymbals</td>
<td>2</td>
</tr>
<tr>
<td>Euphonium</td>
<td>2</td>
</tr>
<tr>
<td>Flute</td>
<td>4</td>
</tr>
<tr>
<td>Piano</td>
<td>3</td>
</tr>
<tr>
<td>Clarinet</td>
<td>2</td>
</tr>
<tr>
<td>Trumpet</td>
<td>7</td>
</tr>
<tr>
<td>Viola</td>
<td>2</td>
</tr>
<tr>
<td>Percussion</td>
<td>3</td>
</tr>
</tbody>
</table>
CHAPTER V

Discussion

Musicians are constantly exposed to high noise levels from rehearsals or performances. NIHL can destroy a musician’s ability to monitor their own performance, which can end a successful career. The purpose of this study was to determine if musicians presented significant changes in EHF thresholds due to their repeated noise exposures as compared to nonmusicians. The importance of determining differences in EHF thresholds between musicians and nonmusicians for the preservation of hearing of those consistently exposed to damaging noise levels cannot be underestimated. The high frequency hearing of musicians is necessary because of the requirement to delineate pitches above those necessary for understanding speech. Maintenance of appropriate musical dynamics necessary for aesthetically acceptable performance may be difficult to attain for the musician with hearing loss. Certain nuances of performance require extreme changes in dynamics and hearing loss will create difficulty hearing one’s own performance accurately without increasing loudness (Einhorn, 1999). Additionally, the higher frequencies of hearing are closer in proximity to the mid-frequency range of the continuum of music experienced by musicians (Hall & Santucci, 1995).

The present study found a marked trend in the EHF thresholds of musicians compared to nonmusicians. At 10 K Hz, there was no difference in the EHF thresholds between musicians and nonmusicians. As the EHF increased in frequency, greater differences in thresholds were found between groups. The musicians with the poorest thresholds at 10K Hz were those that played the cymbals, flute and piano. The best threshold among musicians at 10K Hz was the euphonium player. As compared to
present normative data (Osterhammel & Osterhammel, 1979) regarding EHF thresholds, both groups are within the stated normative value ranges (Table 8). At 12.5K Hz the musicians mean threshold was 23.931 (standard deviation of 5.7) and the mean for nonmusicians was 26.541 (standard deviation of 5.630) and a P-value of .0677 when comparing the two groups. The better thresholds within the musician group were not statistically significant but the beginning of a marked trend seen throughout the data. The 14,000 Hz ranges of data found the pianists and vocalists with the best hearing thresholds even when compared to other musicians and nonmusicians. All thresholds were similar within and between groups at this frequency. The 16,000 Hz range found the euphonium player and the vocalist with the best thresholds as compared to the other musicians and the nonmusicians.

The difference seen in the data regarding EHF thresholds between musicians and nonmusicians increased as frequency increased through 20,000 Hz. The limited amount acquired data at 18,000 and 20,000 Hz prevented adequate analysis at these frequencies. The reported difference in noise exposure between groups, the increased hearing acuity and perception of musicians, type of instrument played, gender and age could have been contributing factors. A study by Johnson et al. (1986) supports finding similar hearing acuity among musicians and nonmusicians despite a history of noise exposure common among musicians. Stelmachowicz et al. (1989) found that gender and age could affect EHF thresholds. Age affects the frequencies 15,000 to 18,000 Hz the most and variability between subjects was greatest from 12,000 to 16,000 Hz (Stelmachowicz et al. 1989). Subjects who smoked may have also affected the EHF thresholds obtained. Chung et al. (2002) reported that several studies have noted a trend between smoking and
hearing loss in higher frequencies. Smoking induces the production of nicotine and carbon dioxide in large amounts which triggers spasm of blood vessels (vasospasm) and occluding blood clots potentially affecting blood supply to the inner ear. Additionally, smoking is thought to facilitate the destruction of natural antioxidant defense mechanisms and permitting damage via reactive oxygen species (ROS) (Chung et al. 2002). Given the low number of subjects reporting smoking and the wide range of use (heavy to once per month), no further statistical analysis was conducted.

