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Pitch perception of musicians and non-musicians: a comparison of psychological tuning curves and frequency limens

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PITCH PERCEPTION OF MUSICIANS AND NON-MUSICIANS: A COMPARISON OF PSYCHOPHYSICAL TUNING CURVES AND FREQUENCY DIFFERENCE LIMENS

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ABSTRACT

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A group of classically trained musicians and a group of non-musicians were compared using psychophysical tasks of pitch perception to determine the effect of musical training on the auditory mechanism. Two measurements, frequency difference limens (DLFs) and psychophysical tuning curves (PTCs) were gathered for each subject at four frequencies in each ear separately. Results indicated a significant difference between musicians and non-musicians at three frequencies for DLF measures, and no significant findings regarding PTC measurements. These findings reveal a significant musical training effect on DLF outcomes, while the effect of musical training on PTCs, if any, remains to be determined. Implications of this study support changes in measureable auditory skills resulting from auditory training through music, and suggest that the frequency selectivity at the level of the cochlea is different between musicians and non-musicians. Additional studies are needed to demonstrate auditory differences between musicians and non-musicians using other psychophysical measurements beyond DLFs.

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LIST OF ABBREVIATIONS

dB	decibel
dB HL	decibel hearing level
dB SL	decibel sensation level
dB SPL	decibel sound pressure level
DLF	difference limen for frequency
DPOAE	distortion product otoacoustic emissions
Hz	hertz
kHz	kilohertz
NIHL	noise-induced hearing loss
PTC	psychophysical tuning curve
SOAE	spontaneous otoacoustic emission
TEOAE	transient evoked otoacoustic emission

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CHAPTER I

Introduction

Statement of the Problem

Pitch perception, the psychological correlate to frequency discrimination, is one of the least understood auditory processes in humans. While research supports that tonotopic organization exists at all levels of the central auditory nervous system, including the cortex, the exact processes involved in pitch perception are largely unknown. Closely related to pitch perception is masking, which is the ability of one sound to be covered, or masked, by another sound to the point that the original sound is inaudible. Several theories regarding pitch perception and masking have been hypothesized and tested, including theories of how pitch perception is affected by timing, location of maximum displacement on the basilar membrane, and neural organization (Gelfand, 2010). One such theory explaining the dynamics of pitch perception is critical band theory, which describes the basics of masking principals as well as the limits of pitch perception (Fletcher, 1940). Ideas surrounding critical band theory are largely supported through psychophysical experiments, which measure the psychological perception of frequency changes; the smaller the noticeable difference between pitches, the more accurate the pitch perception.

Musicians are known for their outstanding ability to distinguish pitch, at times perfectly, in several timbres of instruments, voices, and tones. Studies comparing musicians and non-musicians show a quantifiable difference in pitch perception, speech in noise abilities, and even cortical differences (Kishon-Rabin, Amir, Vexler, & Zaltz, 2001; Micheyl, Delhommeau, Oxenham, & Perrot, 2006; Nikjah, Lister, & Frisch, 2008; Spiegel & Watson, 1984); but no studies comparing musicians and non-musicians using psychophysical tuning curves (PTCs) currently exist. Psychophysical tuning curves are a measure of critical bands in the cochlea. Through psychophysical experiments, it is possible to measure the pitch perception of musicians against that of non-musicians (such as with frequency difference limens [DLFs], which measure the smallest perceptible pitch change from a center frequency), and compare the results quantifiably with a figure of PTC slope called the Q10 value. Research has also shown that otoacoustic emissions (OAEs) have an effect on PTC measurements. Spontaneous otoacoustic emissions (SOAEs), when found at or near tested center frequencies, increase overall Q10 values, and should be taken into account during PTC assessments. The results of these experiments could support the assumption that musicians have superior pitch perception capabilities than non-musicians, which might imply that strenuous aural training experienced by musicians effectively sharpens their frequency resolution abilities. It may be possible to measure the limits of human pitch perception by comparing non-musician, normal-hearing listeners to expertly trained musicians (Kishon-Rabin et al., 2001).

Rationale

- Research comparing the difference limens for frequency (DLFs) between musicians and non-musicians has shown that the DLFs for musicians are significantly smaller than those of non-musicians (Kishon-Rabin, Amir, Vexler, &

Zaltz, 2001; Micheyl, Delhommeau, Oxenham, & Perrot, 2006; Nikjah et al., 2008; Spiegel & Watson, 1984).

- Research comparing psychophysical tuning curves of musicians against non-musicians has not yet been accomplished.
- Psychophysical tuning curves give a more accurate representation of the critical bandwidth of the basilar membrane than difference limens for frequency; by using PTCs as a measurement of pitch perception, more information about the physical properties of the cochlea are known. Tuning curves are quantified by quality, or Q10 values, which are measurements of the slope of the PTC, 10dB above the lowest point in the tuning curve (Kluk & Moore, 2004; Micheyl & Collet, 1994).
- Research has shown a relationship between SOAEs and PTC Q10 values, which could potentially skew PTC comparisons between musicians and non-musicians (Micheyl and Collet, 1994; Bright, 1985).
- More research is needed to confirm the quantifiable differences between musicians and non-musicians in the field of audiology.
- Further research on the effect of aural training on the auditory filter, or critical band, is needed in the field of audiology.

Research Goal

The purpose of this study was to investigate the effect of musical training on pitch perception capabilities and the auditory filter, measured by psychophysical tuning curves and frequency difference limens. By comparing the two groups of musicians and non-musicians, more information about the nature of pitch perception and the effect of aural training on the hearing mechanism can be obtained.

Research Questions

Q1: Are frequency difference limens significantly smaller in musicians than non-musicians?

Q2: Are Q10 values for psychophysical tuning curves significantly higher for musicians than non-musicians?

Q3: Is there a correlation between small frequency difference limens and high Q10 values for psychophysical tuning curves?

Hypotheses

H1: There will be smaller difference limens for frequency observed in the musician participants than the non-musicians.

H2: There will be higher Q10 values for psychophysical tuning curves observed in the musician participants than the non-musicians.

H3: There will be a negative correlation between DLFs and Q10 values, in that the smaller the DLF, the higher the Q10 value.

CHAPTER 2

Review of the Literature

Pitch Perception in Humans

The auditory system functions on a network of redundancies and checkpoints that allow a signal to reach the brain uninterrupted. When sound signals reach the ear, they are processed by several different structures, and are perceived by the listener to have a specific pitch, loudness, duration, and timbre, or quality. Pitch perception in particular is one of the least understood mechanisms of the auditory system, especially as it relates to differences between listeners with special auditory experiences, such as musicians.

Pitch is the psychological correlate to frequency; it is dependent on the acoustic parameters of the stimulus (Loven, 2009). The frequency at which a sound wave oscillates determines the perceived pitch. The cochlea, as well as parts of the higher auditory system, is organized tonotopically, meaning that sounds that are similar in frequency are processed in distinct cochlear locations and beyond. The tonotopic nature of the central auditory system has been demonstrated through fMRI studies measuring cortical activation during listening tasks (Humphries, Liebenthal, & Binder, 2010).

Though some major landmarks in the auditory system are tonotopically organized, frequency information is also deciphered by timing differences in the neural firing of the auditory pathway. These two conditions are separated into theories of pitch perception called place theory and timing theory (Gelfand, 2010). Place theory is the idea that pitch perception is dependent on the tonotopic organization of the basilar membrane, organization of frequency-specific fibers in the vestibulocochlear nerve, and the further tonotopic organization of the auditory cortex. Timing theory is the conjecture that pitch perception is dependent on the synchronous, organized firing of neurons in the auditory system that correlate to specific frequencies. Most hearing scientists agree that pitch perception is a result of a merging of both theories, with lower frequencies distinguished via timing, and higher frequencies starting around 5000 Hertz (Hz) relying on place, and the frequencies in between perceived via both processes (Moore, 1973). Despite the auditory system being composed of several tonotopic "checkpoints," most frequency selectivity occurs at the level of the cochlea (Micheyl & Collet, 1994).

While an increase in frequency also correlates to an increase in perceived pitch, the relationship is not linear. Typically, normal-hearing listeners are capable of perceiving frequencies between 20 and 20,000 Hz. A doubling in frequency corresponds to an octave of pitch, and is measured by a specific number of Hz. Pitch, unlike frequency, is measured by the mel scale, a subjective unit for pitch, that is only exactly correlated to the reference frequency of 1000 Hz at 40 dB SPL, or 1000 mels (Siegel, 1965). In comparison to the number of frequencies perceived by normal humans, the mel scale is much smaller, fitting 20,000 Hz of frequency into only 3,330 mels (Gelfand, 2010).

Musicians vs. Non-musicians as Listeners

Musicians in general are specialized listeners, both because of their exposure to sound and because of their use of sound as a profession. Experiments not specifically measuring pitch perception indicate differences between musicians and non-musicians as listeners (Chartrand & Belin, 2006; Parbery-Clark, Skoe, Lam, & Kraus, 2009). These studies have compared timbre discrimination, speech discrimination in background noise, and the aging auditory system in musicians versus non-musicians.

In an experiment by Chartrand and Belin (2006), timbre discrimination, the musical quality that distinguishes the source of a musical sound from another, was compared for musicians and non-musicians. Thirty-six participants, both male and female, were recruited for the study. The 17 musicians included a mixture of vocalists and instrumentalists who had at least three years of formal training. Two groups of stimuli, one of sounds produced by musical instruments and one of vocal presentations, were used in the experiment in groups of two. Participants were required to choose if both the stimuli in each trial came from the same or a different source. Results proved to be statistically significant for musicians versus non-musicians; musicians performed better at distinguishing within both groups of stimuli, suggesting that training in instrument timbre made them more advanced at distinguishing vocal differences as well, though the vocal tasks were more difficult for both groups (Chartrand & Belin, 2006).

Musicians have also been found to have better discrimination of speech in the presence of background noise (Parbery-Clark et al., 2009). Using the *Quick Speech-in-Noise* test (QuickSIN) and the *Hearing in Noise Test* (HINT), 16 musicians were tested against 15 non-musicians to determine whether or not musical training has any effect on speech-in-noise testing; a frequency discrimination task was also included to confirm the correlation between improved frequency discrimination and speech-in-noise discrimination scores. Both the QuickSIN and the HINT are speech-in-noise tests that assess a listener's ability to distinguish a target message in the presence of competing sound, either broadband noise or speech. Participants included young adult males and females, and musicians were all required to have no less than ten years of formal training; unlike other studies comparing the abilities of musicians and non-musicians, some of the non-musician participants had some past musical experience, but no more than three years of training. Assuming that musicians have better working memory and frequency discrimination than non-musicians, it was hypothesized that scores for both tests would differ significantly. Results confirmed that years of musical training had a positive correlation with QuickSIN scores; musicians were able to repeat sentences at more challenging signal-to-noise ratios than non-musicians. While performance on the QuickSIN confirmed the authors' hypothesis, the HINT scores were not significantly different between musicians and non-musicians, which suggest that while the tests are similar, they may not be measuring the same skill (Parbery-Clark et al., 2009).

Musical experience also has an effect on the aging auditory system (Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011). As shown by Parbery-Clark et al. (2009), enhancement of understanding speech in noise as a result of musical training supports malleability of the auditory system; however, that study included only young adult participants. Parbery-Clark et al. (2011) evaluated normal-hearing musicians and non-musicians between the ages of 45 and 65. All 18 musician participants began musical training at or before the age of nine, and consistently, as well as currently, played their musical instruments. Nineteen non-musician participants either had no musical experience whatsoever, or minimal experience playing an instrument (less than three years). For auditory acuity, all participants completed the HINT, the QuickSIN, the

Words in Noise test (WIN) and a test of visual working memory (VWM). The results of all three speech-in-noise tests were significantly better for the musician participants (meaning that corresponding signal-to-noise ratios were smaller for musician participants, indicating less difficulty in more challenging situations). The only test that was not statistically different between musicians and non-musicians was the VWM test. In addition, an assessment for auditory working memory, a subtest in the *Woodcock-Johnson III Test of Cognitive Abilities*, correlated positively to lower thresholds on the QuickSIN and the HINT, but not on the WIN test. It is possible that the WIN test evaluates a different auditory mechanism than the other two tests, which may rely more on auditory working memory. Overall, the results suggest that musical training may offset some of the negative auditory consequences of aging, specifically auditory working memory and understanding speech in noise (Parbery-Clark et al., 2011).

