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BONE CONDUCTION EQUAL LOUDNESS CONTOURS AT DIFFERENT PLACEMENTS, CONDITIONS, AND INTENSITIES

by

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A thesis proposal in partial fulfillment of the requirements for the degree of Doctor of Audiology

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Approval Page

This is to certify that the thesis prepared by Sanghmitra Arvindekar entitled Bone Conduction Equal Loudness Contours at Different Placements, Conditions, and Intensities has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree of Doctor of Audiology.

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Abstract Page

Bone conduction transmission has been studied for decades; however, equal loudness contours for bone conduction have not been established. The purpose of the current study was to establish bone conduction equal loudness contours at two different placements (mastoid and condyle), in two different conditions (unilateral and bilateral) and at two different intensities (20 and 40 dB HL). The study included three parts, soundfield equal loudness contours, soundfield to bone conduction loudness comparisons and bone conduction equal loudness contours. Results showed that there was no difference between any of the conditions or placements for bone conduction equal loudness contours. Also, the bone conduction equal loudness values closely matched the published ISO values established with a 1000 Hz reference at 20 and 40 dB HL.

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Chapter 1

Introduction

Humans hear sounds via two ways, air conduction and bone conduction; however, the loudness perception through each way is different (Pollard, Tran, & Letowski, 2013). The perception of loudness has been studied via soundfield for almost a century, including early studies of loudness scaling and loudness equalization. The first disseminated equal loudness contour study was conducted in 1927 by Kingsbury. Although the early studies did not provide reliable data due to crude instruments, they laid the groundwork for subsequent studies which took advantage of refined methodology and equipment. Various variables that may affect equal loudness contours in air conduction studies include delivery modality (e.g., free field, earphones), and sidedness (monaural, binaural). Within the past few years, a few studies have focused on the examination of equal loudness judgments between bone conduction delivered stimuli and air conduction or soundfield delivery. However, limited data are available regarding the shapes of equal loudness contours for bone conduction.

Bone conduction transmission has been used as part of hearing aid and other communication systems for many years; and bone conduction technologies are now part of many modern communication systems, including military communication systems. Recent studies have shown that various factors can affect loudness perception for bone conduction signals, such as the placement of the bone vibrator (Patrick, Kring, McBride, & Letowski, 2012). Therefore it is essential to continue to study the factors that affect loudness, to optimize the use of bone conduction in modern communication systems.

Chapter 2

Review of the Literature

Loudness and Equal Loudness Definition

Loudness is a psychoacoustic construct; specifically, it is subjective and affected by physiological factors such as number of neurons firing, hearing threshold, response criterion, and attention state. Fletcher and Munson (1933), who provided the first set of air conduction equal loudness contours binaurally in a free field, defined loudness as “the magnitude of an auditory sensation.”

Equal loudness contours have been studied over the past century using various stimuli (e.g., pure tones, noise) and delivery mechanisms (e.g., headphones, free field) (Molino, 1973). Churcher and King (1937) defined equal loudness as “the intensity level relative to some accepted reference intensity of a standard pure tone of specified frequency, which is judged by a normal observer to be as loud as the sound.” In simple words, equal loudness is when the loudness of one sound is perceived as the same as the loudness of a different sound (Fletcher & Munson, 1933). Both Fletcher and Munson (1933) and Churcher and King (1937) conducted experiments using via air conduction to deliver the stimuli.

Early Loudness Research

Early research was conducted with crude instruments like telephone meters suspended from the ceiling and very few participants (n=6). Kingsbury (1927) measured the first set of equal loudness contours based on comparing monaural air conduction stimuli and Fletcher and Munson (1933) provided the first set of equal loudness contour binaurally in a free field condition. The Kingsbury (1927) study demonstrated that the concept of equal loudness contours was viable as he was able to successfully study it using early telephone technology. In their later study, Fletcher and Munson (1933) used more carefully calibrated equipment to deliver sound stimuli in the free field. The similarities between the findings of the two studies provided the groundwork for further study.

Following the work of Fletcher and Munson (1933), Churcher and King (1937) conducted similar equal loudness contour measurements in free field with telephone receivers which were suspended from the ceiling. The loudness of 2500 Hz and 4500 Hz tones was compared to 1000 Hz at 85 dB SPL, for a small number of participants (n=10). The variability in the data was generally low, with an average error of 1 dB and a standard deviation of 2.6 dB; however, Churcher and King (1937) found that the inclination of the participants' head and age of the participant influenced loudness measures for higher frequencies.

Pollack (1952) conducted an experiment with frequency specific bands of noise with series of cut-off filters. The loudness of 62 Hz to 5800 Hz was compared to 1000 Hz at different loudness levels in each version of noise band. The participants constantly heard the reference stimuli to which they had to adjust the test stimuli to match the loudness. The loudness levels were presented in random order to prevent any bias from the participants. The overall loudness values were lower than the previous studies. This was explained due to the spread of excitation in the end organ with different bands of noise (Pollack 1952).

Robinson and Dadson (1956) conducted an experiment to compare equal loudness contours in free field versus earphones and found that a free field listening condition resulted in less variable results than an earphone condition. These researchers improved some procedures from previous studies, for example, the equipment was calibrated and a reference tone of 20 µPa (0 dB SPL) was used. Also, a wide range of frequencies (25 Hz to 15000 Hz) was tested in a large sample of 90 individuals between the ages of 16 and 63, all of whom had normal hearing sensitivity. Also, researchers used a reference tone in a free field condition. Because these researchers used a larger sample than prior studies, and used a calibrated reference tone, the equal loudness contour measurements presented by Robinson and Dadson (1956) have been widely accepted. However, concerns arose later regarding the results at 4000 Hz. This resulted in further studies. It was found subsequently that loudness contours were significantly higher for frequencies below 800 Hz than the ones reported by Robinson and Dadson (1956) (Suzuki & Takeshima, 2004).

Many researchers followed the results of Robinson and Dadson (1956). Molino (1973) also tested equal loudness contours using a small sample (n=6) at three different frequencies (125 Hz, 1000 Hz, and 8000 Hz) and four intensities (10 dB SL, 20 dB SL, 40 dB SL, 70 dB SL, re: absolute threshold). Molino (1973) used a reference tone similar to that of Robinson and Dadson (1956), however, all three frequencies tested served as reference tones. Equal loudness measurements were obtained in comparison to the three different frequencies mentioned above. In Molino's study, the participants were asked to adjust the loudness of each frequency to the loudness of the reference tone. Molino (1973) found that his results closely matched the results of Kingsbury (1927), as well as Fletcher and Munson (1933) for the equal loudness curve at 1000 Hz. He found greater discrepancies in the lower frequencies when compared to the results of Churcher and King (1937), as well as Robinson and Dadson (1956).

Recent Equal Loudness Research

To further investigate the discrepancies between study results at 400 Hz, Fastl, Jaroszewski, Schorer, and Zwicker (1990), established equal loudness contours for 100 Hz to 1000 Hz at 30, 50 and 70 phons. Individuals with normal hearing sensitivity (n=12) and normal otologic history adjusted the loudness of tonal stimuli in free field. Their results indicated overall higher loudness values for equal loudness contours as compared to the previous studies (Fastl et al., 1990).

Takeshima, Suzuki, Ashihara, and Fujimori (2002), compared the loudness contours between 1000 Hz and 12500 Hz at 60 and 80 phons for 21 adults with normal hearing sensitivity. A bracketing method of 2 dB steps was used to adjust the loudness level of a comparison tone to the 1000 Hz reference tone, both presented via loudspeaker. Results indicated significantly higher loudness levels for frequencies above 1000 Hz when compared to data obtained by Robinson and Dadson (1956).

Suzuki and Takeshima (2004) examined if the variability in the lower frequencies found by Robinson and Dadson (1956) could be explained. A difference of 14 dB was noted in the lower frequencies compared to data provided by Robinson and Dadson (1956). Therefore, a new set of equal loudness contour measurements was estimated from this study. Although some inconsistencies were noted in the lower frequencies, the results for the higher frequencies closely matched that of Fletcher and Munson (1933), Churcher and King (1937), and Robinson and Dadson (1956).

Stenfelt and Hakansson (2001) compared the loudness contours of pure tone stimuli via air conduction and bone conduction. Twenty three individuals with normal hearing sensitivity and eight individuals with mild sensorineural hearing loss adjusted the bone conduction stimuli through bracketing method compared to air conduction stimuli. This was tested over a limited range of frequencies (250Hz to 4000Hz) at 10 dB increments from 30dB HL to 80 dB HL. Results indicated that the difference between bone conduction and air conduction levels was about 4-5 dB (Stenfelt & Hakansson, 2001).

Patrick et al., (2012) studied intensity differences for air conduction and bone conduction at three bone vibrator placements: mastoid, condyle, and forehead. Participants (n=20) adjusted the loudness of the bone vibrators to the loudness perception of the stimuli presented via speakers for every octave from 250 Hz - 4000 Hz at 40, 60 and 80 dB SPL. Results indicated different loudness perception for each bone vibrator placement. In addition, it was observed that the loudness growth for bone conduction was faster than loudness growth for air conduction, especially for low frequencies. These results were attributed to the non-linear traits of the bone conduction transducer. This means that the bone transducer has voltage changes depending on the frequency presented and this affects the intensity of the sound. Also, it was noted that forehead placement was closest, whereas the condyle placement was farthest, from the perceived loudness of air conduction stimuli (Patrick et al., 2012).

The most recent study on bone conduction loudness was by Pollard et al. (2013). These researchers used two different bone vibrators (RadioEar B-71 & Oiido SD02) at two different skull locations (mastoid and condyle) and compared these values to the soundfield values. The participants (n=6) adjusted the loudness of the bone vibrator to match the stimuli presented through loudspeakers. Furthermore, a mechanical coupler was used to compare the same values. These values were then compared to the human perception values. A large discrepancy was noted in low and high frequencies between the two transducers. The commercially used RadioEar B-71 bone vibrator closely matched the soundfield values in frequencies above 4000 Hz whereas the Oiido SD02 bone vibrator closely matched the soundfield values in frequencies below 630 Hz. Also, the results from the mechanical coupler did not match the results of human perception for either transducer or skull placement (Pollard et al., 2013).

Clinical Applications

Loudness is subjective and varies by frequency and across individuals. Humans are very sensitive to loudness and frequency changes. These changes in frequency can provide much information. One of most common situations where change in frequency provides information is intonation of speech. Music is another domain where frequency is of critical importance (Thompson, Peter, Olsen & Stevens, 2012). The variability of frequency and loudness perception across the population makes it difficult for electrical engineers to use strictly physical data when working with instruments that produce sound (Churcher & King, 1937). Therefore, it is important to obtain the perceived growth of loudness over a wide range of frequencies to accurately implement sound adjustments in electrical instruments such as hearing aids (Churcher & King, 1937). Over the years, researchers have noted that the perception of loudness varies with different frequencies. It has been observed that the study of loudness contours can provide information about the loudness growth in the human auditory system (Suzuki & Takeshima, 2004). It is essential that equal loudness contours are as precise as possible, because some of the current loudness weighting scales are based on them, for example, the dB A scale, used for hearing conservation purposes, is based the equal loudness contour at 40 phons (Suzuki & Takeshima, 2004).

Equal loudness contours have helped scientists develop improved hearing aid technology in recent years. One of the advances in hearing aids is the technology of adaptive active noise control that has a gained lot of attention in the past few years. This technology reduces the intensity of noise through hearing aids. Gan (2000) proposed that via the use of equal loudness contours, this adaptive active noise controller can be improved in hearing aids. As mentioned previously, loudness is subjective and perceived differently for each frequency. To study this concept further, researchers calculated the equal loudness compensation values, which indicating a need to increase the gain in the low and high frequencies to match the mid-frequencies, with the help of equal loudness contours for every frequency. Results showed significant improvement in reducing the noise at every frequency in the hearing aid (Gan, 2000).

Statement of Purpose

Bone conduction technology has been studied as a mode of communication for the past decade; however, bone conduction equal loudness contours have not been established. Bone anchored hearing aids, military communication devices, and recreational devices are some examples of bone conduction devices. Some of the advantages of communication through bone conduction are noted to be unobstructed ears, low leakage of sound, and no interference with hearing protection devices. The variety of skull placements for the bone vibrator allows the communication device to be worn with protective gear and enhance comfort of the user (Pollard et al., 2013). Because of the importance of optimal communication for bone anchored hearing aids, military purposes, etc. an extensive body of knowledge regarding bone conduction transmission, including loudness perception, must be generated. Therefore, the purpose of this study was to examine loudness contours for bone conduction in a sample of individuals for whom some information about bone to soundfield and soundfield loudness contours was also collected. Specifically, the purpose of this study was to establish the equal loudness contours for:

1. Bone-to-bone at 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz at 20dB HL and 40 dB HL for two different skull placements and conditions,
2. Soundfield-to-soundfield at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz at 40 dB HL,

3. Soundfield-to-bone at 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz at 40 dB HL with the bone vibrator on the right mastoid.

