ABSTRACT

Title of dissertation: TEMPORARY CHANGES IN AUDITORY FUNCTION AMONG COLLEGE MARCHING BAND MEMBERS

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The purpose of this study was to evaluate temporary changes in auditory function associated with marching band practice among college-aged marching band participants. Each eligible musician was tested before and after two practices in the time span of one week. Sound level recordings at a location close to the center of the marching band were documented to be 85 – 105 dB(A), with peaks measured at 114 dB(A). Pure-tone thresholds and transient evoked (TEOAE) and distortion product (DPOAE) otoacoustic emissions were tested to evaluate if any changes occurred as a result of the marching band practices. If clinically significant changes were noted from pre- to post-practice testing, the band member returned the following morning to evaluate if any recovery had occurred. The principal finding was a significant effect of test time (pre versus post-practice), which was observed in the pure-tone data (3000, 4000, 6000 and 8000 Hz), DPOAE data (3000 Hz, left ear only) and TEOAE data (narrowband and broadband) in the marching band group. For those participants who showed clinically significant changes in auditory function, these changes were found to recover by the next morning. The results suggest that the measured changes in this study are temporary in nature; however, they might be an early indication of future permanent changes. Comparison of

data from the marching band members and the control group participants revealed a significant difference between the groups in two measures: pure-tone thresholds at 8000 Hz and TEOAEs (broadband and narrowband). Overall, participation in the two-hour, outdoor marching band practice was not found to be more detrimental to auditory functioning than everyday noise exposure. However, there is evidence that exposure to marching band music produces subtle changes in auditory functioning, particularly as measured with pure-tone thresholds and TEOAEs.

TEMPORARY CHANGES IN AUDITORY FUNCTION AMONG COLLEGE MARCHING BAND MEMBERS

By

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Dedication

This dissertation is dedicated to my amazing husband, Gary, without whose support and encouragement my dream would not have become a reality. Thank you also to all my family and friends for listening to me brainstorm ideas and for providing guidance and support for the past four years.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Marching band music reaches hazardous noise levels and has the potential to cause hearing loss for the musicians, the band director and other individuals involved in its successful operation (Keefe, n.d.). Musicians complain of hearing loss and ringing in their ears after practices due to the extreme noise levels (Kahari, Zachau, Sandsjo, Eklof, & Moller, 2003). Band members' hearing must be tested to determine if there is cochlear damage, a precursor to hearing loss.

Hearing abilities can be decreased temporarily or permanently. A temporary threshold shift (TTS) is an impermanent decrease in hearing sensitivity at one or more frequencies, usually as a result of exposure to loud sounds. This temporary hearing loss can be an early warning sign of an impending permanent threshold shift (PTS); however, only weak correlations have been found between the severity of a TTS and a future PTS (Borg, Canlon, & Engstrom, 1995). For example, the offending noise causing the TTS might not be of the same frequency as the offending noise that later induced a PTS. Therefore, the temporary and permanent damage may occur at different locations along the cochlea, as the response in the cochlea is organized by frequency. It has been found, however, that a longer TTS recovery time leads to an increased chance of developing a PTS in the same frequency region, as cochlear hair cells are especially vulnerable during the TTS (Quaranta, Portalatini, & Henderson, 1998).

An individual's overall susceptibility to noise-induced hearing loss, regardless of the type of stimulus, is dependent on lifestyle and genetic factors. Overall health, stress levels and habits such as smoking can alter the body's susceptibility to the loud sounds (Barone, Peters, Garabrant, Bernstein, & Krebsbach, 1987). However, the location and extent of the cochlear damage is highly dependent upon the intermittency, level and frequency range of the stimulus, not an individual's health (Quaranta, et al., 1998; Patuzzi, 1998; Rintelmann, Lindberg, & Smitley, 1972). While noises with periods of quiet have been found to cause less hearing loss than continuous noises, the recovery process for both types of noise is very similar (Rintelmann, et al., 1972)

The hair cells in the cochlea transduce mechanical energy to electric energy before sending the information to the higher levels of the auditory system. When a TTS occurs, the hair cells are temporarily affected and are unable to transduce and transmit the sound efficiently. Some patients report an associated ringing in their ears, sensitivity to loud sounds, or reduced speech understanding during periods of temporary hearing loss.

During the first minute post-noise exposure, hearing improves rapidly. However, the maximum amount of TTS can be detected during minutes two and three post-noise exposure, after variability in hearing thresholds has decelerated and stabilized. The TTS_2 measure (recorded at two minutes post-exposure), is regarded as the maximum amount of TTS caused by the damaging stimuli (Quaranta, et al., 1998; Rintelman, et al., 1972). Afterwards, hearing improves slowly within the next 24-48 hours, usually returning to the individual's pre-exposure hearing sensitivity. However, the rate and amount of recovery depend on the duration and intensity of the stimuli causing the TTS. Hearing sensitivity is not always restored to the pre-TTS thresholds. During a TTS, individuals might not understand speech clearly, regardless of the amount of threshold shift (Stephenson & Wall, 1984).

In contrast to a temporary shift in hearing thresholds, hearing can be affected without the chance of recovery. A PTS occurs when cochlear hair cells are permanently damaged. A PTS is diagnosed when a hearing loss persists for 20-30 days (Quaranta, et al., 1998). Regardless of the severity of the PTS, speech may not be clear and may be difficult to decipher, and patients might also experience additional symptoms, such as tinnitus.

Specific details regarding types of noises that cause TTS, differences in recovery time and the physical structures involved in TTS have been studied extensively. The type of stimuli causing the hearing loss might be intermittent or continuous in nature. Researchers agree that intermittent noise produces less TTS and therefore less cochlear damage than exposure to a continuous noise of equal sound energy (Quaranta, et al., 1998). Recently, the necessary decibel level of the “quiet periods” within the intermittent noise needed for humans to benefit from that type of noise, relative to steady-state noise, has been investigated. Researchers have learned that the periods of quiet do not need to be entirely devoid of sound; however, the sound during the “quiet periods” must be below a determined noise level to be beneficial. The amount of TTS induced from intermittent noise can be as little as half the amount that would have been induced from a continuous noise. Regardless of the type of noise, there is increased susceptibility to TTS as the frequency of the noise increases, with high frequency noises producing the most TTS (Quaranta, et al., 1998).

Since the advent of audiology in the 1920s, hearing has been tested using pure-tone audiometry. Pure-tone stimuli, presented through air- or bone-conduction modes, permit assessment of an individual’s ability to hear. However, when used in isolation, pure-tone testing can be ambiguous regarding the exact location of a hearing loss. Outer hair cells, located in the cochlea, are finely tuned to a specific frequency. However, when a hearing loss occurs and regions of hair cells do not function properly, neighboring hair cells might compensate by responding to additional frequencies near their resonant frequency, thereby masking the damage. As a result of this compensation, the individual might perceive speech as distorted, but might not have any hearing loss as measured by pure-tone thresholds. Therefore, another test, in addition to pure tone testing, was required to detect damage to these cochlear hair cells.

Otoacoustic emissions (OAEs) were first discovered in 1978 by Dr. David Kemp (Kemp, 1978). OAEs are low-level sounds present in the ear canal that are generally thought to result from motile action of the outer hair cells during their processing of stimuli. During transduction of the incoming stimuli, energy is generated by the outer hair cells, which then travels back toward the periphery, through the middle and outer ears. OAEs can be recorded in the ear canal and are used to determine the presence of healthy, functioning outer hair cells. The caveat with OAE testing is that a healthy outer ear and middle ear are needed to record the emissions effectively.

There are two general classes of otoacoustic emissions. The first are spontaneous otoacoustic emissions (SOAEs) that are present without any stimuli. However, these are of limited clinical use because they are not present in all healthy, normal hearing ears. The second class is evoked otoacoustic emissions (EOAE). This class has many different types, which are elicited using different types of stimuli. EOAEs can be obtained using clicks or tonebursts (click-evoked or tone-evoked otoacoustic emissions - TEOAEs) or two distinct tones presented simultaneously that generate a distortion product (distortion product otoacoustic emissions - DPOAEs). TEOAEs are useful for screening purposes and detecting the functioning of outer hair cells in specific frequency regions.

In contrast, DPOAEs, measured using two distinct tones (f1 and f2 with f2>f1 and f2/f1 typically equal 1.2), are useful for determining outer hair cell function at the specific frequency of the f2 tone. The non-linear characteristics of a normal cochlea facilitate the interaction of the two tones on the basilar membrane, which results in the generation of other tones, one of which can be recorded at the frequency 2f1-f2. The level of this emission is recorded and compared to establish normative values to determine the status of outer hair cell functioning (Sutton, Lonsbury-Martin, Martin, & Whitehead, 1994).

While OAEs are useful for indirectly determining outer hair cell function, a test battery that includes multiple types of measures should still be used (Attias, Bresloff, Reshef, Horowitz, & Furman, 1998). Each component of the audiological test battery can provide direct or indirect information about different regions of the auditory system (outer ear, middle ear, inner ear, or central auditory nervous system) and assess each region's functioning using behavioral methods or objective measures. Interpreting the combination of all of the results allows the professional to understand any abnormalities that may be present in a patient's auditory system.

One issue of relevance to the effects of noise exposure on the hearing of musicians is "toughening of the ear." Researchers have investigated if pre-exposing ears to a non-damaging, low-level sound protects the ears from a later, potentially damaging sound. Studies have shown that participants who are pre-exposed to low-level noise are less susceptible to TTS from later noises at damaging noise levels (White, Boettcher, Miles, & Gratten, 1998). However, this is only successful if the quiet and loud sounds are in similar frequency regions. If the sounds are in different frequency regions, the "toughening" could have the opposite effect and cause additional, unexpected hearing loss.

Individuals who work with machinery, hunt, or attend many rock concerts in their leisure time place themselves at risk for a hearing loss from noise exposure. Musicians and band directors, whether involved professionally or for enjoyment, are exposed to long hours of loud noise while practicing, teaching or performing (Cutietta, Millin, & Royse, 1988; Harding & Owens, n.d.). Their work might take place indoors in reverberant rooms, in crowded orchestra "pits," or in large auditoriums. Even musicians and band directors who practice or perform in outdoor venues are exposed to damaging noise levels from the instruments. For all these reasons, musicians are at risk of developing TTS.

There have not been any studies conducted that directly examine alterations in cochlear function following noise exposure among marching band musicians. The multitude of sophisticated audiological tests currently available should permit assessment of subtle changes in cochlear function following exposure to marching band music among these musicians. A significant finding could encourage them to utilize hearing protection, such as specially designed earplugs that attenuate damaging levels of sounds while retaining the spectrum of the music. The purpose of the current investigation is to evaluate temporary changes in the hearing and/or cochlear function among college marching band members, following band practice.

Chapter 2: Literature Review

Noise Qualities Influencing Temporary Threshold Shift

There are many factors that influence the magnitude of TTS. The exposure time and the level of the stimuli are important factors determining the amount of TTS. Noises vary in their spectrum, from narrow-band noises spanning a few frequencies to broadband noises covering many frequency regions. The differences in the noise spectra affect the amount of TTS. Noises can be continuous or intermittent sounds, with periods of quiet during the loud noise that allow time for hair cell repair.

Mills, Gilbert and Adkins (1979) demonstrated the growth of TTS with college students exposed to one octave bandwidth noises for 16-24 hours. They found that stimuli between 75-88 dB SPL caused an almost linear increase in the amount of TTS until a maximum level of TTS was reached by 1-16 hours of exposure (mode = 8 hours), followed by a plateau or decrease in the amount of hearing loss sustained (Mills, et al., 1979). A noise above 120 dB SPL has been found to result in a non-linear growth of TTS (Davis, Morgan, Hawkins, Galambos & Smith, 1950).

In addition to the exposure time and the level of the stimulus, TTS is dependent on the spectrum of the stimulus. A broadband noise causes TTS at the 3000-5000 Hz region of the cochlea, with the greatest amount of shift at 4000 Hz, where the typical audiometric noise notch is found (McBride & Williams, 2001). Cochlear vulnerability is partly due to the inability of the naturally occurring acoustic reflex to protect the ear at frequencies above 2000 Hz. However, a very brief, intense sound, such as a gun shot, regardless of its frequency, will cause a TTS, as the acoustic reflex does not have time to activate before the damage to the ear occurs (Johansson, Kylin & Langfy, 1967).

Depending on the level and frequency of the stimulus, the TTS will affect different locations of the cochlea. TTS will be restricted to a narrow section of the organ of Corti in response to a moderate level pure-tone stimulus or narrow band noise. A loud sound produces a TTS shifted towards the high-frequency region of the human cochlea, affecting the hair cells one-half an octave above the center frequency of the incoming stimuli (Engdahl & Kemp, 1996; Mills, et al., 1979; Yamamoto, Takagi, Shoji, & Yoneda, 1970). However, Mills, Gilbert and Adkins (1979) found that threshold shifts in response to a narrow band noise centered at 4000 Hz were located within the same octave band as the noise.

A stimulus with brief moments of quiet, characteristic of intermittent noise, provides some relief for the ear. Intermittent noise exposure, that is, exposure to noises with periods of effective quiet, are less damaging to the human cochlea and cause less threshold shift than continuous noise (Clark, Bohne, & Boettcher, 1987; Patuzzi, 1998; Rintelmann, et al., 1972). Intermittent noise has been shown to reduce the amount of TTS by up to 30% (Smitley & Rintelmann, 1971). This reduction in the amount of threshold shift can be seen particularly at frequencies between 2000-8000 Hz, where the naturally occurring acoustic reflex does not protect the ear. However, many of the studies on this topic have been flawed or limited in their participant sample. For example, Patuzzi (1998) performed his study using himself as the sole subject, and Rintelmann, Lindberg and Smitley (1972) researched only female college students. The reason why individuals do not experience an equivalent amount of TTS when exposed to intermittent noise compared to continuous noise for the same amount of time at an equivalent noise level is still under investigation (Pourbakht and Yamasoba, 2003).

In summary, the amount of TTS can increase for up to 16 hours during or post-exposure to damaging noise levels. The spectrum of the noise affects the location of damage in the organ of Corti, and the naturally occurring acoustic reflex protects the ear from the effects of the damaging noise in a limited frequency range. Intermittent noise provides rest for the hair cells and therefore has been shown to cause less TTS than continuous noise. Marching band practice includes periods of quiet; however, it is unclear if those brief interludes are sufficient to protect cochlear function.

Mechanisms of TTS

While many investigators have sought to uncover the mechanisms that lead to TTS or PTS, a definitive answer is still lacking. Some researchers' hypotheses focus on the physical properties of the hair cells and the stereocilia, some center on the chemical changes that occur within the hair cell, while others' hypotheses are a combination of both factors. Researchers who believe that PTS is caused by cell death are not in agreement as to which cells die: the hair cells or the afferent neurons that carry information from the hair cells to the next level of the central auditory nervous system (Henry & Mulroy, 1995; Patuzzi, 1998).

Patuzzi (1998), who investigated TTS and the recovery pattern, states that the hearing loss might be dependent on the duration and level of the hazardous noise. During the resultant temporary hearing loss, the tallest hair cells detach from the tectorial membrane, a thin sheath located above the hair cells, and there is a change in the tip links, which connect the stereocilia on a hair cell or across outer hair cells or inner hair cells. The hair cells then respond in an atypical, linear fashion to incoming stimuli and are unable to transmit the exact frequencies of the stimuli, causing a broader frequency response on the basilar membrane. It is hypothesized that while the stimulus is on, there is also a temporary disturbance in communication between the inner hair cells of the cochlea and the afferent neurons with which they communicate (Patuzzi, 1998).

Hu, Guo, Wang, Henderson and Jiang (2000) studied noise-induced cell death in adult guinea pigs. They exposed three groups of guinea pigs to narrow-band noise centered at 4000 Hz (either at 110, 115 or 120 dB SPL) for four hours; one additional group of guinea pigs was kept out of the noise to act as the control group. Within each group, the animals were euthanized three hours, three days or 14 days following the noise exposure. The nuclei of the hair cells were stained to study cell death during the post-noise exposure period. The group that was sacrificed three hours post-noise exposure had outer hair cells that were in disarray; their shape, size and their location relative to the other hair cells was abnormal, and they were missing nuclei. The groups that were studied at three and 14 days post-noise exposure were found to have hair cells with swollen nuclei, especially in the region apical to that tuned to the frequency of the noise. Additionally, in some guinea pigs, there were chromatin fragments in the outer hair cells and there was shrinkage of the nuclei. The results from this study suggest that the cellular changes that occurred in the noise- exposed guinea pigs stemmed from multiple biological processes.

The chemical changes that occur in the hair cells can also lead to cell death, called apoptosis. Boettcher, Henderson, Gratton, Danielson and Byrne (1987) describe how noise-induced physical changes in the cells, such as a break in the cell's membrane, can allow chemicals already present in a healthy cochlea (endolymph and perilymph) to mix with each other and cause the cell to die. Henderson, McFadden, Liu, Hight and

Zheng (1999) concluded that reactive oxygen species, including free radicals, are found in ears that have been exposed to damaging levels of noise. The reactive oxygen species have a role in cell death; however, naturally occurring antioxidants, such as glutathione (GSH) can protect cells from the damage caused by free radicals. The researchers stimulated the production of GSH in one group of noise-exposed chinchillas, causing their cells to produce a high amount of the antioxidant. The control group of chinchillas that was not treated to produce extra GSH, but was still exposed to the same damaging levels of noise, sustained more hearing loss and more hair cell death than the experimental group (Henderson, et al., 1999).

In summary, mechanical, physical and chemical changes in cochlear hair cells cause noise-induced hearing loss. Detachment of the cilia of the outer hair cells, both from the tectorial membrane and from their corresponding inner hair cells, alters the hair cell response to incoming stimuli. The outer hair cells change in shape and size, and their orderly configuration is destroyed and the nuclei within the cells swell. When the membranes that surround the cells break, chemicals that were previously separated within the cochlea mix and poison the cells. Free radicals are released during excessive noise exposure. The amount of free radicals overwhelms the amount of antioxidants produced to fight the free radicals and therefore cell death occurs. Although these effects of noise exposure have been demonstrated only in laboratory animals, it is assumed that similar mechanisms occur in humans, as well. It is possible that band members experience at least some of these changes in the cochlea following band practice.

Recovery from TTS

After the intense noise concludes, the cochlea begins its recovery. The different attributes of the noise, such as spectrum and exposure time, shape the recovery process. Regardless of whether the offending noise is continuous or intermittent, the recovery process is similar (Rintelmann, et al., 1972; Smitley, et al., 1971). After the stimulus concludes, there is a rapid, one-minute recovery period. Immediately after the conclusion of the sound, the communication between the inner hair cells and the afferent neurons is restored and therefore appears as a rapid recovery of the TTS (Patuzzi, 1998). During the second minute post-exposure, the maximum amount of TTS re-occurs (Rintelmann, et al., 1972). For this reason, many studies report a TTS_2 value.

Within a 24-hour period, one investigation found that college students' thresholds returned to within 5 dB of their pre-exposure threshold (Mills, et al., 1979). Other studies have shown that recovery can take up to two and a half days (Patuzzi, 1998, Plinkert, Hemmert, Wagner, Just, & Zenner, 1999).

As previously stated, recovery from TTS can take varying amounts of time, occasionally up to a few days. This can be problematic in cases of repeated noise exposure, either professionally or during leisure time. The cochlea might not be able to make a full recovery before the next exposure, causing additional damage to the already vulnerable, damaged hair cells.

Pure-Tone Thresholds and Hearing Loss

Current audiological test batteries include a multitude of objective and subjective tests to assess hair cell functioning indirectly and determine hearing sensitivity.

Interpretation of the test battery provides professionals with detailed information about an individual's auditory system.

During the early years of audiology, the only measure used to infer the extent of cochlear hair cell damage following intense noise exposure was pure-tone thresholds. While some investigations have shown that pure-tone thresholds are sensitive to cochlear damage, many report that OAEs are more sensitive to detecting cochlear damage (Attias, Bresloff, Reshef, Horowitz, & Furman, 1998; Konopka, Zalewski, & Pietkiewicz, 2001). Outer hair cell damage can occur before the TTS is apparent in behavioral tests, such as pure tone audiometry (Konopka, et al., 2001; Plinkert, et al., 1999; Sliwinska-Kowalska, Kotylo, & Hendler, 1999; Sutton, Lonsbury-Martin, Martin, & Whitehead, 1994). Konopka et al. (2001) recorded the hearing sensitivity and cochlear function of 10 male soldiers who were participating in target practice for their military service. The researchers measured the soldiers' pure-tone thresholds, TEOAEs and DPOAEs before shooting practice and 10 minutes after practice. The soldiers' pure-tone thresholds were not altered as a result of shooting practice for any frequency tested (250-8000 Hz). However, there was a change in the TEOAEs and the DPOAEs after practice, and many of these changes were statistically significant. The pure-tone thresholds for 250-3000 Hz pre- and post-practice were in the normal-hearing range; however, there was still a noticeable decrease in the OAE measurements at those frequencies. The authors concluded that the pure-tone measurements were not sensitive enough to detect first signs of cochlear damage. However, there were some limitations in the study's methodology. The audiometric testing was not conducted in a sound-attenuating booth, the duration of shooting practice was unclear, the participants' proximity to other soldiers' guns was unspecified, and the location of the practice (indoors versus outdoors) was not provided. However, this study still demonstrates that noise exposure can produce significant changes in OAEs without affecting pure-tone thresholds.