Johnson et al. (1985) studied the effects of instrument type and orchestral position on hearing thresholds from 250-20,000 Hz. Although a wide age range was accepted in this study (24-64 years of age), there were no statistically significant differences between the thresholds of different orchestral instrumentalists. There was no clear correlation between orchestral position and amount of hearing loss incurred by musicians. This type of study must analyze the level of noise created by the musician’s instrument in addition to instrument players surrounding the musician. Further investigation is required to clarify the effects of instrument position and type upon hearing thresholds among musicians (Johnson et al., 1985).

The present study examining the hearing acuity of musicians versus nonmusicians discovered similar thresholds between groups through 8,000 Hz and slight differences in EHF thresholds between groups. Johnson et al (1986) found similar hearing acuity among musicians as well when comparing musicians versus nonmusicians. Conversely, Johnson et al (1986) found that as frequency increased, hearing acuity decreased, which is in conflict with the results of the current study. A steady decrease in hearing acuity as frequency increased with no trend regarding superior EHF among musicians with an
increase in threshold was reported by Johnson et al (1986). Axelsson and Lindgren’s (1978) classic study regarding MIHL among pop musicians revealed a low incidence of hearing loss among these musicians. Axelsson and Lindgren (1981) to clarify the incidence of MIHL among musicians performed a follow-up study. They again found what they considered to be a low incidence of hearing loss but found drummers are at a greater risk for hearing loss and women appear to be less affected by TTS than men are. Downs et al. (1971) found that damage due to noise is apparent first in frequencies above 8000 Hz. The present study did not support such findings assuming the musicians had the greatest history of noise exposure.

Excessive noise can cause structural damage and metabolic changes to the outer hair cells of the inner ear. Recent investigation concerning the pathophysiology of hair cell damage found that damage occurs in the same manner for NIHL as it does for damage due to ototoxic drugs. The reactive oxygen species (ROS) that are responsible for oxidative stress are found in excess after acoustic trauma or administration of ototoxic drugs. Normal antioxidant defenses found in the ear usually can overcome the ROS. However, the amount of ROS exceeds the amount of antioxidant defenses capable of deterring oxidative stress during acoustic trauma and administration of ototoxic treatments (Kopke et al., 1999). EHF audiometry is currently used as a method of monitoring the effects of ototoxic drugs on the auditory system. Therefore, EHF thresholds should be a viable option for monitoring the effects of noise on a population such as musicians. If the damage in the cochlea occurs similarly through these two distinct destructive events, a similar monitoring method should be efficacious.
The comparison of fitness level between the musicians and nonmusicians was determined by examining the predicted VO$_2$ max measurements. Cardiovascular health has been linked to hearing loss indicating poor fitness initiates a poorer blood supply to the cochlea (Manson, Alessio, Cristell & Hutchinson, 1994). Between the two groups, there was no statistically significant difference in their fitness level, which indicates fitness level did not play a role in the hearing trend seen in the EHF of musicians. The mean VO$_2$ max for musicians was 38.932 and the mean for nonmusicians was 41.322. An attempt was made to compare the limited number of predicted and actual VO$_2$ max measurements obtained from the subjects. The great discrepancy between measurements was attributed to the unreliable exercise schedule and weight reported by the subjects (Kolkhorst et al., 1997). Due to the similarity in VO$_2$ max measurements, a distinction could not be made regarding the variable of physical fitness as related to hearing loss. The inconsistencies between actual VO$_2$ max measurements and predicted measures are further complicated by the small, biased sample of the actual measurements attained. The ten subjects that participated in the VO$_2$ max measurements may have willingly participated because their overall fitness was good. Another difficulty is the assumption that VO$_2$ max measurements were the only determinant used to define good physical fitness. Part of the musical training of some musicians involves breathing exercises. The possibility exists that a better VO$_2$ max measurement may have been obtained by a musician who consistently participates in breathing exercises, thereby biasing the results.

Noise is an increasingly prevalent irritant in our society. The increased presence of noise can be demonstrated by documented research regarding NIHL among adults, children, adolescents and young adults or even in noise ordinances found in some
NIHL is often thought of in terms of industrial hearing loss but over 30 million people in the United States and 600 million worldwide are exposed to unsafe sound levels repeatedly (Kopke, 2003). Familiar items, whether functional or recreational, induce potentially harmful noise levels to our hearing. Motorcycles, power tools, lawn mowers, hairdryers, kitchen appliances, firecrackers, firearms, car stereos, personal stereo systems, video arcades, movie theatres, health clubs, children’s toys and boom cars, all can threaten the integrity of the hearing mechanism (NIDCD, 1999; League for the Hard of Hearing, 1998). Noise is a major contributor to the 28 million people with hearing impairment in the United States. The Deafness Research foundation sponsors the National Campaign for Hearing Health to increase awareness of this growing problem in our society. The campaign seeks to educate the public regarding the dangers of excessive noise and the prevalence of hearing loss among children and adults alike (Deafness Research Foundation, 2000).