This thesis is based on a dataset collected collaboratively by three doctoral students, merged, and then used in the aggregate by all three students to answer different research questions. In this study, each of the three doctoral students was responsible for a specific area of analysis yielding three unique thesis projects. Study one, described in this thesis focused on equal loudness contours and previous studies that have yielded some results relevant to bone conduction equal loudness contours. Study two, written by Andreaggi (2015), focused on laterality, subject variability, and the differences between the unilateral and bilateral conditions. Study three, described by Lasman (2015), focused on soundfield-to-bone equivalent loudness levels, intensity differences and mastoid versus condyle perception of bone conduction.

Chapter 3

Methods

Institutional Review Board (IRB) for the protection of human subjects permission was obtained for this study (See appendix A). The statement of purpose, methodology, and results were prepared as a group effort by Jennifer Lasman, Sanghmitra Arvindekar, and David Andreaggi. In addition, three separate types of analyses were conducted individually by the three researchers to answer their unique study questions. All other written portions of this thesis are the individual work of Sanghmitra Arvindekar. The focus of the Arvindekar (2015) study was bone conduction equal loudness contours.

Participants

A group of 30 otologically normal participants (14 women and 16 men), aged 18 to 30 years, with normal hearing sensitivity were recruited, via posted fliers and personal contact, to participate in the study. A small incentive (e.g. movie coupons, candy) was offered to encourage participation. Prior to participation in the study, each participant had a hearing screening. All participants had normal hearing thresholds ($\leq$15 dB HL at 500, 1000, 2000 and 4000 Hz). Participants also had normal tympanometric results based on standard tympanometric screening procedures (Jerger, Anthony, Jerger, & Mauldin, 1974). The 30 participants consisted of three groups of 10 participants, each tested by one of the three researchers involved in this study. Data were aggregated across all 30 participants for the purposes of all statistical analyses. However, each of the three doctoral students was responsible for a specific area of analysis yielding three unique thesis projects.

Equipment

Tympanometry was screened using a GSI-38 tympanometer. A two-channel Astera audiometer was used to present pure tone stimuli for the hearing screening and the experiment. Channel 1 was used to present the reference signal and Channel 2 to present the test signal. All sound stimuli were played from a Sony Compact Disc Player (model CDP-CE535) connected to the audiometer. Two Radio Ear B-71 bone vibrators (serial numbers 00864 and 00862) attached with elastic and Velcro strips were used to examine soundfield to bone and bone-to-bone loudness comparisons (Appendix D). The bone vibrators were located on either the condyle or mastoid placements unilaterally or bilaterally. The force of the bone vibrator against the head was measured by a Mark 10 series force gauge using the procedure described in Toll, Emanuel and Letowski (2011). The air conduction stimuli were presented through a loudspeaker positioned 3.5 feet in front of the subject at 0° azimuth. The subject was seated in a sound treated test room and the tester was seated in a separate room with sound proof glass separating the two rooms. The test room met maximum permissible ambient noise level standards (Frank, 2000). The tester and participant could see each other at all times during the testing. The study was conducted in the Towson University Institute for Well Being, Hearing and Balance Center.

Stimuli

The stimuli used in the study were 1 second long, one-third-octave bands of noise with a rise and fall time of 25 ms and plateau duration of 950 ms; these stimuli were digitally generated. These stimuli were developed by Pollard et al. (2013) and made available for this study. The original stimuli were modified in intensity as needed for this study using computer software (Audacity) and transferred to a CD. Stimuli were delivered to the participants using the CD player connected to the audiometer, allowing intensity changes separately in each channel. For bone-to–bone comparisons (see description under procedures), the noise stimulus in Channel 1, previously described, was one-third octave band of noise centered at 1000 Hz and presented at either 20 dB or 40 dB HL. Noise stimuli in Channel 2 were one-third octave noise centered at 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz frequency (Note 1: high frequency limit for the Astera audiometer coupled to a B-71 bone vibrator is 6000 Hz). In Channel 1 and 2, stimuli were being played out of two bone vibrators in the bilateral bone to bone conditions. For bone to soundfield comparisons, the signal in channel 1 and channel 2 were the same and they were noises with a center frequency corresponding to one of the frequencies listed above. Channel 1 emitted a 40 dB HL reference noise band via the soundfield and the test stimuli were presented through channel 2 with the bone vibrator placed on the right mastoid. 20 dB HL was not tested in the bone to soundfield comparisons. For soundfield-to-soundfield, channel 1 emitted a 40 dB HL tone at various reference frequencies, while channel 2 emitted the test stimuli at various intensities.

Procedure

Three types of comparisons were made as part of the experiment. First, a soundfield-to-soundfield comparison was made. This was included as part of the training procedure and as a way to examine individual participant responses compared with normative ISO 226. 2003 equal loudness curves (ISO, 2003). This task was used to increase the validity of the other comparisons in this study. Second, a soundfield-to-bone conduction comparison was made. This task was done to provide additional data as a follow up to data collected by Pollard et al. (2013). Third, a bone-to-bone comparison using unilateral and bilateral stimulation was used to generate data not previously examined. The procedures for each of these three portions are explained below. All equipment and transducers were calibrated prior to and mid-way through experimental testing.

The loudspeakers were calibrated by using a sound level meter at the distance of the seated participant at the height of the ears with the listener absent. The bone vibrators were calibrated using a B&K 4930 artificial mastoid.

Soundfield-to-Soundfield

To minimize participants' difficulty in comparing loudness of signals having different pitch, test instruction and the soundfield-to-soundfield training experiment were conducted for each participant before the main bone conduction collection data was started. Training included adjusting the loudness level for comparison of soundfield-to-soundfield stimuli. Instructions to participants are included as Appendix B. Test frequencies included in testing were 250, 500, 750, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Channel 1 presented a reference tone of 1000 Hz at 40 dB SPL and Channel 2 presented the test stimuli at the various frequencies. Stimuli were alternated between channels but both were directed through the same loudspeaker. The loudspeaker was located at a 0° angle from the participant. The participant signaled to the tester to increase or decrease the intensity of the Channel 2 stimuli until all of the tones appeared to be equally loud. The signal was increased or decreased in 2 dB steps for three trials. This procedure was repeated for each test frequency through Channel 2.

Soundfield-to-Bone

This task included comparison of loudness between air conduction stimuli via a loudspeaker and bone conduction stimuli via a bone vibrator. Channel 1 stimuli were presented through the loudspeaker and Channel 2 stimuli were presented through the bone vibrator. The stimuli were presented in both channels with noises centered at 250, 500, 1000, 2000, 3000, 4000, or 6000 Hz. Stimuli were alternating continuously between channels 1 and 2 with no gaps (Pollard et al., 2013). Stimulus intensity was increased or decreased by 1 dB steps with the examiner adjusting the attenuation of channel 2 of the audiometer per the patient's instruction. At the beginning of each trial, the channels were set to different intensity levels so as not to allow the participant to predict the amount of steps needed to equal the loudness from channel 2 to channel 1. The participant's tasks were to compare loudness of the bone conduction test stimulus to the air conduction (reference) stimulus and adjust the level of the former stimulus to be equally loud to the reference stimulus. The participant would then signal to the tester when they wanted the intensity increased or decreased and the tester made the adjustment on the attenuation dial on Channel 2 of the audiometer. The task was repeated for each frequency of the test stimulus. The intensity dial on the audiometer was increased or decreased in 2 dB steps. The location of the bone vibrator was on the right mastoid and was tested only in the unilateral condition. The orders of the test frequencies and intensities of the reference stimulus were randomized using an algorithm available at the website Random.org. Stimuli from channel 1 were the control stimuli. The participants were seated in a sound treated booth with the audiometer located on the other tester side of the booth. The participant was instructed to adjust the intensity of the bone conduction stimulus using a method of adjustment. The subject indicated to the tester to increase or decrease the intensity of the bone conduction stimulus so that it perceptually equal in loudness compared to the reference stimulus. In total, three ascending trials were included and the adjusted values were averaged.

Bone-to-Bone

The procedure for obtaining bone-to-bone equal loudness contours was the same as the procedure for soundfield-to-bone. However, the reference stimulus was presented at 20 and 40 dB HL via bone conduction and stayed at 1000 Hz. The stimulus from channel 1 (the reference frequency) and the test stimuli were presented alternatively through the same bone vibrator. The reference frequency was presented at 20 and 40 dB HL to obtain bone-to-bone equal loudness contours. The participant again used a method of adjustment, as mentioned above in the soundfield-to-bone section, to adjust the intensity dial on Channel 2 of the audiometer until the test frequency was perceptually equal in loudness compared to the reference stimulus.

Equipment Calibration and Data Conversion

Each figure in the results section and all data used for descriptive and inferential analysis were based upon raw data that had been adjusted for each frequency and measured output level differences between devices, as described below. Electroacoustic calibration of the 2-channel Astera audiometer was conducted a year prior to and midway through testing by a professional calibration company. The equipment was found to be in good working order, it met ANSI S3.6-2010 standards on all testing occasions, and minimal adjustments were needed at the mid-way calibration point. These minor adjustments were taken into account in data processing. Immediately prior to the study and at the mid-way point, the output was measured by the researchers of the study.

The value of the reference signal was always set to 20 dB HL or 40 dB HL, based on the audiometer dial reading, except in the soundfield condition, which only had a reference signal of 40 dB HL. All other raw data were audiometer dial readings that, in isolation, could not be compared.

In addition calibration issues had to be taken into account for bone conduction data because of equipment limitations. The two Radio Ear B-71 bone vibrators output levels were measured with a B&K artificial mastoid attached to a frequency spectrum analyzer, which reported the output with the label of "dB SPL." A conversion sheet was created which indicated the correspondence between the audiometer dial reading and the level from the analyzer. Only one bone vibrator output jack was available on the audiometer; therefore, one bone vibrator (00864) was connected to the bone vibrator output jack (channel 1, reference signal) and the other bone vibrator (00862) was connected to the earphone output jack from the audiometer (channel 2, comparison signal). For all frequencies, the reference signal presented via the audiometer was set to channel 1 to elicit a 20 dB HL or 40 dB HL output through the bone vibrator in the bone output (00864). The level of channel 2 was adjusted until the bone vibrator produced an almost identical output, with at most a 1.2 dB difference between the two channel outputs.

The values recorded for the conversion sheet are provided in Appendix C. These values provide a comparison between the output levels for each channel. For example, note, in the first table of Appendix C, the values associated with 1000 Hz. With the audiometer dial set to 20 dB HL, the analyzer reported the output level of the bone vibrator to correspond to 46.3 dB SPL. Channel 2 was adjusted until the bone vibrator connected to the earphone jack produced an almost identical level (46 dB SPL). Channel 2 had to be set to a much higher number, 71, for the outputs to be equal. The difference between the output levels for the two bone vibrators was used to correct for the difference between the outputs of the two bone vibrators in the different jacks, so the raw data could be adjusted such that all data would be reported using the same relative scale. In this case, 51 dB (71-20 from the table) had to be subtracted from the raw data (audiometer dial reading of channel 2) in order to compare the reference and comparison levels using the same scale.

Chapter 4

Results

Analysis and Authorship Plan

Recall, the three researchers were responsible for data collection for ten participants and the data were combined for analysis. Each researcher was responsible for conversion of data to identical units and submission of an Excel data file. These files were then merged to include the data for all 30 participants. Some analyses were conducted and some tables and figures were created as a group. When one of the three took a primary role, it was indicated in the text. Sections of texts that are identical across the three thesis projects are cited as well. Line graphs, t-tests, and analysis of variance (ANOVA) were based upon data that had been adjusted to account for calibration factors, described below. All statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS) software version 21.

Data analysis was divided into three distinct parts. Part two was conducted by Lasman (2015), part three was conducted by Andreaggi (2015) and part one was conducted by this author and is described in this thesis. Specifically, this thesis focused on examining similarities and differences between established equal loudness contours for soundfield and equal loudness contours for the soundfield from the current study. Additionally, this thesis focuses on similarities and differences between equal loudness contours for bone conduction and established equal loudness contours for the soundfield and from the current study. The results section is comprised of all the testers' data figures, and statistical analysis. Statistical analysis includes using a repeated measures analysis of variance (ANOVA) to compare laterality, placements, frequency, and intensity differences in the bone conduction data. To compare ISO data and published data to the soundfield, soundfield-to-bone and bone conduction data from the current study, paired sample t-tests were used. To compare gender and tester differences and possible interaction effects, a repeated measures ANOVA was used. Statistical Analysis for each comparison is described in detail in the Data Analysis and Discussion Section.