Ultra-high frequency testing has been useful for specific audiologic purposes, such as ototoxicity monitoring for patients who take medication that could damage their cochleas. Ultra-high frequency audiometry (9000 Hz-20000 Hz) has also been used for detecting early signs of noise-induced hearing loss in musicians (Johnson, Sherman, Aldridge, & Lorraine, 1986). However, studies have demonstrated that both musicians and non-musicians experienced a hearing loss in the ultra-high frequency range, attributable solely to age (Johnson, et al., 1986).

Johnson et al. (1986) compared 60 members of the Minnesota Orchestra to 30 non-musicians of the same age range, who reported no history of noise exposure. The investigators tested all of the participants' hearing sensitivity, from 250 Hz to 20,000 Hz. However, they reported that there was no standardized calibration of the high frequency audiometers. They found no significant difference between the two groups' thresholds in any frequency. The investigators concluded that there was no difference between the musicians and the non-musicians; rather, the most important factor in testing hearing sensitivity in the ultra-high frequency range was the age of the participants (Johnson, et al, 1986).

Another investigation found that soldiers exposed to a brief, intense noise who had their TTS assessed using ultra-high frequency audiometry recovered after 12 minutes of the onset of the noise (Plinkert, et al., 1999). Although this isolated study showed the usefulness of high frequency audiometry in detecting early cochlear damage attributed to noise, it may not be feasible to use this measure due to the limited time window required.

Pure-tone threshold testing, while an important component of the audiological test battery, may not be sufficiently sensitive to cochlear functioning to be used in isolation for purposes of assessing the effects of noise on auditory function. The subtle, first signs of outer hair cell damage resulting from excessive noise exposure might not be detected using pure-tone testing, in the absence of a noticeable TTS. It is important to recognize the beginnings of hair cell damage to be able to prevent further damage and subsequent hearing loss. Ultra-high frequency audiometry is useful in some facets of audiology, but does not appear to be useful for detecting TTS due to the influence of the aging process on high frequency thresholds, and the rapid recovery time of TTS in the ultra-high frequencies.

Otoacoustic Emissions and Cochlear Functioning

Otoacousic emissions (OAEs), which indirectly measure outer hair cell functioning, are sensitive to the first signs of outer hair cell damage (Olszewski, Milonski, Sulkowski, Majak, & Olszewski, 2005; Sliwinska-Kowalska, et al., 1999; Vedantam & Musiek, 1991; Zhao & Stephens, 1999). The tests that measure OAEs are widely accepted, stable, quick and objective methods to measure cochlear function (Olszewski, et al., 2005). OAEs currently appear to be the best way to detect the onset of outer hair cell damage, before a hearing loss develops (Namyslowski, Morawski, Trybalska, & Urbaniec, 1998; Olszewski, et al., 2005). There are two types of OAEs that are most often used to monitor cochlear damage: distortion product otoacoustic emissions (DPOAEs) and transient evoked otoacoustic emissions (TEOAEs).

DPOAEs are generated by outer hair cells following the presentation of two tones simultaneously to the ear. They are reduced in amplitude in noise-exposed ears, even in the absence of reduced pure-tone thresholds (Attias, et al., 1998). However, there is a controversy regarding the correlation between the amount of amplitude reduction and the amount of TTS (Attias, et al., 1998; Engdahl & Kemp, 1996; Olszewski, et al., 2005).

Attias and colleagues (1998) measured DPOAEs from 76 military personnel during their routine medical examination. While a number of the participants had normal hearing sensitivity when measured with pure-tone audiometry, others had varying degrees of a permanent hearing loss from noise exposure. Those with normal hearing were further separated into participants with previous noise exposure and those without noise exposure. DPOAEs were tested with the levels of f1 and f2 held constant at 70 dB SPL and 2f1-f2 was measured. The emissions were tested at f2 frequencies of 1000, 2000, 3000, 4000 and 6000 Hz. Results indicated that among participants in the normal hearing group, those previously exposed to noise had DPOAEs that were significantly reduced in amplitude, as compared to normal amplitude DPOAEs in the non-exposed, normal hearing ears. The participants who demonstrated a decrease in hearing sensitivity also had DPOAEs that were decreased in amplitude correlating with the amount of their hearing loss. The investigators concluded that there is a relationship between the amount of hearing loss and the decrease in amplitude of the DPOAE. They stressed the ability of the DPOAEs to indicate a reduction in cochlear outer hair cell functioning, even in the presence of normal pure-tone thresholds.

Engdahl and Kemp (1996) investigated the components of the DPOAE measurements, including the amplitude and fine structure, following intense noise exposure. DPOAEs were measured for nine healthy, normal hearing participants, using varying decibel levels of the f1 and f2 tones. After this first measurement, the participants were then exposed to a narrow-band noise, centered at 2000 Hz, at 102 dB SPL. DPOAEs were recorded again within the first 33 minutes post-exposure. The second DPOAE measurements revealed lower amplitudes, with the greatest reduction observed at half an octave above the noise, especially in the 3000-5000 Hz region. DPOAEs measured with lower levels of the primary tones were maximally affected. The maximum-to-minimum ratio of the DPOAE shape (the measurement from peak to peak of the micro-structure) decreased and the micro-structure of the OAEs shifted towards the lower frequencies post-noise exposure.

DPOAE data can indicate the frequency range where pure-tone thresholds might be affected. Investigations using relatively low level primary tones (less than 60 dB SPL) have shown that changes following noise exposure affect specific frequency regions in the DPOAE response, alerting researchers to specific cochlear regions at risk for damage. (Attias, et al., 1998; Engdahl & Kemp, 1996). DPOAEs are found to be the most reduced at one-half an octave above the offending noise (Engdahl & Kemp, 1996). While some researchers rely on objective DPOAE amplitudes instead of behavioral pure-tone thresholds to record the first damaging effects of noise on the cochlea, other researchers caution that occasionally normally functioning ears might have absent emissions. Therefore, this test, as with any audiometric test, should not be used in isolation (Attias, et al., 1998; Namyslowski, et al., 1998; Seixas, et al., 2004).

TEOAEs, like DPOAEs, have been measured from 90-100% of normal hearing ears (Vadantam & Musiek, 1991). TEOAEs, like other types of OAEs, appear to be more sensitive to the effects of early cochlear damage than traditional pure tone testing (Attias, 1995; Plinkert, et al., 1999). Investigators found altered TEOAE responses, even in the absence of a pure-tone hearing loss (Konopka, et al., 2001). Plinkert et al. (1999) hypothesized that other areas of the cochlea may be able to compensate for a location with damaged outer hair cells so that noise damage is not observable with only pure tone audiometry. In their study of 46 soldiers, they found that TEOAE levels were more sensitive to noise-induced changes in auditory functioning than DPOAE amplitudes. DPOAE measurements might be less sensitive to outer hair cell changes because of the complex mechanisms required to generate the distortion product. The outer hair cells must create a distortion-product from two incoming stimuli (f1 and f2) versus the TEOAEs, which simply emit a reverse transmission sound stemming from one incoming click.

Sliwinska-Kowalska, Kotylo and Hendler (1999) tested 32 metal-factory, male workers to measure the effects of noise exposure on their pure-tone thresholds and TEOAE emission levels (1000, 2000, 3000, 4000 and 5000 Hz). At the workplace, employees were exposed to six hours of noise at 85-97 dB(A), each day. No hearing protection was used. Statistical analyses revealed a significant TTS after the noise exposure, especially at 6000 Hz. TEOAEs were very sensitive to the effects of noise-exposure on the auditory system. However, a correlation between the post-noise pure-tone thresholds and the TEOAE amplitude was not observed. The investigators concluded that TEOAEs are an objective, repeatable test that is sensitive to the effects of noise damage on cochlear function and should be used in hearing conservation programs.

Otoacoustic emissions are an important component of the audiological test battery. The test focuses on the outer hair cells and provides early information about noise-damaged hair cells that could lead to a hearing loss. DPOAEs and TEOAEs are reduced in amplitude in noise-exposed ears (Engdahl & Kemp, 1996; Konopka, et al., 2001). Emissions in certain frequency regions are more affected than those in other frequency regions following noise exposure, allowing insight regarding the cochlear region affected by the noise. Presently, it is unknown whether TEOAEs or DPOAEs are more sensitive for revealing early effects of noise exposure or whether the two types of OAEs are equally sensitive.

Ear Toughening

Researchers are investigating the prevention of noise-induced cochlear damage using low-level noise exposure. They have assessed the effectiveness of different frequencies, decibel levels and sound spectra to monitor cochlear response. They have found that the ear is capable of being "toughened" against intense noises using specific types and levels of preceding stimuli.

Exposing individuals to low-level sounds for a number of days before exposure to a loud sound has the ability to decrease the amount of TTS, as long as both sounds occur in the same frequency region (Attanasio, Quaranta, & Sallustio, 1998; Boettcher, 1993). This has been demonstrated in animals, such as gerbils, who have been a good model for investigating the effects of noise-induced hearing loss and recovery from exposure (White, Boettcher, Miles, & Gratton, 1998). Boettcher (1993) raised six Mongolian gerbils in an environment with 35-40 dB(A) noise for six to 12 months. The gerbils were then exposed to an 80 dB SPL octave band of noise centered at 4000 Hz for six hours each day for 12 days. During the first day of exposure, immediately following the six hour exposure, hearing sensitivity was decreased 20-50 dB between 4000-8000 Hz and up to 10 dB at 1000-2000 Hz and 16,000 Hz. After the 12th day of noise exposure, the gerbils only had 10 dB or less hearing loss at all frequencies. The gerbils demonstrated a nearly 40 dB improvement in their hearing within the 12 consecutive days of noise exposure (Boettcher, 1993). Additionally, chinchillas demonstrated a reduction in the amount of TTS sustained after multiple days of exposure to intermittent or continuous loud signals (Hamernik, Qui, & Davis, 2003).

Researchers are beginning to understand how to assist the natural components of the ear in the prevention of hearing loss. Studies show that the ear is able to be "toughened" using stimuli that are within the same frequency range. This line of research suggests that musicians' ears may not demonstrate as much TTS as predicted due to their history of noise exposure that has "toughened" their ears. More research is needed to fully understand the scope of these findings.

Additional Factors in TTS

While TTS is highly dependent on the spectrum, duration and level of the stimuli, there are other factors that influence the amount of TTS as well. Overall good health can help protect the cochlea from damage due to noise exposure. Medications and lifestyle habits can contribute as well. There are also genetically determined factors that influence an individual's susceptibility factors (Barrenas & Hellstrom, 1996).

Smoking lessens the amount of TTS, however this benefit is likely attributable to the inhalation of carbon monoxide (Dengerink, Trueblood, & Dengerink, 1984; Dengerink, Lindgren, Axelsson, & Dengerink, 1987; Dengerink, Lindgren, & Axelsson, 1992). Females taking oral contraception have an increase in susceptibility to TTS (Swanson & Dengerink, 1998). Individuals who are physically fit and find appropriate ways to lessen their stress are generally less susceptible to TTS (Horner, Giraudet, Lucciano, & Cazals, 2001; Kolkhorst, et al., 1998).

Genetically determined factors could play a role in TTS as well. Eye color has an effect on amount of TTS. Brown eyed people develop less TTS than their blue-eyed counterparts (Barrenas & Lindgren, 1991); however, when attempting to toughen the ear for future noise exposure, investigators found that blue-eyed participants were more receptive to the toughening effects and later developed less TTS than brown-eyed individuals (Barrenas & Hellstrom, 1996).

There are some ways individuals can assist their ears in resisting cochlear damage. Staying healthy and monitoring the possible side effects of medication can play a role in cochlear damage. However, there are other factors, such as eye color, that play a role in susceptibility to cochlear damage that an individual cannot control.

Musicians and Hearing Loss

Previous investigations have exposed the dangers of participating in a classical orchestra, a Broadway show orchestra, or playing in a rock band (Johnson, et al., 1986; Kahari, et al., 2003) The sound levels experienced by musicians often exceed recommended safe listening levels, and hearing loss has been noted after practices and performances (Keefe, n.d.). Keefe (n.d.) researched the sound levels of college marching bands and reported the hazardous levels their music produces. However, there have not been studies to test the musicians themselves who participate in such marching bands.

Taking into account individual factors, musicians as a group must be cautious of sound levels to which they are exposed on a regular basis. While one study on orchestras and hearing loss did not find any difference in hearing between the musicians and the non-musician control group, most studies have found hearing loss in their sample of musicians (Johnson, et al., 1986; Ostri, Eller, Dahlin, & Skylv, 1989).

Studies have shown a greater likelihood for hearing loss among college-level jazz musicians versus non-musicians, especially those who play wind instruments (Henoch & Chesky, 2000). Henoch and Chesky (2000) measured sound levels during a 50-minute class period for three days. Dosimeters measured the sound pressure level for five musicians during each class period for a total of 15 measurements. The measurements revealed different sound levels in the different sections of the jazz band. The lead trombone and saxophone players listened to 99 dB(A) during the 50-minute class session. While this decibel level is safe for the 50 minute class period, according to OSHA, the level exceeds safe decibel levels when extended to three-hour or eight-hour practices or performances (Henoch & Chesky, 2000). The second trombone and saxophone players experienced a slightly lower, but still hazardous, noise level than the lead players (96.5-98.5 dB(A)). The wind instrument section was louder than the string bass and percussion sections, however the latter sections still exceeded the recommended noise levels. While these results can be generalized to musicians within each section, the room acoustics and placement of each type of instrument in relationship to the other sections was not standardized. However, these findings do suggest that musicians are exposed to very high levels of sound within a short period of time. This noise exposure, which is loud enough to cause cochlear damage and hearing loss, does not account for other activities that musicians might engage in during their day, such as working around machinery or teaching music lessons, which would expose them to additional potentially damaging noise.

One study of rock and jazz musicians found that hearing loss was prevalent among musicians and that most demonstrated the characteristic "notched" pattern of hearing loss (Kahari, Zachau, Sandsjo, Eklof, & Moller, 2003). Male musicians demonstrated more hearing loss and ringing in the ears than the women in their cohort. The investigators tested the hearing sensitivity of 139 musicians using pure-tone audiometry. In addition, all participants filled out a questionnaire regarding hearing loss, tinnitus and hyperacusis (sensitivity to loud sounds). Participants were tested using standard pure-tone, air conduction testing. However, they were only required to be out of noise for eight hours before their hearing test, which might not have allowed hearing to be restored from any prior TTS. The investigators found better hearing sensitivity from 3000-6000 Hz for the female musicians, as compared to the male musicians. The females who demonstrated a hearing loss revealed bilaterally symmetrical hearing losses, while their male counterparts had worse hearing sensitivity in their left ears at 250-4000 Hz; however, at 1000 Hz, the men had poorer hearing thresholds for their right ear. Overall, the researchers found that 74% of the participants had a hearing loss, which was similar to results from other comparable studies (Kahari, et al., 2003). However, these studies are not fully applicable to marching band music, as rock music, for example, is amplified, electric music and marching band music is unamplified, acoustical music. Therefore, the marching band must play their music at full-on strength at all times, as opposed to amplified music played by jazz or orchestra musicians, which can be played quieter because it is amplified for the audience.

Although band directors are not playing the instruments, they are exposed to the same damaging noise levels as musicians. The sound levels in school band rooms exceed the OSHA maximum permissible exposure levels, and have been recorded to be as high as 112 dB (A) (Harding & Owens, n.d.). Band directors typically work in reverberant, small, cramped rooms, with low ceilings and minimal sound absorbing material (Harding & Owen, n.d.). They might direct multiple types of bands and orchestras during the day, and teach music lessons in the evening, increasing the time spent in such settings.

Typical noise-notch audiometric patterns have been found for as many as 66% of school band directors (Cutietta, et al., 1989). While many band directors were found to have a mild hearing loss, the concern is that repeated exposure over the course of the band leader's professional life will lead to a significant hearing loss. Even mild hearing losses can be associated with reduced speech clarity and altered music perception. Although some studies have shown that the noise level in a band room might be quieter than sound levels at a rock concert, band directors tend to have longer careers than rock stars (Pang-Ching, 1982). Therefore, investigations that focus on damage to musicians' auditory function are applicable to the band directors, as well.

Marching bands present a different type of problem. Although they practice and perform outdoors, the proximity of the musicians to each other and the loud volume at which they must play their instruments to be heard in the football stands have the potential to cause a measurable noise-induced hearing loss. College-level marching bands often practice four to five times a week, for at least two hours each time and also perform for approximately four hours a week. These hours of exposure are in addition to exposure to high noise levels from music classes, private practice time, teaching time, or other bands with which they practice. The mix of brass, percussion, and woodwind instruments creates a broad frequency range of the music. This increases the chance for a TTS in multiple frequency regions along the cochlea. The sound pressure level measured for the marching band peaks at 144 dB SPL, which far exceeds any published noise criteria for safe exposure levels, even for brief periods of time, placing band members at a high risk for a noise-induced hearing loss (Keefe, n.d.). While a previous investigation measured sound levels in college marching bands, there has not been any research examining the cochlear function or hearing loss experienced by the college marching band musicians themselves.

Summary of Literature

Intense noise exposure can cause a TTS, which can continue to worsen for up to 16 hours. Intermittent noise with periods of effective quiet can help to reduce the effects of the damaging noise, as compared to continuous noise of the same sound level. Prior exposure to low levels of noise can reduce the effects of exposure to intense noise. In general, exposure to damaging noise causes external physical changes in the hair cells, such as destroying their connections to surrounding hair cells and the overlying tectorial membrane; however, chemical changes within each cell occur and cause programmed cell death. Studies with antioxidants have shown the limited yet protective effect they have in combating free radicals that are released during intense noise exposure. Recovery from noise-induced TTS occurs over many hours or days, which leaves the hair cells vulnerable to additional damage from loud sounds.

TTS can be measured using the pure tone test of hearing sensitivity. However, more sophisticated tests to measure the functioning of outer hair cells indirectly include measurement of DPOAEs and TEOAEs. Both types of OAEs are reduced after intense noise exposure and this can be apparent before a change in hearing sensitivity is measurable. Therefore, DPOAEs and TEOAEs appear to be effective measures of noise-induced cochlear damage.

It is estimated that 50% of musicians have hearing loss. The presumption is that most cases of PTS are preceded by TTS; however, few studies have investigated TTS among band musicians. Additionally, OAEs are thought to provide an early indication of cochlear changes that result from noise exposure. No studies have examined changes in OAEs among band members following band practice. The principal purpose of this research is to study damages in cochlear function and/or hearing sensitivity of college marching band members before and after their two-hour practices. The secondary purpose is to monitor the recovery, if any damage should be present, during the following day.

Chapter 3: Experimental Questions and Hypotheses

The current investigation explores the following questions:

1. Is there a change in hearing sensitivity, in either ear, as measured by air conduction pure-tone thresholds, from before band practice to after band practice for the selected high frequencies of 2000, 3000, 4000, 6000, and 8000 Hz?
2. Is there a change in cochlear function, in either ear, as measured by the change in DPOAE amplitude at selected high frequencies (3000, 4000 and 6000 Hz), from before band practice to after band practice?
3. Is there a change in cochlear function, in either ear, as measured by the change in TEOAE level in the 3500-4500 Hz band and in the overall emission level (750-4500 Hz), from before band practice to after band practice?
4. Is there a difference in the pure tone thresholds, DPOAE and TEOAE levels between the control subjects and the marching band members, over the course of the four-day experimental period?
5. For marching band members who demonstrate shifts in hearing sensitivity and/or otoacoustic emissions following noise exposure, is there evidence of recovery?

The hypothesis was that noise exposure at band practice will produce changes in outer hair cell functioning, given the high sound levels and duration of the practice (e.g., Konopka, et al., 2001). However, after band practice there was not expected to be a decrease in pure-tone, behavioral thresholds at any frequency. The rationale for this hypothesis is that the auditory system is able to compensate for small amounts of hair cell damage in signal detection measures; thus, hearing sensitivity will not be altered following the relatively brief (two hour) noise exposure (Johnson, et al., 1986). Because all participants had normal thresholds at the commencement of the investigation, all participants were expected to maintain those normal pure-tone thresholds (within a standard test-retest margin) throughout the duration of the study.