However, while musicians are specialized listeners, they may be more susceptible to noise-induced hearing loss because of their consistent exposure to loud sound. Noise-induced hearing loss is typically described clinically as a loss of hearing sensitivity in the high frequencies, specifically between 4 and 6 kHz, as a result of exposure to loud sounds (Cooper & Owen, 1976). Damage to the inner ear structures by noise is not limited to the inner and outer hair cells; supporting cells and the vascular system may also be affected. Injury to these structures may be caused by direct mechanical damage to the cochlea as a result of high-level impact noise or continuous noise greater than 115 dB, or by indirect damage to sensitive structures in the cochlea from long-term noise exposure and the resulting influx of neurotransmitters to the vestibulocochlear nerve (Bielefeld, Henderson, Hu, & Nicotera, 2007). The outer hair cells are the most susceptible to damage as a result of noise exposure because of their mechanical role in the cochlea; their ability to expand and contract in sync with the basilar membrane enhances frequency sensitivity because the presence of active mechanical energy amplifies the signal, contributing to the tuning and sensitivity of the organ of Corti (Brownell, Bader, Bertrand, & de Ribaupierre, 1985). This means that damage to the outer hair cells as a result of noise has a direct effect on pitch perception.

Musicians are exposed to everyday loud sound hazards as well as occupational noise due to their profession. Orchestral noise has been found to cause noise-induced hearing loss in musicians (Pawlaczyk-Luszczynska, Dudarewicz, Zamojska, & Sliwinska-Kowalska, 2011). Pawlaczyk-Luszczynska et al. (2011) measured sound pressure level exposure of orchestral musicians in one opera and three concert halls; not including personal practice time, they found that musicians were commonly exposed above the Polish standard for occupational noise intensity (85 dB) and, therefore, the musicians were at risk of developing noise-induced hearing loss. Individually by instrument, orchestral noise was measured at continuous levels in excess of 85 dB for flutes, oboes, clarinets, bassoons, trumpets, trombones, tubas, and percussion instruments; stringed instruments did not exceed 85 dB in continuous measurements, but all instruments exceeded 90 dB peak levels of intensity. Pawlaczyk-Luszczynska et al. (2011) developed a risk analysis for the musicians in the study in regards to noise exposure and age in relation to hearing loss; musicians that played the trumpet, horn, tuba and percussion instruments had the highest risk of developing hearing loss.

Another study conducted by Phillips, Henrich, and Mace (2009) focused specifically on prevalence of noise-induced hearing loss in student musicians at the college level. The level of noise exposure typically experienced by student musicians is less than that of industrial workers exposed to continuous noise for 8 hours per day, but their exposure is still beyond what can be considered risk-free. Over three hundred classical music students at the undergraduate college level were used in the study; 86% of the participants reported no use of personal hearing protection. The few that did use hearing protection did so less than half of the time. Overall, 45% of the students tested exhibited a notched audiogram at 4 or 6 kHz, typically associated with noise-induced hearing loss, in at least one ear. Notched audiograms were not specifically associated with a particular class of instruments; however, more fourth-year students had bilateral notches than the other three classes (Phillips et al., 2009). Noise-induced hearing loss may very well be a confounding factor in determining frequency discrimination between musicians and non-musicians due to the risk associated with orchestral noise exposure and the resulting damage to the hearing mechanism and outer hair cells.

Cortical Differences between Musicians and Non-Musicians

Musicians and non-musicians not only have subjective differences in distinguishing pitches, but there are physical differences at the level of the cortex between these two groups. In a study by Gaser and Schlaug (2003), 40 musicians were divided equally into professional and non-professional groups by gauging practice time per day. Professional musicians practiced at least one hour per day, which was roughly double that of the non-professional group. Forty non-musicians were age and IQ comparable to the musician groups. The results indicated a statistically significant positive correlation between practice time and gray matter changes, with amateur musicians falling directly between the high-practice professional musicians and the non-musicians. As determined through full body scan imaging, gray matter in professional keyboard musicians was denser than that of non-musicians; it was also denser than gray matter in non-professional musicians. The study was one example of musicians exhibiting use-dependent structural changes of the cortex; however, because this analysis was limited to male keyboardist participants, a generalization about all musicians based on this study should not be made (Gaser & Schlaug, 2003).

While the previously mentioned study did not demonstrate white matter differences between musicians and non-musicians, there is evidence to support the idea that normal pitch perception is tied to white matter connections as well. A study by Hyde, Zatorre, and Peretz (2011) showed that people with abnormal pitch perception capabilities suffering from amusia, or congenital tone-deafness, had reduced white matter in comparison to a group of normal-hearing controls. A functional MRI analysis of minute pitch changes in melodic sequences illustrated activation areas similar to those of normal listeners, suggesting that individuals with amusia may have normal functioning auditory cortices but have impaired connections between the auditory cortex and the inferior frontal gyrus, which results in pitch perception abnormalities.

Critical Band Theory and Psychophysical Tuning Curves

The cochlea is theorized as a series of filters, all responsible for separating specific frequencies into a range of responses. These filters, called critical bands, are activated by specific frequencies within their area of the basilar membrane in the cochlea. When a pure tone stimulus enters the cochlea, more than just a single point is activated; a small range of frequencies surrounding the central frequency is triggered. The filters overlap each other, and can actively be “shifted” by the listener when in situations of overwhelming background noise, in a phenomenon known as "off-frequency listening" (Gelfand, 2010). Off frequency listening makes it possible to focus on a particular stimulus in the presence of competing sound. Fletcher (1940) theorized that the cochlea is made up of these constantly shifting auditory filters. No studies currently exist to show whether or not these filters may be altered by the strenuous auditory training experienced by musicians. Normal listeners have narrow critical bands that allow for standard listening. Hearing loss may cause the filters to widen and become less accurate at picking out specific sounds. Other factors, such as intensity, affect the critical bandwidth: the louder the stimulus, the wider the critical band, and the larger the area of stimulation within the cochlea (Moore, 2007). The widening of the critical band in people with hearing loss may be a direct result of the phenomenon associated with increased intensity required to adequately hear the center frequency.

Critical bands can be measured and mapped on a graph called a psychophysical tuning curve (PTC). Tuning curves measure the frequency resolution of the cochlear response to a particular pure tone by determining the width of the auditory filter, or critical band; by obtaining a masked threshold above, at, and below a signal frequency, the responses are plotted to visually represent the neural response at a given frequency (Klein & Mills, 1981). Psychophysical tuning curves are measured through masking experiments, in which participants must report when they detect a signal with the presence of another tone or masking sound (Moore, 2007). Types of masking include forward masking, in which a narrow-band masking noise or tone is presented before the center frequency tone, and simultaneous masking, in which the masking noise or tone is presented with the center frequency tone (Moore, 1978). The shape of the PTC determines the frequency selectivity of the auditory filter; typically, PTCs have a pointed tip centered on the stimulus frequency, with a wider, lingering region as the data points move away from the center frequency (Halpin, 2002). Psychophysical tuning curves may be used to distinguish abnormalities in specific areas of the cochlea (Kluk & Moore, 2006). In ears with hearing loss, these tuning curves have altered shapes; ears with cochlear hearing loss, for example, have wide tuning curves and, if dead regions of the cochlea are present, the tip of the tuning curve may have a blunt end or a point that is shifted away from the desired center frequency to the nearest functioning outer hair cell (Kluk & Moore, 2006). This is because hair cell death in the cochlea results in areas with hyper-functioning hair cells that become responsible for the sound perception of previously present neighboring cells; the shifted point generally indicates the "edge" of the dead region. A dead region is an area of the cochlea in which both the outer hair cells and inner hair cells are damaged, to the point that no neuronal stimulation occurs in that area; therefore, basilar membrane stimulation is somewhat shifted to the closest functioning area (Moore, 2007). Moore does not illustrate the exact mechanisms involved in causing a cochlear dead region; he describes these insults as being identified through widened PTCs, but they may or may not be apparent on the pure-tone audiogram.

Conversely, a steep (higher) slope of a PTC indicates more accurate pitch perception; the quality value (Q10) measurement of PTC width quantifies the determined slope (Kluk & Moore, 2004; Micheyl & Collet, 1994). High Q10 values are consistent with steep PTCs and good frequency selectivity; low Q10 values indicate the opposite (Micheyl & Collet, 1994). Q10 values are calculated 10dB above the lowest level, dividing the stimulus frequency by the bandwidth of the PTC (Kluk & Moore, 2004).

Expected Q10 values from normal listeners using forward masking are approximately 6.5 for .5 kHz, 11.5 for 1 kHz, 15 for 2 kHz and 25 at 4 kHz (Moore, 1978). It is important to note that PTCs obtained with simultaneous masking have smaller Q10 values than PTCs obtained with forward masking, which is a result of a larger masking effect at lower intensities on the high frequency side of the tuning curve. For example, the mean Q10 value obtained at 1 kHz using simultaneous masking was 4.1, compared to the mean Q10 value using forward masking, 11.2; another measure at 6 kHz revealed a mean Q10 of 9 for simultaneous masking, and a mean Q10 of 16 in the forward masking condition (Moore, 1978). Both of these results indicate a decrease in Q10 value by a fraction no larger than 56% when simultaneous masking is used instead of forward masking. These values are used to evaluate pitch perception capabilities between groups in a quantifiable manner, but no research has currently been conducted to compare Q10 values for trained musicians and non-musicians.

While PTCs show differences in patients with normal hearing versus patients with hearing loss, some factors may still cause PTC abnormalities in participants with normal hearing (Kluk & Moore, 2004; Micheyl & Collet, 1994). In Kluk and Moore's 2004 study, technical problems in obtaining psychophysical tuning curves in normal participants were tested. Aural beats, interactions of two sinusoidal tones close in proximity, were purposely created to view the effect on PTCs by using a sinusoidal masker. Different masking bandwidths were also used to observe the altered shapes. It was discovered that the use of sinusoidal, or tone, maskers cause the PTC to have an abnormally sharp tip that is not an appropriate representation of the auditory filter; this was suspected to be a result of the easy to identify aural beats, even at low sensation levels. Narrow-band masking noise eliminated the aural beats altogether, and resulted in an appropriately shaped tuning curve. However, bandwidth of the noise masker did affect results: the wider the bandwidth of the auditory filter, the louder the masking stimulus. An appropriate masker bandwidth estimation of 0.8 times that of the stimulus tone was suggested by Kluk and Moore to achieve the most appropriate and accurate tuning curves, without the presence of aural beats or overwhelming masking noise (2004).

Another psychophysical experiment involving PTCs in normal listeners addressed the issues of quantifying PTCs through different methods, test-retest reliability of PTC testing, and probe tone levels (Stelmachowicz & Jesteadt, 1984). Psychophysical tuning curves were quantified using five methods in 19 normal-hearing participants, including: Q10 value, tip-to-tail difference, $d_{1\text{-oct}}$, low-frequency tail slope and high-frequency tail slope. While all the measurements made compared to prior research and proved to be viable quantitative measures, Q10 values and low-frequency slopes were shown to be possibly inappropriate in identifying changes in frequency analysis when hearing loss is present; tip-to-tail differences proved to be similar across all compared studies, which was a surprising finding because of the large variety of collection procedures used in said research. For test-retest reliability, 10 normal-hearing participants repeated a PTC experiment six times. Results indicated that the protocol used, a simultaneous noise masker and a 20 dB SL probe tone, created primarily consistent results supporting adequate test-retest reliability of PTC testing for group comparison as long as the same parameters for testing are used across all participants. Probe-tone effects were measured by repeating the same PTC experiment in all 19 normal-hearing participants at 20 to 70 dB SPL. Results showed that Q10 values were the only quantitative measures that were not drastically affected by increased probe tone level; tip-to-tail differences and $d_{1\text{-oct}}$ decreased with increased probe tone levels. These measurements are primarily relevant when comparing PTC results between normal-hearing and hard-of-hearing individuals, and may not be as significant when comparing two normal-hearing groups. This article is also significant because it provides specific normative values for the normal listeners used in the study (Stelmachowicz & Jesteadt, 1984).