Equal Loudness Contours

Figure 1 illustrates a comparison between our study's soundfield data, ISO (2003) data, and the average of all the bone conduction curves when the intensity level of the reference was set to 40 dB HL. The soundfield equal loudness contours from the current study were lower than the established ISO 2003 values for soundfield at 40 dB at all tested frequencies except 6000 Hz. The loudness values were similar except at 250 Hz, where they were approximately 10 dB different. The average bone conduction curve closely approximates soundfield data from the current study, except at 6000 Hz, where the bone conduction value was approximately 10 dB lower than the soundfield value.

Figure 2 illustrates a comparison between our study's soundfield data, ISO (2003) data, and the published data from Pollack (1952) when the intensity level of the reference was set to 40 dB HL. The soundfield equal loudness contours from the current study were almost identical to the ISO 2003 values except at 250, 6000 and 8000 Hz, where they were approximately 10-12 dB lower. The Pollack (1952) curve closely approximates soundfield data from the current study, except at 250, where the soundfield value is approximately 9 dB lower. Figure 3 illustrates a comparison between our study's soundfield data, ISO (2003) data, and Pollack (1952) data at 40 dB HL. In addition, the line graph includes this study's soundfield-to-bone data and published data from Patrick et al. (2012), Stenfelt and Hakansson (2002), and Pollard et al. (2013). The loudness values were similar except at 250 Hz, where they were approximately 10 dB different.

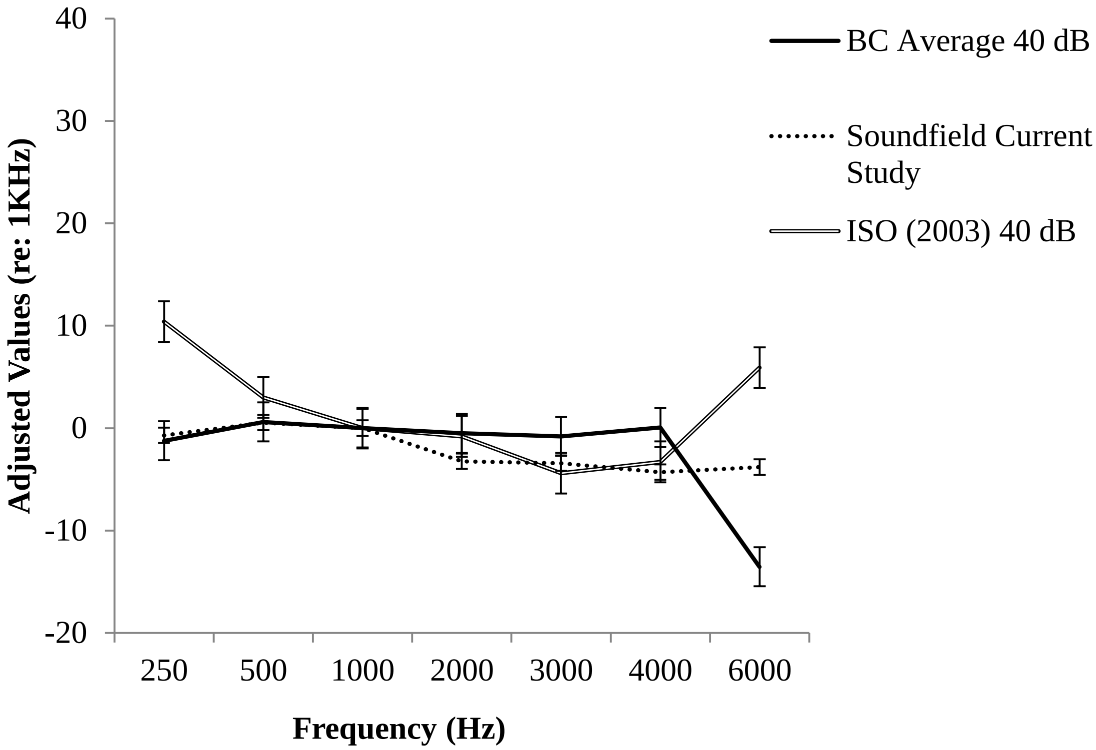


Figure 1. Adjusted mean values as a function of frequency for the soundfield current study data, the ISO 2003 curve, and the average bone conduction curve determined with a 1000 Hz reference set to 40 dB HL. For all of the ISO 2003 published values 3150 Hz value was used for 3000 Hz and 6300 Hz was used for 6000 Hz

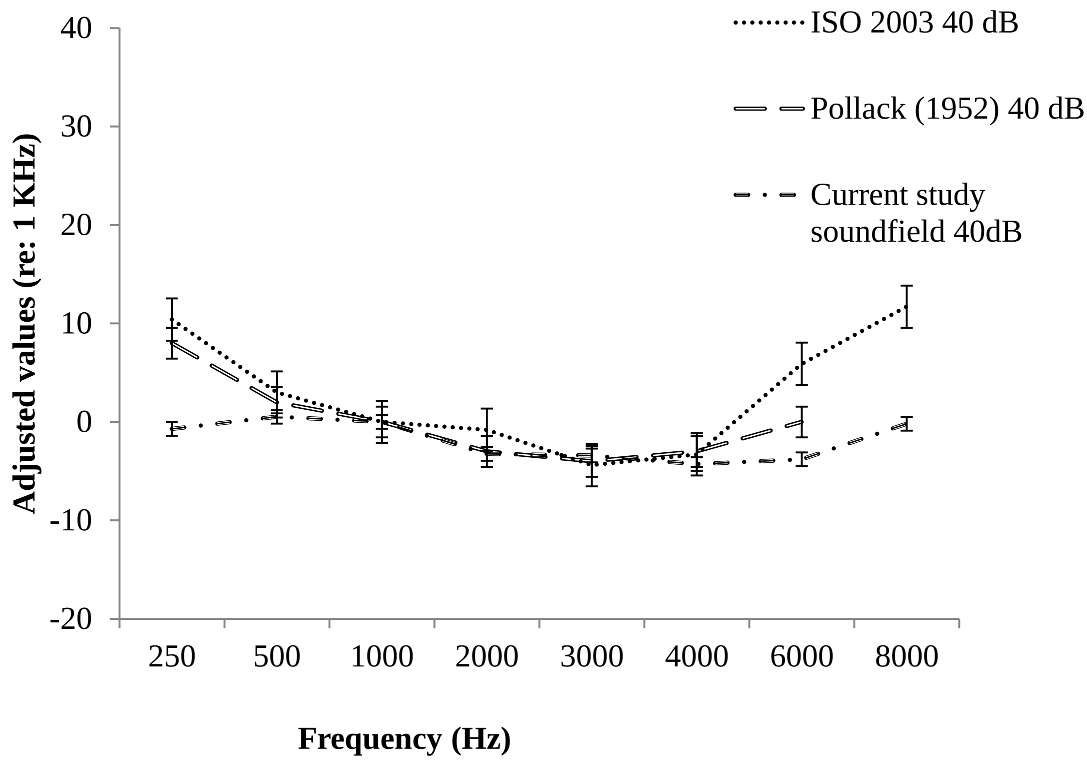


Figure 2. Adjusted mean values as a function of frequency for the soundfield current study data determined with a 1000 Hz reference set to 40 dB HL, the ISO 2003 curve, and the published data from Pollack (1952) at 40 dB HL.

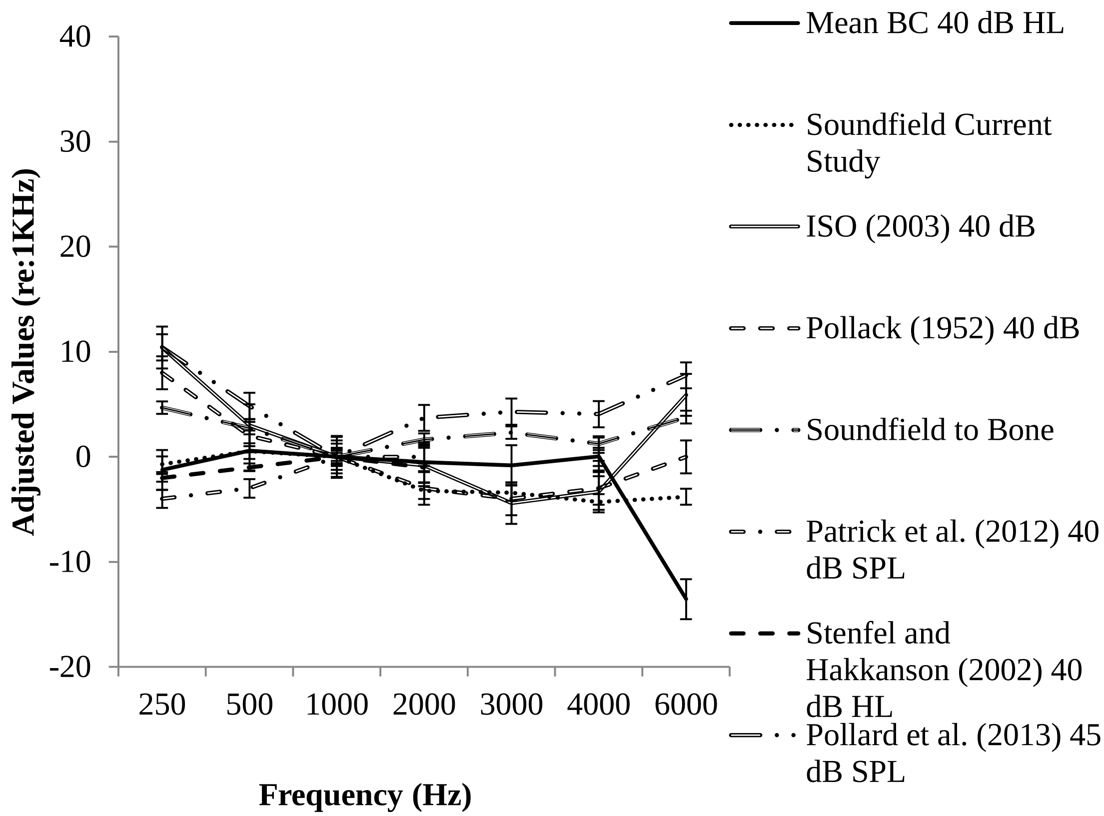


Figure 3. Adjusted mean values as a function of frequency for the current study's soundfield data determined with a 1000 Hz reference set to 40 dB HL, ISO 2003 data, and Pollack (1952) data at 40 dB HL. In addition, the line graph includes this study's soundfield-to-bone data and published data from Patrick et al. (2012), Stenfelt and Hakansson (2002), and Pollard et al. (2013). For the Pollard et al. (2013) values, 3150 Hz was used in the graph to replace 3000 Hz, and 6300 Hz was used to replace 6000 Hz.

The average bone conduction curve closely approximates soundfield data from the current study, except at 6000 Hz, where the bone conduction value was approximately 10 dB lower than the soundfield value. The Pollack (1952) curve closely approximates soundfield data from the current study, except at 250, where the soundfield value was approximately 9 dB lower. The soundfield equal loudness contours from the current study did not closely approximate the Pollard et al. (2013) curve across all of the test frequencies. The soundfield curve from the current study was approximately 4 -10 dB lower than the Pollard et al. (2013) curve. The soundfield equal loudness contours from the current study approximated the Patrick et al. (2012) values except at 250 and 500 Hz, where they were approximately 3-4 dB different. Compared to the Stenfelt and Hakansson (2002) values, the soundfield equal loudness values from the current study were almost identical, with a difference between the two curves not exceeding 3 dB. The soundfield equal loudness contours closely approximates soundfield data from the current study, with slight difference of approximately 4 dB at 2000, 3000, and 4000 Hz.

Figure 4 illustrates the bone conduction values for unilateral mastoid, bilateral mastoid, unilateral condyle and bilateral condyle at 20 dB HL compared to the published ISO values for 20 dB and the soundfield loudness contour values from the current study. All of the bone conduction equal loudness contours were similar to each other as well as to the published ISO values for 20 dB. The bone conduction equal loudness values were lower than the established ISO 2003 values for soundfield at 20 dB at all tested frequencies, except at 2000 and 4000 Hz. Differences were quite small, except at 250 and 6000 Hz, where they were approximately 3-8 dB different.