A decrease was expected in the DPOAE amplitudes at all frequencies and in the TEOAE emission levels, both in the narrowband of 3500-4500 Hz and in the broadband overall level (Sliwinska-Kowalska, et al., 1999). As noted above, the exposure to loud music during the two-hour practice sessions is hypothesized to cause damage to the outer hair cells and because the outer hair cells are the generator site for OAEs, these measures should be affected by outer hair cell damage.

However, it was hypothesized that there would be a difference between the DPOAE and TEOAE amplitudes of the control and experimental groups throughout the investigation. The OAE amplitudes were expected to decrease following band practice for marching band members. The damage to the outer hair cells caused by noise exposure was expected to affect OAE measures. This decrease in emissions for the marching band group was expected to be observed in each DPOAE frequency and the broadband and narrowband TEOAEs. It was hypothesized that the band members' decreased OAE amplitudes would recover to their pre-practice levels by the next morning, as the damage was expected to be temporary. The control group was expected to exhibit stable OAE amplitudes throughout the duration of the study.

Chapter 4: Method

Participants

Participants were between the ages of 18 and 25 years and were students at the University of Maryland, College Park. They had no known history of family hearing loss, use of ototoxic medications or frequent noise exposure greater than 80 dB (A), aside from band practice. The participants' previous noise exposure was determined by a verbal report from each participant at the eligibility test session. To be eligible for the study, a participant must have had air conduction thresholds equal to or better than 15 dB HL for all frequencies tested (250-8000 Hz) and no air-bone gaps greater than 10 dB at any frequency at the time of eligibility testing. Air-bone gaps, even in the presence of normal hearing, could indicate a problem with the conductive mechanism. All participants were required to have excellent word recognition scores (90-100%). Potential participants had normal middle ear functioning (pressure between +50 to -50 daPa, and peak admittance between 0.3-1.6 mmhos), normal acoustic reflexes for all conditions (65-100 dB HL), and negative acoustic reflex adaptation at the time of eligibility testing to be considered for the study. Reduced mobility of the middle ear system could cause an artificial decrease in otoacoustic emissions. Potential participants also had DPOAEs that were measurable above the ambient noise, as determined by the Capella otoacoustic emission system (+3 dB SNR), as well as TEOAEs that were measurable above the ambient noise, also as determined by the Capella otoacoustic emission system (+3 dB SNR).

There were two groups of participants. The experimental group was comprised of 20 members of The Mighty Sound of Maryland Marching Band. The mean age of the participants in this group was 20.3 years (range 19 -22 years). There were 10 males and 10 females in the experimental group. The average years of musical experience was 9.05 years (range 6-13 years). Additional information about the members of the experimental group can be found in Table 1. The control group was comprised of 20 college students who were not involved in any musical ensembles. The mean age of the participants in this group was 19.4 years (range 18-21). There were 6 males and 14 females included in the control group. Figure 1 presents the average pure-tone thresholds, at each frequency, of the two groups of participants at the commencement of the study. Figures 2 and 3 present the average DPOAE amplitudes and TEOAE levels at the beginning of the study. These three figures show the equivalence of the marching band and control groups at the start of the study. Eight potential experimental group members were excluded: two due to unilateral hearing loss, two due to negative middle ear pressure, three due to abnormal or absent middle ear reflexes and one due to not showing for the scheduled appointment. There were nine potential participants excluded from the control group: one due to unilateral hearing loss, three due to negative middle ear pressure, four due to abnormal or absent middle ear reflexes and one due to noise exposure greater than 80 dB (A) on a regular basis.

The selected participants were not exposed to any loud noises (other than band practices for the experimental group) for 48 hours before or during their designated four-day experimental period because such noise exposure could produce temporary threshold shifts (TTS) in hearing. Every effort was made to perform eligibility testing when potential participants were not exposed to loud noises, especially band music, for the previous 12 hours. Each eligible participant was provided with a detailed explanation

Table 1

Demographic Data for Participants in Marching Band Group

Age	Instrument Played	Years played
20	Piccolo	11
20	Mellophone	6
22	Alto Saxophone	13
22	French Horn/Mellophone	9
21	Saxophone	12
21	Saxophone	7
19	Flute	6
21	Saxophone	Unknown
19	Trumpet	10
21	Trombone	6
19	Trombone	9
19	Tuba	6
20	Percussion/Cymbals	10
20	Flute	10
20	Percussion/Cymbals	10
22	Trumpet	12
19	Piccolo	9
21	Trumpet	8
21	Trumpet	9
19	Baritone Saxophone	9

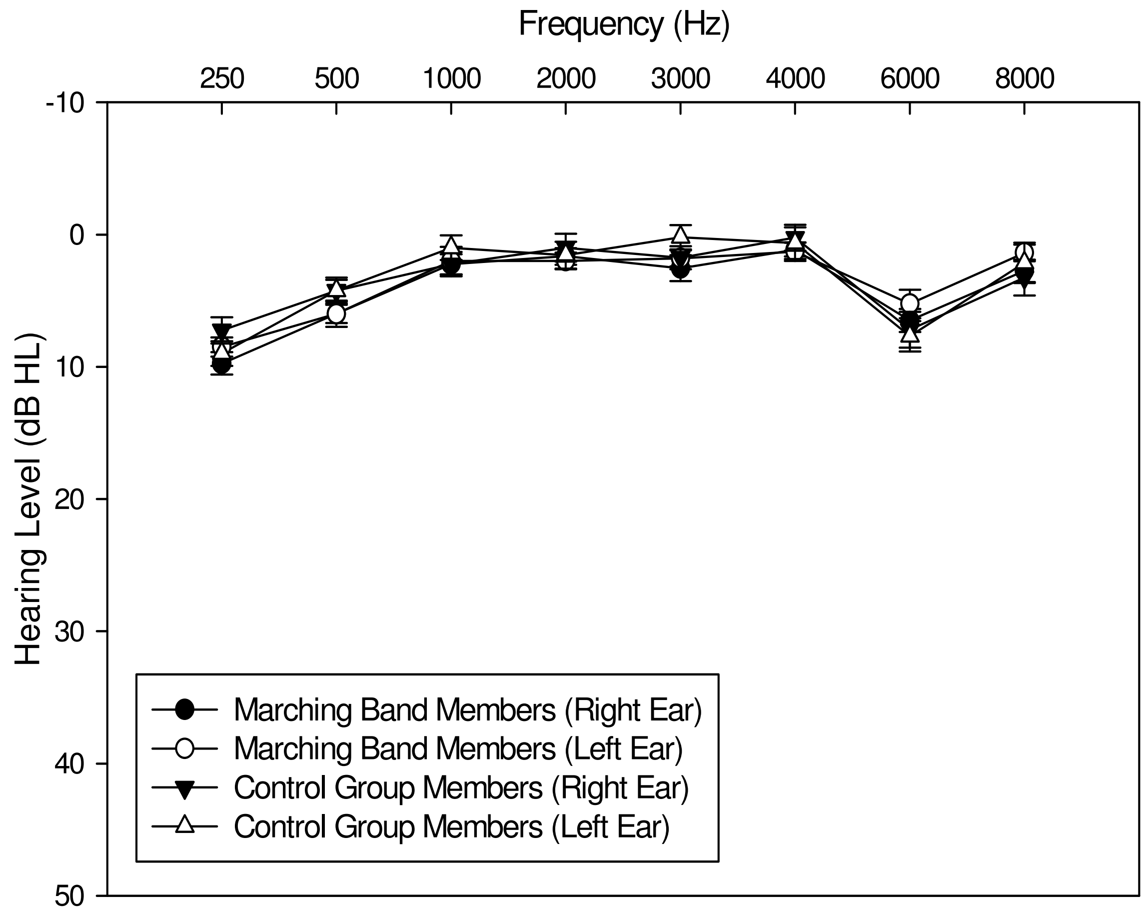

Figure 1. Average pure-tone thresholds at five frequencies in the right and left ear of marching band members and control participants at commencement of study.

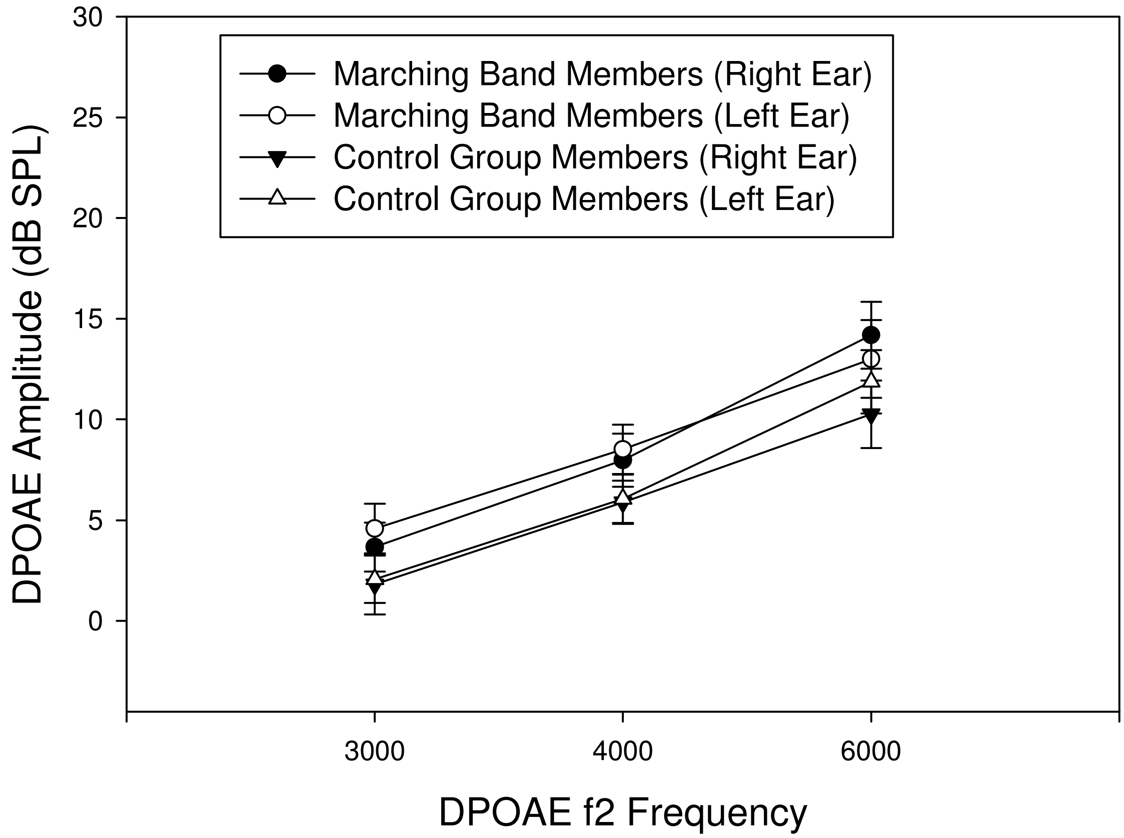

Figure 2. Average DPOAE amplitudes at selected frequencies in the right and left ears of marching band members and control participants at the commencement of the study.

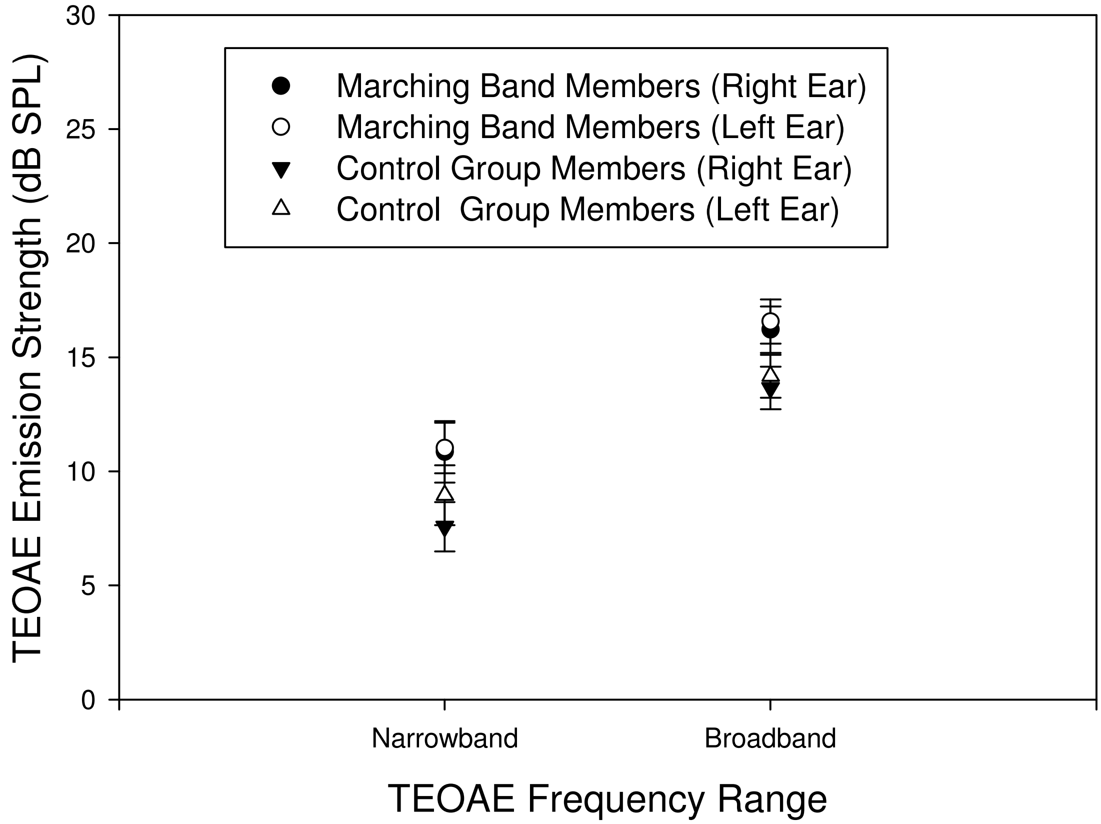

Figure 3. Average TEOAE level of marching band members and control participants at commencement of study.

and handout regarding noise levels to be avoided during the experimental time period (Appendix A).

Procedures

Preliminary Measures.

Before the study commenced, every potential participant filled out a consent form and a case history form (Consent form for band members: Appendix B; Consent form for non-band members: Appendix C; Case history form for all participants: Appendix D; Additional case history form for band members: Appendix E). Questions about eye color, race and enjoyment of their music repertoire were included on the case history. These factors may have an impact on the amount of hearing loss incurred following noise exposure (Barrenas & Lindgren, 1991; Swanson, et al., 1987). Consent and case history forms were filled out at the University of Maryland Audiology Clinic when potential participants arrived for their appointments.

Immediately following completion of the forms, each potential participant had a full audiological evaluation, using standard audiometric procedures to determine their eligibility for the study. Otoscopic evaluation was completed by visualizing both ears (using an otoscope) to ensure that the ear canal was not obstructed by cerumen, that there were no foreign bodies in the canal, and that no signs of obvious outer or middle ear pathologies.

The potential participant was brought into a sound-attenuated booth and supra-aural headphones were placed on the participant. If collapsing canals were suspected, or a conductive hearing loss was noted, insert earphones were used. Speech and pure-tone testing was conducted through a calibrated audiometer (ANSI, 2004).

First, speech recognition threshold testing and suprathreshold word recognition testing were conducted. Pure-tone detection thresholds were measured next. Thresholds were measured at 250, 500, 750, 1000, 2000, 3000, 4000, 6000 and 8000 Hz for air conduction for the right and left ears and at 250, 500, 750, 1000, 2000, 3000 and 4000 Hz for unmasked bone conduction. All pure-tone testing was completed using 1 dB steps. Acoustic immittance measures were conducted to assess the integrity of their middle ear system. Tympanometry was conducted at 226 Hz, at a level of 85 dB SPL, with pressure placed in the external ear canal from +200 to -200 daPa. Contralateral and ipsilatateral acoustic reflex thresholds were tested at 500, 1000, and 2000 Hz and acoustic reflex adaptation was tested at 500 and 1000 Hz. All immitance testing was completed using the Grason-Stadler (GSI) Middle Ear Analyzer 33.

The functioning of the outer hair cells in the cochlea of all participants was assessed with TEOAEs and DPOAEs. The OAE system (the CAPELLA Cochlear Emissions Analyzer) checked the probe fit and stimulus level in the ear canal. TEOAE testing was conducted by collecting subsets of four clicks in the nonlinear mode (3 of one polarity and 1 of opposite polarity) presented at 80 dB SPL. The opposite polarity clicks allowed the stimulus artifact to be removed from the response during analysis. Each click lasted for 40 μsec and TEOAE testing concluded after 2080 sweeps. Testing was conducted in the narrowband frequency range of 3500-4500 Hz and in the broadband frequency range of 750-4500 Hz. DPOAE testing was conducted using two tones (f_1= 65 dB SPL, f_2= 55 dB SPL) separated in frequency by an f2/f1 ratio of 1.2. Testing was conducted at three frequencies (f_2=3000, 4000, 6000 Hz). The DPOAE was measured at the $2f_1$-f_2 frequency and was plotted on a graph called a DPgram (DPOAE levels as a function of the f2 frequency).

All testing during this investigation (otoscopy, pure tone detection thresholds, tympanometry, acoustic reflex thresholds and adaptation, and OAEs) was completed using sterilized or new eartips to prevent the spread of infection. Testing of both ears took a total of 1 hour to complete for each participant. Participants were notified immediately following testing if they were eligible to complete the experimental portion of the study, which occurred within three months of the eligibility testing. Participants were not paid for their involvement in the study.

Experimental Procedures: Band Members.

All band members were tested at least 4 times with additional testing if there was evidence of a change in pure-tone thresholds and/or OAEs. Testing occurred prior to two separate band practices and immediately following each of these two band practices within a four day period of time. At the commencement of the experimental period, before the first of the two designated practices or performances, the selected band members reported to the University of Maryland Audiology Clinic for a limited audiological evaluation that included the following tests measured in each ear: air conduction thresholds (2000, 3000, 4000, 6000, 8000 Hz), tympanometry, TEOAEs and DPOAEs, using the same procedures as were used for the eligibility testing. Every attempt was made to keep the insertion depth of the probe and probe size similar between testing sessions by using the same diameter probe tip and ensuring proper probe fit as designated by the OAE program, because changes in these methods have been shown to cause differences in OAE recordings. The pure tone tests were conducted in a sound-attenuated booth, while typanometry and OAEs were tested in a quiet room. The duration of the testing was approximately 20 minutes and was completed within six hours prior to the practice, with no individual practice time occurring between the time of testing and the practice with the band.

Following the pre-practice audiometric test session, the band members participated in band practice. Marching band practice at the University of Maryland occurred Monday, Tuesday and Wednesday for two hours a day. Monday and Wednesday practices were held in the late afternoon and typically occurred outdoors on the Chapel Field, located in front of the Memorial Chapel at the University of Maryland, College Park. These practices allowed the musicians to march in formation while playing their music, to simulate football game performances. Tuesday night practices took place in the band practice room in the Clarice Smith Performing Arts Center at the University of Maryland, College Park, and the focus was on the music pieces and perfecting playing techniques. There were approximately 200 musicians in the marching band, who were expected to attend each practice in its entirety.

Immediately following the practices on Monday and Wednesday (within 90 minutes post-exposure), the participant returned to the clinic for repeat testing using the exact protocol as before band practice. These repeated tests permitted the investigators to check for evidence of a temporarily reduced ability to detect sounds and/or a change in status of cochlear function. The total test time was approximately 20 minutes. This test protocol occurred before and after two practices within the same week, with the first practice on a Monday.

If a clinically significant change in hearing was revealed after any practice, the band member returned to the clinic the following morning to be retested on the ear(s) that demonstrated a change. The levels that qualified as a change were: a greater than 5 dB worsening in any single pure-tone air conduction threshold, a greater than 2 dB decrease in overall TEOAE level across the wideband response or within the 3500-4500 Hz TEOAE band, or a 2 dB decrease in DPOAE level at 3000, 4000 or 6000 Hz (Beattie & Bleech, 2000; Marshall & Heller, 1996). Only the test(s) that revealed such differences (greater than test-retest differences using the criteria stated above) were repeated to determine if hearing levels and/or OAEs returned to pre-practice levels. The band member was encouraged to avoid exposure to any intense acoustic stimuli between the post-practice testing and the follow-up testing the next morning.

At each participant's last post-practice hearing test, he or she filled out a "recent noise exposure" form (see Appendix F). Total testing time was approximately 3 hours for each member of the marching band group, including the preliminary testing and all experimental testing.