The design of the study included 33 musicians with a known history of consistent noise exposure and 33 nonmusicians with no known exposure to noise. When comparing the hearing thresholds of musicians and nonmusicians obtained in the study, the difference in thresholds is negligible. The assumption would be the musicians would have greater hearing loss due to their constant noise exposure. The present study did not indicate such findings. Both groups had essentially the same hearing thresholds in the 4,000-8,000 Hz ranges, which are frequencies usually damaged by noise exposure. Possible explanations are attributed to the widespread occurrence of excessive noise exposure and the desensitization of individuals to the high noise levels in our society. Nonmusicians may not have been able to report an exact representation of their noise
history. Possible contributing factors to the inconsistent result include variations among individuals regarding amount of NIHL incurred due to genetic factors.

Accurate evaluation of musicians and their noise environment is crucial to facilitating advantageous hearing protection strategies. An indispensable evaluation component is the acquisition of a detailed case history. A useful case history should include history of noise and music exposure, family history of hearing loss, medical history, presence of change in hearing, presence of tinnitus, and the use of hearing protection (Hall, 2000). Pertinent questions are useful in determining if a musician’s environment is too noisy. Examples of such questions include: 1) Are voices muffled at the end of an extensive exposure to music? 2) Do your ears have a feeling of fullness or stuffiness? 3) And do your practice or performance areas require you to shout to be heard? (Hall & Santucci, 1995). Otoscopic evaluation, tympanometry, acoustic reflex testing, pure tone testing, speech recognition testing, otoacoustic emission testing and extended high frequency audiometry is the recommended protocol for musician assessment (Hall, 2000). Chasin (1996) also suggests inclusion of instrumental spectral analysis, a detailed corrective procedure plan and verification of the efficacy of hearing protection. The spectral analysis combined with a depiction of the noise environment will allow the determination to be made concerning which instrument is the threat to hearing preservation, the musician’s instrument or those around them (Chasin, 1996).

Chasin and Chong (1992) developed the technique for spectral analysis of an instrument output measured at the person’s ear canal. Real ear measurement (REM) is used to appraise the output characteristics of hearing aids while in the person’s ear canal. The REM equipment can be used for spectral analysis by immobilizing the speaker and
the reference microphone. The probe microphone is placed in the ear canal near the
tympanic membrane and a low note, a middle range note and a high range note are played
on the instrument. Each note is played at the piano, mezzo-forte and forte dynamic levels
and is prolonged until a spectral analysis is achieved. Analyzing the frequencies and
intensities allows musician specific precaution and protective procedures to be
implemented. Placing the probe microphone near the site on the instrument where sound
is emitted may also be an effective approach. A musical note to frequency conversion
chart is used to further clarify the meaning of the spectral analysis. Instruments such as
the piano, guitar and percussion do not produce sustained notes therefore spectral
analysis software programs must be used to analyze those instruments in sound field
(Chasin, 1996).

Preventative measures are extremely important when promoting healthy hearing
among musicians. Marshall Chasin (2003) suggests that as audiologists we delude
musicians regarding the loudness of the music. Detecting subtle differences in loudness
is a difficult task and the intensity or sound pressure level is the culprit of noise damage.
Convincing musicians that music is sufficiently loud, a lesser intensity will remain
undetected and therefore protect the hearing of the musician. Many musicians feel
wearing hearing protection will hamper their ability to effectively monitor their playing
and achieve balance among the instrumentalists around them. The present study supports
musician’s reluctance to wear hearing protection. Four musicians out of 33 in the sample
reported wearing hearing protection and of the 15 nonmusicians reporting noise exposure,
only one stated they wore hearing protection. The unwillingness the use hearing
protection is obvious. Falsifying mistaken ideas regarding hearing protection will require

37
educating musicians regarding the available technology and the benefits associated with protecting their hearing. Acceptance of hearing protection as a viable option for musicians has been the trend in recent years. A positive attitude toward hearing protection is due to well executed hearing protection awareness campaigns, technological improvement in hearing protection, and support for protective hearing measures given by recognized music professionals (Chasin, 1999).