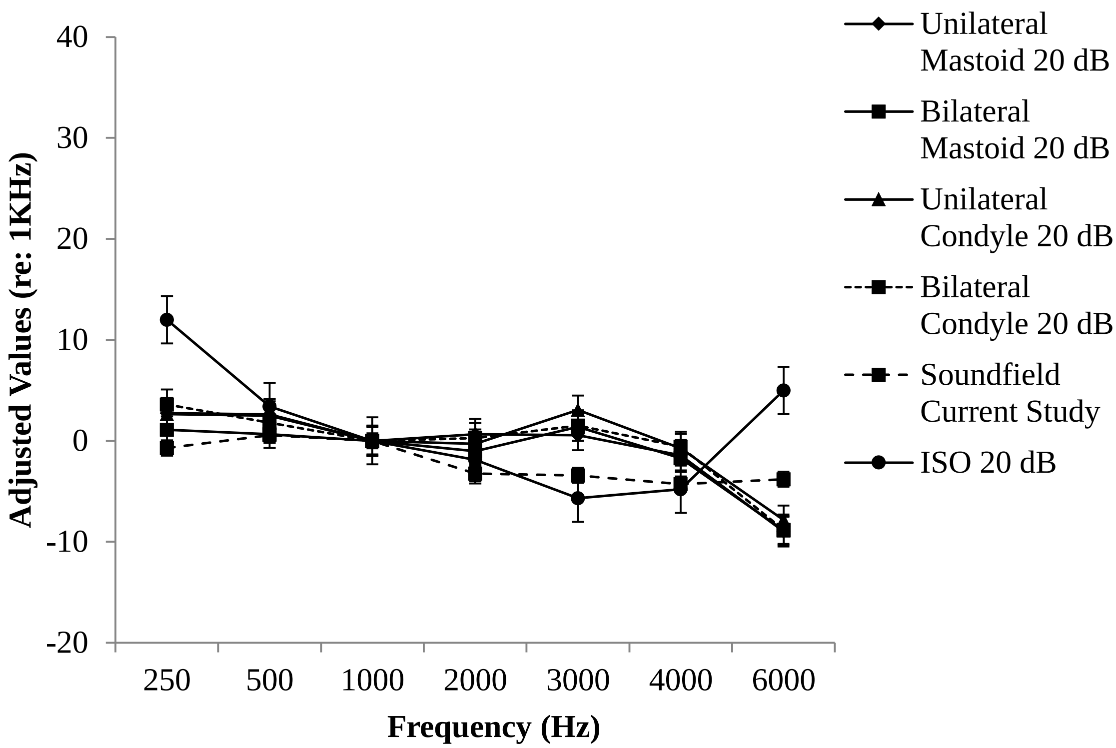


Figure 4. Adjusted mean values as a function of frequency for the unilateral mastoid, bilateral mastoid, unilateral condyle, and bilateral condyle determined with a 1000 Hz reference set to 20 dB HL.

The soundfield equal loudness curve from the current study, approximates bone conduction data from the current study, except at 3000 and 6000 Hz, where the soundfield value was approximately 3 dB lower than the bone conduction value.

Figure 5 illustrates the bone conduction values for unilateral mastoid, bilateral mastoid, unilateral condyle and bilateral condyle at 40 dB HL compared to the published ISO values for 40 dB and the soundfield loudness contour values from the current study. All of the bone conduction equal loudness contours were similar to each other as well as to the published ISO values for 40 dB. The bone conduction equal loudness values were lower than the established ISO 2003 values for soundfield at 40 dB at all tested frequencies, except at 2000 and 4000 Hz. Differences were quite small, except at 250 and 6000 Hz, where they were approximately 8-10 dB different. The soundfield equal loudness curve from the current study, approximates bone conduction data from the current study, except at 3000, 4000 and 6000 Hz, where the soundfield value was approximately 3 dB lower than the bone conduction value.

Soundfield to bone conduction loudness level comparisons indicated loudness levels were similar across all test frequencies regardless of delivery modality (Figure 6). The figure below included published data from Patrick et al. (2012), Pollard et al. (2013) and Stenfelt and Hakansson (2002) studies which examined equal loudness contour comparisons between soundfield and bone conduction stimuli. Patrick et al. (2012) conducted their study using a 40 dB SPL air conduction reference tone, Stenfelt and Hakansson (2002) used a 40 dB HL air conduction reference tone which is the same intensity used in this study, and Pollard et al. (2013) used a 45 dB SPL air conduction reference tone.

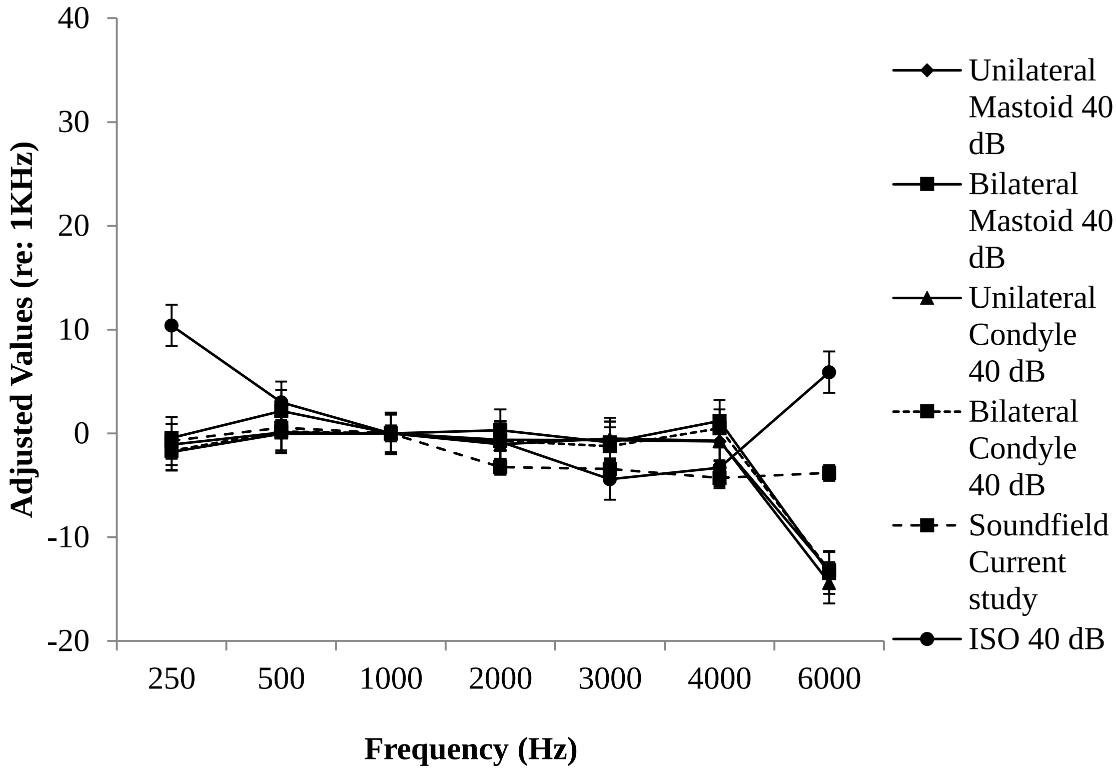


Figure 5. Adjusted mean values as a function for the unilateral mastoid, bilateral mastoid, unilateral condyle, and bilateral condyle determined with a 1000 Hz reference set to 40 dB HL.

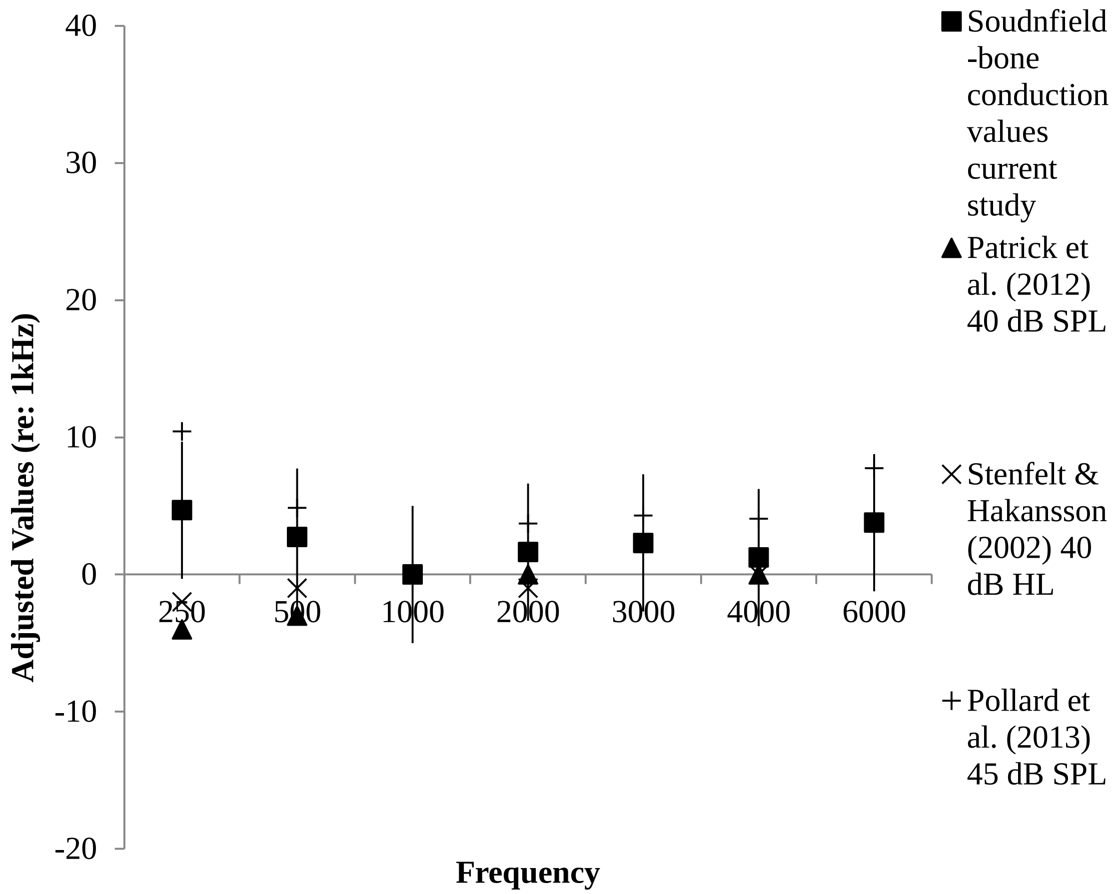


Figure 6. Adjusted mean values as a function of frequency for mean participant unilateral mastoid bone conduction values compared to a reference soundfield value presented at 40 dB HL and published data from Patrick et al. (2012), Pollard et al. (2013) and Stenfelt & Hakansson (2002). For the Pollard et al. (2013) values, 3150 Hz was used in the graph to replace 3000 Hz, and 6300 Ha was used to replace 6000 Hz.

As is indicated in the figure, the general trend for the Stenfelt and Hakansson (2002) and Patrick et al. (2012) studies is that less intensity is needed for bone conduction loudness levels to have equal loudness compared to the soundfield reference tone at 0 dB. The soundfield-to-bone values from the current study were higher than the soundfield reference tone equalized at 0 dB at all tested frequencies. Differences were quite small, with differences between the value from the current study and the reference tone equalized at 0 dB not exceeding 5 dB. The Stenfelt and Hakansson (2002) curve closely approximates the soundfield-to-bone data from the current study, except at 250, where the Stenfelt and Hakansson (2002) value is approximately 6 dB lower. The Patrick et al. (2012) values were almost identical to the soundfield-to-bone values, except at 250 and 500 Hz, where it was approximately 10 dB different. The Pollard et al. (2013) data did not closely approximate the values from the current study across all tested frequencies, where the Pollard et al. (2013) values were 2-6 dB higher.

Laterality

Figure 7 illustrates a comparison between the unilateral and bilateral condition at the condyle placement at a 1000 Hz reference tone at an intensity level of 40 dB HL. The contours show a pattern that indicates that laterality had similar contours in morphology and proportion. Examination of Figure 7 indicates that there are slight differences of 2-3 dB between laterality at each test frequency, especially in the higher frequencies (4000-6000) where the bilateral condition has slightly larger mean adjusted values compared to the unilateral condition. Figure 8 illustrates a comparison between the unilateral and bilateral condition at the mastoid placement at an intensity level of 40 dB HL.