Experimental Measures: Control Group

The non-band members filled out the consent form and the case history form, and underwent a full audiological evaluation to determine eligibility for the investigation at the beginning of a designated four-day test period. The consent form was slightly altered from the band member's form (see Appendix C) and the case history form is identical to the first two pages of the band member's case history form (see Appendix D). The initial test results served as the first experimental session for eligible participants. The test battery followed the same procedures as described for the eligibility testing for the experimental group, and lasted approximately one hour. Members of half of the control group (n=10) also had otoscopy, binaural pure tone air conduction testing, tympanometry, TEOAE and DPOAE testing for both ears completed at the end of the four-day experimental period (to follow the exact protocol as the before-practice test for the band members). The remaining control participants followed the same schedule as the band member group, having their hearing and auditory function tested before and after practices; however, they were not exposed to any noise during the "practice time." All subsequent test sessions lasted approximately 20 minutes. At the last test session, participants were asked to fill out the recent noise exposure questionnaire (Appendix F). Total testing time for members of the control group was approximately 1.5 hours for one half of the group, and 3 hours for the remainder of the group.

All data for both listener groups were recorded using participant code numbers only. All data were written on hard copies of audiograms and printouts of OAE testing. These records are stored in a locked file cabinet in the locked Hearing Science Suite (0119) in LeFrak Hall, at the University of Maryland, in College Park, Maryland.

Follow-up: Band and Control Groups

At the end of the testing period, a summary of audiological data was shared with each participant (10 minute conference). Recommendations on how to reduce noise-induced hearing loss were discussed with all participants. They were additionally provided with printed information regarding the risks of noise-induced hearing loss and prevention strategies (see Appendix G).

Sound level recordings

During one practice each week (during which band members were evaluated before and after), the sound level of the band music was recorded by the investigator for 30 minutes using a hand-held Radio Shack Digital Sound Level Meter (Catalogue #33-2055) positioned as close as possible to the center of the marching band. The sound level meter was set to measure A-weighted noise in the fast mode and a reading was taken once each minute. While monitoring the sound level at a location close to the center of the band, the sound level recordings were documented to be 85 – 105 dB(A), with peaks measured at 114 dB(A). The musicians in the Mighty Sound of Maryland were exposed to these sound levels, intermittently, for two hours during each practice session.

This study was reviewed and approved by the University of Maryland Institutional Review Board for Human Subjects Research (Protocol #1505).

Chapter 5: Data Analyses

There were 20 band members from whom data were collected between four and six times (twice before and after band practice and the following mornings, if changes were noted after the band practice). Pure-tone air conduction thresholds were measured at 2000, 3000, 4000, 6000 and 8000 Hz. DPOAE amplitudes were measured at 3000, 4000 and 6000 Hz. Broadband TEOAEs (750 to 4500 Hz) and narrowband TEOAEs (3500 to 4500 Hz) were also recorded during each testing session. The control participants were tested on all of these measures as well. A subgroup of 10 control participants was tested two times on these measures (pre-practice, day one and post-practice, day two) and the remaining 10 participants were tested four times (following the band members' schedule) on these measures.

To address the first experimental question regarding decreases in pure-tone thresholds from pre- to post-band practice in band members, the thresholds were analyzed using repeated measures analyses of variance (ANOVA). There were three within-subject variables: ear (two levels), time of the test period (two levels: pre-practice and post-practice) and day (two levels). Separate ANOVAs were conducted at each test frequency.

The second experimental question addressed the change in cochlear function as measured by the DPOAE amplitude. A repeated measures ANOVA was conducted on the DPOAE data, with three within-subjects variables: ear (two levels), time of the test period (two levels: pre-practice and post-practice) and day (two levels). Separate ANOVAs were conducted at each f2 frequency.

The third experimental question addressed the change in cochlear function as measured by the TEOAEs. There were three within-subjects variables for this question: ear tested (two levels), time of the test period (two levels: pre-practice and post-practice), and day (two levels). The data for the TEOAE measures were analyzed in two separate ANOVAs, once for the narrow-band response and once for the broad-band response. There were no between-subject variables for these first three experimental questions.

The fourth experimental question addressed the differences between the control participants and the marching band members for any recorded changes in hearing sensitivity and/or cochlear function over the course of the experimental period as measured on the first (pre-practice, day one) and last (post-practice, day two) visits. Pure-tone thresholds were compared between the two groups using a split-plot (mixed) factorial design (ANOVA), with one between-subjects variable (group [two levels: marching band members and non-marching band members]) and one within-subjects variable: test time (pre-practice, day one and post-practice, day two) (Kirk, 1995). The right and left ears were collapsed for all analyses between the marching band and control groups. These analyses were conducted separately for each frequency, to allow investigators a straightforward method to parse out the effect of each frequency on test time. Appropriate post-hoc tests were performed (simple main effects, multiple comparison tests) as needed. DPOAE amplitudes between the two groups were also compared using a split-plot factorial design (ANOVA), with one between-subjects variable (group) and one within-subjects variable (test time [pre-practice, day one and post-practice, day two]). These analyses were also conducted separately for each frequency. Post-hoc tests were performed on the data as needed. TEOAEs measured in the 3500-4500 Hz band were compared using a split-plot factorial design (ANOVA). There was one between-subjects variable (group) and one within-subjects variable for the narrowband TEOAEs comparisons (test time [pre-practice, day one and post-practice, day two]). Similarly, the broadband TEOAEs were analyzed using another split-plot factorial design (ANOVA), with one between-subjects variable (group) and one within-subjects variable (time [two levels: first and last experimental sessions]).

A general linear model was used to analyze the control sub-group (n=10) that followed the same testing schedule as the marching band members. These analyses were conducted to ensure no differences occurred between the measurements made early in the day (equivalent to pre-practice time) and later in the day (post-practice time). There were no between group variables and there were three within group variables (ear, time, day).

The last experimental question concerned TTS recovery. Only data from the marching band members were used; however, only those musicians within the band who demonstrated a clinically significant change in one or all of the test measures (pure-tone thresholds, DPOAE amplitude, or TEOAE decibel level) were included in this analysis. The data used for this question were from experimental days one and two (pre- and post-practice measurements, with the follow-up testing the next morning, on whichever day significant data were recorded from that participant). Thus, data from three test sessions were included in the analysis. Before these analyzes were performed, the data were normalized to reduce the variability between the pre-practice scores. Pre-practice scores were treated as zero and the post-practice and follow-up scores were modified to reflect the amount of deviation from the pre-practice score.

There were not a sufficient number of participants who demonstrated a shift in their pure-tone thresholds to conduct a meaningful statistical analysis on the data. There were a sufficient number of participants whose DPOAE emission level and TEOAEs shifted from pre- to post-practice. Therefore, an ANOVA was conducted on the relevant data to analyze the DPOAE data (one within-subjects variable: test visit [pre-practice, post-practice and the follow-up testing the next morning]), separately for each frequency, with a post hoc Bonferroni test performed on each possible test interval (pre-practice to post-practice, post-practice to follow-up, pre-practice to follow-up) to determine during which, if any, intervals produced significant changes. To determine if there was a significant change in TEOAE level, a one-way ANOVA was conducted for the narrow-band data (one within-subjects variable: test time [three levels]), and a separate one-way ANOVA was conduced for the broadband data (one within-subjects variable: test time [three levels]). A post hoc (Bonferroni test) was performed on each possible test interval (pre-practice to post-practice, post-practice to follow-up, pre-practice to follow-up) to determine during which, if any, intervals exhibited a significant change in the measure of interest.

Chapter 6: Results

Average Marching Band Performance: Pre- and Post-Practice

Pure-tone thresholds of the marching band members at five test frequencies were measured before and after band practice on two separate occasions. The averages of the pure-tone thresholds at each frequency in both ears, from pre- and post-practice test sessions on both test days, are depicted in Figure 4. The pure-tone thresholds for the marching band members were consistent between the two practice days for 2000 and 3000 Hz, while there were subtle changes between the pre- and post-test intervals for 4000 and 8000 Hz. At 6000 Hz, there were notable changes in pure-tone thresholds between the pre- and post-practice test sessions. Pure-tone thresholds of the marching band members, from pre- to post-band practice, were compared using a repeated measures ANOVA, with three within-subject variables: ear, test day (two levels: day 1 and day 2) and the time of the test (pre-practice and post-practice). ANOVAs were conducted separately at each frequency. Results from this analysis are shown in Table 2. There were no significant main effects or interactions found at 2000 Hz. At 3000 Hz, there was a significant interaction between time and day. Post-hoc analyses (t-tests) (refer to Table 3) revealed that pre-practice thresholds were significantly different from post-practice thresholds on day 2 ($p<.01$) and that pre-practice thresholds on day 1 were significantly different from pre-practice thresholds on day 2 ($p<.05$). Analysis of pure-tone thresholds at 4000 Hz demonstrated a significant main effect of time ($p<.01$). Therefore, the marching band members' hearing sensitivity at 4000 Hz was affected by participation during each individual band practice. At 6000 Hz, there was a significant

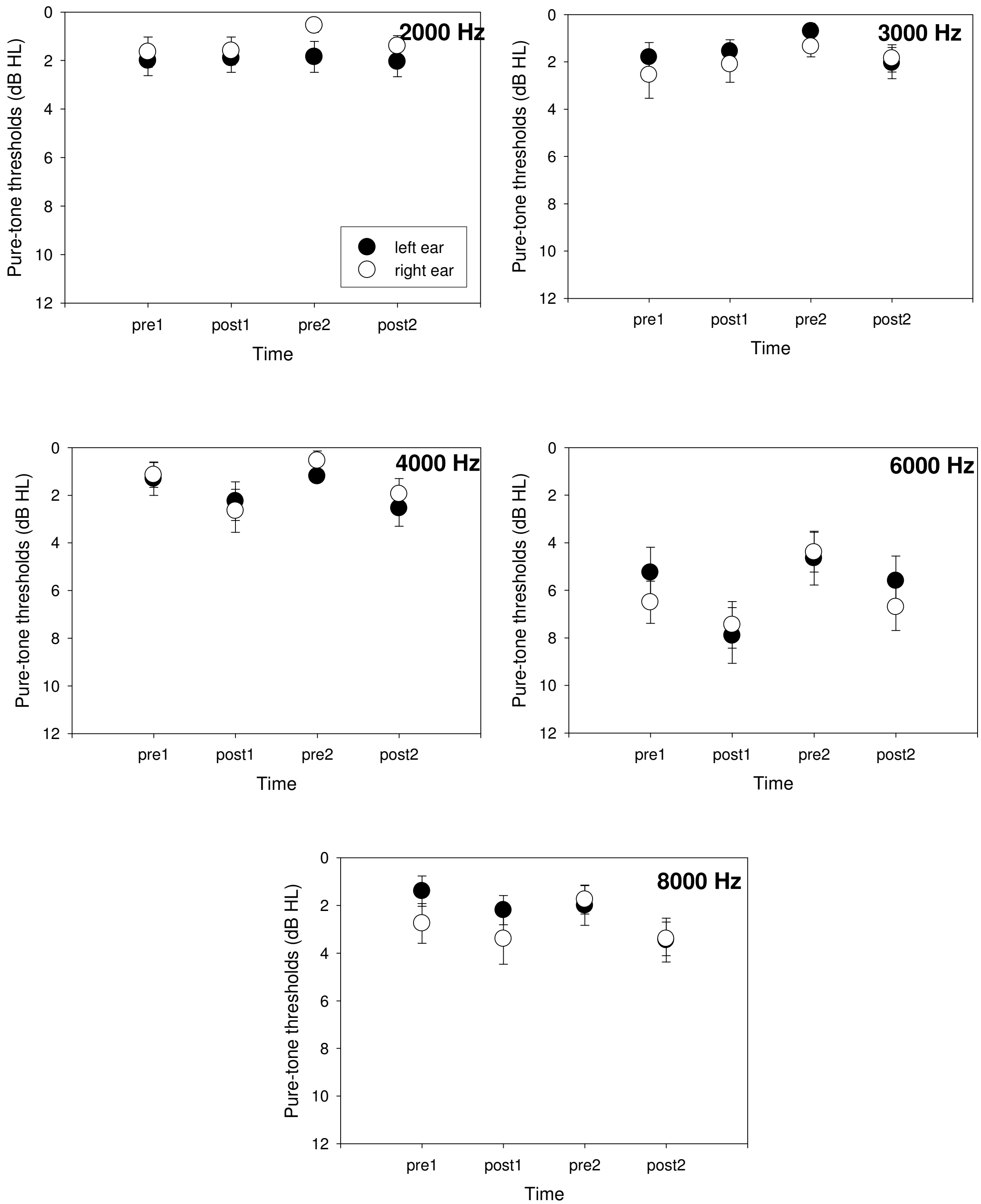

Figure 4. Average pure-tone thresholds for marching band members over time (N=20). (Error bars = 1 standard error of the mean; pre1= pre-test, day 1; post1= post-test, day 1; pre2= pre-test, day 2; post2= post-test, day 2).

Table 2

Results from Repeated Measures ANOVA Performed on Marching Band Members' Pure-Tone Data

	F	(*df*)	*p*
Pure tone 2000 Hz			
Ear	1.245	1, 19	0.278
Time	1.693	1, 19	0.209
Day	0.991	1, 19	0.332
Ear by time	2.730	1, 19	0.115
Ear by day	0.819	1, 19	0.377
Time by day	3.481	1, 19	0.078
Ear by time by day	2.327	1, 19	0.144
Pure tone 3000 Hz			
Ear	0.701	1, 19	0.413
Time	0.503	1, 19	0.487
Day	1.299	1, 19	0.268
Ear by time	2.509	1, 19	0.130
Ear by day	0.299	1, 19	0.591
Time by day	6.256	1, 19	0.022*
Ear by time by day	1.813	1, 19	0.194
Pure tone 4000 Hz			
Ear	0.201	1, 19	0.659
Time	12.100	1, 19	0.003**
Day	0.349	1, 19	0.562
Ear by time	0.291	1, 19	0.596
Ear by day	1.057	1, 19	0.317

Table 2 (continued)

Results from Repeated Measures ANOVA Performed on Marching Band Members' Pure-Tone Data

	F	(*df*)	*p*
Pure tone 4000 Hz (continued)			
Time by day	0.078	1, 19	0.783
Ear by time by day	0.168	1, 19	0.686
Pure tone 6000 Hz			
Ear	0.191	1, 19	0.667
Time	44.294	1, 19	0.000**
Day	7.357	1, 19	0.014*
Ear by time	0.090	1, 19	0.768
Ear by day	0.000	1, 19	0.983
Time by day	0.192	1, 19	0.666
Ear by time by day	6.235	1, 19	0.022*
Pure tone 8000 Hz			
Ear	0.287	1, 19	0.598
Time	4.706	1, 19	0.001**
Day	0.380	1, 19	0.545
Ear by time	0.005	1, 19	0.944
Ear by day	3.405	1, 19	0.081
Time by day	7.689	1, 19	0.012*
Ear by time by day	0.189	1,19	0.669

*p<.05. **p<.01.

Table 3

Post Hoc Analyses (Simple Main Effects and T-Tests)

Frequency	Interaction Effect	Simple Main Effect	*F or t*	*df*	*p*
3000 Hz	Time x day	Time at day 1	.858	1,39	.397
		Time at day 2	-2.899	1, 39	.006**
		Day at time 1	2.213	1, 39	.033*
		Day at time 2	-.317	1, 39	.753
6000 Hz	Ear x time x day	Ear within day1 time 1	1.01	1,19	.325
		Ear within day 2 time 1	-.219	1,19	.829
		Ear within day 1 time 2	-.368	1,19	.717
		Ear within day 2 time 2	.969	1,19	.345
		Time within day 1 right ear	-1.758	1,19	.095
		Time within day 2 right ear	-4.524	1,19	.000**
		Time within day 1 left ear	-4.958	1,19	.000**
		Time within day 2 left ear	-1.727	1,19	.100
		Day within time 1 right ear	2.644	1,19	.016*
		Day within time 2 right ear	.973	1,19	.343
		Day within time 1 left ear	.679	1,19	.505
		Day within time 2 left ear	2.305	1,19	.033*
8000 Hz	Time x day	Time at day 1	-2.328	1,79	.022*
		Time at day 2	-3.001	1,79	.004**

Table 3 (continued)

Post Hoc Analyses (Simple Main Effects and T-Tests)

Frequency	Interaction Effect	Simple Main Effect	*F*	*df*	*p*
8000 Hz	Time x day	Day at time 1	-1.280	1,79	.204
		Day at time 2	-3.853	1,79	.000**

*p<.05. **p<.01.

main effect of time ($p<.01$) and day ($p<.05$), and a significant interaction between day, time and ear ($p<.05$). Post-hoc testing (t-tests) was performed on the data and showed a significant effect of time for the left ear at day 1 ($p<.01$), a significant effect of time for the right ear at day 2 ($p<.01$), a significant effect of day for the pre-tests for the right ear ($p<.05$) and a significant effect of day for the post-tests for the left ear ($p<.05$). At 8000 Hz, there was a significant main effect of time ($p<.01$) and a significant interaction of day and time ($p<.05$). Post hoc testing showed that thresholds increased significantly from pre to post testing, for both test days ($p<.05$). The source of the interaction effect may be attributed to a larger change in day 2 compared to day 1. Also, post hoc testing showed that post-testing on day 1 versus day 2 was significant ($p<.01$). In general, it appears that band members' thresholds decreased after each individual practice, especially in the high frequencies (3000-8000 Hz).

The second experimental question addressed whether or not exposure to marching band music would affect DPOAE amplitudes. Analyses were performed on the DPOAE data separately for each of the test frequencies. For these analyses, there were three variables: ear, test day (two levels: day 1 and day 2) and the time of the test (two levels: pre-practice and post-practice). Average DPOAE emission levels measured at f2=3000, 4000 and 6000 Hz for the marching band members in pre- and post-practice conditions on two separate days are shown in Figure 5. A review of these data suggests that large changes in DPOAE amplitudes did not occur after band practice.

Results from the DPOAE analyses can be found in Table 4. Analysis of DPOAEs, with the f2 tone centered at 3000 Hz, revealed a significant interaction of ear

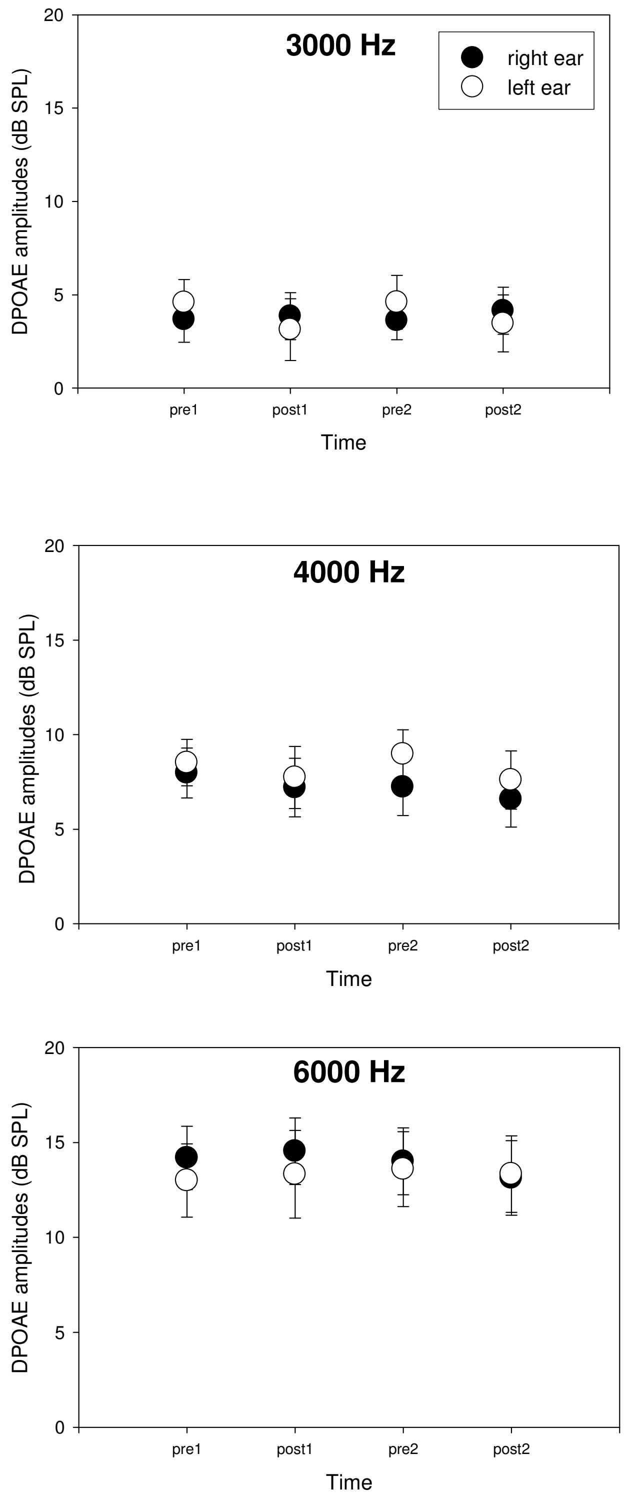

Figure 5. Average DPOAE amplitudes for marching band members over time (N=20). (Error bars = 1 standard error of the mean.)