Otoacoustic emissions (OAEs) may also affect PTCs. In a study performed by Micheyl and Collet (1994), it was found that spontaneous otoacoustic emissions (SOAEs) and amplitudes of transient-evoked otoacoustic emissions (TEOAEs) significantly altered psychophysical tuning curve Q10 values. For participants with present SOAEs, Q10 values for PTCs at 2kHz were higher than those without SOAEs, indicating greater pitch selectivity at that particular frequency; all participants with SOAEs were not included in the TEOAE portion of the experiment to eliminate an overlapping effect of both variables in the data. In participants with high-amplitude TEOAEs, Q10 values were significantly smaller than in participants with low-amplitude TEOAE results, also at 2kHz. Though these results are consistent with the theory that OAEs and frequency selectivity are related by active cochlear mechanisms, the precise reason why high Q10 values appear with present SOAEs and low-amplitude TEOAEs remains unknown. The authors hypothesized that the measurements made may not be sensitive enough to identify all active mechanism relationships, only those that are most significant, which could account for similar results at 2kHz for both groups (Micheyl & Collet, 1994). Bright (1985) found similar results confirming that frequency selectivity, as shown with PTCs, was improved in ears with SOAEs when the center frequency was at or near the SOAE frequency. In normal- hearing participants with SOAEs present in one ear and none in the opposite ear, Q10 values were higher in the ears with present SOAEs. More research on both the relationship between OAEs and frequency selectivity is needed; further research regarding OAE testing and PTC results in musicians has yet to be conducted.

Difference Limens for Frequency

A difference limen for frequency is a measure of the smallest difference in Hz needed to identify a pitch change for a given frequency. Historically, difference limens for frequency were difficult to obtain and verify due to the lack of controls in test stimuli and presentation, as well as controls in subject selection (Harris, 1952). Some of the first DLF experiments used devices such as tuning forks, whistles, strings, and rudimentary electronic sine waves to present stimuli to participants; these methods were difficult to control and validate as consistent due to the presence of harmonics and intensity differences. Participants then responded to stimuli, typically presented in pairs, by labeling stimuli as higher or lower/same or different in a method that would be described in modern experiments as a two alternative-forced-choice procedure (2AFC) (Harris, 1952). Frequency difference limens were then quantified by Weber's fraction, which takes the overall change in Hz divided by the center frequency ($DL=\Delta f/f$, where f = frequency in Hz); modern experiments use a variation on the original Weber fraction to assign percentages to DLF values, $rel\mathrm{DLF}\%=\Delta f/f \times 100$ (Kishon-Rabin, Amir, Vexler, & Zaltz, 2001; Spiegel & Watson, 1984).

One of the most comprehensive and controlled experiments on frequency difference limens was presented by Shower and Biddulph (1931). By using frequency-modulated stimuli instead of single continuous tones, difference limens were obtained bilaterally for five male respondents. Frequency modulation was used to eliminate harmonics as much as possible, as well as to reduce frequency variation. External filters were also used to eliminate harmonics in the amplifier circuit and power supply noise. Participants pushed a button when the frequency-modulated stimulus occurred in the presence of a non-modulated tone; the modulation was reduced continually until the subject could just detect a change in the stimulus. Shower and Biddulph tested each frequency at 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, and 90 dB SL for each subject to control for intensity. Results, calculated with the Weber fraction, indicated that difference limens were significantly smaller for lower-frequency stimuli, which is still consistent with current data on DLFs (Moore, 2007; Vaerenberg et al., 2011).

Generally, DLFs are measured two ways: with single-tone sine wave stimuli, or frequency-modulated (warble) stimuli. In comparison to the Shower and Biddulph (1931) experiment, frequency-modulated DLFs were larger than single-tone sine wave DLFs as measured by Harris in 1952. However, an experiment was conducted by Grisanti, Cusimano and D'Amico (1986) specifically comparing frequency-modulated DLFs and single-tone DLFs. In this experiment, 16 participants completed two automated tests. The first test was a single-tone sine wave experiment that presented two tone bursts; the first is the center frequency (f = .5, 1, 2, 3, 4, or 6 kHz) and the second is the center frequency + Δf, up to 20% (using a modified Weber fraction). This method used a Bekesy method-of-limits procedure, in which the subject held down a button as long as two different tones were heard, and the Δf decreased with each pair of tones as long as the button was held down. The number of reversals used in the experiment to approximate DLF was not specified. The second test used frequency-modulated stimuli, and the center frequency was modulated by Δf instead of adding it; participants were asked to press a button if a 300-msec frequency-modulated tone was perceived during a seven-second window, essentially answering “yes” or “no” if a warble tone was perceived. Overall, results of DLFs for frequency-modulated stimuli were smaller than for single-tone stimuli; however, the researchers commented that this may be due to the fact that the frequency-modulated test is much longer and demands more judgments from participants (Grisanti et al., 1986).

Wier, Jesteadt, and Green (1977) also experimented with DLFs; using a 2AFC procedure, Wier et al. (1977) compared DLF values at different sensation levels of Hz in a similar fashion to Shower and Biddulph (1931), only with single-tone stimuli. Using four participants, all with over 20 hours of experience with psychophysical experiments and two with musical backgrounds, they were able to use modern equipment and a computerized system to present stimuli and collect responses. The participants completed each trial of the center frequencies (f = .2, .4, .6, .8, 1, 2, 4, and 8 kHz) at 5, 10, 20, 40, and 80 dB SL to measure intensity differences; only results at 40 dB SL were used for study comparisons. In comparison to the Shower and Biddulph (1931) data, Wier et al. (1977) compiled results from other studies using single-tone stimuli and found that DLFs were larger in the low frequencies when frequency modulated stimuli was used, yet DLFs were smaller with the frequency modulated tones above 2 kHz, supporting a significant difference between the two methods. Using single-tone stimuli, expected DLFs in normal listeners fall between 1 and 2 Hz for .5 and 1 kHz, between 2 and 5 Hz at 2 kHz, and between 10 and 20 Hz at 4 kHz when presented at 40 dBSL (Harris, 1952; Moore, 1973; Moore, 2003; Wier et al., 1977).

Normal listeners accurately perceive pitch changes in familiar tunes, and can identify familiar tunes without the aid of lyrics (Peretz, Cummings & Dube, 2007). It is speculated that musical ability, much like language ability, is part of human nature. While it is known that normal listeners have the ability to distinguish minute changes in frequency, research suggests that musicians "perceive minute changes in musical pitch that are otherwise undetectable by non-musicians" (Bidelman, Krishnan, & Gandour, 2011, p. 534). Listeners with normal hearing are known to have a DLF for pitch of about 2 to 3Hz depending on frequency; lower frequencies result in larger DLFs when calculated as a percentage of center frequency (Moore, 2007; Vaerenberg et al., 2011). Frequency difference limens have been shown to be smaller for musicians than non-musical, otherwise normal listeners (Kishon-Rabin et al., 2001; Micheyl et al., 2006; Nikjah et al., 2008; Spiegel & Watson, 1984).

The Spiegel and Watson (1984) study of professional musicians versus non-musicians was an extensive venture to see if musicians had better pitch perception capabilities than the latter. A preliminary study of undergraduate students measured pitch discrimination abilities regardless of musical background; a survey post-selection was administered to gauge the musical ability of the participants. No significant correlation was found. Eleven graduate students of the Washington University School of Music were then used for a follow-up study, due to a possible lack of highly trained musician participants; because the graduate students had significantly higher scores on the pitch discrimination task, the researchers decided to use 30 musicians of a symphony orchestra as participants in the primary study. The musicians were compared against a group of age- and education-matched non-musicians; sex of the participants was not specified in this study. Musicians were separated into categories of instruments played, including brass, strings, woodwinds, and other instruments. Using two discrimination subtests, participants were asked to identify pitch changes in 300ms sine and square wave tones; results were plotted as line graphs for visual comparison. The stimuli were presented through speakers at about 75 dB SPL; the use of speakers as opposed to headphones, which are traditionally used in psychophysical experiments, may have somewhat altered the validity of this study because the results should not be directly compared to outcomes of research where headphones were used.

About one-half of non-musicians had DLFs significantly larger than those of the musicians in the single-tone sine wave DLF subtest; this test was essentially a traditional DLF experiment with two 300ms tones presented in succession, and participants needed to declare whether the stimuli were the same or different (Spiegel & Watson, 1984). All musicians had difference thresholds comparable to one another. Of those with thresholds near those of the musician group, it was revealed that those particular participants either had a high degree of musical experience despite not being musicians themselves, or they had extensive experience in psychophysical experiments and had learned to listen more carefully. This finding suggests that aural training affects DLFs. There were no significant differences in DLF results for musicians or non-musicians when using musical scale tones over non-musical scale frequencies. However, musicians who did not tune their own instruments regularly (participants in the “other instrument” category, using electronic tuners) had thresholds almost twice those of their self-tuning counterparts; this finding may or may not be valid due to small sample size. The DLF values reported in this study were converted from Hz to percentages, using the formula $rel\mathrm{DLF}\% = \Delta f/f \times 100$, where f = frequency in Hz, which was also used in the Kishon-Rabin et al. study (2001). This formula is consistent with early studies' use of Weber's Law for DLF values (Harris, 1952; Shower & Biddulph, 1931).

The results of psychoacoustic tests with professional musician participants may provide a standard limit of abilities of the human auditory system (Kishon-Rabin et al., 2001). In the Kishon-Rabin et al. (2001) study, a group of age-matched, normal-hearing, male participants completed a frequency discrimination task to measure DLFs. Of 30 total participants, 16 were professional musicians who played at least one musical instrument and performed in a musical group of some kind. The 14 non-musicians had no musical background or psychoacoustic testing experience, which was required to avoid the situation observed in the Spiegel and Watson (1984) experiment. Results were obtained first by using a three-interval forced choice procedure with three sets of non-musically indicative pure tones, meaning they selected the one different (higher pitched) stimulus among all three choices; these results were then compared to a two-interval forced choice procedure. As found in the Spiegel and Watson (1984) data, musicians had significantly smaller DLFs than the non-musicians, and over time, DLFs for both groups decreased. Frequency difference limen values were converted from Hz to relative DLF. Classically trained musicians had DLFs still smaller than the contemporary musicians; a similar trend in the musician group comparing years of musical training was also observed, specifically that less than 15 years of training resulted in larger DLFs. All DLFs were decreased during the two-interval forced choice procedure compared to the three-interval forced choice responses; however, because the experiment did not control for the 50% probability of a correct response during the two-interval forced choice procedure, the decrease may have been a result of chance. Overall, the authors concluded that persons with expertise in musical ability and training would out-perform normal listeners regardless of training on specific auditory tasks (Kishon-Rabin et al., 2001).

In a follow-up study performed by Micheyl et al. (2006), the measures used in the Spiegel and Watson (1984) study as well as the Kishon-Rabin et al. (2001) experiments were questioned. The authors felt that the non-musician participants in the Spiegel and Watson (1984) study were not adequately screened for either previous musical experience or history of participating in psychophysical experiments. Micheyl et al. (2006) evaluated both males and females, screened their non-musician participants for prior musical training and psychophysical experience, and included only musicians who worked full-time in a classical music setting and had at least 10 years of experience playing their instruments; they chose to use only classically trained musicians as a result of the Kishon-Rabin et al. (2001) study, which indicated that classically trained musicians had the smallest DLFs of any group tested. They separated their study into two parts, the first experiment consisting of a two-alternative forced choice procedure of about 2400 trials per subject to measure any possible training effect. The second experiment was even more extensive than the first, extending over numerous days per subject and explored several different test conditions, including testing each ear monaurally with and without contralateral noise masking, ensuring each subject performed around 6000 trials, again to measure training effect. The authors also tested monaurally to monitor possible ear effect. A 330 Hz DLF was repeated several times for this experiment, as opposed to a series of DLFs obtained at several different frequencies as in the Kishon-Rabin et al. (2001) and Spiegel and Watson (1984) studies; this frequency was chosen because it corresponds to the E4 note on the Western musical scale.