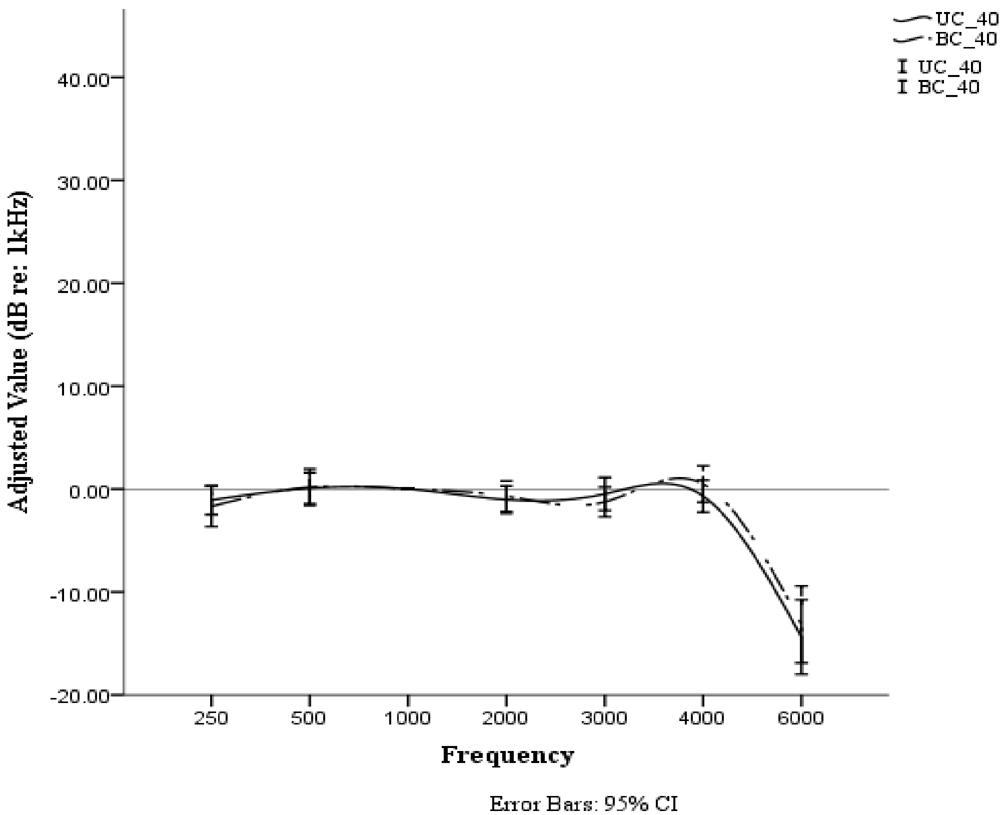


Figure 7. Adjusted mean values as a function of frequency in unilateral and bilateral condyle condition determined with a 1000 Hz reference set to 40 dB HL.

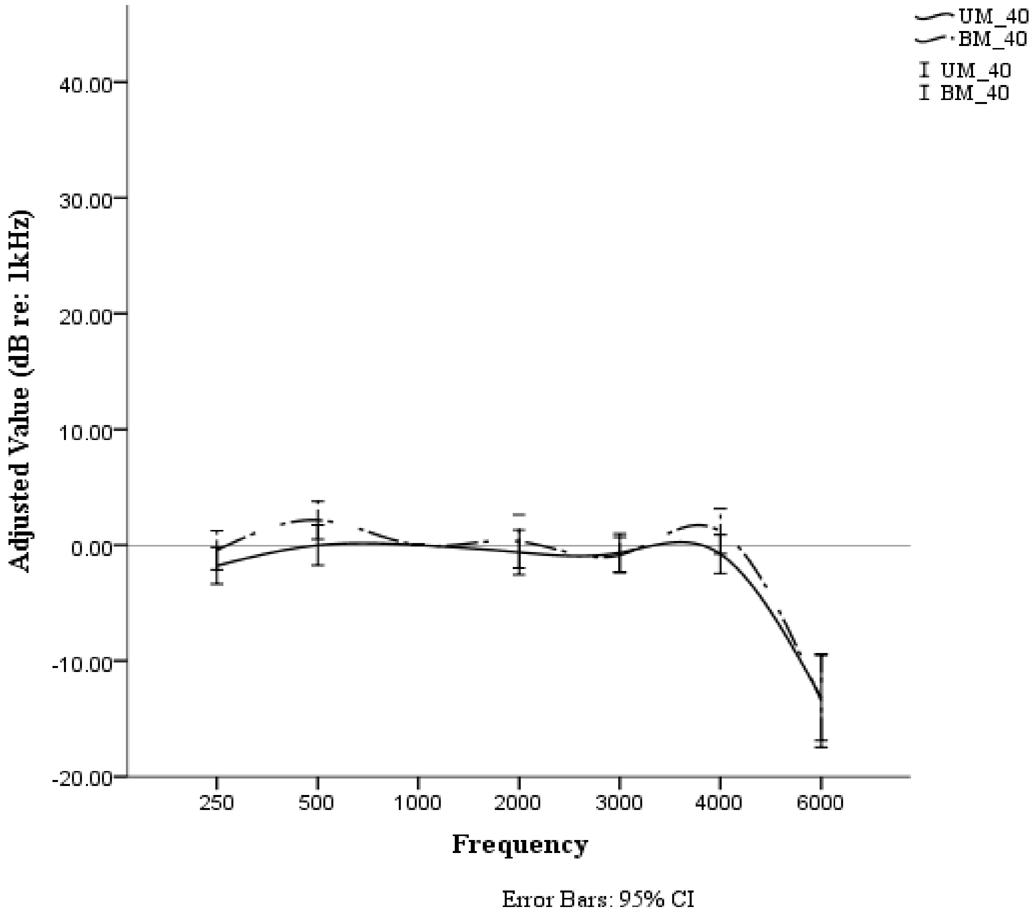


Figure 8. Adjusted mean values as a function of frequency in unilateral and bilateral mastoid condition determined with a 1000 Hz reference set to 40 dB HL.

The contours show a pattern that indicates that both conditions create similar contours in morphology and proportion. Examination of figure 8 indicated that there are slight differences of 2-3 dB between laterality at each test frequency, especially at the lower frequencies (250-500 Hz) and higher frequencies (4000-6000 Hz) where the bilateral condition has slightly larger mean adjusted values compared to the unilateral condition.

Figure 9 illustrates a comparison between the unilateral and bilateral condition at the condyle placement to a 1000 Hz reference tone at an intensity level of 20 dB HL. The contours show a pattern that indicates that laterality has similar contours in morphology and shape of the curve. Examination of Figure 9 indicates that there are slight differences of 2-3 dB in laterality at each test frequency, especially at 500 and 3000 Hz where the bilateral condition has slightly smaller mean adjusted values compared to the unilateral condition.

Figure 10 illustrates a comparison between the unilateral and bilateral condition at the mastoid placement to a 1000 Hz reference tone at an intensity level of 20 dB HL. The contours show a pattern that indicates that both conditions create similar contours in morphology and shape of the curve. Examination of figure 10 indicated that there are slight differences of 2-3 dB between laterality at each test frequency, especially at the lower frequencies (250-500 Hz) where the bilateral condition has slightly smaller mean adjusted values compared to the unilateral condition.

Placement

Figure 11 illustrates a comparison between the mastoid and condyle placement in the unilateral condition at an intensity level of 40 dB HL. The contours show a pattern that indicates that both placements create similar contours in morphology and proportion.

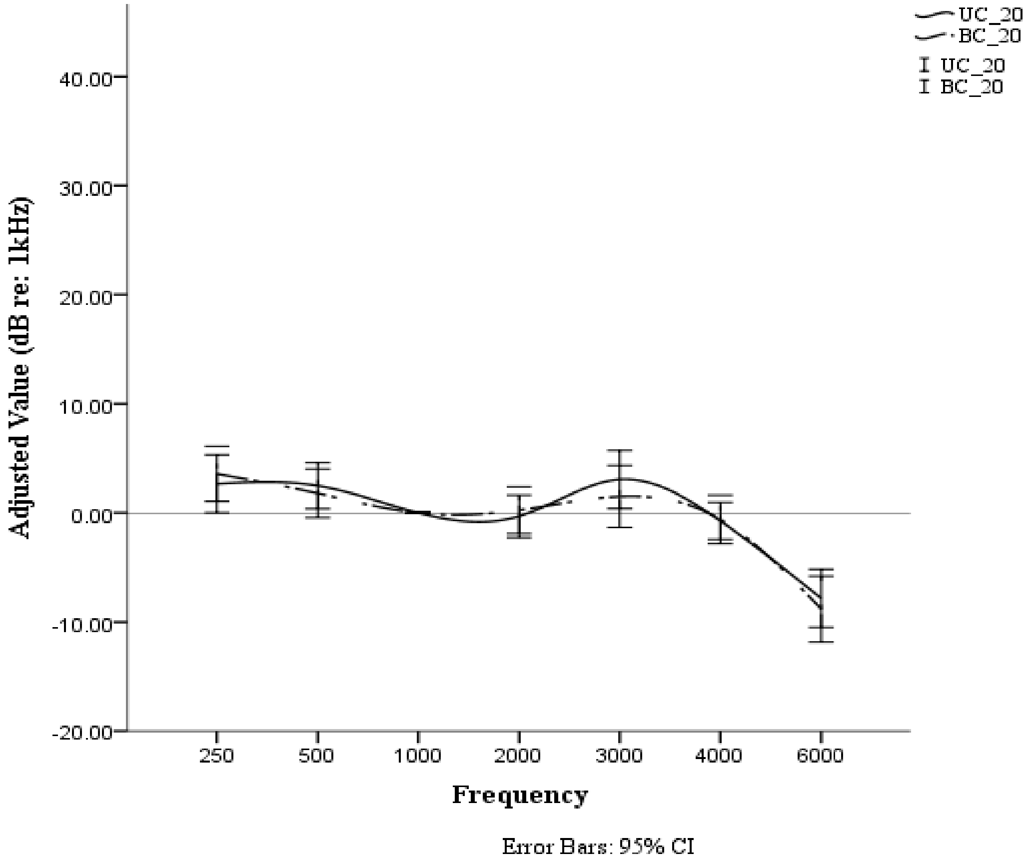


Figure 9. Adjusted mean values as a function of frequency in unilateral and bilateral condyle condition determined with a 1000 Hz reference set to 20 dB HL.

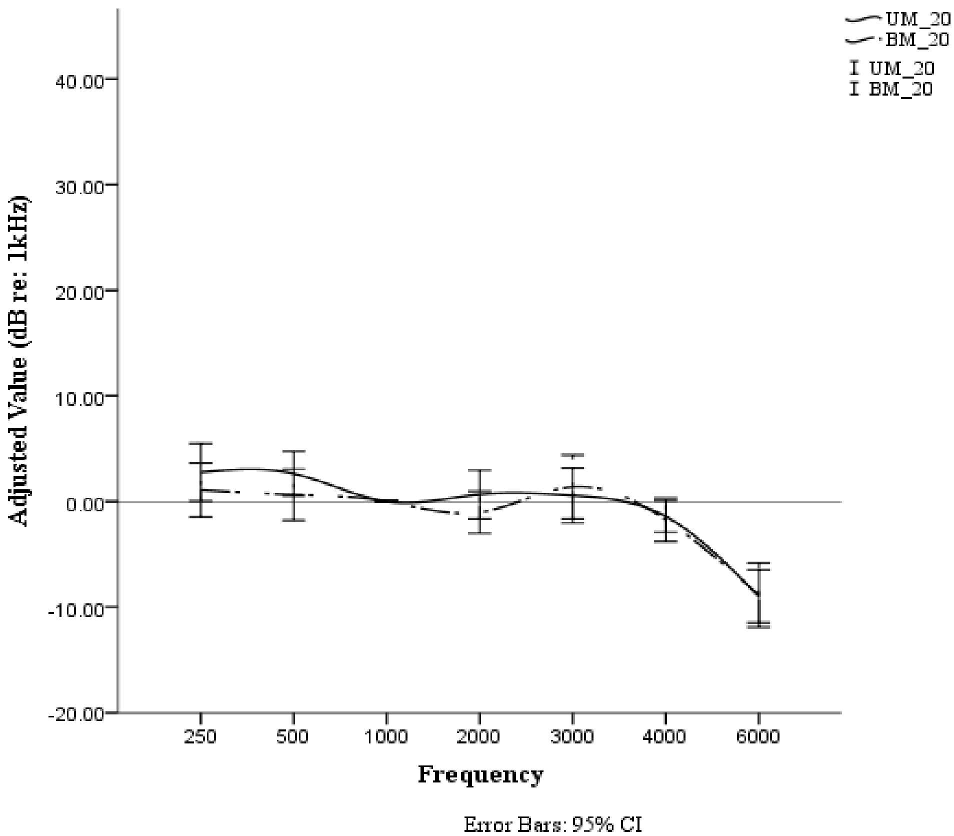


Figure 10. Adjusted mean values as a function of frequency in unilateral and bilateral mastoid condition determined with a 1000 Hz reference set to 20 dB HL.