Table 4

Results from Repeated Measures ANOVA Performed on Marching Band Members' DPOAE Amplitude Data

	F	(*df*)	*p*
DPOAE 3000 Hz			
Ear	0.009	1, 19	0.927
Time	1.157	1, 19	0.296
Day	0.101	1, 19	0.755
Ear by time	7.376	1, 19	0.014*
Ear by day	0.004	1, 19	0.949
Time by day	0.331	1, 19	0.572
Ear by time by day	0.001	1, 19	0.976
DPOAE 4000 Hz			
Ear	1.049	1, 19	0.319
Time	4.329	1, 19	0.051
Day	0.476	1, 19	0.499
Ear by time	0.571	1, 19	0.459
Ear by day	1.661	1, 19	0.213
Time by day	0.125	1, 19	0.728
Ear by time by day	0.740	1, 19	0.400

Table 4 (continued)

Results from Repeated Measures ANOVA Performed on Marching Band Members' DPOAE Amplitude Data

	F	(*df*)	*p*
DPOAE 6000 Hz			
Ear	0.419	1, 19	0.525
Time	0.095	1, 19	0.761
Day	0.270	1, 19	0.610
Ear by time	0.536	1, 19	0.473
Ear by day	2.000	1, 19	0.173
Time by day	1.890	1, 19	0.185
Ear by time by day	0.230	1, 19	0.637

*p<.05. **p<.01.

and time (p<.05). Post-hoc testing, shown in Table 5, indicated a significant difference in DPOAE amplitudes recorded in pre- versus post-practice sessions for the left ear only. The analyses of DPOAEs, with f2 frequency centered at 4000 Hz and 6000 Hz, did not yield any significant main effects or interactions.

The third experimental question focused on whether or not exposure to marching band music would affect TEOAE emission levels. Average TEOAE emission levels, measured on two days, pre- and post- practice, for the marching band members are shown in Figure 6. Analysis of narrowband TEOAE data, shown in Table 6, revealed a significant main effect of time (p<.01). Similarly, analysis of the broadband TEOAE data, shown in Table 6, revealed a significant main effect of time (p<.01) only. For both of these analyses, the significant main effect of time reflected lower OAE emission levels following band practice, compared to before band practice.

Comparison Between Marching Band Members and Control Participants

The fourth experimental question compared the hearing thresholds and OAE data obtained from the control participants and the marching band members. To answer this question, differences in hearing sensitivity and/or cochlear function over the course of the experimental period as measured on the first and last visits were analyzed. Results of these analyses can be found in Tables 7, 8, 9, and 10.

Prior to analyzing the pertinent data, the results from the two control subgroups were analyzed and compared. Recall that one subgroup was tested on the first and the fourth testing time only, whereas the second subgroup was tested following the marching band schedule (two test times each day for two days). First, the data from the control sub-group that followed the same schedule as the marching band (n=10) were analyzed

Table 5

DPOAE Post-Hoc Analysis

Frequency	Interaction Effect		*F*	*df*	*p*
3000 Hz	Ear x time	Effect of time for right ear	-.693	1,39	.492
		Effect of time for left ear	3.072	1,39	.004**
		Effect of ear for pre-test	-.929	1,39	.359
		Effect of ear for post-test	.697	1,39	.490

*p<.05. **p<.01.

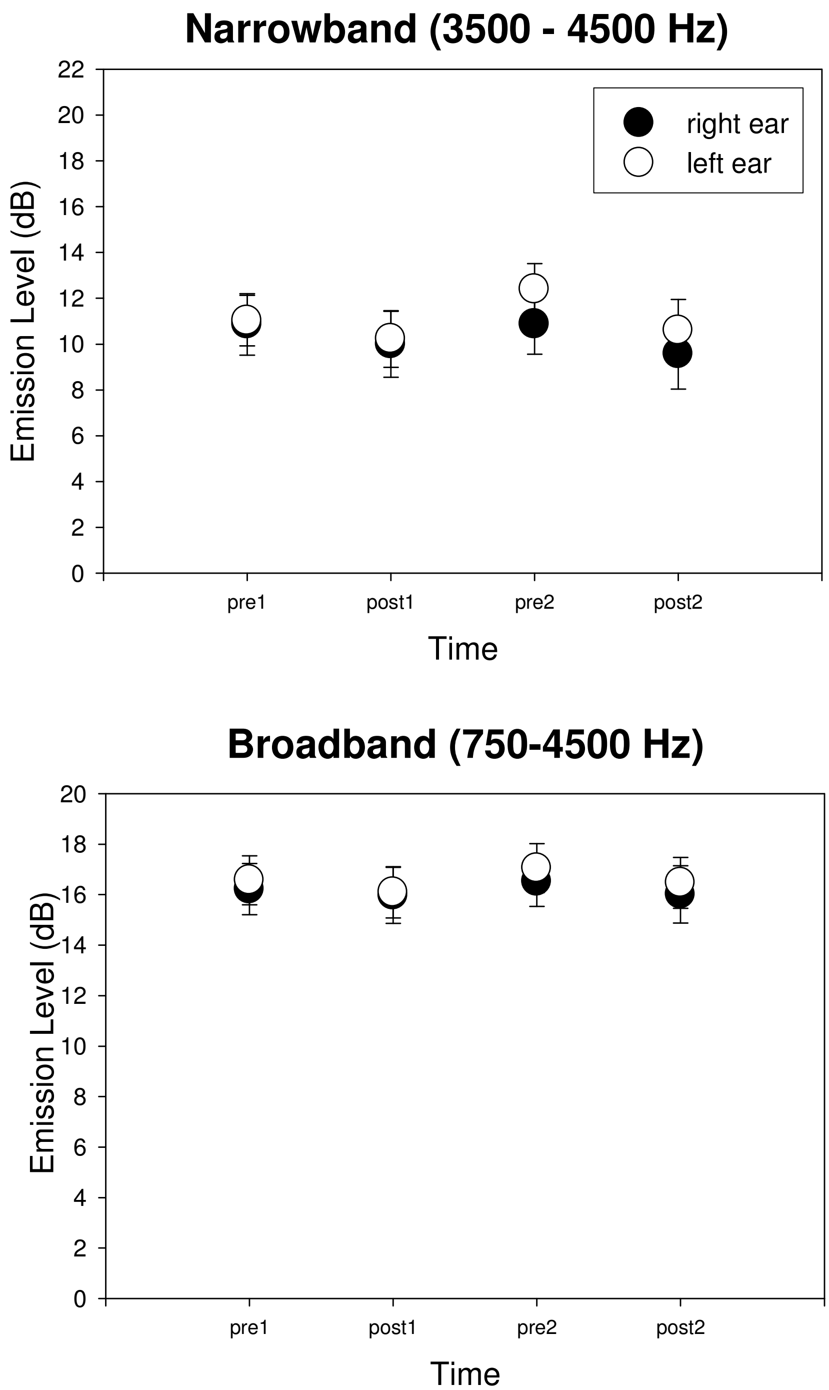

Figure 6. Average narrow-band (top) and broad-band (bottom) TEOAE levels for marching band members over time (N=20). (Error bars = 1 standard error of the mean.)

Table 6

Results from Two Separate Repeated Measures ANOVA Performed on Marching Band Member's Narrowband and Broadband TEOAE Data

	F	(*df*)	*p*
Narrowband			
Ear	0.548	1, 19	0.468
Time	15.250	1, 19	0.001**
Day	0.965	1, 19	0.338
Ear by time	0.141	1, 19	0.711
Ear by day	4.216	1, 19	0.054
Time by day	1.322	1, 19	0.265
Ear by time by day	0.277	1, 19	0.605
Broadband			
Ear	0.608	1, 19	0.445
Time	8.696	1, 19	0.008**
Day	1.645	1, 19	0.215
Ear by time	0.270	1, 19	0.609
Ear by day	0.604	1, 19	0.447
Time by day	0.243	1, 19	0.628
Ear by time by day	0.073	1, 19	0.791

*p<.05. **p<.01.

using a general linear model with no between group variables and three within group variables (ear, time , day) to determine if there were any differences in thresholds or OAE emissions between the test times. The only significant effect was observed for pure-tone thresholds at 4000 Hz. At this frequency, the participants' pure-tone thresholds were significantly poorer at the second measurement compared to the first measurement ($F=23.824$, $df=1,9$, $p<.01$). However, the thresholds only worsened an average of 0.3 to 1.4 dB, which is within the clinically accepted test-retest margin. Additionally, this statistically significant finding was the only one, out of 10 analyses, that showed an effect of time. The second analysis compared the data of the two normal control groups at the initial and final measurement times. The data were not significantly different between the two control subgroups at the day one pre-practice and the day two post-practice test times and therefore the analyses were conducted between the marching band group and the control group as a whole.

Pure-tone thresholds for the two groups (marching band members and all control participants) at the five test frequencies are shown in Figure 7. Pure-tone thresholds were compared using a split-plot factorial design (ANOVA), with one between-subjects variable (group [two levels: marching band members and non-marching band members]) and one within-subjects variable: test time (pre-practice, day one and post-practice, day two). For this, and the subsequent analyses comparing the marching band and the entire control group (n=20), the data for the two ears were combined, as there were no differences found in the data between the two ears. This analysis was conducted separately at each frequency. There was a significant main effect of time at 4000 Hz ($p<.01$), 6000 Hz ($p<.05$) and 8000 Hz ($p<.01$). There was a significant interaction found

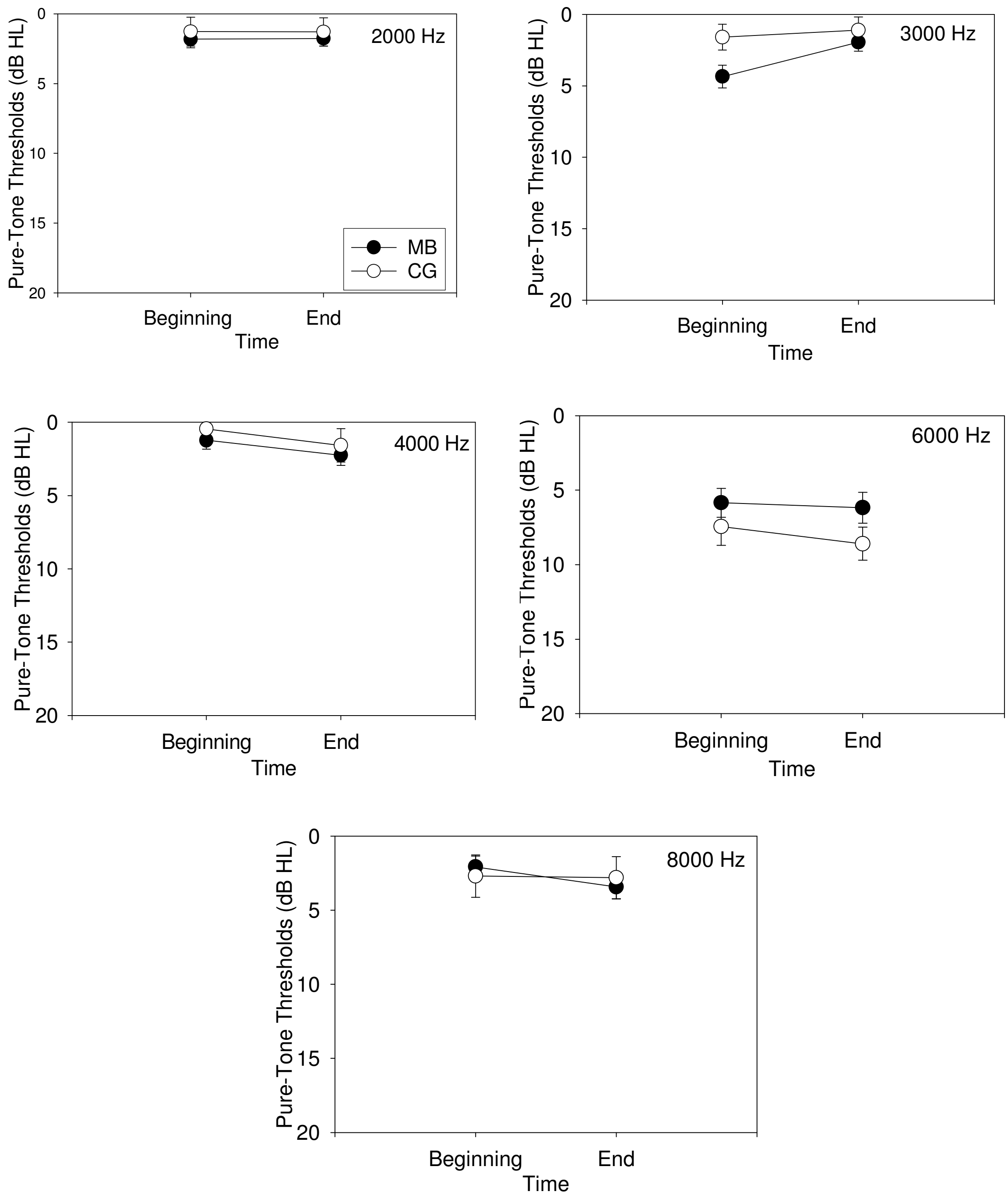

Figure 7. Comparison of marching band members' (MB) and control group participants' (CG) pure-tone thresholds in each ear at the beginning and end of the study. (Error bars = 1 standard error of the mean.)

for the two groups at the pre-practice versus the post-practice at 8000 Hz. When further analyses were conducted to examine this interaction (Table 7), it was found that the effect of group was significant at both pre- and post-practice time periods ($p<.01$). However, in the pre-practice condition, the marching band members had better thresholds than the control participants, but in the post-practice time period, the marching band members had poorer thresholds than the control participants (see Figure 7).

DPOAE amplitudes for the two groups at three test frequencies at the beginning and end of the study are shown in Figure 8. The data were analyzed using a split-plot factorial design (ANOVA), with one between-subjects variable (group) and one within-subjects variable (test time). Each f2 frequency was analyzed separately. There was a significant main effect of time at 4000 Hz ($p<.01$). However, there was no difference found between the experimental and control groups for DPOAE amplitudes.

TEOAE emission levels of the two groups are shown in Figure 9. The data are presented in Table 9. The data were analyzed using a split-plot factorial design (ANOVA), with one between-subjects variable (group) and one within-subjects variable (test time), with narrowband and broadband emissions analyzed separately. Analysis of the narrowband TEOAEs revealed a significant main effect of time ($p<.01$), but not a significant interaction between time and group.

Analysis of the broadband TEOAE data revealed a significant main effect of group ($p<.05$). Marching band members had stronger emission levels at both test times. There was no significant interaction noted between time and group for the broadband TEOAEs. The decreased emission levels post-practice seen in the narrowband and the broadband measurements of both groups may, in part, be attributable to the test-retest

Table 7

Results from General Linear Model Analyses Performed on Marching Band Members' and Control Group Participants' Pure-Tone Threshold Data, Analyzed Separately by Frequency

	F	(*df*)	*p*
2000 Hz			
Time	.003	1,78	.958
Group	.418	1,78	.520
Time by group	.025	1,78	.874
3000 Hz			
Time	.051	1,78	.822
Group	1.419	1,78	.237
Time by group	.811	1,78	.371
4000 Hz			
Time	12.277	1,78	.001**
Group	.713	1,78	.401
Time by group	.027	1,78	.871
6000 Hz			
Time	4.020	1,78	.048*
Group	3.844	1,78	.053
Time by group	1.415	1,78	.238
8000 Hz			
Time	7.593	1,78	.007**

Table 7 (continued)

Results from General Linear Model Analyses Performed on Marching Band Members' and Control Group Participants' Pure-Tone Threshold Data, Analyzed Separately by Frequency

	F	(*df*)	*p*
Group	0.000	1,78	.991
Time by group	5.674	1,78	.020*
8000 Hz Post Hoc:			
Group at pre-practice	12.308	1,78	.001**
Group at post-practice	7.725	1,78	.007**

*p<.05. **p<.01.

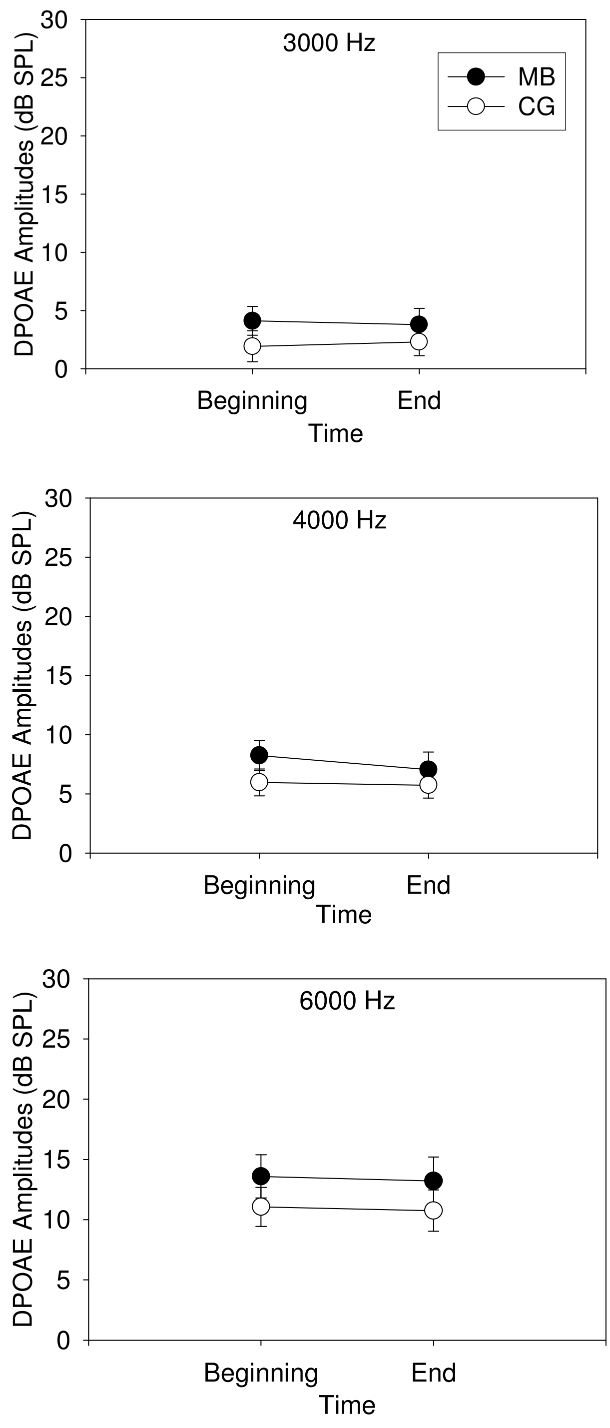

Figure 8. Comparison of marching band members' (MB) and control group participants' (CG) DPOAE emission levels at the beginning and end of the study. (Error bars = 1 standard error of the mean.)