Several hearing protection options exist including custom earplugs with and without venting, in-the-ear monitors and a variety of specific options for each instrument group. The most common earplugs available are the ER-15, which is a custom made earplug that offers 15 dB of reduction of the noise up to 8000 Hz. The ER-15 earplug is able to compensate for the reduction of ear canal resonance by creating an enhancement of resonance around 3000 Hz caused by a combination of compliance and mass. During production of the earplug the mass of the sound bore is confirmed to have the accurate volume of air to achieve a flat pattern of reduction of sound. The ER-25 earplug is also a custom made earplug designed to decrease sound by 25 dB up to 6000 Hz. The ER-20 HI-FI earplug is a noncustom earplug, which enhances higher frequencies and seeks to avert attenuation of higher frequency sounds. Earplugs may also be vented with a select-a-vent (SAV) option. Venting allows flexibility in adjusting the attenuation of sound and emphasizing certain frequency resonances. The musician has a variety of hearing protection options and should find one suited to his or her needs. (Chasin, 1996)

Conventional stage monitoring during live musical performances has the capability of causing dangerously high levels of noise. Two separate monitoring systems are ongoing during conventional stage monitoring. The audience listens to one
monitoring system and the second provides a different blend of the music for the musicians. Several musicians are usually on stage simultaneously. A request for adjustment in sound level for one musician in turn may require another sound level change for a different musician. The competitive monitoring has the potential for reaching extremely high levels of noise. In-ear monitoring is an option to circumvent the dangers associated with conventional stage monitoring. In-ear monitoring guards the musician from hazardous noise levels and enables access to the complete dynamic range of the performance, their own performance and preservation of balance between other musicians on stage. An in-ear monitor is placed in the ear canal deep enough to eliminate external sound, consequently the musician utilizes the sound mix given to them from the sound engineer without the unsafe levels associated with conventional stage monitoring. Another advantage of in-ear monitoring is the deterrence of vocal exhaustion and feedback issues related to stage monitoring. (Hall & Santucci, 1995) Freedom to move around the performance area and enhanced, dependable sound quality despite the acoustical nature of the performance area are other positive advantages of in-ear monitoring.

Woodwinds and large stringed instruments are usually located in front of the brass and percussion sections, which are areas of potential threat for MIHL. The woodwinds and large stringed instruments have primarily lower frequency energy whereas the brass instruments produce damaging levels of noise in higher frequency areas. Therefore, a successful type of ear protection would be one designed to enhance lower frequency sound but decrease higher frequency sounds. The vented earplug permits the musician to monitor their own performance but attenuate the damaging noise levels (Chasin, 1996).
Violas and violins are capable of producing levels loud enough to cause hearing damage. The left ear is usually affected the most due to the fact this ear is closest to the instrument. Often, many instruments of this type encompass the viola and violin player, increasing the chance of noise damage. Musicians in this category need to hear sound at higher frequencies. Protective measures must include techniques to protect hearing and allow detection of high frequency sounds. The orchestra pit usually has an overhang and violin and violas should not be positioned under these overhangs. The overhangs cause attenuation of higher frequencies creating a muffled quality of sound. Compensation by the musicians forces them to play more aggressively and in turn increased the overall sound level. Acoustic baffles can help reduce intensity of instruments behind the violin and viola players. Using mutes during practice times help to reduce noise exposure and earplugs such as the ER-15 attenuates sound evenly across all frequencies and is effective for these musicians.

Brass and percussionists often have similar types of noise exposure due to positioning within the orchestra or band. Shakers are miniature speakers that can be affixed to the seat or affixed to plywood and situated on the floor in close proximity to brass or percussion players. Shakers create the sensation of playing louder, when in reality they are not, thereby protecting the hearing mechanism. Drummers should wear ER-25 earplugs but be cautious not to over exert themselves physically to compensate for the attenuation of signal. Plexiglas\textsuperscript{[\ref{p:14}]} baffles can be used to decrease the noise level of the percussion section. Humming with the music during practice and performance will engage the stapedial reflex before higher decibel sounds arise and will serve as further
protection from intense sounds for the brass musicians as well as percussionists (Chasin, 1996).