The researchers found that not only were DLFs for musicians smaller than those of non-musicians, they were about one-fourth to one-sixth the size of the non-musician group (Micheyl et al., 2006). This finding was surprising, considering that the Spiegel and Watson (1984) and Kishon-Rabin et al. (2001) authors found difference limens only about half the size of the non-musician participants. The authors hypothesized that the reason this particular study showed such drastic DLF differences was due to more stringent selection criteria. One particular finding regarding the musicians' instrument of choice agreed with data found in the Kishon-Rabin et al. (2001) study, namely that musicians who did not tune their own instruments (keyboards) had larger DLFs than musicians who tuned their instruments themselves (strings and wind instruments). However, while the musician thresholds were smaller than those of the non-musicians, a training effect was discovered in the non-musician group. As the experiment progressed, the non-musician thresholds approached the musician thresholds; musician thresholds also decreased, but not at the rate or significance of the non-musicians. It was concluded that four to eight hours of psychoacoustic training was necessary to obtain thresholds comparable to the musician group from the non-musicians. Despite the training effect, none of the non-musicians surpassed the musician thresholds for DLFs, indicating that a possible absolute limit to DLFs could be determined by musicians. A slight left ear advantage was found in the musician participants, which is consistent with prior research examining hemisphere advantage in pitch-perception tasks (Ohnishi et al., 2001).

Other researchers who have since compared psychophysical measures of pitch perception between musicians and non-musicians specifically examined the effect of vocal ability on DLFs. Nikjeh, Lister, and Frisch (2008) looked at the differences among 21 instrumentalists, 20 vocalists, and 20 instrumental vocalists (singers who were also trained in at least one musical instrument) compared to 20 non-musicians. The participants used in this study were all female, and musicians were required to have had a minimum of five years professional training for their respective instruments. The DLF method used in this study was a three alternative-forced-choice procedure of the frequencies 261.63 Hz, 329.63 Hz, and 392 Hz, which all correspond to notes in the Western musical scale. Frequency difference limen values were calculated in the same fashion as the Kishon-Rabin et al. (2001) and Micheyl et al. (2006) studies, using the formula $rel\mathrm{DLF\%}=\Delta f/f \times 100$. While the difference between DLFs in the musician groups were not statistically significant, the mean DLF for the non-musician group was significantly larger than all musician groups across all center frequencies (3.19% versus 1.35%, respectively) (Nikjeh, Lister, & Frisch, 2008).

Conclusion

Musicians and non-musicians have been compared and shown to have specific differences in frequency discrimination, cortical functioning, and distinguishing listening tasks. Despite previous studies indicating smaller DLFs for musicians than non-musicians, methods for each of these studies were significantly different enough, potentially, to cloud the results. As no data currently exists comparing PTCs for musicians and non-musicians, including that measurement could draw more accurate and specific conclusions about the physical properties of the critical band in musicians. By utilizing stringent recruitment criteria, male and female participants, and the most effective and practical procedure for data collection, reliable and valid results comparing musicians' versus non-musicians' pitch perception can be achieved.

CHAPTER 3

Methodology

Participants

Ten normal-hearing musicians as well as 10 normal-hearing non-musicians participated in the study, which included measurements of spontaneous otoacoustic emissions (SOAEs), difference limens for frequency (DLFs) and psychophysical tuning curves (PTCs). Participants included 9 males and 11 females, all between 21 and 31 years of age (mean age 26.5).

All participants completed a questionnaire regarding their musical experience, including: years of musical study, primary and secondary instruments, tuning habits, practice time per day, noise exposure, and whether or not they considered themselves to have tone deafness or perfect pitch. Musicians in the study were required to have an average practice time per day of at least one hour, excluding performance time. They must have studied in an undergraduate or graduate level education program for instrumental or vocal performance, and must have been trained as an instrumentalist or vocalist (including any organized band, orchestra, choir, or private lessons) for at least eight years, including college education. Non-musicians were defined as 1) not currently playing a musical instrument, 2) having no more than three years experience playing a musical instrument, 3) not participating as recreational vocalist in a band or choir, and 4) currently enrolled in college or having graduated from college. A summary of all participants can be found in Table 1.

Table 1

Individual Musical Background Information

Subject	**Sex**	**Age**	**Tone Deaf**	**Musician**	**Years of Study**	**Practice/Day (in hours)**	**Primary Instrument**	**Secondary Instrument**
1	F	26						
2	F	25						
5	M	26						
10	F	25						
12	F	23						
13	F	24	Y					
14	M	31						
15	M	27	Y					
17	F	26						
20	M	31						
3	F	26		X	8	3	Piano	
4	F	31		X	18	3	Flute	
6	M	21		X	11	2	Violin	
8	M	27		X	8	2	Bass	Guitar
9	M	23		X	10	2.5	Saxophone	Clarinet
11	M	31		X	20	3	Violin	Guitar
18	F	21		X	12	3.5	Violin	Piano
21	F	27		X	10	1.5	Vocalist	Piano
22	F	23		X	15	1	Flute	Piano
23	M	27		X	15	3	Clarinet	Sax
Mean		**26.05**			**12.7**	**2.45**		

The music history questionnaire included all of the categories in Table 1, as well as: perceived absolute pitch, history of noise exposure, experience as a solo vocalist, and tuning method. None of the participants reported having absolute (perfect) pitch perception, and the musician participants did not report noise exposure beyond musical experience in a concert setting. One non-musician participant reported target shooting with hearing protection as history of noise exposure, and did not show any indication of noise induced hearing loss during testing. The vocalist did have experience as a soloist.

All participants requiring tuning of an instrument claimed to tune by ear (5 participants), using an electronic tuner (2 participants), or both (2 participants).

All participants were required to have normal hearing sensitivity with thresholds $\leq$ 20 dB HL in both ears at .5, 1, 2, and 4, kHz, which was necessary to fulfill sensation level requirements for the DLF and PTC protocols. Exclusion criteria for both groups included history of ototoxic medication, significant head injury, and trauma to the eardrum evident through otoscopy, which were all determined with an initial case history/music history questionnaire and otoscopy. Participants with excessive cerumen and occluded ear canals, as well as those with notable scarring on the tympanic membrane, were not included in the study.

Musician participants were recruited via public flyers in the University of Northern Colorado's Frasier Hall, which houses the musical performing arts department, as well as by word of mouth. Non-musicians were also recruited via public flyers in the University Center building on the University of Northern Colorado campus, as well as by word of mouth. Participants were required to have the ability to read and write English proficiently in order to adequately understand consent forms. Informed consent was received from each participant before data were collected.

Data Collection Measures and Procedures

Prior to the administration of the test, participants were required to sign a consent form notifying them of their privacy rights, voluntary participation guidelines, risks and benefits, and a summary of the study protocol. Participants were given the option to receive a copy of their audiogram and test results if they desired, and were given researcher contact information. Participants were also required to fill out a questionnaire regarding their musical training and history. Air conduction thresholds and immittance audiometry were obtained prior to psychoacoustic measures. This was essential for ensuring qualified enrollment in the study.

Air-conduction hearing thresholds were attained at .5, 1, 2, and 4 kHz bilaterally for each subject using supra-aural headphones and a pulsed pure-tone stimulus delivered via a calibrated GSI-16 audiometer. Otoscopy was performed to identify any confounding factors such as tympanic membrane perforation or ear canal occlusion. Spontaneous otoacoustic emissions were collected using Otodynamics ILO-92 version 6 software and the built-in synchronized spontaneous otoacoustic emission protocol.

Participants were asked to respond to psychophysical tasks presented through Tucker-Davis Technologies RP2.1 hardware, and a Dell desktop computer with a Microsoft Windows 7 processing system. Tucker-Davis Technologies (TDT) PsychRP software was used to present, collect, and graph data from each participant for DLF experiments. SWPTC, a software program developed by Dr. Brian C.J. Moore, was used to present, collect, and analyze data from each participant for PTC experiments. Numerical values of DLFs were recorded by PsychRP and re-entered in a Microsoft Windows EXCEL spreadsheet for data analysis and comparison; results from PTC experiments were calculated and recorded by SWPTC and were also re-entered into a Microsoft Windows EXCEL spreadsheet.

Difference limens for frequency were collected with a pure tone, 3 alternative forced choice (3AFC) procedure at .5, 1, 2, and 4 kHz for both ears. Stimuli were pure-tones presented at 40 dB SL (or 40 dB HL, whichever was greater) for all participants, with 500ms stimulus duration and 500ms interstimulus duration. Participants listened to stimuli through TDH-39 headphones, calibrated on 4/17/2012 with a Quest 2700 model sound level meter, #HU2040042. Participants were instructed to press a button on a response pad that corresponded to which stimulus was different from the other two (i.e., if the first sound is different from the last two, the first button will be pushed, etc.). Each DLF experiment was regulated by the TDT equipment on a 3 correct, 1 incorrect paradigm. This means that for every 3 correct responses by the subject, the amount of Hz difference above center frequency decreased, and for every incorrect response, the Hz difference increased. Every increase or decrease in change from center frequency represented a reversal in the experiment; the testing concluded after 12 reversals, ignoring the first 4 while the subject acclimated to the experiment. Ceilings of 20, 20, 25, and 50 Hz above center frequency were set for .5, 1, 2, and 4 kHz, respectively. Right ears were tested first at .5, 1, 2, and 4 kHz in random order, followed by the left ear, also in random order. Only one measurement was conducted at each frequency for each ear. Individual experiments lasted about 2 minutes per single frequency, totaling approximately 15 minutes for both ears. An example of a DLF results for a single frequency can be found in Figure 1.

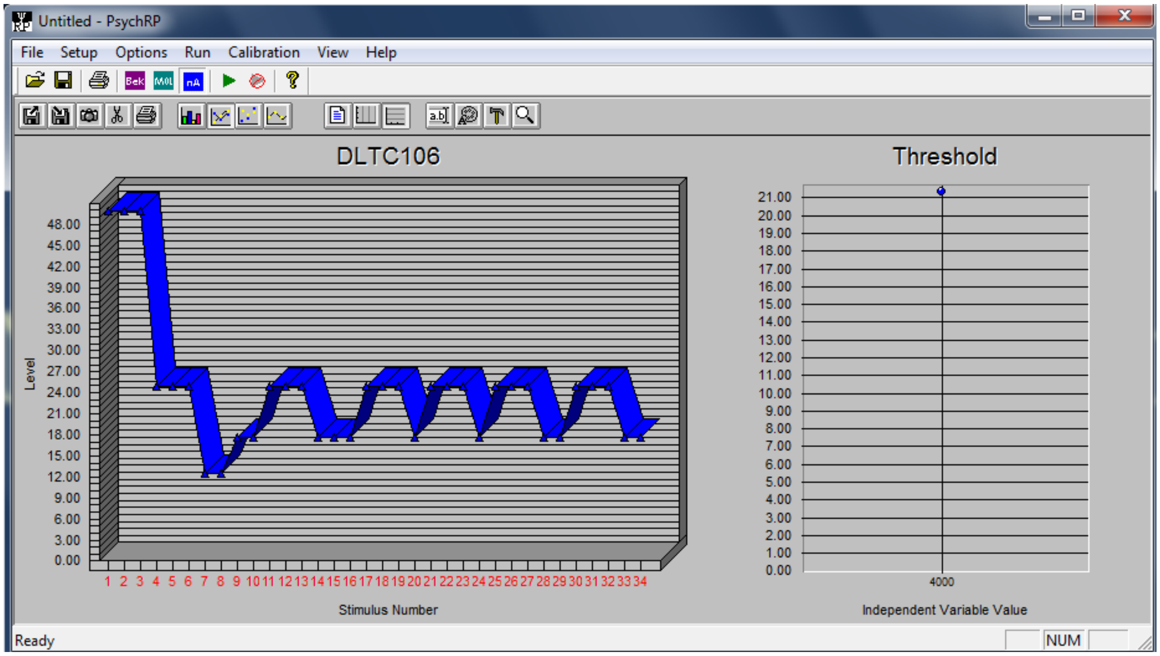

Figure 1: Example Frequency Difference Limen Experiment. Screenshot of completed DLF experiment for Subject 6, right ear at 4 kHz. The bottom axis represents individual trials and the left axis represents amount of Hz above center frequency.