Table 8

Comparison of Experimental and Control Group Members' DPOAEs, Analyzed Separately by Frequency

	F	(*df*)	*p*
3000 Hz			
Time	.007	1,78	.934
Group	2.148	1,78	.147
Time by group	1.473	1,78	.229
4000 Hz			
Time	6.996	1,78	.010**
Group	2.127	1,78	.149
Time by group	3.218	1,78	.077
6000 Hz			
Time	1.124	1,78	.292
Group	2.038	1,78	.157
Time by group	.010	1,78	.919

**p<.01.

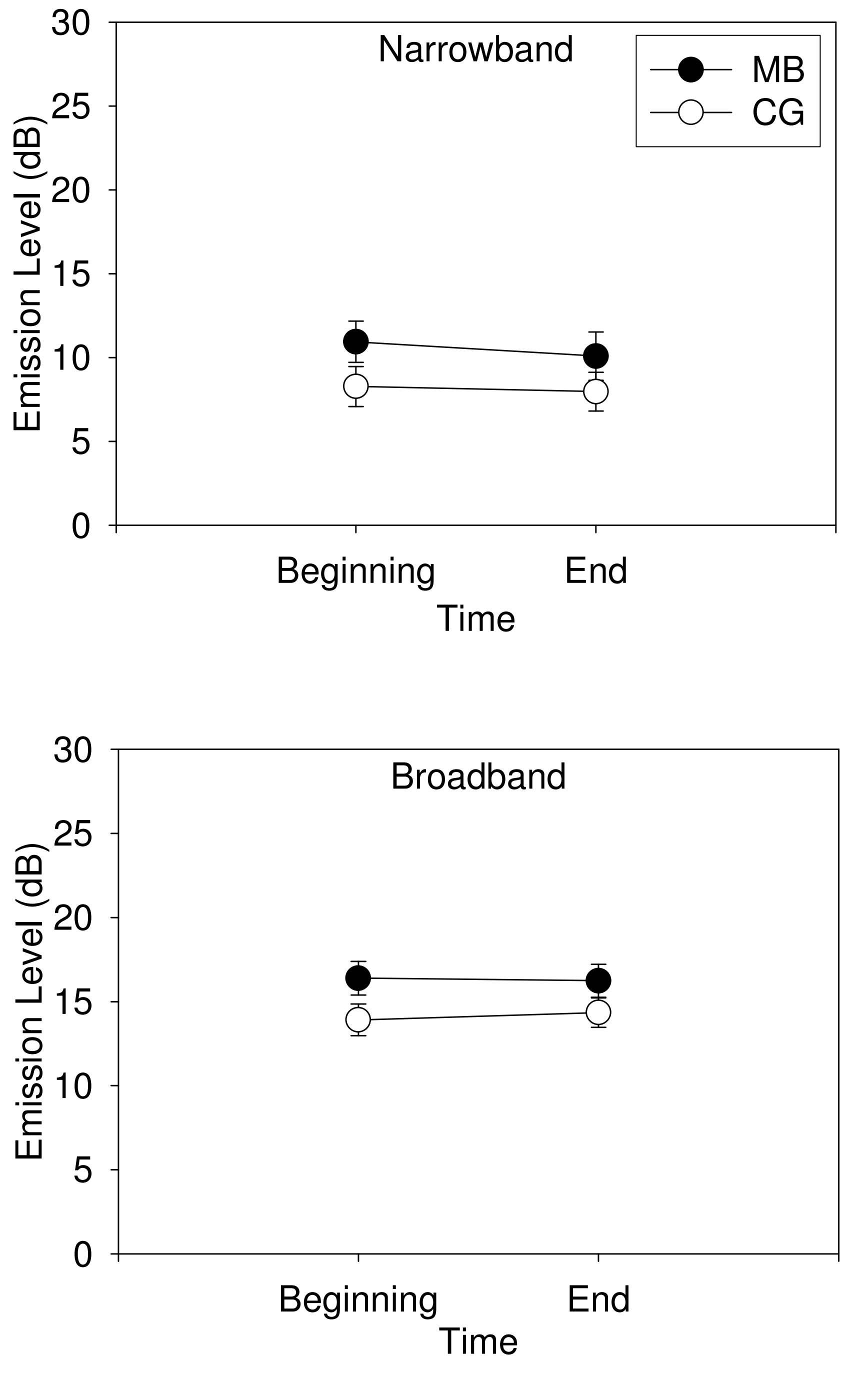

Figure 9. Comparison of marching band members (MB) and control group participants' (CG) narrowband (top) and broadband (bottom) TEOAE emission levels for each ear at the beginning and end of the study. (Error bars = 1 standard error of the mean.)

Table 9

Comparison of Experimental and Control Group Members' TEOAEs

	F	(*df*)	*p*
Narrowband			
Time	6.555	1,78	.012*
Group	3.738	1,78	.057
Time by group	1.468	1,78	.229
Broadband			
Time	.798	1,78	.375
Group	5.270	1,78	.024*
Time by group	3.645	1,78	.060

*p<.05.

variability of the measurement. It is also possible that the decreased emission levels in the control group could be due to their unintentional noise exposure during their test period.

Recovery from Changes in Auditory Functioning: Marching Band Members

Recovery from TTS was also analyzed. There were six ears from four different participants that demonstrated clinically significant pure-tone shifts during the study. A clinically significant pure-tone shift was defined as 5 dB for any single pure-tone air conduction frequency. The ears that demonstrated a pure-tone shift are depicted in Figure 10. These shifts occurred at varying frequencies and days: one ear at 3000 Hz on day two, two ears at 4000 Hz on day one, two ears at 6000 Hz, one on each day, and one ear at 8000 Hz on day two. Five of the six ears recovered completely (thresholds returned to pre-practice levels), while the sixth threshold shift demonstrated partial recovery (improvement from post-practice threshold levels, but not fully returned to pre-practice levels; at 8000 Hz: initial threshold at 0 dB HL, post-practice threshold at 9 dB HL, next morning threshold at 2 dB HL).

There were no participants in this study who demonstrated a Standard Threshold Shift, defined as a hearing threshold that has changed (relative to the baseline audiogram) an average of 10dB or more at 2000, 3000, or 4000 Hz in either ear (OSHA, 1983). There were not enough participants who demonstrated a pure-tone threshold shift (greater than 5 dB worsening in any single pure-tone threshold, at any one frequency) to conduct a meaningful statistical analysis.

The ears that experienced a decrease in DPOAEs amplitudes and their varying amounts of recovery can be seen in Figure 11. Recall that the level that qualified as a

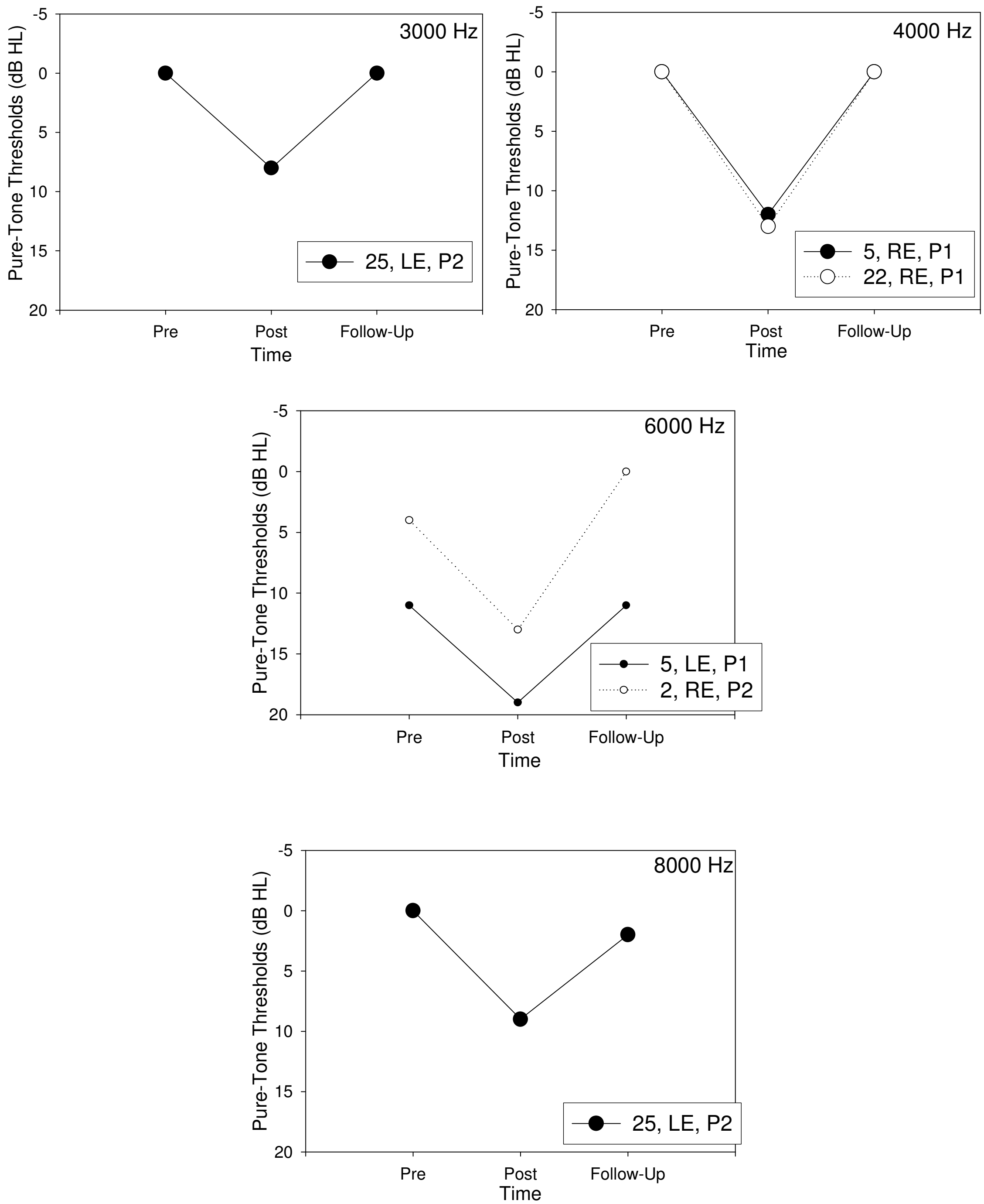

Figure 10. Pure-tone threshold recovery in marching band members.

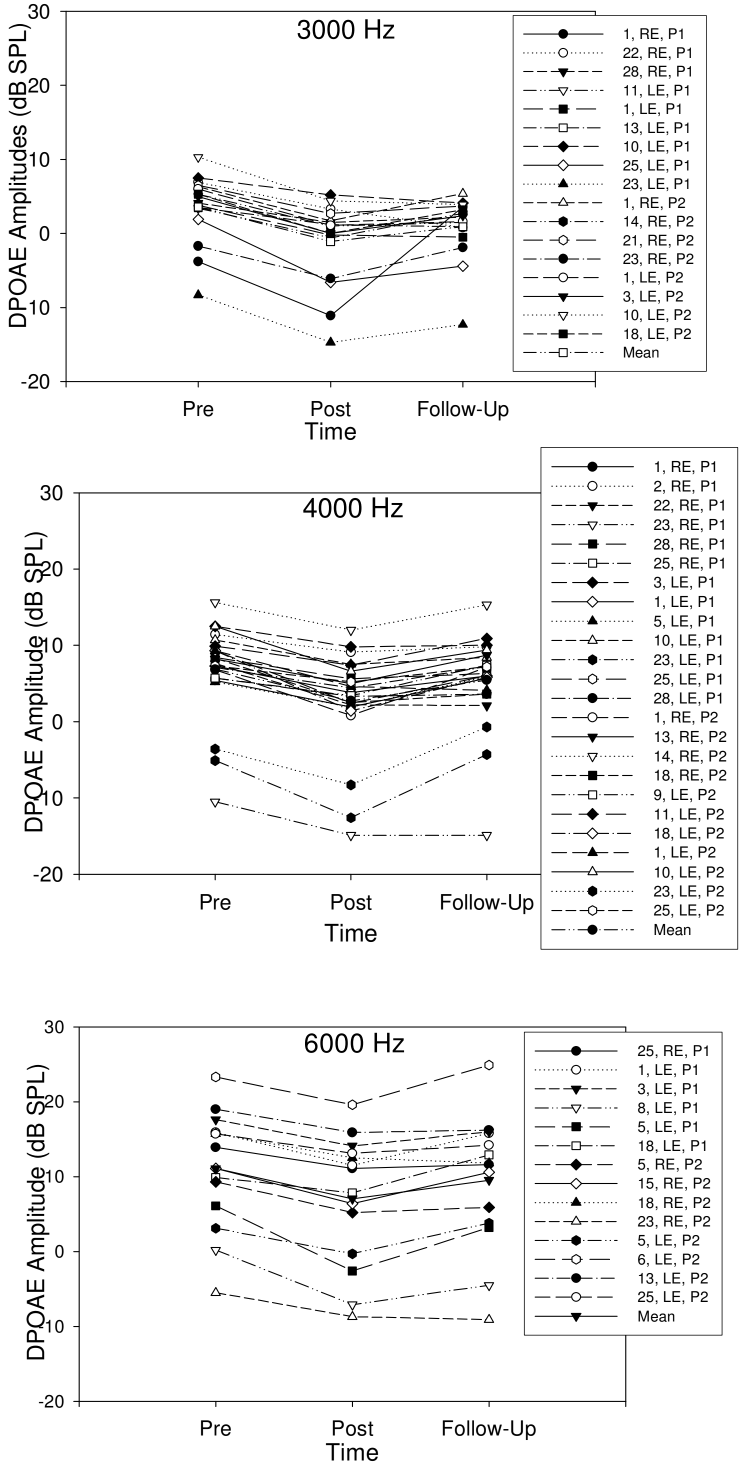

Figure 11. DPOAE amplitude recovery of marching band members (individual participant indicated by participant number), in both ears, for practice 1 (P1) and practice 2 (P2).

significant change was a 2 dB decrease in DPOAE level from pre- to post-practice test times at 3000, 4000 or 6000 Hz. Due to the large numbers of ears that demonstrated changes, a one-way ANOVA was conducted to determine if the DPOAE levels were significantly different across the three test times. The data were normalized individually for all DPOAE frequencies (3000, 4000 and 6000 Hz) by assigning a value of zero to all pre-practice amplitudes, thereby reducing the variability in the pre-practice scores. This permitted an analysis of the changes between the intervals. The post-practice and follow-up scores were modified to reflect the deviation from pre-practice amplitude. A one-way ANOVA with a Bonferroni post-hoc test was conducted on the data.

During DPOAE testing, there were 12 participants who demonstrated a total of 17 amplitude shifts, divided essentially equally between days one and two, when the f2 frequency was centered at 3000 Hz. Of these shifts, 12 ears demonstrated partial recovery (improvement from post-practice threshold levels, but not fully returned to pre-practice levels), one demonstrated complete recovery, and four ears showed no recovery. At the f2 frequency of 3000 Hz, there was a significant decrease from the pre-practice DPOAE amplitudes to post-practice amplitudes ($p<.01$). There was also a significant recovery found between the post-practice amplitudes and the follow-up amplitudes ($p<.05$). At the f2 frequency of 4000 Hz, there were 14 participants who demonstrate a total of 24 amplitude shifts, 13 which occurred on day one and 11 which occurred on day two. Of these shifts, 12 demonstrated partial recovery, nine demonstrated complete recovery, and three ears showed no recovery. At the f2 frequency of 4000 Hz, there was a significant decrease from the pre-practice DPOAE amplitudes to post-practice amplitudes ($p<.01$). There was also a significant recovery found between the post-

Table 10

Marching Band Members' DPOAE Recovery (One Way ANOVA with Bonferroni post-hoc test)

	F	(*df*)	*p*
3000Hz			
Pre- to post-practice	21.35	2,48	.000**
Post to follow-up	21.35	2,48	.022*
Pre- to follow-up	21.35	2,48	.002**
4000 Hz			
Pre- to post-practice	36.05	2,66	.000**
Post to follow-up	36.05	2,66	.000**
Pre- to follow-up	36.05	2,66	.012*
6000 Hz			
Pre- to post-practice	20.90	2,39	.000**
Post to follow-up	20.90	2,39	.001**
Pre- to follow-up	20.90	2,39	.052

*p<.05. **p<.01.

practice amplitudes and the follow-up amplitudes (*p*<.01). Amplitude shifts at the f2 frequency of 6000 Hz were observed in the data of 10 participants, with a total of 14 amplitude shifts, six of which happened on day one. Of these shifts, nine demonstrated partial recovery, three demonstrated complete recovery, and two showed no recovery. At the f2 frequency of 6000 Hz, there was a significant decrease from the. pre-practice DPOAE amplitudes to post-practice amplitudes (*p*<.01). There was also a significant recovery found between the post-practice amplitudes and the follow-up amplitudes (*p*<.01).

Refer to Figure 12 to see the ears that demonstrated a decrease in TEOAEs, and their possible recovery. Recall that the level that qualified as a significant change was a greater than 2 dB decrease in overall TEOAE level across the wideband response or within the 3500-4500 Hz TEOAE band. The data for the TEOAEs were also normalized by assigning the pre-practice emission level to zero, thereby reducing the variability in the pre-practice scores. The post-practice and follow-up scores were modified to reflect the change from pre-practice. A one-way ANOVA with a Bonferroni post-hoc test was conducted on the data. During narrowband TEOAE testing, there were 14 participants who demonstrated a total of 22 amplitude shifts, most of which occurred on day one. Of these ears, 13 demonstrated partial recovery (improvement from post-practice threshold levels, but not returned to pre-practice levels) and six ears recovered completely. The narrowband data showed a significant decrease from the pre-practice emission levels to post-practice levels *(p*<.01*).* There was also a significant recovery found between the post-practice emission levels and the follow-up levels *(p*<.01) (see Table 11). During broadband TEOAE testing, there were seven participants who demonstrated a total of

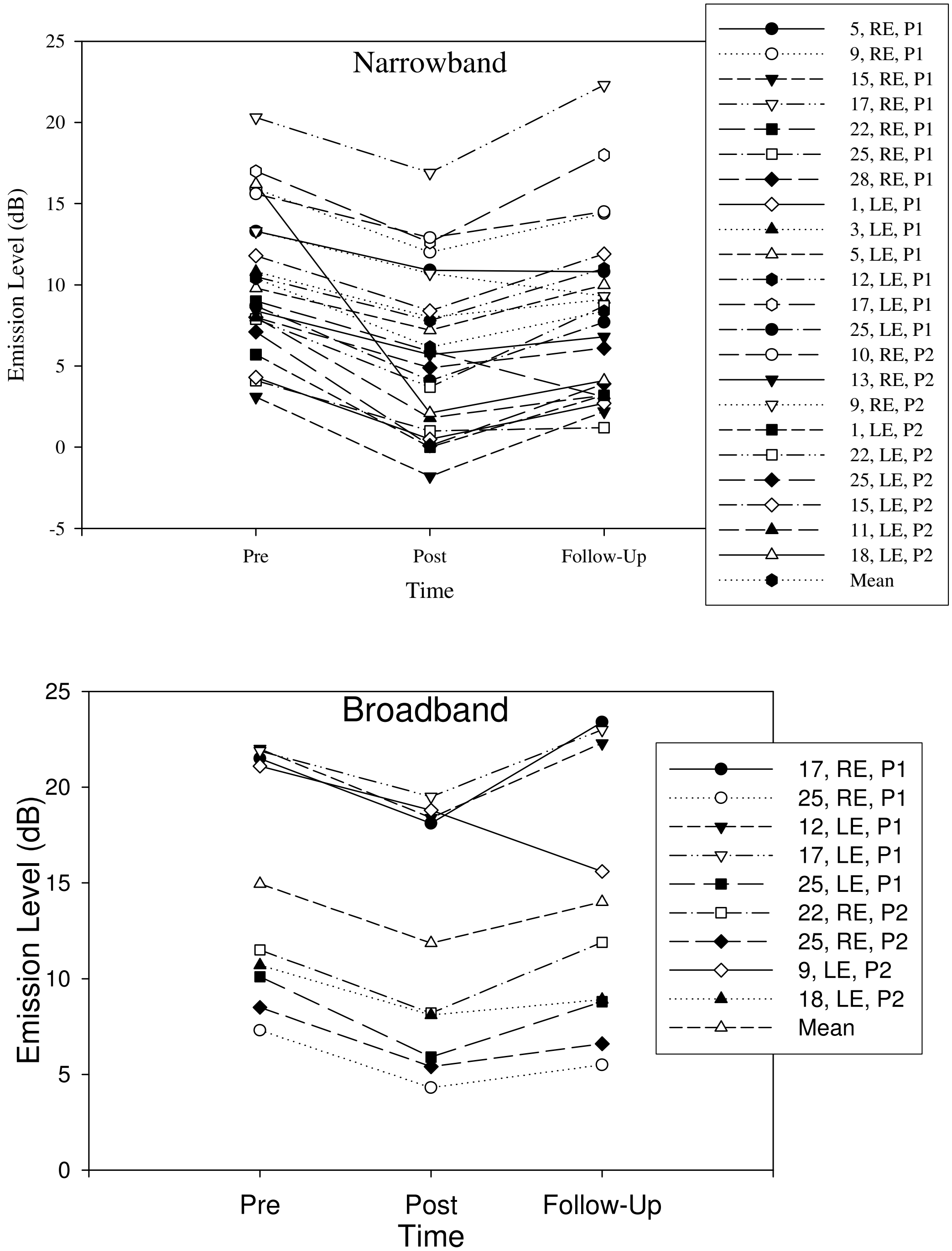

Figure 12. Narrowband (top) and broadband (bottom) TEOAE emission level recovery of marching band members (individual participant indicated by participant number), in both ears, for practice 1 (P1) and practice 2 (P2).

Table 11

Marching Band Members' TEOAE Recovery (One Way ANOVA with Bonferroni Post-Hoc Testing)

	F	(*df*)	*p*
Narrowband			
Pre-practice to post-practice	19.603	2,63	.000**
Post-practice to follow-up	19.603	2,63	.005**
Pre-practice to follow-up	19.603	2,63	.012*
Broadband			
Pre-practice to post-practice	13.004	2,24	.000**
Post-practice to follow-up	13.004	2,24	.006**
Pre-practice to follow-up	13.004	2,24	.414

*p<.05. **p<.01.

nine amplitude shifts, divided almost equally between days one and two. Of these ears, three demonstrated partial recovery and four ears demonstrated complete recovery. For the broadband TEOAE levels, there was a significant decrease from the pre-practice to post-practice levels ($p<.01$). There was also a significant recovery found between the post-practice and the follow-up levels ($p<.01$).

Chapter 7: Discussion

The overall purpose of this study was to assess the changes that occur in the auditory system as a result of participating in a college marching band. The possible changes were measured using pure-tone thresholds, DPOAE amplitudes and TEOAE emissions. These three measures encompassed detectable behavioral changes, such as increases in pure-tone thresholds, and other changes that can go undetected, such as decreases in OAE amplitudes, both of which can be temporary or long-lasting in nature.