Allowing ears to recuperate after extreme noise exposure is another way to protect the hearing mechanism in all musicians. Sixteen to eighteen hours should be allowed between subsequent noise exposures to return the hearing threshold to the level occupied prior to the TTS. Additional preventative measures include elevation of speakers from the floor and allowance of at least two meters of distance from the front of the stage for the entire orchestra. The distance creates a high frequency emphasis and reduces the probability of musicians over exerting themselves to play louder (Chasin, 1996).

Counseling the musician is an integral piece in the overall approach executed to preserve hearing acuity. Several counseling options have been successful. Teaching the musician basic inner ear physiology will enable them to realize the complexity of the system and optimistically prompt a desire to preserve such an important system. Obtain a baseline of hearing threshold, even if the musician wants the results to remain undisclosed, to prove the effects of noise over time. Advocate the use of two in-ear monitors to increase the perception of loudness without an actual increase in volume. Encourage all members on stage to use in-ear monitors to decrease the possibility of competing and higher sound levels in the performance area (Santucci, 1999).

The task of identifying a successful monitoring technique for the prevention of MIHL is vital. EHF thresholds, with more research, have the potential to be an effective monitoring tool after the acquisition of baseline threshold data. The current trend in data in this study shows a difference in EHF thresholds in favor of musicians. Research
involving the EHF of 18,000 and 20,000 Hz with a larger sample size will likely yield a statistically significant difference between musician and nonmusician EHF thresholds. Actual VO$_2$ max measurements will be an effective route to identify individuals with a high cardiovascular fitness level in relation to hearing thresholds. Correlating high fitness level with hearing threshold will enable a relationship to be established between fitness and protection of the hearing mechanism for musicians. The promotion of hearing protection will also be critical. Education regarding the potential dangers of MIHL and the advantages of hearing protection will continue to be an important issue for audiologists working with musicians. Extensive knowledge relating to hearing protection will enable a musician quality hearing protection with the least adverse effects musically.

Limitations

A threat to internal validity included selection bias in reference to the noise exposures of the subjects. As stated previously finding a control group with little or no noise exposure becomes increasingly difficult. The desensitization to the noise around us creates the misconception that our exposure to noise is small. Therefore, finding a group of individuals who are without significant noise exposure is challenging. Accurate examination of the effects of noise on EHF were to be verified by comparing the musicians with a known history of noise exposure with the nonmusicians with little or no known significant noise exposure. In addition, comparison of groups with different noise exposures is important because subsequent noise exposure can increase the chances of further damage from noise.

Future Research
The improvement of musician’s EHF as the frequency increased indicates further research is needed including the EHF of 18KHz and 20KHz. An increase in sample size may provide a statistically significant relationship between the EHF in musicians versus nonmusicians. The viability of EHF has been proven effective when monitoring the effects of medicines considered ototoxic and with further research, may be proven a valuable technique for monitoring the hearing of musicians or any person exposed to noise. The subjects will need to be in an age range of 18-30 years due to the effects of aging and the negative impact on high frequency hearing sensitivity (Harrell, 2001). In addition, musicians should be matched as closely as possible for instrument, history of noise exposure and practice, rehearsal and performance patterns. The musician questionnaire should have specific questions regarding how many hours daily a musician practices and if there is a history of noise exposure other than music.

Several studies have indicated the importance of antioxidants in the protection of the inner ear from NIHL. The compelling results of two specific research areas have provided the basis for this line of thinking. The first area of research studied the effects of “toughening” the ear to decrease susceptibility to the effects of noise. The ear is exposed to noise that is not harmful during several short instances. The results showed once the ear is again exposed to harmful noise levels, the TTS is lessened by at least 20-30 dB. Upon further study, an increase in antioxidant enzymes after harmful noise exposures was discovered. The increase in antioxidant enzymes was found specifically in the Organ of Corti and the stria vascularis and was greater in ears that had been toughened by previous exposures (Henderson, McFadden, Liu, Hight & Zheng, 1999). Toughening of the auditory system is intended to protect the ear from noise damage.
Musicians could be exposed to toughening procedures with verification of affect on temporary threshold shifts after rehearsals or performance (Henderson, McFadden, Liu, Hight & Zheng, 1999).