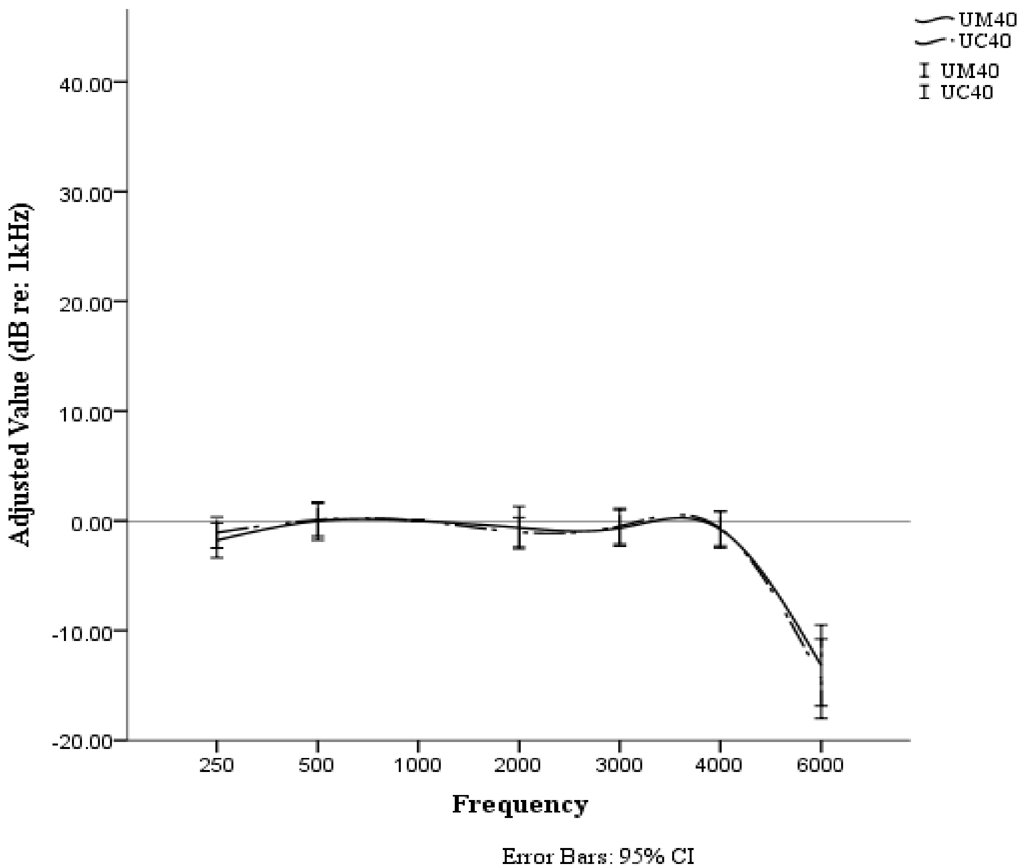


Figure 11. Adjusted mean values as a function of frequency in the unilateral condition at the mastoid and condyle placement determined with a 1000 Hz reference set to 40 dB HL.

Examination of figure 11 indicates that there are slight differences of 1 dB or less between the two placements at each test frequency, with differences not exceeding 2 dB.

Figure 12 illustrates a comparison between the mastoid and condyle placement in the bilateral condition to a 1000 Hz reference tone at an intensity level of 40 dB HL. The contours show a pattern that indicates that both placements create similar contours in morphology and proportion. Examination of figure 12 indicated that there are slight differences of 2-3 dB between the two placements at each test frequency, especially at the lower frequencies (250-500 Hz) and higher frequencies (2000-4000) where the condyle placement has slightly smaller mean adjusted values compared to the mastoid placement.

Figure 13 illustrates a comparison between the mastoid and condyle placement in the bilateral condition to a 1000 Hz reference tone at an intensity level of 20 dB HL. The contours show a pattern that indicates that both conditions create similar contours in morphology and proportion. Examination of figure 13 indicated that there are slight differences of 2-4 dB between the two placements at each frequency, especially at the lower frequencies (250-500 Hz) and higher frequencies (2000, 4000, and 6000 Hz) where the condyle condition has slightly larger mean adjusted values compared to the mastoid placement.

Figure 14 illustrates a comparison between the mastoid and condyle placement in the unilateral condition t a 1000 Hz reference tone at an intensity level of 20 dB HL. The contours show a pattern that indicates that both conditions create similar contours in morphology and proportion. Examination of figure 14 indicated that there are slight differences of 2-3 dB between the two placements at each frequency, especially at 2000 Hz where the condyle placement had slightly smaller mean adjusted values and at 3000

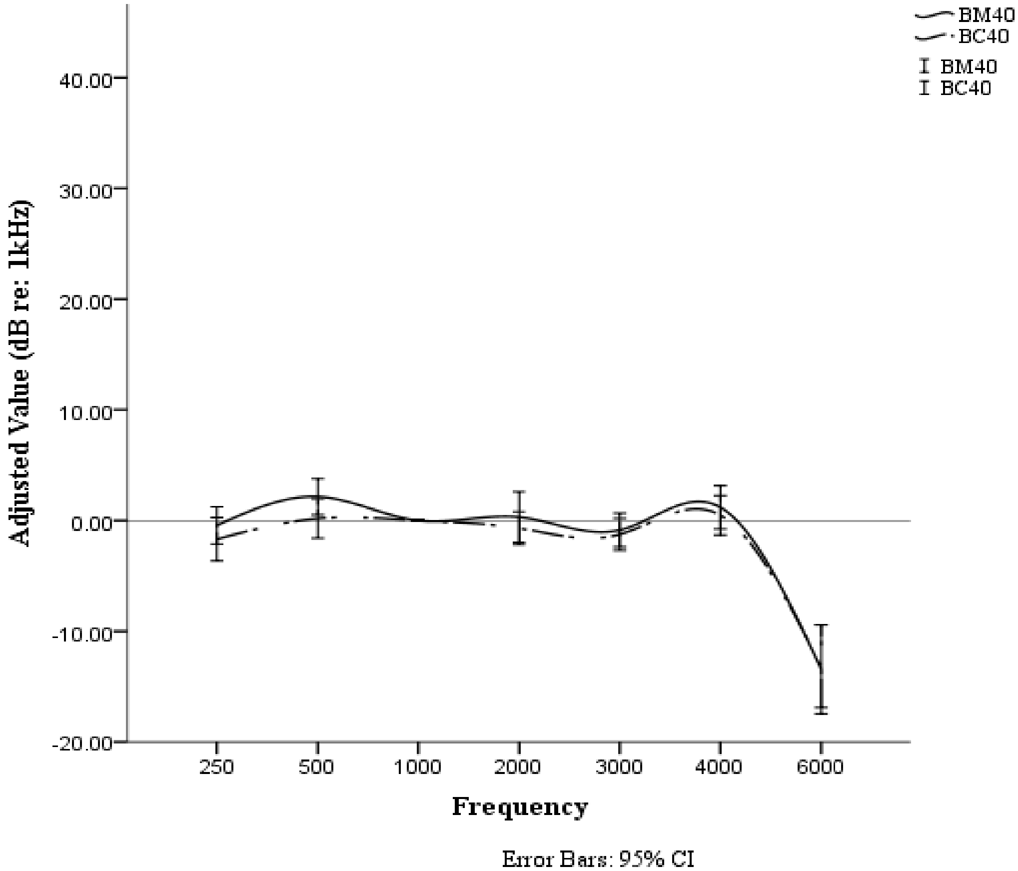


Figure 12. Adjusted mean values as a function of frequency in the bilateral condition at the mastoid and condyle placement determined with a 1000 Hz reference set to 40 dB HL.

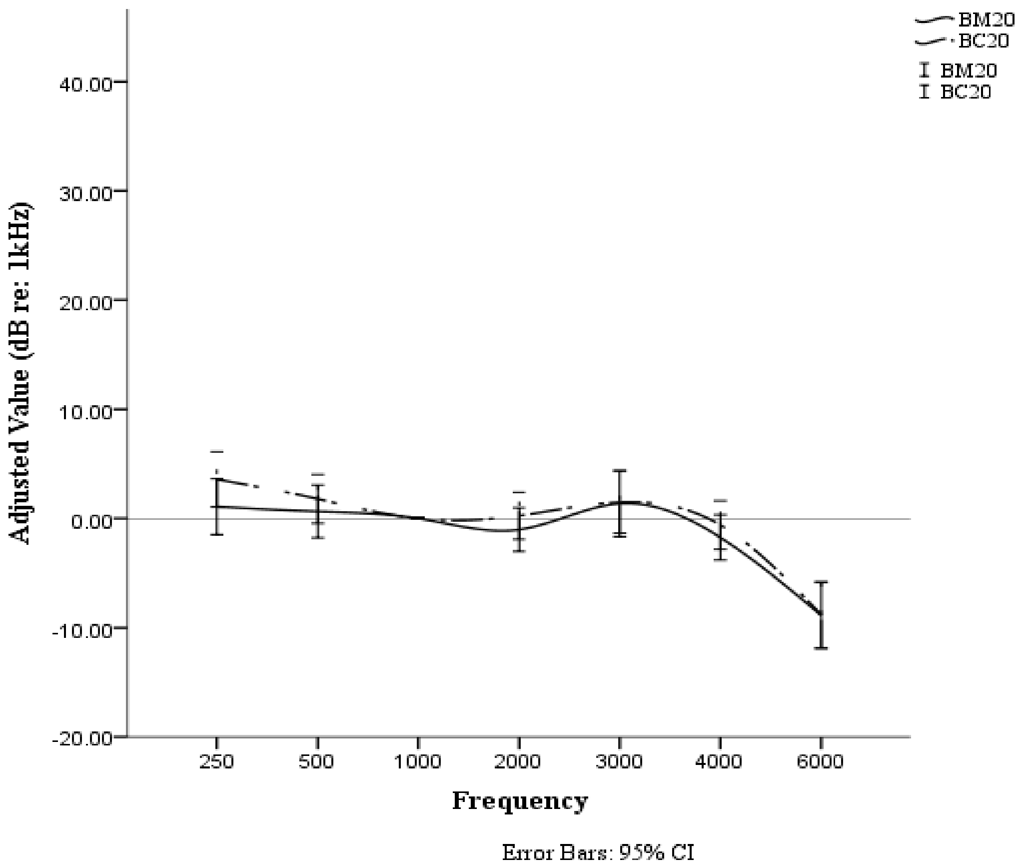


Figure 13. Adjusted mean values as a function of frequency in the bilateral condition at the mastoid and condyle placement determined with a 1000 Hz reference set to 20 dB HL.

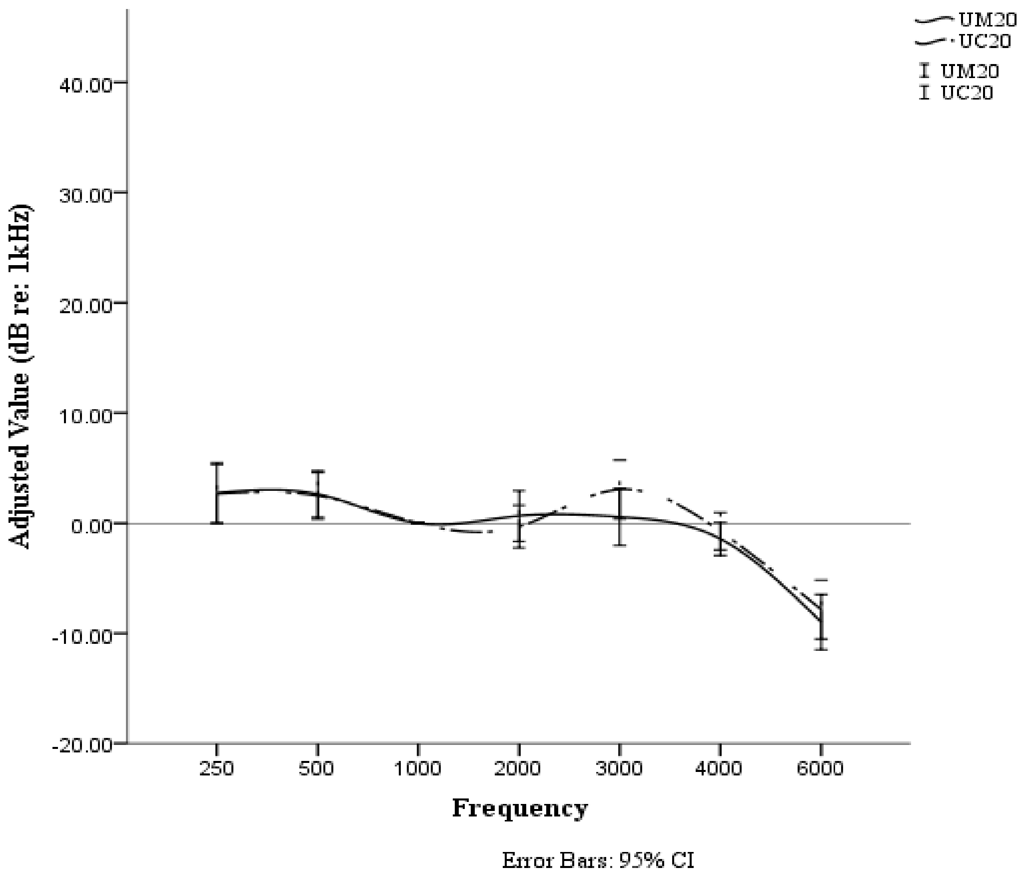


Figure 14. Adjusted mean values as a function of frequency in the unilateral condition at the mastoid and condyle placement determined with a 1000 Hz reference set to 20 dB HL.