During the course of this study, marching band members' pure-tone thresholds and OAE levels were measured before and after band practices over the course of one week. If a significant change was detected in any measure, the band member returned the next morning for retesting on the affected measure(s), to determine if the changes were temporary. A control group, consisting of college students who were not exposed to loud noises during the testing week, was also evaluated to monitor if any changes occurred in their pure-tone thresholds, DPOAE amplitudes or TEOAE emissions. Additionally, during the course of the study, sound level recordings were monitored at a location close to the center of the band. They were documented to be 85 – 105 dB(A), with peaks measured at 114 dB(A). These sound levels confirm that marching band music is sufficiently high in level to produce changes in auditory function.

Effect of marching band music exposure on auditory measures

Effect of marching band music on pure-tone thresholds.

The first question examined in this study explored the possible changes in hearing sensitivity, in either ear, as measured by air conduction pure-tone thresholds, from before band practice to after band practice for the selected high frequencies of 2000, 3000, 4000, 6000 and 8000 Hz. It was hypothesized that there would not be a decrease in pure-tone, behavioral thresholds at any tested frequency, as the auditory system is able to compensate for small amounts of hair cell damage in signal detection measures. Analyses of the marching band members' data revealed significant main effects of test time (pre- versus post-practice) on pure-tone thresholds at 4000, 6000 and 8000 Hz, contrary to the stated hypothesis. The effect of time was also involved in interaction effects at 3000, 6000 and 8000 Hz and post-hoc analyses showed the significant interactions to be time by day at 3000 and 8000 Hz, and ear by time by day at 6000 Hz. In the interaction between time and day at 3000 Hz, the marching band members' pre-practice versus post-practice pure-tone thresholds on day 2 were significantly worsened ($p<.01$), which demonstrates the negative effect the marching band music had on their auditory system. Also, the time and day interaction at 3000 Hz revealed that the marching band members' pre-practice pure-tone thresholds on day 1 were significantly worse than their pre-practice thresholds on day 2 ($p<.05$). Both of these interactions at 3000 Hz, while demonstrating statistically significant changes in pure-tone thresholds between the two test days, are within the test-retest margin of 5 dB and therefore should be interpreted with caution. However, if results are statistically significant, but not clinically significant, they are still relevant to the clinical environment, as even small changes in the auditory system are important to be aware of, as they can become larger changes if the causative behaviors are not modified.

The results obtained at 6000 Hz revealed a significant worsening of thresholds in pre-practice versus post-practice on day one for the left ear and day two for the right ear. These findings demonstrate that the musicians' exposure to the marching band music during the two-hour practice did cause a decrease in their ability to hear. This was also shown in the interaction at 8000 Hz. The largest magnitude of change occurred at 6000 Hz, which is in the region usually affected by noise exposure. During this short amount of exposure time, the band members listened to sound levels measured between 85 and 105 dB(A), which appeared to cause temporary increases of up to 5 dB HL in their pure-tone thresholds.

When band members perform at football games or parades they are exposed to these sound levels for longer durations, as opposed to two-hour practice sessions. Also, sound levels during the actual events might be louder with the addition of cheering crowds of people. The Occupational Safety and Health Administration (OSHA) establishes criteria for safe noise levels (OSHA, 1983). OSHA states that for two hours of exposure, individuals should not listen to sounds louder than 100 dB(A). However, as the length of exposure increases to three hours, such as during a football game or during a musician's solo practice prior to group practice, the permissible sound level decreases to 97 dB(A). Therefore, based on OSHA's criteria, it would be expected that the marching band members would experience temporary or permanent changes in pure-tone thresholds after their marching band practices or performances, because it is likely that the weighted sound level over the course of the practice is over 100 dB(A).

These changes in hearing were detected at frequencies that previously have been found to be the most susceptible to noise (Ciazzo & Tonndorf, 1977). While marching band music includes a broad frequency range, the resulting hearing loss or decrease in auditory functioning occurs at frequencies higher than the actual frequencies of the music (Borg, et al., 1995). Ciazzo and Tonndorf (1977) explained that noise damage typically occurs one-half octave above the frequency of the offending noise. The affected frequencies in the current study agree with other authors' findings, which also demonstrated the greatest susceptibility to TTS in the range from 2000 to 8000 Hz for continuous music (e.g. Rintelmann, et al., 1971).

The decreases in pure-tone thresholds confirm previous studies which also demonstrated that exposure to loud music affects one's hearing (Seixas, et al., 2005). However, direct comparison between previous studies and the present study is problematic because of differing methodologies. Previous studies examined musicians who practiced or performed in indoor locations and played different musical genres for varying lengths of time (e.g., Ostri, et al., 1989). The current study, while also revealing a decrease in marching band member's pure-tone thresholds, took place in an outdoor venue for two hours per day.

Many related studies confirm a decline in pure-tone thresholds as a result of exposure to loud music; however, those studies measured PTS, not TTS (e.g., Kahari, et al., 2003). Despite those differences, they are nonetheless pertinent to the current study, as repeated TTS might lead to PTS (Jerger & Carhart, 1956). Any noise exposure that is able to cause a TTS is capable of producing a PTS. Pang-Ching's 1982 study, which reported that band directors had worsened pure-tone thresholds, found that the level of decrement corresponded to their years of experience in the field. Therefore, if a temporary change in auditory functioning occurs after band practice, it is possible that in the future, those impermanent changes might become permanent.

There were no Standard Threshold Shifts (STS) found during this study (OSHA, 1983). A Standard Threshold Shift, a term used mostly in occupational settings, is a predetermined amount of hearing loss which requires follow-up action. The absence of any STS means that the decrement in the marching band members' hearing would not be considered significant according to OSHA standards (Borg, Canlon & Engstrom, 1995; OSHA, 1983).

Effect of marching band music on DPOAEs.

The second experimental question considered the possible change in cochlear function, in either ear, as measured by the change in DPOAE amplitude at selected high frequencies (3000, 4000 and 6000 Hz), from before band practice to after band practice. The hypothesis was that noise exposure during band practice would produce changes in outer hair cell functioning and therefore DPOAE amplitudes, given the high sound levels measured during the two-hour practice. Analyses of the data revealed no significant changes in DPOAE amplitudes for f2 = 4000 and f2 = 6000 Hz. The only significant decrease in DPOAE amplitudes was at f2=3000 Hz, pre- versus post-practice, for the left ear only.

A possible explanation for the change in the left ear only could be the configuration of the band on the practice field. The band members move around into varying configurations on the field as they practice. It is possible that the loudest instruments in the band could have been located on the left side of the field for the majority of the practice times during the study. Also, the configuration of previous bands that the individuals played in is unknown, which might have contributed to their right ear having additional auditory toughening.

Overall, the findings suggest that the loud marching band music minimally affected the outer hair cell functioning in the musicians' cochleas, as measured with

DPOAEs. This null result for the right ear should be interpreted with caution and not as a definitive indicator of the complete absence of outer hair cell damage occurring in that ear.

Previous studies have suggested that DPOAEs might not be precise enough to detect the first signs of a noise-induced hearing loss, as compared to TEOAEs (e.g. Attias, et al., 1998). Attias, et al. (1998) also reported a weak relationship between DPOAEs and pure-tone thresholds. The authors cautioned that a presence or lack of a decrease in pure-tone thresholds should not be interpolated solely from the OAE results, as there are many variables which may affect this measure. A possible explanation for the lack of significant DPOAE amplitude changes in the present study could be the noise floor, stemming from muscle movements and other internal body noises, which might have altered the signal to noise ratio being measured. The DPOAE equipment was located in a quiet room and every attempt was made to take the measurement during the quietest times. It would have been preferable to move the equipment into a sound-attenuating booth, where the pure-tone threshold measurements were obtained.

While every effort was made to keep the probe tip size and insertion depth constant, errors were possible which might have also affected measurement outcomes (Zhao & Stephens, 1999). Beattie and Bleech (2000) state that an individual's accurate DPOAE amplitude level will be within 4.4 dB of the obtained measurement. This variation is large enough to cause an ear's DPOAE amplitude to erroneously appear to have remained constant or changed. Therefore, a more accurate measurement should be obtained, possibly by increasing the number of sweeps per f2 frequency, or obtaining the measurement multiple times.

It is possible that significant findings were not found for f2=4000 and 6000 Hz due to previous ear toughening at those frequencies. Namyslowski, et al. (1998) did not find any change in DPOAEs in their sample of musicians. They remarked that regular, long term musical training does not damage, but instead strengthens the outer hair cells in the cochlea, which is additional support for the concept of ear toughening. The musicians in the current study have been playing, on average, for longer than 10 years, which is sufficient time for ear toughening to have occurred. It is also possible that this group of participants was self-selected among those marching band members with excellent hearing. Additionally, pre-selection criteria required participants to have normal hearing sensitivity and otoacoustic emissions, despite having played loud music for a period of years. This suggests that these musicians may have exceptional auditory systems.

Effect of marching band music on TEOAEs.

There was a significant main effect of time for narrowband TEOAEs (3500-4500 Hz) and broadband TEOAEs (750-4500 Hz). Marching band members showed lower TEOAE emission levels post- noise exposure compared to pre- noise exposure. Therefore, the results suggest that the harmful exposure to 85-105 dB(A) marching band music during the two-hour practice affected their outer hair cells and consequently decreased their TEOAE emission levels.

As compared to DPOAE amplitude levels, TEOAEs were more sensitive to the effects of exposure to marching band music in the current study. The greater sensitivity of TEOAEs to noise exposure, as compared to DPOAEs, has been found by other authors as well. One example is Plinkert, et al. (1999), who found that TEOAEs are more sensitive to changes in outer hair cells, as compared to DPOAEs or pure-tone thresholds.

In their study of 46 soldiers, half were found to have increased susceptibility to TTS after firearm training. They exposed all of the participants to a variety of noise types (e.g., impulse, steady state) with a maximum peak of 106 dB SPL. The authors found that even in the absence of TTS, there were decreases in the TEOAE emission amplitudes. They found that TEOAEs were more sensitive in determining “noise susceptible cochleas,” as compared with DPOAEs. The decreased sensitivity of DPOAEs could be due to the outer hair cells having to respond to two incoming stimuli and creating a distortion-product emission, as opposed to the TEOAE measurements which are produced from one incoming click presented to the outer hair cells.

The difference between the results obtained from behavioral, pure-tone thresholds and the DPOAEs can be explained because the behavioral tests involve the entire auditory system, including the higher level processing and decision-making systems in the brain. The participant is charged with the task of deciding if a stimulus was presented. Each participant might have a different loudness criterion for whether the stimulus was presented or not, which affects the results. The objective OAE measures test only up to the level of the inner ear. It is purely an objective measure of the integrity of the outer hair cells and their structural ability to transduce the incoming stimuli. There is no option for the participant to decide if the sound was present or not. Therefore, the outcomes of these two types of measures might not completely correlate.

These findings underscore the importance of monitoring sound levels and hearing thresholds of young musicians, in order to implement hearing protection before any damage to the auditory system becomes permanent. It is crucial to monitor and protect the hearing and auditory systems of young musicians before they develop permanent changes. Marching band musicians should be encouraged to participate in a hearing conservation program, because of the loud noise levels to which they are exposed during regular practice sessions. This sentiment is echoed by Henoch and Chesky (2000) who found that the music produced by the college jazz band ensemble exceeded allowable OSHA noise levels.

Comparison of marching band members and control participants

Pure-tone thresholds and OAE data were compared at the beginning and end of the four-day test period for marching band members and control participants. The purpose of this comparison was to verify that no significant differences existed between the groups at the beginning of the study. It was hypothesized that the comparison would reveal significant between-group differences at the end of the study, reflecting the effects of noise exposure on marching band members. The control group was not expected to show any evidence of ear toughening, as the stimuli that cause ear toughening to occur must be of the same frequency as the later offending noise. Therefore, because the control group is exposed to many different types of noises during the day, it is unlikely that they will develop any ear toughening in any specific frequency region.

Pure-tone threshold comparison.

When the marching band members were compared to their non-marching band peers, there was no difference found between the pure-tone thresholds of the two groups at the beginning of the study with the exception of 8000 Hz, where thresholds were better for marching band members than control participants. The lack of any major differences in pure-tone thresholds between the marching band members and the control participants at the beginning of the study indicated that the two groups were well matched on their pure-tone thresholds. This is due to the stringent eligibility criteria for normal hearing (≤15 dB HL) that was used for this study. However, at the end of the study, there were also no differences revealed between the two groups, with the exception of 8000 Hz.

It is possible that the musicians did not experience as severe, long-lasting TTS because they enjoy the music that they are practicing and performing. Swanson, et al. (1987) found that participants who enjoyed the music they were exposed to were less likely to experience TTS, when compared to those who did not enjoy the music, despite exposure to music at the same level. Another possible explanation is that the auditory system was able to compensate for small changes in outer hair cell functioning during behavioral pure-tone testing at frequencies other than 8000 Hz. Konopka, et al. (2001) found that after a shooting practice, there were changes in DPOAE amplitudes and TEOAE emission levels, even in the presence of unaltered pure-tone thresholds. This demonstrates the ability of the auditory system to compensate for small amounts of damage to outer hair cells in behavioral measures. In the current study, it is possible that the marching band members had small amounts of damage to their outer hair cells, but were able to compensate during behavioral measures and therefore showed little difference in pure-tone thresholds from the control group.

Previous studies have shown that exposure to continuous music causes more pure-tone TTS than exposure to intermittent music (Rintelmann, et al., 1971). This is especially pertinent to marching band practice because while the musicians are learning their placement on the field and new musical scores, the band director starts and stops the music frequently. Therefore, the musicians are being exposed to intermittent music during the two-hour band practices. The intermittency provides the musicians with times of effective quiet, which allows for periods of hair cell recovery. As the semester progresses and the musicians are increasingly comfortable with the music and placements on the field, the music exposure becomes more continuous in nature and the musicians have fewer periods of effective quiet. However, the band members did show an increase in pure-tone thresholds in selected higher frequencies following band practice, even with the effective quiet times.

Another explanation for the lack of group effects at the post-exposure measures is that the control participants were exposed to more noisy situations than they realized during their test week. Although they were asked to have a relatively quiet week and not expose themselves to loud noises during the week (refer to Appendix A), there might have been unavoidable loud sounds or those that they were unaware of during their day. They might walk along a busy road to get to class, blow dry their hair or watch a loud movie during a class. This was demonstrated in the statistics performed on the control sub-group that followed the marching band schedule. At 4000 Hz, their pure-tone thresholds worsened from pre- to post-practice test times on both test days. Although this statistically significant finding was demonstrated in only one out of 10 analyses performed on this sub-group, this finding could have been due to the control sub-group's inadvertent noise exposure during their experimental week. The frequency where the thresholds worsened, 4000 Hz, is the frequency that is most susceptible to noise-induced damage.

The control group also might not have as toughened auditory systems as band members. Therefore, a particular sound might cause alterations in pure-tone thresholds in the control participants' ears, while the same everyday sounds would not affect the marching band members' auditory systems. This difference could be attributable to ear toughening. It is thus possible that both groups experienced the same amount of changes in their pure-tone thresholds, resulting from very different levels of noise exposure (i.e., band practice for the band members versus a loud movie for the control group members).

The results from the current study were similar to findings by Johnson et al. (1986), who also reported no differences between their orchestra musicians' and the non-musicians' pure-tone thresholds. Instead, the authors found that age had a greater impact on the tested frequencies. In the Johnson et al. study, their participants had also been playing their instruments for many more years, since they were more advanced in age. Age was not a factor in the current study, because all participants were college-aged (18-25 years old) and therefore did not experience any age-related hearing loss.

Kahari, et al. (2003), reported that a majority of musicians (74%) in their study had an "auditory disorder." That study differed from the current study, because the authors did not use a control group and their participants' median age was 37 years. This older participant sample, compared to the participants in the current study, could have experienced some amount of age-related hearing loss, which might have confounded their results. Also, the authors analyzed hearing loss of musicians who had been removed from music for more than eight hours, while the current study analyzed musicians immediately following their marching band practice. However, as mentioned earlier, TTS and PTS are related, and temporary hearing loss and changes in auditory functioning can provide insight for studying long-term auditory damage.

Another study found that more than half of the musicians sampled had a hearing loss (Ostri, et al., 1989). It is possible that these authors might have found that even more of their sample had hearing loss if they had used the stricter definition of normal hearing that was followed in the current study (< 15 dB HL). In the current study, there were three potential participants excluded because they did not meet the strict criteria of normal hearing. In addition, other studies' participants were professional musicians who were exposed to music for eight hours a day or more; the current study focuses on college marching band musicians, many of whom are not exposed to performance music for more than eight to 10 hours per week. While there are significant differences in methodology between previous studies and the current study, the findings consistently reveal that exposure to loud music has an effect on musicians' hearing sensitivity in the high frequencies.

The present study focused on temporary hearing loss and impaired auditory function; however, it is unknown how many times hair cells can undergo temporary changes associated with noise exposure and maintain their ability to transduce sound. Noise exposure can cause damage to hair cells, metabolic changes in the inner ear and eventually cell death (Liberman & Mulroy, 1982). Cutietta, et al. (1988) found that band directors had a permanent noise-induced hearing loss from their many years of noise exposure, which presumably was preceded by TTS. However, the limitation of the study conducted by Cutietta and colleagues was poor control of the age of the participants. Because their participants were between 20-50 years old, it is difficult to discern how much of the hearing loss was attributed to noise exposure versus aging.

DPOAE Comparison.

Analysis of the DPOAE data measured from the marching band members and control participants revealed a change *at* the f2 frequency of 4000 Hz in relation to time.

However, there were no differences revealed between the marching band members and the control groups. It is possible that the control group did not have a sufficiently quiet week and therefore they experienced slight decreases in DPOAE amplitudes, similar to the decreases the marching band members experienced for the selected f2 high frequencies. While every attempt was made to maintain consistency between the two groups, the slight difference in testing times could have added variability into the data. Also, as discussed earlier, the control participants might have more sensitive outer hair cells, as they have not experienced cochlear toughening.

Overall there was not much decrease in DPOAE amplitudes for either group, which might indicate that this is not as sensitive as other types of measures, such as TEOAEs. One possible explanation could be differences in spontaneous otoacoustic emissions (SOAEs) between the two groups. SOAEs were not measured in the current study, but it has been found that people with stronger SOAEs tend to have more robust DPOAE amplitudes and TEOAE levels (Moulin, Collet, Veuillet, & Morgon, 1993). There also might have been variations resulting from probe insertion depth, or from participant movement. As discussed earlier, some studies have shown greater sensitivity of TEOAEs to changes in cochlear function.

TEOAE Comparison.

Comparison of TEOAEs measured from the marching band members and the control participants revealed that narrowband TEOAEs demonstrated a significant main effect of time for both groups, but no significant effect of group when the entire control group (n=20) was compared to the marching band group.

Analysis of broadband TEOAEs did not reveal any interaction effects between the entire control group and the experimental group. However, the emissions of the two groups were significantly different at each test session; the marching band had stronger emission levels at both test times. This group difference may be related to the selection of marching band members with exceptional auditory systems.

Recovery from Noise Exposure

Recovery from TTS was also analyzed in the present study. Any marching band member who demonstrated a significant increase in pure-tone thresholds, decrease in DPOAE amplitude or TEOAE emission level was asked to return the following morning for re-testing. The levels that qualified as a change were: a greater than 5 dB worsening in any single pure-tone air conduction threshold, a 2 dB decrease in DPOAE level at 3000, 4000 or 6000 Hz or a greater than 2 dB decrease in overall TEOAE level across the wideband response or within the 3500-4500 Hz TEOAE band (Beattie & Bleech, 2000; Marshall & Heller, 1996). Only the test(s) that had results greater than test-retest differences using the criteria stated above were repeated to determine if hearing levels and/or OAEs returned to pre-practice levels. The band member was encouraged to avoid exposure to any intense acoustic stimuli between the post-practice testing and the follow-up testing the next morning.

Pure-tone Recovery.

The six ears that demonstrated clinically significant pure-tone shifts ($\geq$5 dB) all showed some degree of recovery. After practice, while those six ears might have had increased difficulty hearing quiet sounds due to a worsening of their pure-tone thresholds, their hearing sensitivity improved before they were retested the next morning. This is consistent with a temporary threshold shift, in which thresholds are expected to improve within a 16-hour period of time (Mills, et al., 1979). The cohort of marching band members (N=4 people) that experienced an increase in pure-tone thresholds after practice represented 20% of the group. Thus, most of the marching band members were not affected by the marching band music exposure, as measured by changes in pure-tone thresholds. It is possible that most of these musicians' ears have developed some protection, due to their many years of musical training (i.e., prior low level noise exposure), known as cochlear toughening.