The second line of research concerning antioxidants involves dispensation of antioxidants directly to the inner, by injection, or by mouth. The human body has natural defense mechanisms for prohibiting oxidative stress. The natural antioxidant mechanisms can be overwhelmed by the amount of ROS present after injury or trauma. Supplemental antioxidant therapy has been shown to improve the negative effects of noise exposure. Vitamin A and vitamin E are considered important antioxidants due to their curative properties. Vitamin A has been linked to therapeutic benefit for vision difficulties, prevention of cancer and increase of immunity to infection. Vitamin E has been proposed to help such diseases as diabetes, coronary disease, arteriosclerosis and skin disorders. Vitamins A and E have also been linked to improvement of hearing thresholds. Two studies by Romeo (1985) studied the effects of vitamin A and E in combination to reduce the effects of sensorineural hearing loss. Each study revealed an improvement of thresholds from 5-15 dB (Romeo, 1985). Other protective treatments include glutathione (GSH), iron chelators, calcium-binding proteins, ROS scavengers, and trophic factors. Previous research shows all of these protective agents minimize the effects of noise when the agent was administered preceding the acoustic trauma or ototoxic exposure (Kopke et al., 1999).

One final area of future research involves the use of the antioxidant N-acetylcysteine (NAC) for prevention of hearing damage due to noise. NAC is FDA approved and has been in clinical use for more than 30 years as a treatment for Tylenol
overdose. NAC is inexpensive and can be used in high doses for an extended time. Research by Kopke et al has found a mechanism-based tool to suppress free radical production, protect from mitochondrial insult, and prevention of apoptosis. Reproducibility has been possible among different labs and different species of animals and future research in this area involves clinical trials and alternate antioxidant for prevention of NIHL.

Implications for Clinical Use

As awareness of NIHL becomes more prevalent, audiologists will be faced with the challenge of protecting the hearing of musicians. Monitoring the effects of music upon hearing and providing solutions for musicians will be a necessity. Knowledge of techniques for monitoring the effects of noise will be useful in providing quality care for our patients. The findings of this study indicate the extended high frequency thresholds yield no viable difference from those not involved in recurring music exposure at high levels.
Table 8

Mean Binaural Extended High Frequency Thresholds

<table>
<thead>
<tr>
<th>Hz</th>
<th>NORMS$_1$ (dB SPL)</th>
<th>MUSICIANS (dB SPL)</th>
<th>NONMUSICIANS (dB SPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>10,000</td>
<td>21</td>
<td>9.6</td>
<td>17.89</td>
</tr>
<tr>
<td>12,500</td>
<td>31</td>
<td>11.2</td>
<td>29.11</td>
</tr>
<tr>
<td>14,000</td>
<td>41</td>
<td>14.9</td>
<td>23.14</td>
</tr>
<tr>
<td>16,000</td>
<td>67</td>
<td>17</td>
<td>50.77</td>
</tr>
<tr>
<td>18,000</td>
<td>88</td>
<td>-</td>
<td>79.46</td>
</tr>
<tr>
<td>20,000</td>
<td>90</td>
<td>-</td>
<td>93.17</td>
</tr>
</tbody>
</table>

1. Normative thresholds obtained from Osterhammel and Osterhammel (1979) thresholds (directly obtained data).
References


Appendix 1 *Subject Consent Form*

Research Project: “Normal Hearing Musicians and Nonmusicians Hearing Status”

The study will consist of three parts:
1. Two brief questionnaires
2. Complete audiological hearing evaluation
3. Health Assessment

The entire process should only require a 55 minutes of your time to complete all the testing.

The testing will begin on January 18, 2002 and end when 60 or more subjects are tested. All testing will be complete at the Miami University Speech and Hearing Clinic at a time that is convenient to you. There are no risks involved in this study and research results could provide benefits in prevention of music-induced hearing loss and may improve subjects’ hearing health.

Your participation in this project is completely voluntary and would be greatly appreciated. In addition, you are permitted to withdraw from the project at any time throughout the research project. All identifying information will be kept confidential through a number code system. Only the student investigator and faculty advisor will have access to your name and identifying information. Please feel free to contact Maribeth DiSalvo or Tricia Deatherage, the graduate students at 529-2500, for any questions or concerns you may have. Further questions may be directed to our faculty advisor, Dr. Kathleen Hutchinson, at 529-2500. The office for the Advancement of Scholarship and Teaching at 529-3734 can be contacted if you have any questions concerning your rights as a subject.

If you agree to participate in this research project, please sign the slip at the bottom of this page.