Psychophysical tuning curves were collected using a simultaneous-masking, modified-Bekesy procedure surrounding the center frequencies of .5, 1, 2, and 4 kHz for both ears. Center tone stimuli were presented at 10 dB SL (or 10 dB HL, whichever was greater) for all frequencies through TDH-39 headphones, calibrated 4/20/2012. Center tones were presented for 500ms, with an interstimulus interval of 500ms. Participants were given a wireless keyboard for responses, which were collected in the software SWPTC by spacebar movements; they were asked to hold down the spacebar as long as they heard the pulsed pure-tone stimulus behind the masking noise, and release the spacebar when the tones were inaudible. Masking noise was a 100 Hz-wide narrow-band sweep frequency that began one octave below the center frequency and ended one octave above the center frequency; this method is known as a forward sweep. The spacebar prompts increased and decreased the intensity of the masking noise when it was pressed and released, respectively, at a rate of 2 dB/second. The tip of the PTC was calculated by the software via double regression to determine Q10 values; this was because of the potential for hysteresis, where the tip of the PTC is shifted away from the center frequency (Sek & Moore, 2011). Similar to the DLF procedure, right ears were tested first at .5, 1, 2, and 4 kHz in random order, followed by the left ear, also in random order. Only one measurement was conducted at each frequency for each ear. Individual experiments lasted 4 minutes per single frequency, totaling approximately 30 minutes for both ears. An example of a single frequency PTC experiment can be found in Figure 2.

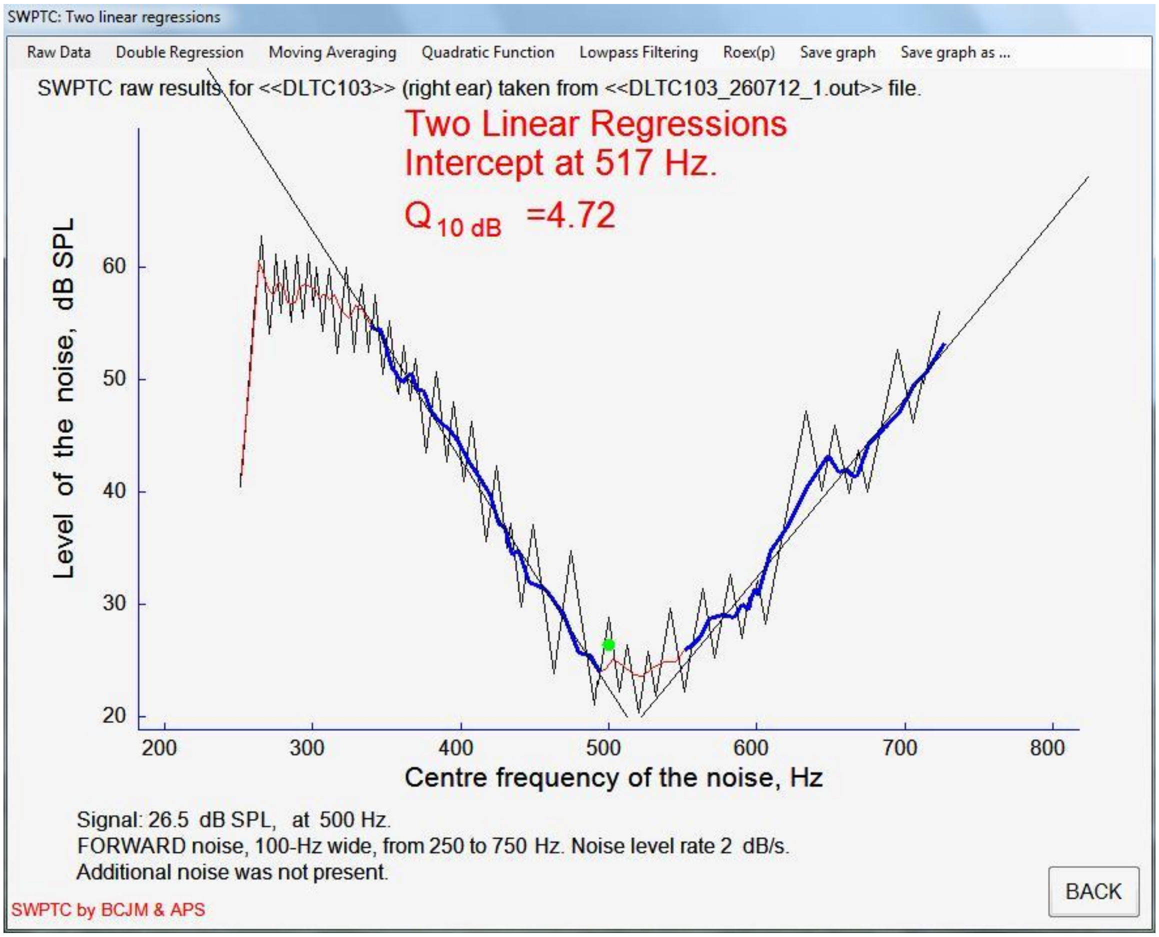

Figure 2: Example Psychophysical Tuning Curve Experiment. Screenshot of completed PTC experiment for Subject 3, right ear at 500 Hz. The bottom axis represents frequency and the left axis represents loudness in dB SPL.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used to determine whether or not musicianship had a significant effect on the dependent variable, DLF or PTC, at each frequency in both ears. The significance level was set at $p \leq .05$ for each analysis. A simple linear regression was also completed at $p \leq .05$ for each frequency to determine whether or not DLF values correlated significantly to PTC Q10 values.

CHAPTER 4

Results

All frequency difference limen (DLF) figures and psychophysical tuning curve (PTC) Q10 values were compiled in a Microsoft Windows EXCEL spreadsheet for further processing. Because DLF results were reported by PsychRP software in raw form (Δf, where f = frequency in Hz), conversion with the $rel\text{DLF\%}=\Delta f/f \times 100$ was necessary prior to statistical analysis and was done within the EXCEL program. Spontaneous otoacoustic emissions data that was collected also needed to be scrutinized and significant proximity to test frequencies determined; SOAEs within 250 Hz of any center frequency (.5, 1, 2, or 4 kHz) were considered significant. None of the SOAEs measured met this criteria, and was therefore not a confounding factor. Psychophysical tuning curve measurements required no additional changes. Raw data and conversions for all measurements are reported in Appendix A.

To analyze the difference limens for frequency (DLFs), a one-way analysis of variance (ANOVA) was used to determine whether or not musicianship had a significant effect on the dependent variable, DLF, at each frequency. For each analysis, $p \leq .05$ was used to indicate significance. All 20 participants completed bilateral DLF measurements at each frequency, resulting in 40 samples (n = 40) per frequency. Frequency difference limen means for musicians were smaller than non-musician means at all test frequencies (see Figure 3). Significant ANOVA results were as follows: 500 Hz, $F(1,38) = 8.91$, $p = 0.005$; 1000 Hz, $F(1,38) = 16.26$, $p = 0.000$; and 4000 Hz, $F(1,38) = 7.27$, $p = 0.010$, indicating that musicians had significantly smaller DLF measures than non-musicians at .5, 1, and 4 kHz. No significance was present at 2000 Hz, $F(1,38) = 2.41$, $p = 0.129$.

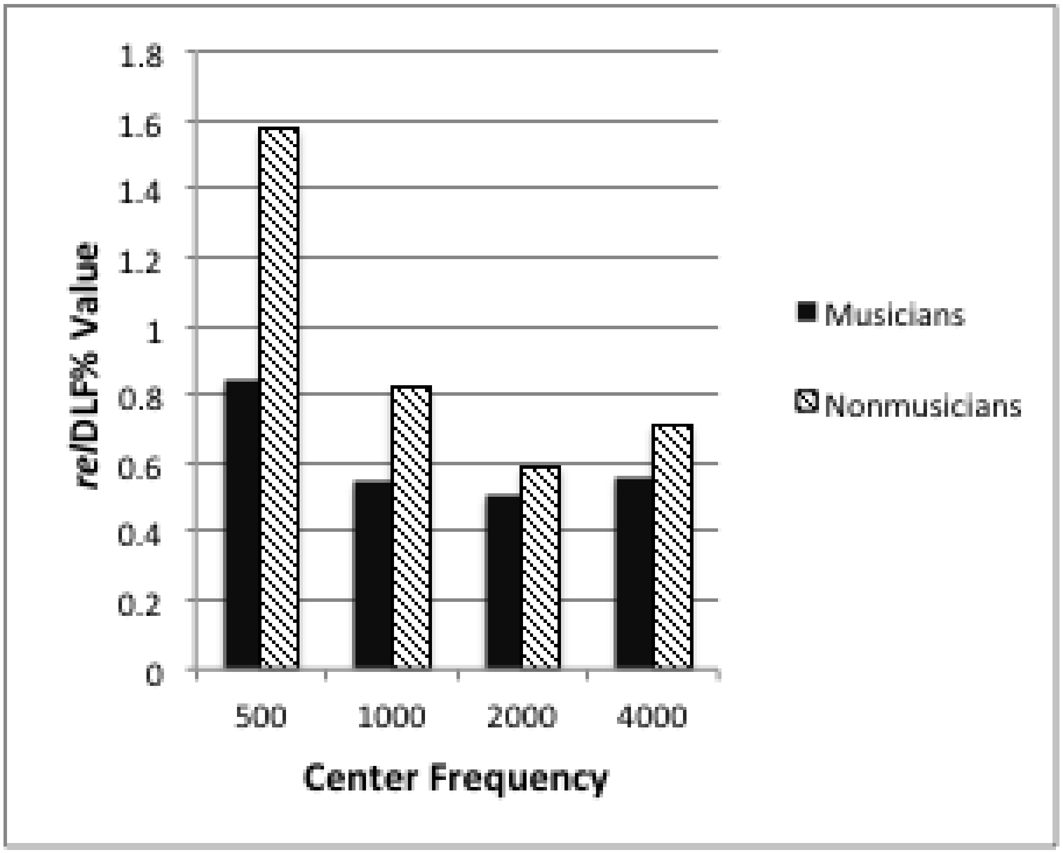

Figure 3: Relative DLF% Values Between Musician and Non-musician Participants by Frequency.

Table 2

Musician and Non-Musician Frequency Difference Limen Means and Standard Deviations

	500 Hz	1000 Hz	2000 Hz	4000 Hz
Musicians				
Mean	1.5769	0.8195	0.59	0.7094
SD	1.0743	0.2745	0.1522	0.1799
Non-Musicians				
Mean	0.8382	0.5454	0.5088	0.5592
SD	0.266	0.1307	0.1775	0.1725

Psychophysical tuning curves (PTCs) were analyzed using a one-way analysis of variance (ANOVA) to determine whether or not musicianship had a significant effect on the dependent variable, psychophysical tuning curve Q10 values, at each frequency. For each analysis, $p \leq .05$ was used to indicate significance. Not all participants were able to complete bilateral PTC measurements at each frequency; however, an equal number of participants still remained in the two major musician and non-musician groups. For PTC Q10 measurements, at .5, 1, 2, and 4 kHz, participants tested were n = 38, n = 39, n = 38, and n = 39, respectively. Psychophysical tuning curve means for musicians were larger than non-musician means at .5, 1, and 4 kHz, with non-musicians holding the greatest mean at 2 kHz (see Figure 4). No frequency difference reached significance. No SOAEs were found within 250 Hz of any center frequency and therefore did not have an effect on PTC results.