4000 Hz where the condyle placement has slightly larger mean adjusted values compared to the mastoid placement.

Intensity

Figure 15 illustrates a comparison between the test intensities (20 and 40 dB HL) in the bilateral condition at the mastoid placement. The contours show a pattern that indicates that both intensities create similar contours in morphology and proportion. Examination of figure 15 indicates that there are slight differences between the two intensities at each test frequency, especially at 500, 2000, and 4000 Hz where the 40 dB HL contour has slightly larger mean adjusted values by approximately 2-3 dB compared to the 20 dB HL contour. The intensity of 20 dB HL had slightly higher values by approximately 2-3 dB at 250, 3000, and 600 Hz.

Figure 16 illustrates a comparison between the test intensities (20 and 40 dB HL) in the bilateral condition at the condyle placement. The contours show a pattern that indicates that both intensities create similar contours in morphology and proportion. Examination of figure 16 indicates that there are slight differences of approximately 3-5 dB between the two intensities at each test frequency, especially at the lower (250-500 Hz) and higher frequencies (2000-3000 Hz) where the 40 dB HL contour has slightly smaller mean adjusted values compared to the 20 dB HL contour.

Figure 17 illustrates a comparison between the test intensities (20 and 40 dB HL) in the unilateral condition at the mastoid placement. The contours show a pattern that indicates that both intensities create similar contours in morphology and proportion. Examination of figure 17 indicates that there are slight differences of 3-4 dB between the two intensities at each test frequency, especially at the lower 250-500 Hz) and higher

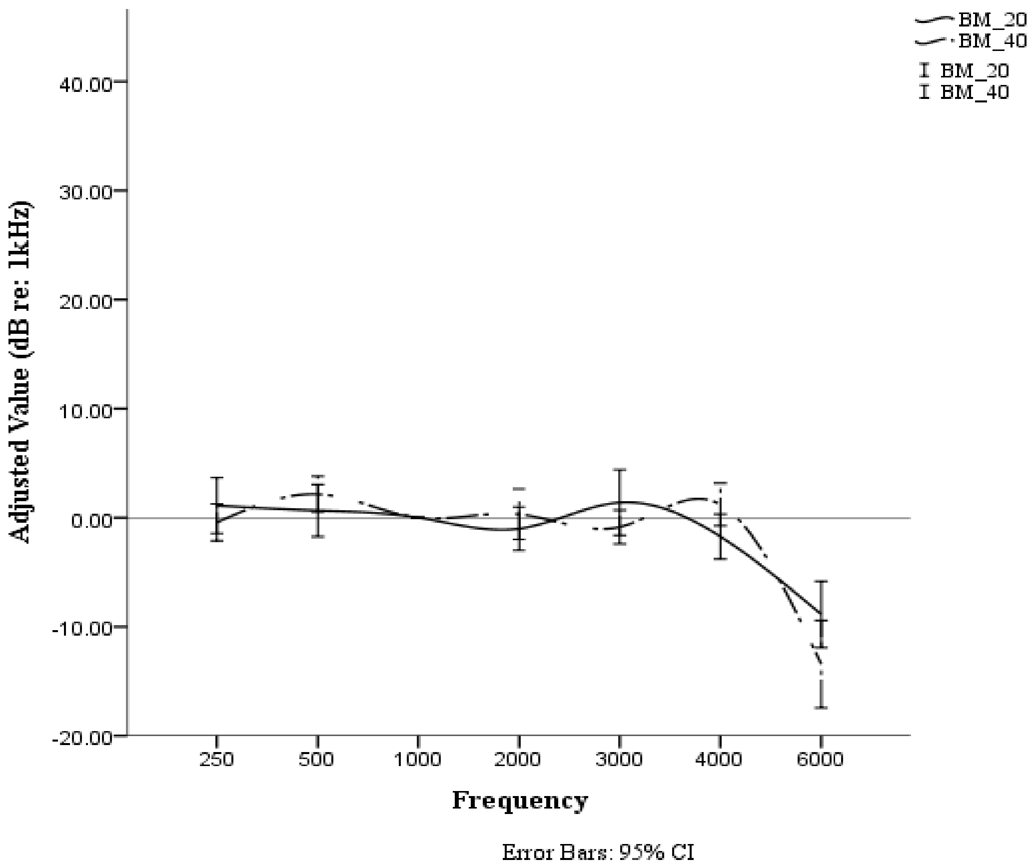


Figure 15. Adjusted mean values as a function of frequency in the bilateral mastoid condition determined with a 1000 Hz reference set to 20 and 40 dB HL.

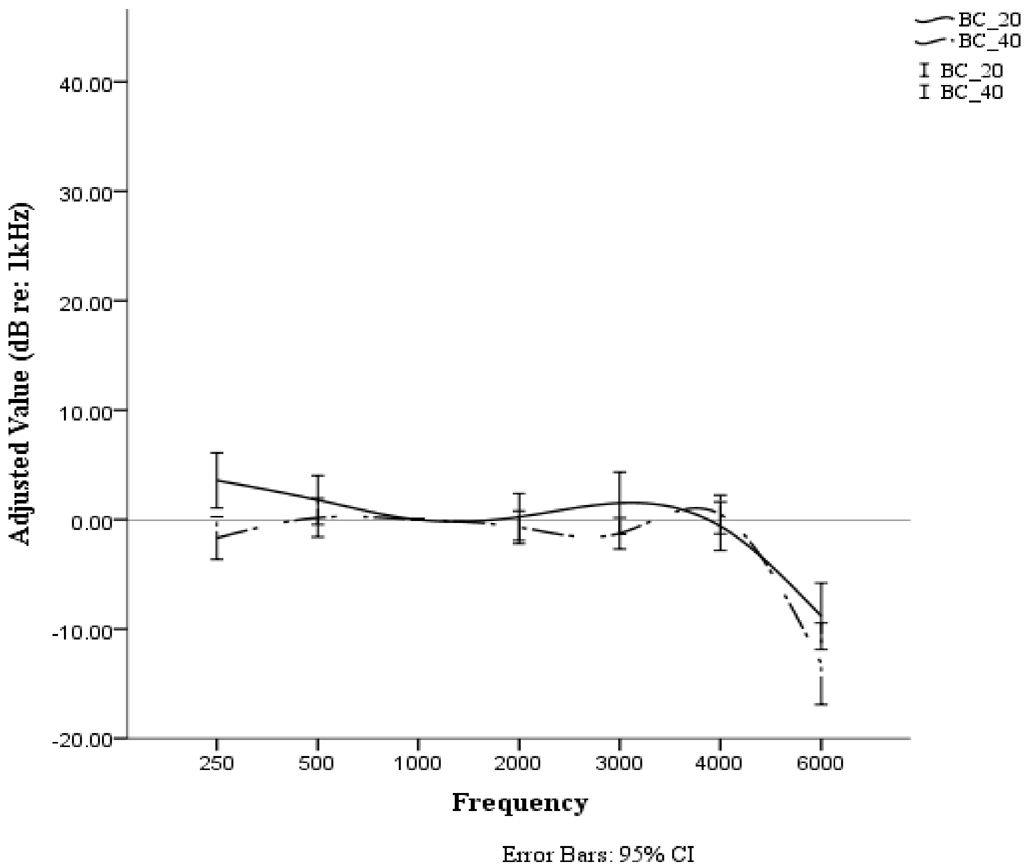


Figure 16. Adjusted mean values as a function of frequency in the bilateral condyle condition determined with a 1000 Hz reference set to 20 and 40 dB HL.

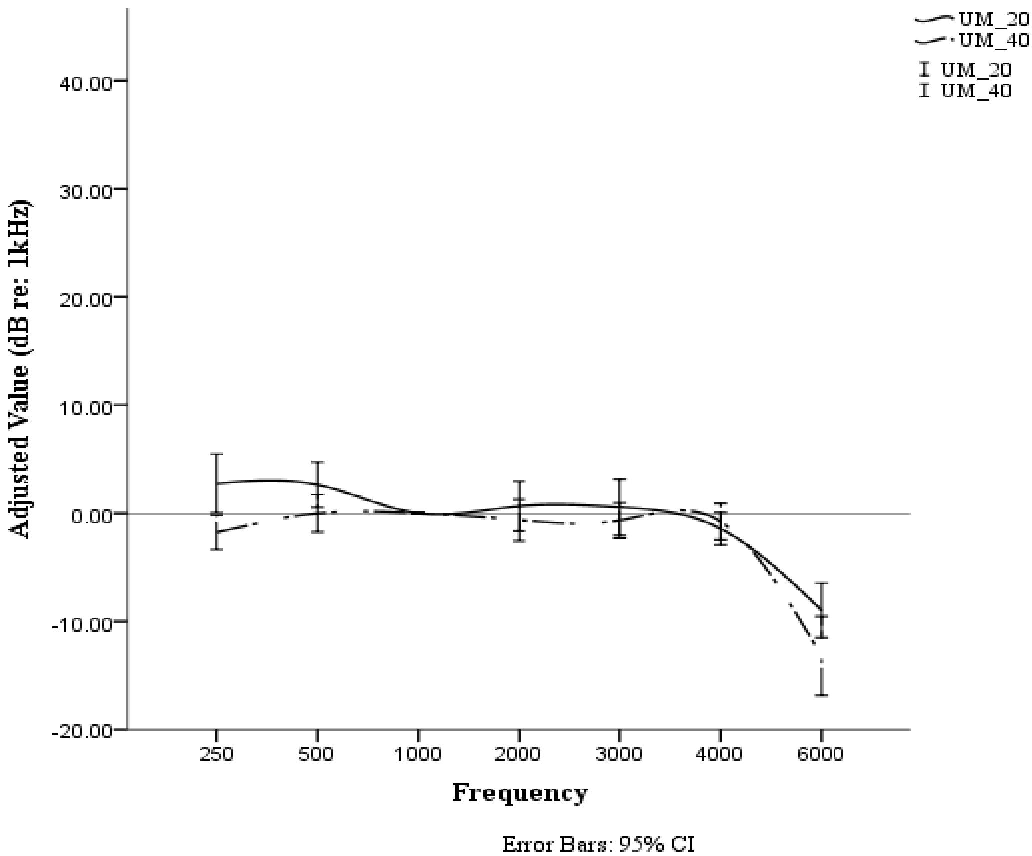


Figure 17. Adjusted mean values as a function of frequency in the unilateral mastoid condition determined with a 1000 Hz reference set to 20 and 40 dB HL.

frequencies (2000-3000, 6000 Hz) where the 40 dB HL contour has slightly smaller mean adjusted values compared to the 20 dB HL contour.

Figure 18 illustrates a comparison between the test intensities (20 and 40 dB HL) in the unilateral condition at the mastoid placement. The contours show a pattern that indicates that both intensities create similar contours in morphology and proportion. Examination of figure 18 indicates that there are slight differences of 3-5 dB between the two intensities at each test frequency, especially at the lower (250-500 Hz) and higher frequencies (2000-3000, 6000 Hz) where the 40 dB HL contour has slightly smaller mean adjusted values compared to the 20 dB HL contour.

Figure 19 represents the soundfield-to-soundfield comparisons separated by tester and frequency as well as published ISO 2003 equal loudness contour values for 40 dB HL. The Soundfield-to-soundfield loudness comparisons were used as training for the bone-to-bone and air-to-bone comparisons. Examination of the figure reveals similar morphology of the responses between all three tester's participants as well as ISO 2003 loudness contour values. All the testers closely matched the each other and the published ISO values for 40 dB SPL in the lower frequencies of 250, 500, and 1000 Hz and in the higher frequency of 8000 Hz. Tester three was the farthest from the published ISO values with a difference ranging from 3 to 15 dB in the mid frequencies of 2000 to 6000 Hz. Tester two was the closest to the published ISO values with a difference ranging from 2 to 5 dB in the mid frequencies of 2000 to 6000 Hz. Tester one had differences ranging from 3 to 10 dB in the mid frequencies of 2000 to 6000 Hz.