____________________________________________________

Name: ____________________________________________

Signature: _________________________________________
Appendix 2 Hearing Health and Music Questionnaire

Research Questionnaire

Name ________________________________ Date __________________
Birthdate ________________________ Age __________________
Address ____________________________________________________________
Home Phone _______________________ Work Phone _____________________
Occupation ____________________________________

General Information

Section 1:
Do you smoke? Yes ________________ No ________________
If so, how often? _________________________________________________________
Have you ever had major surgery? Yes ________________ No ________________
If so, please list date and type _______________________________________________
Have you ever had a head injury? Yes ________________ No ________________
Do you have a family history of hearing loss? Yes ________________
If so, please explain: ______________________________________________________
How long has it been since you were last exposed to loud noise, music, etc.? ____________________________
________________________________________________________________________
______________________________________________________________________________

Section 2:
Are you a musician? Yes ________________ No ________________
(If no, skip the rest of the questions in this section)
What instrument do you play? (drums, guitar, sing, etc.) ____________________________
How long have you been playing? ____________________________
Approximately how many hours are you exposed to loud music per week?
________________________________________
Do you wear ear protection while exposure to loud music? (rate yourself on how often
you wear hearing protectors on a scale from 1 to 4) 1= most of the time, 2= less than
half of the time, 3= seldom, 4= never ____________________________

Section 3:
(When filling out this section keep in mind the following: loud noise is characterized by
the fact that you would have to raise your voice to be heard by another person when
talking to them from arm’s length away)
Have you had a history of noise exposure? (other than music if you are a musician)
Yes ________________ No ________________
If so, please explain: ______________________________________________________

Are you exposed to noise on the job?  Yes ______________  No _______________

If yes, please explain: ______________________________________________________

Are you exposed to loud noise recreationally? (hunting, woodworking, socially, etc.)
Yes ______________  No ______________  If so, please explain: ______________________________________________________

If so, approximately how many hours per week?

Do you wear ear protection when exposed to this noise? (rate yourself on how often you wear hearing protectors on a scale from 1 to 4)  1= most of the time,  2= less than half of the time,  3= seldom,  4= never ________________

Hearing
Have you ever had a change in your hearing?  Yes ______________  No ______________

(If no, skip the rest of the questions in this section)

Has the change in your hearing been Temporary?  Yes ______________  No ______________

Has the change in your hearing been Permanent?  Yes ______________  No ______________

Has the change in your hearing been gradual?  Yes ______________  No ______________

Sudden? ______________

Which ear is your better ear?  Right ______________  Left ______________  Both the same ______________

What is the cause of your hearing loss (if known)? ______________________________________________________

Do you hear better in:    Quiet? ________________  Noise? ________________

Do you hear on the telephone?  Yes ________________  No ________________

Tinnitus
Do you have a ringing, popping, crackling, or cricket-like noise in your ears?

Yes ________________  No ________________

If so, in which ear?  Right ________________  Left ________________  Both ________________

(If no, skip the rest of the questions in this section)

Is the ringing continuous?  Yes ________________  No ________________

Is the pitch of the ringing high?  Yes ________________  No ________________

Is the pitch of the ringing low?  Yes ________________  No ________________

Section 4
Please provide any other information, which might be helpful.
Please indicate your seating position within the orchestra or band in which you perform.
Appendix 3 *University of Houston Non-Exercise Test*

Directions: Use the appropriate number (0-7) which best describes your general physical activity rating for the previous month.

I. Do no participate regularly in programmed recreation sport or physical activity.
   0 Avoid walking or exertion, e.g. always use elevator, drive whenever possible instead of walking.
   1 Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration.

II. Participate regularly in recreation or work requiring modest physical activity, such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weight lifting, yard work.
   2 10 to 60 minutes per week.
   3 Over one hour per week.

III. Participate regularly in heavy physical exercise such as running or jogging, swimming, cycling, rowing, skipping rope, running in place or engaging in vigorous aerobic activity type exercise such as tennis, basketball or handball.
   4 Run less than one mile per week or spend less than 30 minutes per week in comparable physical activity.
   5 Run 1-5 miles per week or spend 30 to 60 minutes per week in comparable physical activity.
   6 Run 5-10 miles per week or spend 1 to 3 hours per week in comparable physical activity.
   7 Run over 10 miles per week or spend over 3 hours per week in comparable physical activity.

Your age (in years) ____________  Your height (in inches) ____________

Your weight (in pounds) ________________ =