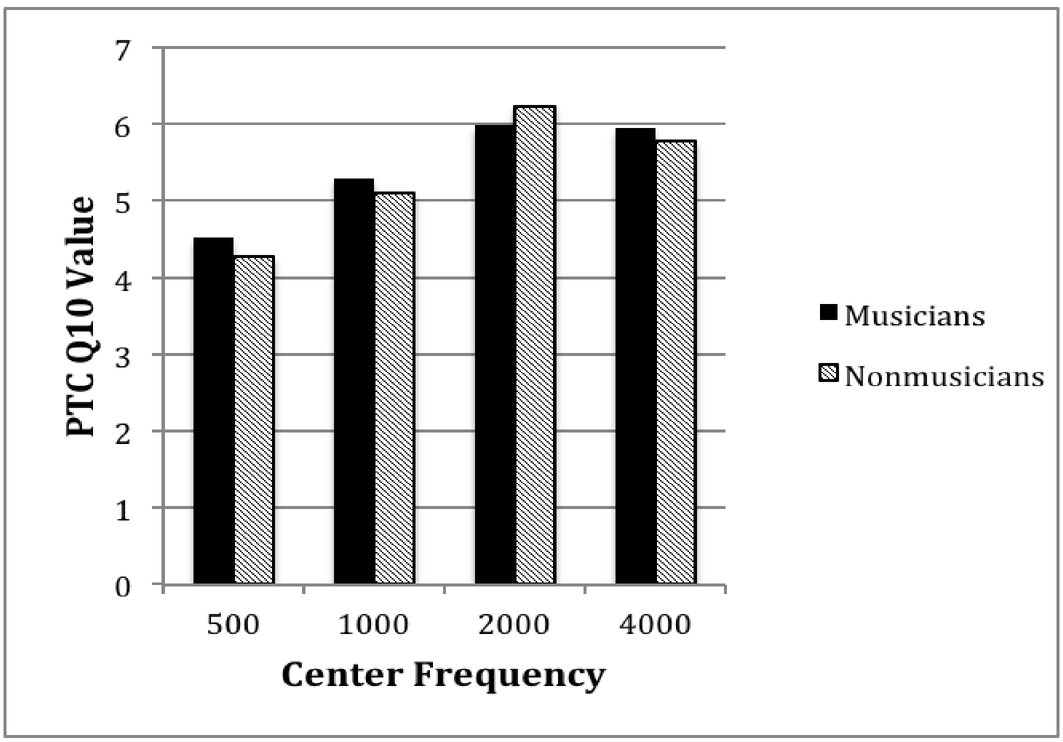

Figure 4: Psychophysical Tuning Curve Q10 Values Between Musician and Non-musician Participants by Frequency.

Table 3

Musician Versus Non-Musician Psychophysical Tuning Curve Q10 Value Means and Standard Deviations

	500 Hz	1000 Hz	2000 Hz	4000 Hz
Musicians				
Mean	4.269	5.0975	6.221	5.776
SD	2.3	2.608	3.213	1.175
Non-Musicians				
Mean	4.511	5.286	5.976	5.948
SD	1.126	1.202	1.227	1.081

Simple linear regression was completed at $p \leq .05$ for each frequency to determine any significant correlation between difference limens and psychophysical tuning curves. None of the coefficients reached significance, indicating no notable relationship between DLF and PTC Q10 values (See Figures 5 - 8).

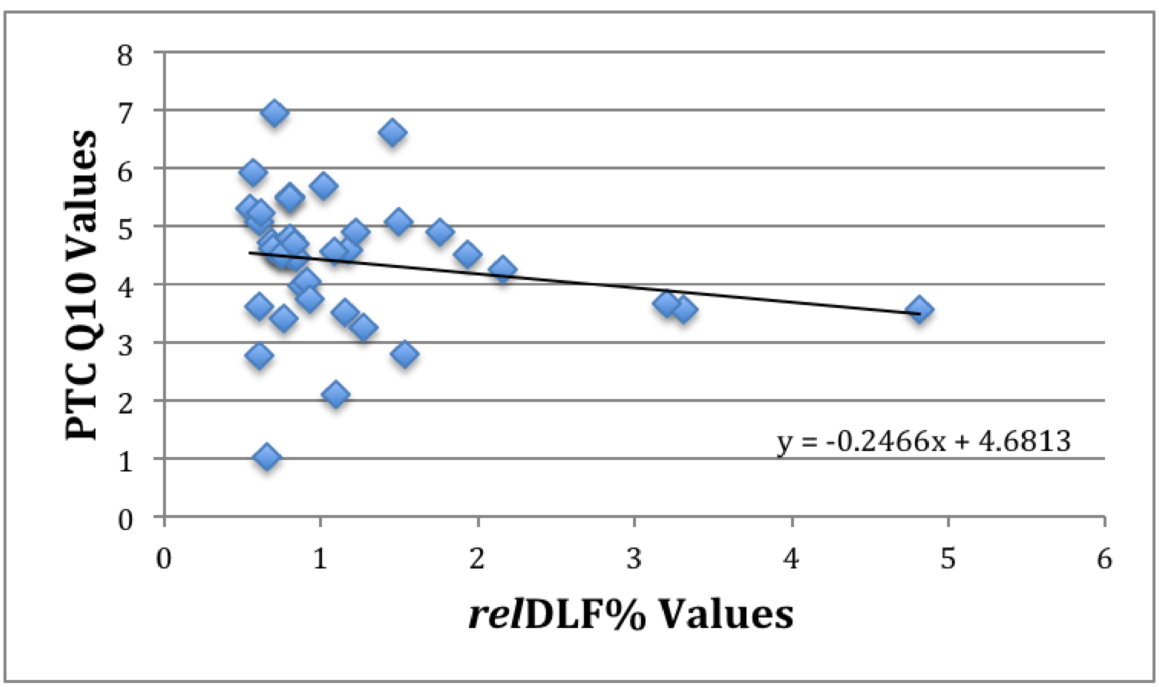

Figure 5: Scatter Plot of 500 Hz *rel*DLF%/Psychophysical Tuning Curve Q10 Values.

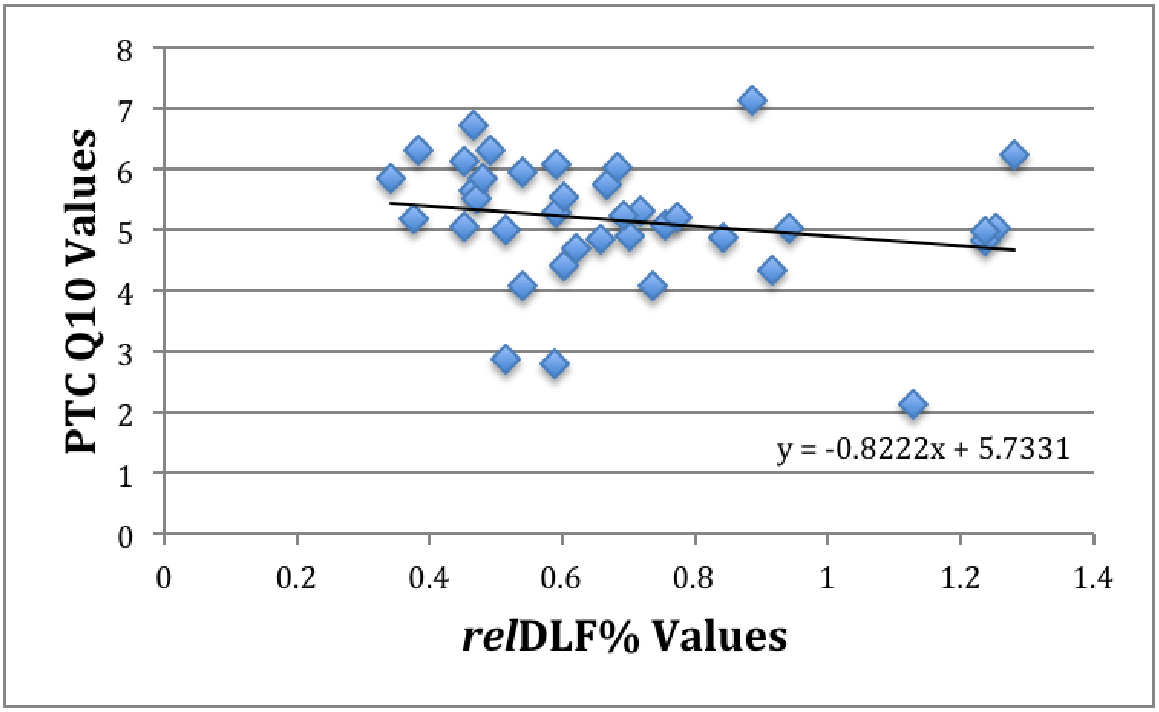

Figure 6: Scatter Plot of 1000 Hz *rel*DLF%/ Psychophysical Tuning Curve Q10 Values.

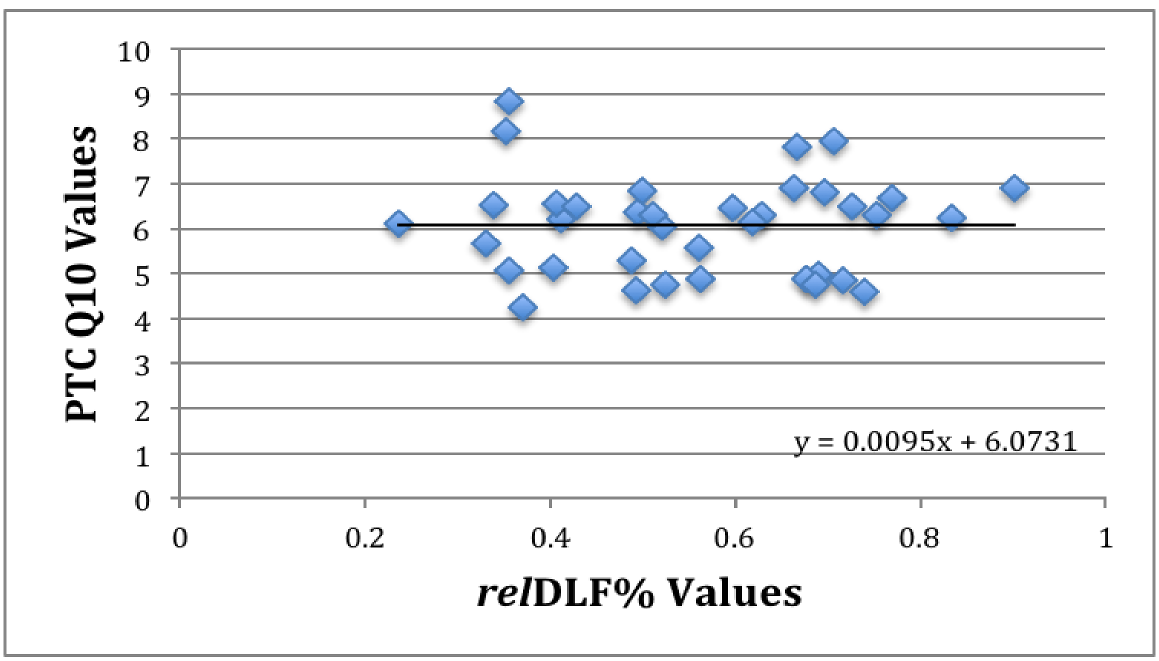

Figure 7: Scatter Plot of 2000 Hz *rel*DLF%/ Psychophysical Tuning Curve Q10 Values.

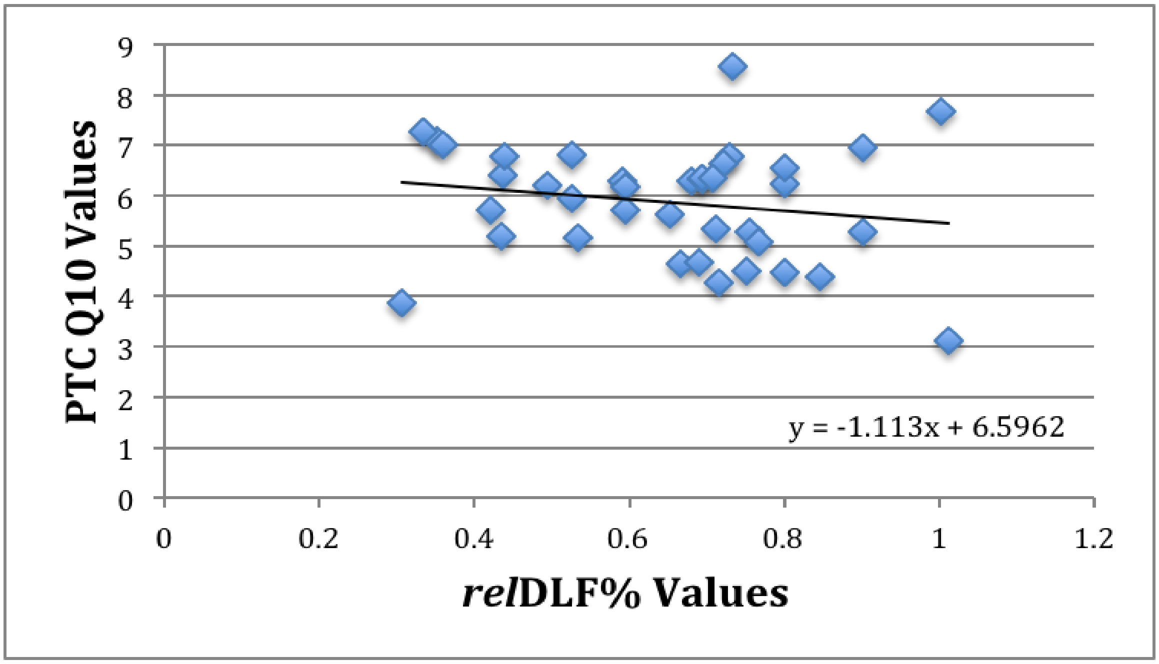

Figure 8: Scatter Plot of 4000 Hz *rel*DLF%/ Psychophysical Tuning Curve Q10 Values.