DPOAE Recovery.

During DPOAE testing, there were approximately 20 ears at each frequency that demonstrated decreased amplitudes. At 3000 Hz, 60% of the group demonstrated some amount of decrease in DPOAE amplitude, at 4000 Hz, 70% demonstrated a decrease, and at 6000 Hz, 50% of the group had a decrease in DPOAE amplitude. The majority of these ears exhibited recovery upon follow-up testing the next morning. The changes between pre-practice and post-practice testing were found to be significant, as well as the recovery between post-practice and follow-up testing the next morning. These findings were expected by the investigators, as the marching band members selected for this study had exceptional auditory systems and it was hypothesized that their outer hair cells would be able to recover quickly. DPOAE recovery patterns have been reported by multiple authors; however, exposure times differ widely from the current study (e.g. three minutes versus two hours) and therefore inter-study comparisons are difficult (e.g. Sutton, et al., 1994). However, the findings are consistent with other studies which have found recovery to occur within 24 hours. It should be noted, however, that a certain portion of the recovery demonstrated in the current investigation could be attributed to regression to the mean, as only those with poor thresholds post-practice were selected for follow-up testing.

TEOAE Recovery.

During broadband and narrowband TEOAE testing, there were approximately 11 amplitude decreases at each frequency range and all recovered to some degree. In the marching band group, 70% had a decrease in narrowband TEOAE emission level, while only 35% of the cohort experienced a decrease in their broadband TEOAE emission levels. The changes between pre-practice and post-practice testing were found to be significant, as well as the recovery between the post-practice and follow-up test intervals. These findings were expected by the investigators, as the marching band members selected for this study had exceptional auditory systems and it was hypothesized that their outer hair cells would be able to recover quickly. These results agree with Marshall and Heller's findings that TEOAE emission levels recovered in approximately a three-hour time span (Marshall and Heller, 1998). However, in the Marshall and Heller study, participants were only exposed to the 105 dB SPL sound for a 10 minute time period. The current results also agree with Quarenta, et al. (1998), who state that for persons exposed to less than eight hours of noise, their TTS will recover linearly in log time, and the authors suggest that for small amounts of TTS, recovery will happen within a 24 hour period. In the current study, it is important that the band members' outer hair cells were able to recover quickly, as the band members did not have a 24-hour noise-free period during the week. This repeated noise exposure without sufficient recovery time might have compounded the amount of outer hair cell damage if not for their quick outer hair cell recovery. As noted for the DPOAEs, some of the recovery observed for TEOAEs could be attributed to regression to the mean.

Personal Factors.

Overall, the band members were in good health, and 100% of the cohort were non-smokers. According to Barrenas and Hellstrom (1996) and Barrenas and Lindgren (1991) eye color might be related to the amount of TTS caused by noise exposure. These studies showed not only that people with brown eyes developed the least amount of TTS when exposed to 105 dB SPL for 10 minutes, but also that blue-eyed participants could be exposed to low-level acoustic stimulation and subsequently experience less TTS due to ear toughening. The results of the current study do not agree with these findings. No statistical tests could be completed, as the sample was too small in each eye color group. While there were blue-eyed and brown-eyed participants in the marching band, there was no systematic relationship between eye color and the amount of pure-tone TTS experienced. Similarly, there was no pattern relating eye color and reduction in DPOAE amplitude or TEOAE emission levels. Participants with both brown and blue eye colors experienced decreases in their DPOAE amplitudes and TEOAE levels. In addition, there was no clear pattern regarding instrument played and amount of significant shifts in pure-tone, DPOAE and TEOAE measures.

Limitations of the Study

The musicians in the present study have been playing their respective instruments for a minimum of six years. Therefore, the experimental group was not a “clean” group of ears who had never been exposed to loud music before the commencement of this study. It would take many years to be able to conduct a prospective study beginning with unexposed ears. A study would have to follow the musicians from their first days of learning the instrument, typically during their elementary school years, and continue to follow them through their time in a university marching band more than six years later. Although this was unrealistic for the current study, it might be an idea for a future investigation.

It is possible that the participants selected for this study had exceptional auditory systems, as the selection criteria were stringent. The musicians and control group members who already experienced a hearing loss were excluded from the study, therefore introducing a possible selection bias. Also, those musicians or control group members who thought that they might already have a hearing loss possibly did not try to become eligible for the study, as they already knew that they would not be selected, or they did not want to find out their current hearing sensitivity.

The measurement of OAEs is a difficult process. Due to the indirect nature of this measurement, there are many interfering factors that affect these measurements. Noise from body movements and breathing can cause differences in the outcomes. The participants were asked to remain as quiet and still as possible during the measurements.

Additionally, the small number of measurement runs at each f2 frequency might have contributed to some variations in the results. Other authors have run their participants in these measures for up to six hours per participant. However, this is unrealistic for assessment of a temporary change in auditory functioning, particularly among college students who have many demands on their time.

All participants were required to have normal hearing thresholds and present OAEs (measurable above the noise floor) at the commencement of the study. Therefore, the musicians who were included in this study might have had exceptionally resilient auditory systems. The prior exposure to moderately loud music for many years might have toughened their auditory systems to become accustomed to the high decibel levels and therefore they may not experience as much TTS as a group of participants who were not regularly exposed to extended periods of moderate levels of any noise source. There have been studies proving the validity of the "toughening" concept, such as White, et al. (1998) who demonstrated in gerbils that the amount of TTS was reduced when the animals were exposed to continuous and intermittent noise, similar to the exposure of the marching band members who are exposed to years of practice and performance. While strict eligibility criteria are important for a well-designed study, as discussed earlier, those criteria excluded some potential participants.

Another limitation of the present study was that the control participants may have been exposed to loud sound during the course of the study. It is possible that their roommates could have turned on loud music or they might have walked alongside the road while fire engines were passing. They might have seen a loud movie or traveled on the subway. Although each participant filled out a questionnaire at the end of the study and claimed to have a "noise-free" week, there is always the possibility of an error or misjudgment in their reports.

Every band practice is not identical. Therefore, a participant's location in the multiple band formations could affect the amount of sound exposure during practice and performances. It is possible that while they practice formation A, the brass section is closer to the louder percussion section. Later in the week, they may practice only formation B, placing the percussion section closest to a different section of the band.

Also, there were some practices when the band split up and practiced on separate areas of the field, with only their respective sections. These changes in exposure can alter the results depending on the day each musician was tested. There were also differences in the amount of exposure that occurred during the two-hour practices. If the band was learning a new musical piece, it is possible that they were playing more intermittently than if they were simply practicing an old favorite of the band. Also, when they were learning new formations, there were times when there was less practicing with the instruments, as they were learning how to walk from one formation to the next formation.

Follow-Up Studies

Follow-up studies might include testing auditory functioning before and after performances at the football games, or focusing on those musicians who have played for a specific number of years or play specific types of instruments. A noise dosimeter attached to each musician's lapel would provide for individualized sound level measurements. It would also be helpful to attach a noise dosimeter to the control group participants during their experimental week to determine the accuracy of their noise exposure levels. It would be useful to conduct a longitudinal study following students from the time that they are learning their instrument, as a child, through the time that they are performing with the university's marching band. Another possible experiment would be to determine the amount of pure-tone threshold and OAE amplitude shifts in beginner musicians who follow a similar practice schedule to the university marching band. It would also be useful to follow the musicians throughout their time at the university.

Chapter 8: Summary/Conclusions

During the course of a one-week period of time, members of the Mighty Sound of Maryland Marching Band are exposed to high sound levels during two practice sessions. Measurements of pure-tone thresholds, DPOAEs and TEOAEs indicate that some aspects of auditory function are affected by participation in the Marching Band. The principal findings were:

1. Sound level recordings at a location close to the center of the marching band were documented to be 85-105 dB(A) with peaks measured at 114 dB(A).
2. Marching band members, on average, show significant changes in auditory function following a two-hour band practice, primarily in high frequency hearing thresholds and TEOAEs. The latter reflects possible alterations in cochlear function.
3. A comparison of auditory measures between the marching band members and the control participants revealed significant differences between their narrowband and broadband TEOAEs and pure-tone thresholds at 8000 Hz.
4. Individual marching band participants showed clinically significant changes in pure-tone thresholds, DPOAEs and TEOAEs, but, on average, these participants also showed significant recovery of auditory functioning within 24 hours.

Taken together, marching band members with good hearing sensitivity exhibit significant, but temporary, changes in auditory function following marching band practice. It is unknown how many times the ear can suffer a TTS and still go through the recovery process, as TTS can be a forewarning of future PTS (Chasin, 1996). Therefore, it is important that musicians wear appropriate earplugs during each practice session and performance to avoid hearing loss. There are specially designed earplugs which attenuate the sound level, while preserving the music. Even if the musician does not perceive that he is experiencing a hearing loss from the music, there could be subtle changes occurring in the cochlea, which over time might cause a permanent hearing loss. Musicians must protect their hearing before it is too late.

List of Appendices

Appendix A

Noise Levels

Noise Levels

Both the amount of noise and the length of time you are exposed to the noise determine its ability to damage your hearing. Noise levels are measured in decibels (dB). The higher the decibel level, the louder the noise. Sounds louder than 80 decibels are considered potentially hazardous.

This noise chart gives an idea of average decibel levels for everyday sounds around you.

Painful:

150 dB = rock music peak (at a concert)
140 dB = firearms, air raid siren, jet engine
130 dB = jackhammer
120 dB = jet plane take-off, amplified rock music at 4-6 ft., car stereo, band practice

Extremely loud:

110 dB = rock music at a concert, model airplane
100 dB = snowmobile, chain saw, drill
90 dB = lawnmower, shop tools, truck traffic, subway

Very loud:

80 dB = busy street
70 dB = busy traffic, vacuum cleaner
60 dB = loud conversation, dishwasher

Moderate:

50 dB = moderate rainfall
40 dB = quiet room

Faint:

30 dB = whisper, quiet library

Please refrain from exposing yourself to sounds in the **extremely loud** and **painful** categories during the 48 hours prior to and during your designated experimental period.

If you are going to listen to your IPOD/personal stereo system: Please listen at a quiet volume setting, which we suggest to be no louder than 1/3 volume.

Adapted from: http://www.asha.org/public/hearing/disorders/

Appendix B

Consent Form for Band Members

Consent Form for Band Members

Initials_______ Date_______

Consent Form

Project Title	Noise Induced Hearing Loss and College Marching Band Members
Why is this research being done?	This is a research project being conducted by Barbara Libbin and Dr. Sandra Gordon-Salant at the University of Maryland, College Park. We are inviting you to participate in this research project because you are a University of Maryland, College Park undergraduate student who is a member of the Mighty Sound of Maryland marching band. The purpose of this research project is to understand the effects of participating in a marching band on your hearing.
What will I be asked to do?	The procedures involve participating in subjective and objective non-invasive auditory tests, as well as completing questionnaires. You will be asked to refrain from exposing yourself to harmful levels of noise (other than marching band practice/ performance) during 48 hours prior to and during a four-day designated experimental period. You will be provided with written information regarding harmful noise levels that should be avoided. You will be asked to come to the University of Maryland Audiology Clinic to fill out a case history form and to have a full hearing evaluation at a determined time. During the first part of the evaluation, a small rubber tip will be placed in your ear and you will hear tones and feel pressure in your ears. This test is automatic, so you will not need to respond. Afterwards, you will be asked to raise your hand when you hear tones through earphones or through a vibrator placed behind your ear. In addition, before and after two predetermined, successive practices/ performances with the marching band, you will come to the audiology clinic for limited evaluations of your hearing sensitivity, to last approximately 20 minutes each. If there is any change noted in your hearing, you will be asked to come back to the Audiology Clinic the following morning to have a short retest of your hearing. Additionally, at your last brief hearing test, you will write down your impressions of your exposure to harmful levels of noise during the four-day experimental period. All of your results will be discussed following the completion of all of the testing sessions (one preliminary testing day and four to six visits during the four-day experimental period).
What about confidentiality?	We will do our best to keep your personal information confidential. During the study, your data will be identified with a code number only. To help protect your confidentiality, your information will be stored in the locked file cabinet in the Hearing Science Laboratory (suite 0119 LeFrak Hall). If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.
What are the risks of this research?	There are no known risks associated with participating in this research project. The levels of sounds presented to your ears will not be at

	levels or durations that are harmful to hearing.
What are the benefits of this research?	The primary benefit to you is a free hearing evaluation. We hope that the information learned in this study might benefit other people through improved understanding of how exposure to marching band music causes temporary and permanent hearing loss.

Initials_______ Date_______

Project Title	Noise Induced Hearing Loss and College Marching Band Members
Do I have to be in this research? May I stop participating at any time?	Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. Your participation may be terminated if during the initial hearing evaluation you are found to have a hearing loss or if you are a part of the control group and are exposed to noise within 48 hours before or during the experimental week.
What if I have questions?	This research is being conducted by Dr. Sandra Gordon-Salant (Department of Hearing and Speech Sciences) at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Dr. Sandra Gordon-Salant at 301-405-4225; 0100 LeFrak Hall, College Park, MD 20742, sgordon@hesp.umd.edu. If you have questions about your rights as a research participant or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; irb@deans.umd.edu; 301-405-0678. This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human participants.
Statement of age of subject and consent	Your signature indicates that: You are at least 18 years of age; The research has been explained to you; Your questions have been fully answered; and You freely and voluntarily choose to participate in this research project.
Signature and Date	Name of Participant________________________ Signature of Participant______________________ Date_______________

Appendix C

Consent Form for Non-Band Members

Consent Form for Non-Band Members

Initials_______ Date_______

Consent Form

Project Title	Noise Induced Hearing Loss and College Marching Band Members
Why is this research being done?	This is a research project being conducted by Barbara Libbin and Dr. Sandra Gordon-Salant at the University of Maryland, College Park. We are inviting you to participate in this research project because you are a college student who is not a member of a band. The purpose of this research project is to understand the effects of participating in a marching band on hearing.
What will I be asked to do?	The procedures involve participating in subjective and objective non-invasive auditory tests, as well as completing questionnaires. You will be asked to refrain from exposing yourself to harmful levels of noise during 48 hours prior to and during a four-day designated experimental period. You will be provided with written information regarding harmful noise levels that should be avoided. At the beginning of the predetermined four-day time period, you will be asked to come to the University of Maryland Audiology Clinic to have a full hearing evaluation and fill out a case history form. During the first part of the evaluation, a small rubber tip will be placed in your ear and you will hear tones and feel pressure in your ears. This test is automatic, so you do not need to respond. Afterwards, you will be asked to raise your hand when you hear tones played through earphones or through a vibrator placed behind your ear. At the end of the experimental period, you will be asked to return to the Audiology Clinic to write down your exposure to harmful levels of noise during the four-day experimental period and you will have a brief hearing test. All of your results will be discussed following the completion of the two audiological tests during the four-day experimental period.
What about confidentiality?	We will do our best to keep your personal information confidential. During the study, your data will be identified with a code number only. To help protect your confidentiality, your information will be stored in the locked file cabinet in the Hearing Science Laboratory (suite 0119 LeFrak Hall). If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.
What are the risks of this research?	There are no known risks associated with participating in this research project. The levels of sounds presented to your ears will not be at levels or durations that are harmful to hearing.
What are the benefits of this research?	The primary benefit to you is a free hearing evaluation. We hope that the information learned in this study might benefit other people through improved understanding of how exposure to marching band music causes temporary and permanent hearing loss.

Initials_______ Date_______

Project Title	Noise Induced Hearing Loss and College Marching Band Members
Do I have to be in this research? May I stop participating at any time?	Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. Your participation may be terminated if during the initial hearing evaluation you are found to have a hearing loss or if you are a part of the control group and are exposed to noise within 48 hours before or during the experimental week.
What if I have questions?	This research is being conducted by Dr. Sandra Gordon-Salant (Department of Hearing and Speech Sciences) at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Dr. Sandra Gordon-Salant at 301-405-4225; 0100 LeFrak Hall, College Park, MD 20742, sgordon@hesp.umd.edu. If you have questions about your rights as a research participant or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; irb@deans.umd.edu; 301-405-0678. This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human participants.
Statement of age of subject and consent	Your signature indicates that: You are at least 18 years of age; The research has been explained to you; Your questions have been fully answered; and You freely and voluntarily choose to participate in this research project.
Signature and Date	Name of Participant________________________ Signature of Participant______________________ Date_______________

Appendix D

Case History Form (For all Participants)

Case History Form **Page 1 of 2**

Code number:

<u>General Information</u>

1. Name:
2. Address (local):
3. Address (permanent):
4. Local phone:
5. E-mail address:
6. Date of birth:
7. Race:
8. Year in school:
9. Major:
10. Are you right or left handed?
11. What is your eye color?
12. Do you smoke currently? Did you smoke in the past? How long ago did you quit?
13. Do you work?
    a. If yes, please list all jobs.

<u>Medical Information</u>

1. Do you suspect you have a hearing loss?
2. Have you had your hearing tested in the past?
    a. What were the results?
3. Do you have any family history of hearing loss?
4. Medical history (including medical conditions):
5. Please list any allergies:
6. Have you had any medical problems involving your ears?
    a. Have you experienced reoccurring ear infections?
    b. If yes, please explain.
7. Please list all current medications:
8. Do you take aspirin? Have you taken aspirin within 24 hours?
9. Please list all past serious illnesses:
10. Please list any head traumas:
11. Please list any hospitalizations:
12. Have you ever had surgery?
    a. If yes, please specify.

Hearing History

1. Please list all past significant noise exposure (ex. hunting, rock concerts, headphone use at loud levels, IPOD use, military, machinery, motorcycle):

2. On a scale of 1-10 (10 being the loudest) how loud do you listen to:
    a. Your car stereo?
    b. You home stereo?
    c. Your IPod?
    d. Your TV?
3. Have you been exposed to noise within the past 48 hours?
    a. What type of noise?
    b. Was hearing protection (earplugs/earmuffs) used?
4. Do you experience ringing in your ears?
    a. On a scale of 1-10 (10 being the loudest), how loud is the ringing?
    b. On a scale of 1-10 (10 being the most),how much does it interfere with your daily activities?
    c. How often do you experience ringing?
    d. When do you experience ringing?
    e. In both ears?
5. Do you ever feel dizzy?
    a. On a scale of 1-10 (10 being the most),how much does it interfere with your daily activities?
    b. How often do you experience dizziness?
    c. When do you experience dizziness?
6. Are there any situations during which you have difficulty hearing the speaker?

Appendix E

Additional Case History Form (For Marching Band Members)

Code number:
Page 1 of 2

Musical History

1. What instrument do you play?
2. How long have you been playing this instrument?
3. Have you played in a band before college?
    a. How many years were you in that band?
    b. What settings did you play in?
4. Do you wear hearing protection while you are practicing?
5. In what setting do you mostly practice your instrument?
6. How many hours per day did you practice during the summer months?
7. How many hours a day do you practice during the school year?
8. How many hours a week do you perform with the University of Maryland marching band?
9. What instruments do you stand next to during the marching band?
10. After practicing, do you hear a ringing in your ears?
    a. In one ear or both?
    b. How long does it continue for?
    c. On a scale of 1-10 (10 being the most), how much ringing do you experience?

11. After <u>performing</u>, do you hear a ringing in your ears?
    a. In one ear or both?
    b. How long does it continue for?
    c. On a scale of 1-10 (10 being the most), how much ringing do you experience?
12. After <u>practicing</u>, do you feel you have a hearing loss?
    a. In one ear or both?
    b. How long does it continue for?
    c. On a scale of 1-10 (10 being the most), how much hearing loss do you experience?
13. After <u>performing</u>, do you feel you have a hearing loss?
    a. In one ear or both?
    b. How long does it continue for?
    c. On a scale of 1-10 (10 being the most), how much hearing loss do you experience?
14. Do you take any music classes? How often?
15. Are you exposed to loud music during those classes?
    a. For how many minutes?
16. Are there other people playing instruments in close proximity to you during those classes?
    a. For how many minutes?
    b. Do you wear hearing protection in those classes?

Appendix F

Recent Noise Exposure Form

Code number:____

Please answer the following questions about your exposure to noise since the time of your first hearing test for this investigation:

1. Amount of noise exposure ____ hours
    a. Types of noise exposure:
        i. Metro
        ii. Hair Dryer
        iii. Concert/Loud Music
        iv. Airport
        v. Traffic
        vi. Fire Alarm
        vii. Mechanical Equipment
        viii. Blender
        ix. IPOD/ Personal Stereo
        x. Other_________________________________
    b. Would you say the noise was loud? Very loud? Extremely loud?
2. Did you experience ringing in your right ear? Yes No
3. Did you experience ringing in your left ear? Yes No
4. Did you experience any dizziness? Yes No
5. Did you experience any amount of hearing loss in your right ear? Yes No
6. Did you experience any amount of hearing loss in your left ear? Yes No

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