CHAPTER 5

Discussion

This study aimed to examine the relationship between consistent musical training and two psychophysical measures of pitch perception, difference limens for frequency (DLFs) and psychophysical tuning curve (PTC) Q10 values. The results suggest that musicians have significantly smaller DLF values at .5, 1, and 4 kHz, and so the hypothesis was accepted for three of the four frequencies evaluated for the first research question. The null hypothesis was accepted for the second research question, indicating no significant differences between musician and non-musician PTC Q10 values. The null hypothesis was also accepted for the third research question, demonstrating no significant relationship between difference limens for frequency and psychophysical tuning curves.

Comparison to Previous Studies

This study echoed components of previous studies comparing DLFs between musicians and non-musicians. Methods for data collection included a 3AFC procedure for DLFs, as well as a 3-correct to 1-incorrect reversal strategy, echoed from previous comparison studies (Kishon-Rabin et al., 2001; Nikjeh, Lister, & Frisch, 2008). Age groups for prior studies closely matched those for the current study (Kishon-Rabin et al., 2001; Micheyl et al, 2006; Nikjeh, Lister, & Frisch, 2008). Subject inclusion criteria, especially for musicians, were similar to previous studies. Nikjeh et al. (2008) used musicians with 10.5 mean years of musical training, while Micheyl et al. (2006) and Kishon-Rabin et al. (2001) had means of 14 and 13 years of experience across musical participants, respectively. The participants in the current study had 12.7 mean years of training. Unlike Micheyl et al. (2006), Nikjeh, Lister and Frisch (2008), and Spiegel and Watson (1984), the current experiment tested four octave center frequencies from 500 Hz to 4000 Hz as opposed to pure-tones corresponding to notes on the western musical scale. This was done to match frequencies tested in PTC experiments because no musician versus non-musician studies had been conducted using this psychophysical measure (Micheyl & Collet, 1994). Possibly as a result of some musician preference for listening to standard musical tones, DLF values for musicians were not as drastically different than non-musicians when compared to these previous DLF studies.

While the results of the experiment did not confirm all outcomes found in the literature, the current study attempted to control more variables than previously tested. Many studies regarding measures on musicians included only males, only females, or had a significant imbalance of participants (Gaser & Schlaug, 2003; Kishon-Rabin et al., 2001; Nikjeh, Lister & Frisch, 2008; Ohnishi et al., 2001). The current study included 11 female and 9 male participants. The musician participants played a variety of instruments, which is also in contrast to previous studies that focused on one or a few primary instrument choices (Gaser & Schlaug, 2003). The participants in this study also had the advantage of listening to stimuli through headphones, while those in the Spiegel and Watson (1984) study distinguished tone differences through sound field speakers.

Absolute pitch and tone-deafness have not yet been shown to potentially affect psychophysical pitch perception measures. Participants in this study self-reported pitch acuity on the musical history questionnaire. Of all the participants, none of the musicians claimed to have perfect or absolute pitch on the musical questionnaire given to all participants, and only two of the non-musician participants reported being tone-deaf. Neither of these participants' results represents extremes in the data set for DLFs or PTC Q10s.

Whether or not musical training or musical ability contributes to more acute pitch perception has yet to be determined. Measureable tone deafness, or amusia, has been shown to have a congenital component, and was present in 39% of first-degree relatives in 9 families (Peretz et al., 2007). Absolute, or perfect, pitch has also been found to aggregate in families (Baharloo, Service, Risch, Gitschier, & Freimer, 2000). It is generally assumed that people with innate musical talent or ability become musicians, but it is possible that some who possess hereditary pitch acuity do not pursue musical training. It is also possible that some who possess congenital amusia may still be inclined to learn musical skills. While it is not impossible for some non-musicians to have absolute pitch capabilities, the assumption made in this study was that musical training enhances any innate abilities, and was superior to hereditary ability alone when comparing pitch perception measures.

Problems and Limitations

The current study had several limitations. Sample sizes of musician and non-musician participants were limited due to strenuous inclusion and exclusion criteria for both groups. Non-musicians with less than 3 years of musical experience were more difficult to find than expected because of some grade-school music requirements to participate in band or choir. Many musicians initially interested in the study did not meet either the 8-year minimum training criteria or the one-hour per day practice minimum. Frequency difference limens were only measured one time per ear at each frequency, which therefore failed to represent a known training effect in DLF measurements that decreases DLF results after repeated measures.

One non-musician subject was found to have had prior experience with psychophysical pitch measures, specifically the difference limen for frequency (DLF) experiment, which was not screened for on the musical history questionnaire. This particular subject's results did not represent an extreme in the non-musician data set. It was not controlled for in previous DLF experiments; however, it was found to be a significant variable in the Spiegel and Watson (1984) study because of a known training effect in DLF testing. This finding is considered a limitation because of the potential to skew the data for the non-musician group in favor of more acute pitch perception as a result of psychophysical training instead of musical training.

Because no data comparing musician and non-musician PTC Q10 values had been reported, simultaneous PTC measurements were chosen for fast acquisition. This PTC measurement proved to vary significantly between participants (musicians and non-musicians alike) and may not have given the most accurate data for comparison, especially compared to forward masking PTCs (Moore, 1978). Some participants had very short, quick releases of the spacebar when they detected pure tones, while others did not have many releases of the spacebar. It is unclear how much of this was related to poor understanding of the task versus poor perception of the pure-tone stimulus. The software program for PTCs, SWPTC, occasionally malfunctioned during data acquisition, stopping experiments before the 4-minute run had completed. When this malfunction occurred, the software was shut down and restarted. On one occasion, the software continued to fail regardless of multiple restarts and a full computer reboot, resulting in one subject not completing all four frequencies in PTC measurement. One subject could not complete PTCs as a result of a power outage in the research lab. Because the simultaneous PTC measurement proved to vary significantly between participants, a more controllable stimulus/masker assessment may have yielded better results for both groups. No spontaneous otoacoustic emissions (SOAEs) were found within 250 Hz of any center frequency and therefore did not have an effect on PTC results, supporting again the need for larger sample size and more accurate measures.

Musician participants are more at risk for noise-induced hearing loss (NIHL) than non-musicians because of the nature of their everyday activities (Pawlaczyk-Luszczynska et al., 2011). Participants' hearing was tested at each PTC center frequency; however, noise-induced hearing loss could have been apparent in auditory assessments not used in this study, affecting both PTC Q10 and DLF measures. Using more discerning measures of cochlear function, such as transient-evoked otoacoustic emissions (TEOAEs) or distortion-product otoacoustic emissions (DPOAEs), a more accurate evaluation of overall hearing and cochlear function across all participants could have been obtained.

Recommendations for Future Research

Repetition of this experiment should strive to include more participants, several repetitions of DLF measures, and more accurate PTCs (such as forward-masking PTCs) to achieve the most accurate results (Kishon-Rabin et al, 2001; Micheyl et al., 2006; Spiegel & Watson, 1984). Future research could also focus on groups that exclusively report perfect pitch or tone-deafness, as well as include measures that evaluate abilities more objectively, so as to not rely solely on self-reported pitch acuity (such as the use of the Montreal Battery for Evaluation of Amusia, MBEA)(Peretz, Champod, & Hyde, 2003). By including more objective pitch perception measures outside of psychophysical experiments, a more accurate assessment of pitch as it relates to personal perception can be obtained.

Conclusion

The implications of this study support changes in measureable auditory skills resulting from auditory training through music, but did suggest that the frequency selectivity at the level of the cochlea is different between musicians and non-musicians. Differences between musician and non-musician DLFs were confirmed at two of the four frequencies tested. While PTC results proved to have no significance and therefore did not represent a change in the cochlear critical band, more discerning psychophysical measures in the future could provide a greater understanding of how cochlear function differs between musicians and non-musicians. Additional studies are needed to demonstrate auditory differences between musicians and non-musicians using other psychophysical measurements beyond DLFs.

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APPENDICES

APPENDIX A

Raw Data

RAW DATA OF PARTICIPANTS AND PTCS

Subject	AGE	Sex	SOAE	Ear	Mus	PTC Data, Q10s			
						500	1000	2000	4000
DLTC101	26	1	0	0	0	4.59	4.91	6.49	5.73
DLTC101	26	1	0	1	0	4.51	4.7	4.84	5.29
DLTC102	25	1	1	0	0	4.25	2.13	5.59	6.29
DLTC102	25	1	0	1	0	4.9	5.03	6.82	7.11
DLTC103	25	1	1	0	1	4.72	5.84	6.06	3.88
DLTC103	25	1	1	1	1	4.61	5.85	6.45	5.08
DLTC104	31	1	1	0	1	4.51	7.13	6.3	7.01
DLTC104	31	1	1	1	1	5.32	6.02	6.84	6.42
DLTC105	26	0	0	0	0	3.56	5.76	6.22	6.28
DLCT105	26	0	0	1	0	3.58	4.87	6.92	4.66
DLTC106	31	0	0	0	1	4.81	2.8	4.98	5.17
DLTC106	31	0	1	1	1	3.41	4.08	4.25	4.68
DLTC108	27	0	0	0	1	CNC	6.07	6.84	5.36
DLTC108	27	0	0	1	1	CNC	CNC	CNC	CNC
DLTC109	23	0	0	0	1	2.11	5.19	4.62	5.21
DLTC109	23	0	0	1	1	2.78	6.07	8.83	6.79
DLTC110	24	1	0	0	0	5.52	6.3	4.75	7.27
DLTC110	24	1	0	1	0	4.9	5.65	5.3	6.97
DLTC111	31	0	0	0	1	4.06	6.12	8.18	8.57
DLTC111	31	0	0	1	1	3.62	6.3	6.11	5.72
DLTC112	23	1	0	0	0	6.61	5.02	6.68	4.39
DLTC112	23	1	0	1	0	5.49	5.31	6.25	4.52
DLTC113	24	1	0	0	0	3.25	4.83	5.66	5.28
DLTC113	24	1	0	1	0	1.02	5.23	6.36	6.31
DLTC114	31	0	1	0	0	5.7	5.29	6.53	6.24
DLTC114	31	0	1	1	0	4.54	5.52	6.57	6.8
DLTC115	27	0	0	0	0	3.66	6.23	7.96	7.68
DLTC115	27	0	0	1	0	4.53	5.08	6.51	6.35
DLTC117	27	1	0	0	0	4.47	4.99	4.6	5.62
DLTC117	27	1	0	1	0	3.97	5.55	CNC	5.34
DLTC118	21	1	0	0	1	6.96	6.72	5.12	6.78
DLTC118	21	1	1	1	1	5.92	5.01	4.88	4.49
DLTC120	31	0	0	0	0	2.81	5.2	7.83	3.11
DLTC120	31	0	0	1	0	3.52	4.35	6.31	4.28

Sex = 1 is female, 0 is male
SOAE = 0 is no SOAEs, 1 is SOAEs present (proximity measured after collection)
Ear = 0 is right, 1 is left
Mus = 1 is musician, 0 is nonmusician
CNC = Could not complete measurement, due to power outage or software malfunction

RAW DATA OF PARTICIPANTS AND PTCS, CONTINUED

Subject	AGE	Sex	SOAE	Ear	Mus	PTC Data, Q10s			
						500	1000	2000	4000
DLTC121	27	1	0	0	1	4.56	4.08	4.87	5.95
DLTC121	27	1	0	1	1	3.74	4.85	6.15	6.55
DLTC122	23	1	0	0	1	5.07	2.88	6.32	6.63
DLTC122	23	1	0	1	1	4.69	5.05	6.91	6.21
DLTC123	27	0	1	0	1	5.08	5.96	5.07	6.17
DLTC123	27	0	0	1	1	5.24	4.41	4.77	6.35
Means	26.5					4.3839 47368	5.1892 30769	6.0984 21053	5.86
					N	38	39	38	39

RAW DATA OF DLFS AND DLF PERCENTAGES

Subject	Sex	Ear	Mus	DLF Raw Data			
				500	1000	2000	4000
DLTC101	1	0	0	5.8525	7.0267	14.5267	23.8166
DLTC101	1	1	0	4.0089	6.2186	14.3122	30.1777
DLTC102	1	0	0	10.7767	11.2944	11.1872	27.1867
DLTC102	1	1	0	8.7944	12.5444	13.9017	14.118
DLTC103	1	0	1	3.4218	4.8012	10.4105	12.2319
DLTC103	1	1	1	3.4597	3.4218	11.9194	30.7138
DLTC104	1	0	1	3.7722	8.8702	10.1961	14.4416
DLTC104	1	1	1	2.7321	6.8436	9.9686	17.4881
DLTC105	0	0	0	24.0847	6.6684	8.2309	23.6826
DLCT105	0	1	0	16.5566	8.4204	13.242	26.6735
DLTC106	0	0	1	4.0089	5.8904	13.7944	21.3388
DLTC106	0	1	1	3.8258	5.4105	7.3928	27.5888
DLTC108	0	0	1	6.2186	4.8928	7.3156	16.6513
DLTC108	0	1	1	6.2186	6.0335	4.7823	10.6694
DLTC109	0	0	1	5.4642	3.7722	9.8614	17.3868
DLTC109	0	1	1	3.058	5.9061	7.0868	17.5666
DLTC110	1	0	0	4.0237	4.9244	10.466	13.4123
DLTC110	1	1	0	6.1114	4.6561	9.7541	36.0485
DLTC111	0	0	1	4.5267	4.5267	7.0394	29.3409
DLTC111	0	1	1	3.0178	3.8258	4.7153	16.8409
DLTC112	1	0	0	7.2855	9.4194	15.3569	33.8388
DLTC112	1	1	0	4.0089	7.1783	16.6513	30.0666
DLTC113	1	0	0	6.3637	12.3614	6.6014	36.0485
DLTC113	1	1	0	3.3035	6.9351	9.8882	27.7784
DLTC114	0	0	0	5.0758	5.9061	6.7632	32.0083
DLTC114	0	1	0	3.6585	4.7097	8.1361	21.0708
DLTC115	0	0	0	16.0355	12.8033	14.1291	40.0888
DLTC115	0	1	0	9.6986	7.5444	8.5512	27.7784
DLTC117	1	0	0	4.2299	12.366	14.7652	26.1374
DLTC117	1	1	0	4.3972	6.0355	13.6604	28.5041
DLTC118	1	0	1	3.5133	4.6561	8.0691	29.1513
DLTC118	1	1	1	2.8236	5.1517	11.2218	32.0083
DLTC120	0	0	0	7.6517	7.7275	13.3368	40.468
DLTC120	0	1	0	5.7767	9.1605	12.5555	28.6152

RAW DATA OF DLFS AND DLF PERCENTAGES, CONTINUED

Subject	Sex	Ear	Mus	DLF Raw Data			
				500	1000	2000	4000
DLTC121	1	0	1	5.4105	7.3614	13.5263	21.0708
DLTC121	1	1	1	4.6561	6.5847	12.366	32.0083
DLTC122	1	0	1	7.4686	5.1517	15.0333	28.8833
DLTC122	1	1	1	4.1383	4.5267	18.0243	19.7763
DLTC123	0	0	1	3.0178	5.4105	7.0868	23.8166
DLTC123	0	1	1	3.0714	6.0355	13.7159	28.3471
	20	40	20	6.03796	6.8243425	10.988555	25.3710025
			N	40	40	40	40

Subject	Sex	Ear	Mus	DLF Percentages			
				500	1000	2000	4000
DLTC101	1	0	0	1.1705	0.70267	0.726335	0.595415
DLTC101	1	1	0	0.80178	0.62186	0.71561	0.7544425
DLTC102	1	0	0	2.15534	1.12944	0.55936	0.6796675
DLTC102	1	1	0	1.75888	1.25444	0.695085	0.35295
DLTC103	1	0	1	0.68436	0.48012	0.520525	0.3057975
DLTC103	1	1	1	0.69194	0.34218	0.59597	0.767845
DLTC104	1	0	1	0.75444	0.88702	0.509805	0.36104
DLTC104	1	1	1	0.54642	0.68436	0.49843	0.4372025
DLTC105	0	0	0	4.81694	0.66684	0.411545	0.592065
DLCT105	0	1	0	3.31132	0.84204	0.6621	0.6668375
DLTC106	0	0	1	0.80178	0.58904	0.68972	0.53347
DLTC106	0	1	1	0.76516	0.54105	0.36964	0.68972
DLTC108	0	0	1	1.24372	0.48928	0.36578	0.4162825
DLTC108	0	1	1	1.24372	0.60335	0.239115	0.266735
DLTC109	0	0	1	1.09284	0.37722	0.49307	0.43467
DLTC109	0	1	1	0.6116	0.59061	0.35434	0.439165
DLTC110	1	0	0	0.80474	0.49244	0.5233	0.3353075
DLTC110	1	1	0	1.22228	0.46561	0.487705	0.9012125
DLTC111	0	0	1	0.90534	0.45267	0.35197	0.7335225
DLTC111	0	1	1	0.60356	0.38258	0.235765	0.4210225
DLTC112	1	0	0	1.4571	0.94194	0.767845	0.84597
DLTC112	1	1	0	0.80178	0.71783	0.832565	0.751665
DLTC113	1	0	0	1.27274	1.23614	0.33007	0.9012125
DLTC113	1	1	0	0.6607	0.69351	0.49441	0.69446

RAW DATA OF DLFS AND DLF PERCENTAGES, CONTINUED

Subject	Sex	Ear	Mus	DLF Percentages			
				500	1000	2000	4000
DLTC114	0	0	0	1.01516	0.59061	0.33816	0.8002075
DLTC114	0	1	0	0.7317	0.47097	0.406805	0.52677
DLTC115	0	0	0	3.2071	1.28033	0.706455	1.00222
DLTC115	0	1	0	1.93972	0.75444	0.42756	0.69446
DLTC117	1	0	0	0.84598	1.2366	0.73826	0.653435
DLTC117	1	1	0	0.87944	0.60355	0.68302	0.7126025
DLTC118	1	0	1	0.70266	0.46561	0.403455	0.7287825
DLTC118	1	1	1	0.56472	0.51517	0.56109	0.8002075
DLTC120	0	0	0	1.53034	0.77275	0.66684	1.0117
DLTC120	0	1	0	1.15534	0.91605	0.627775	0.71538
DLTC121	1	0	1	1.0821	0.73614	0.676315	0.52677
DLTC121	1	1	1	0.93122	0.65847	0.6183	0.8002075
DLTC122	1	0	1	1.49372	0.51517	0.751665	0.7220825
DLTC122	1	1	1	0.82766	0.45267	0.901215	0.4944075
DLTC123	0	0	1	0.60356	0.54105	0.35434	0.595415
DLTC123	0	1	1	0.61428	0.60355	0.685795	0.7086775
	20	40	20	1.207592	0.68243425	0.54942775	0.634275063
			N	40	40	40	40

APPENDIX B

Music History Questionnaire

Health, Hearing, and Musical History

Project Title: *Pitch perception in musicians and non-musicians: A comparison of psychophysical tuning curves and frequency difference limens*

To be filled out by the lead researcher:

Subject #: ___________________________ Date: ____________________

DOB: ______________________________ **Musician / Non-musician**

==

1. Do you have history of musical training for more than one year? **Y N**
   - This includes:
     - Participation in a band or ensemble
     - Participation in a choral group/choir
     - Private lessons
     - Undergraduate and graduate studies
   - **If you answered NO, please skip to number 7.**

2. How many years of musical training have you received in total? This includes all of the criteria mentioned in question 1. ____

3. Are you an instrumentalist, vocalist, or both? ____
   - If you play more than one instrument, please list them in the order of greatest ability/experience:

     ____

     ____

4. If you are a vocalist, do you have experience as a soloist? **Y N N/A**

5. About how many hours per day do you practice your instrument(s), not including performances? ___________________

6. If your instrument requires regular tuning, do you tune by ear, matching a reference tone, detecting beats, or electronically? Please explain if you use more than one method.

____

____

____

7. Do you consider yourself to have absolute (perfect) pitch perception? **Y** **N**

8. Do you consider yourself to be tone deaf? **Y** **N**

9. Do you have a history of loud noise exposure with or without hearing protection? **Y** **N**

If yes, please explain: ____

____

____

APPENDIX C

IRB Documents

UNIVERSITY *of*
NORTHERN COLORADO

Institutional Review Board

June 14, 2012

TO: Spencer Weiler
ELPS

FROM: Maria Lahman, Co-Chair MJ
UNC Institutional Review Board

RE: Expedited Review of *Pitch Perception in Musicians and Nonmusicians: A Comparison of Psychophysical Tuning Curves and Frequency Difference Limens,* submitted by Amber Marjorie Powner (Research Advisor: Katie Bright)

First Consultant: The above proposal is being submitted to you for an expedited review. Please review the proposal in light of the Committee's charge and direct requests for changes directly to the researcher or researcher's advisor. If you have any unresolved concerns, please contact Maria Lahman, Applied Statistics and Research Methods, Campus Box 124, (x1603). When you are ready to recommend approval, sign this form and return to me.

I recommend approval as ~~is~~ Spencer Weiler 6-26-12
Signature of First Consultant Date
w/ accompanying attachment communication

The above referenced prospectus has been reviewed for compliance with HHS guidelines for ethical principles in human subjects research. The decision of the Institutional Review Board is that the project is approved as proposed for a period of one year: 7-1-12 to 7-1-13.

MLL 7-1-12
Maria Lahman, Co-Chair Date

Comments:

25 Kepner Hall ~ Campus Box #143
Greeley, Colorado 80639
Ph: 970.351.1907 ~ Fax: 970.351.1934

Request for IRB Change

Submit this request and all attachments to Sherry May, IRB Administrator, Office of Sponsored Programs, Kepner Hall, Suite #25

UNIVERSITY of NORTHERN COLORADO

Date of Original UNC IRB Approval: 07/01/2012

Project Title: Pitch perception in musicians and nonmusicians: a comparison of psychophysical tuning curves and freque

Lead Investigator	Name:	Amber Powner
	School:	Human Sciences
	Email:	Hans7975@bears.unco.edu
	Phone:	(970) 406-0340
Research Advisor	Name:	Katie Bright
(if applicable)	School:	Human Sciences
	Email:	Katie.Bright@unco.ed
	Phone:	(970) 351- 1589

On a separate page, describe and provide justification for the changes being proposed. Be concise and specific in describing methodological changes that affect the experience of participants and/or relate to the risks/benefits of participation. Explain why these changes are necessary.

○ Yes ⦿ No The proposed changes in protocol will necessitate changes in documents such as recruitment flyers, consent forms, debriefing forms, or other project-related documents.

○ Yes ⦿ No If yes, copies of the revised documents with changes highlighted are attached to this request.

CERTIFICATION OF LEAD INVESTIGATOR

I certify that information contained in this request is complete and accurate.

Signature of Lead Investigator 7/18/2012 Date

CERTIFICATION OF RESEARCH ADVISOR (If Lead Investigator is a Student)

I certify that information contained in this request is complete and accurate.

Signature of Research Advisor 7/26/2012 Date

Approved by:

Chairperson, Institutional Review Board 8/2/2012 Date

SPONSORED PROGRAMS JUL 30 2012

Clear Form

Date Request Received by OSP: ______________