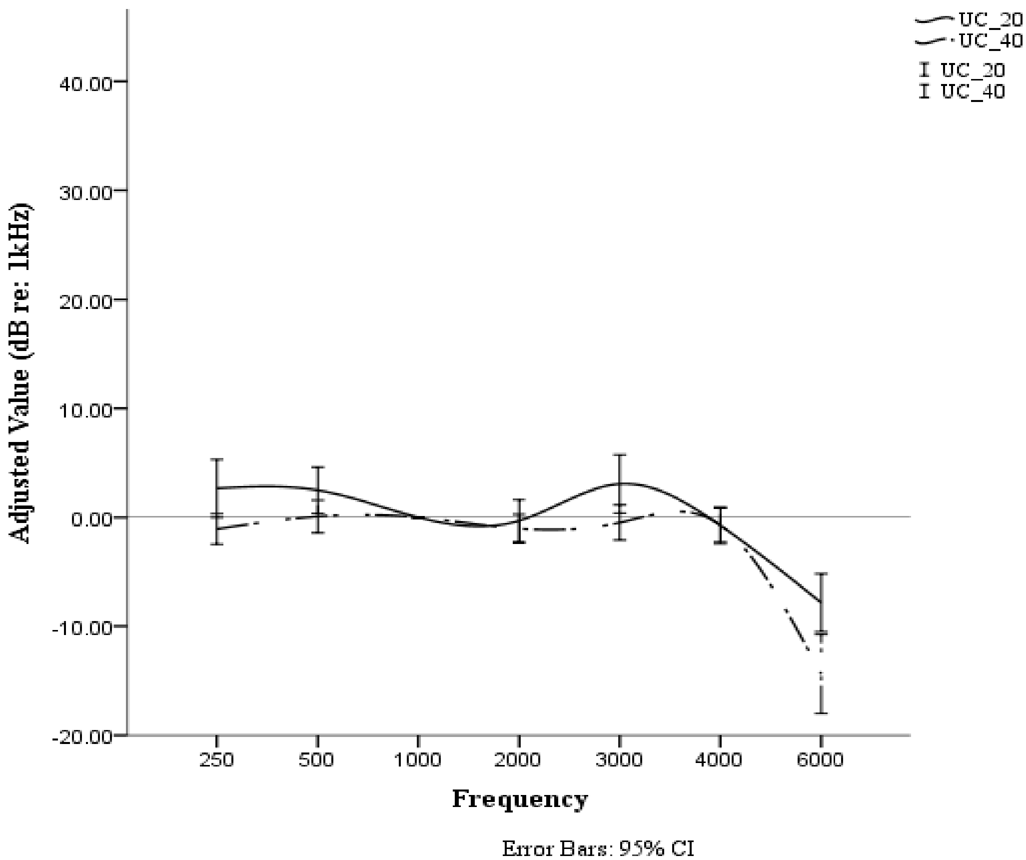


Figure 18. Adjusted mean values as a function of frequency in the unilateral condyle condition determined with a 1000 Hz reference set to 20 and 40 dB HL.

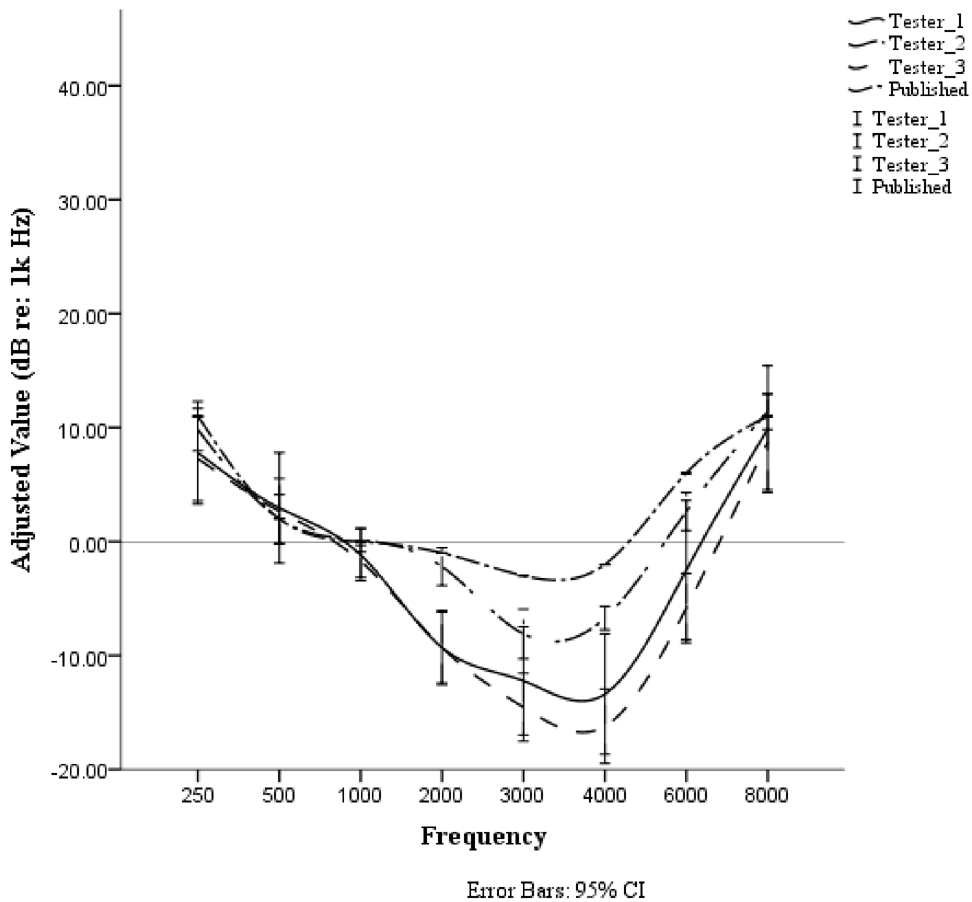


Figure 19. Adjusted mean values for each tester and the published ISO 2003 loudness values determined with a 1000 Hz reference set to 40 dB HL.

Figure 20 illustrates a comparison between male and female participants averaged across all bone conduction conditions determined with 1000 Hz reference set to 20 dB HL. Examination of the figure indicates that male participants had higher values by 5 dB in the lower frequencies of 250 and 500 Hz. No differences were observed in the higher frequencies (2000-3000 Hz).

Figure 21 illustrates a comparison between male and female participants averaged across all bone conduction conditions determined with 1000 Hz reference set to 40 dB HL. Examination of the figure indicates a difference of approximately 5 dB between male and female participants at 250 Hz. No differences were observed in the higher frequencies (2000-3000 Hz).

Figure 22 illustrates a comparison, separated by tester, between male participants averaged across all bone conduction conditions determined with 1000 Hz reference set to 40 dB HL. Examination of figure 25 indicates that tester two had higher values at 250 and 2000 Hz by approximately 3 dB when compared to testers one and three. Tester two had lower values at 500 Hz by approximately 2-3 dB and at 6000 Hz by approximately 20 dB when compared to tester two and three.

Figure 23 illustrates a comparison, separated by tester, between female participants averaged across all bone conduction conditions determined with 1000 Hz reference set to 40 dB HL. Examination of figure 23 indicates that tester one had lower values at 6000 Hz by approximately 20 dB when compared to testers two and three. Tester two had higher values at 500 Hz by approximately 3-5 dB when compared to testers one and three and was higher at 4000 Hz by 2-5 dB when compared to tester one

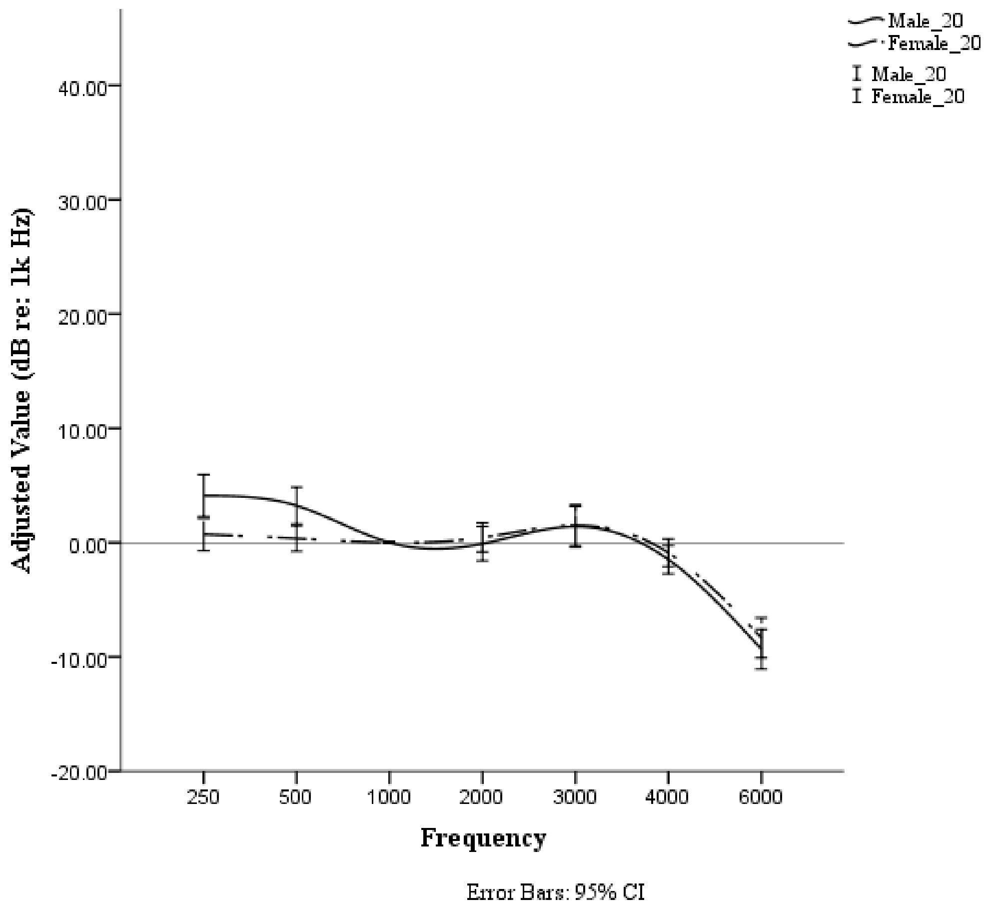


Figure 20. Adjusted mean values separated by gender for all bone conduction conditions with a 1000 Hz reference set to 20 dB HL.

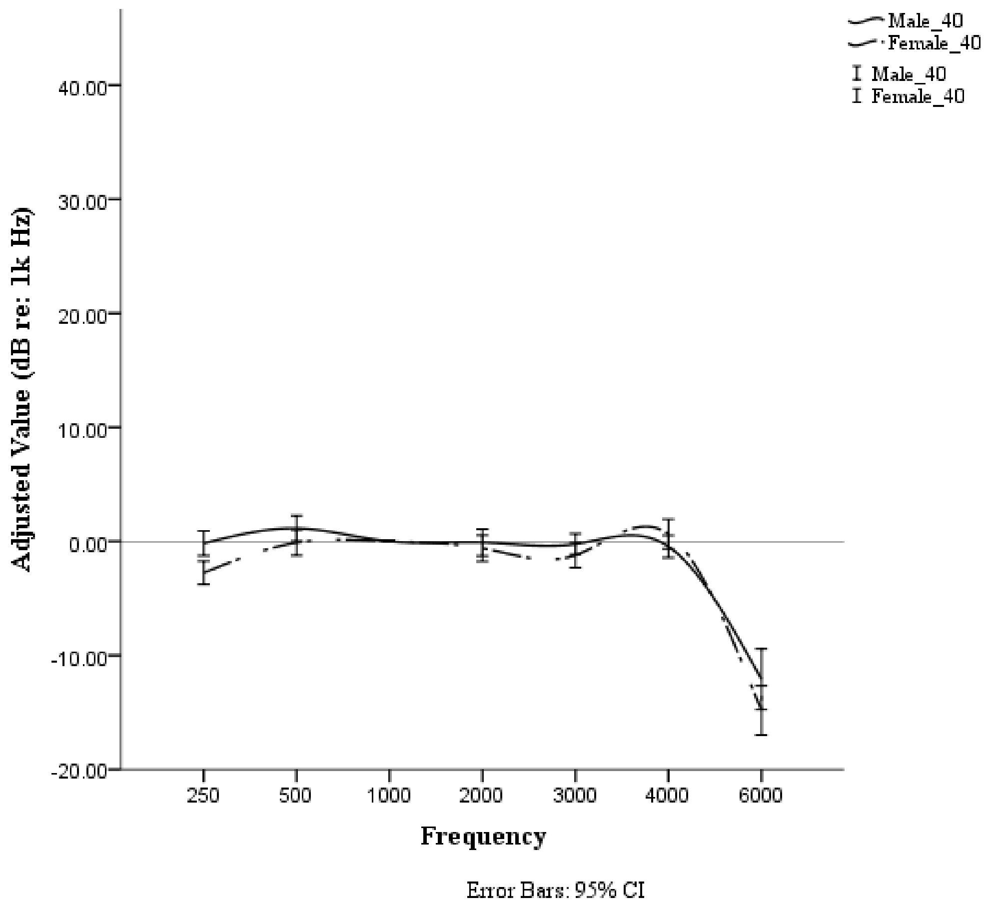


Figure 21. Adjusted mean values separated by gender for all bone conduction conditions with a 1000 Hz reference set to 20 dB HL.

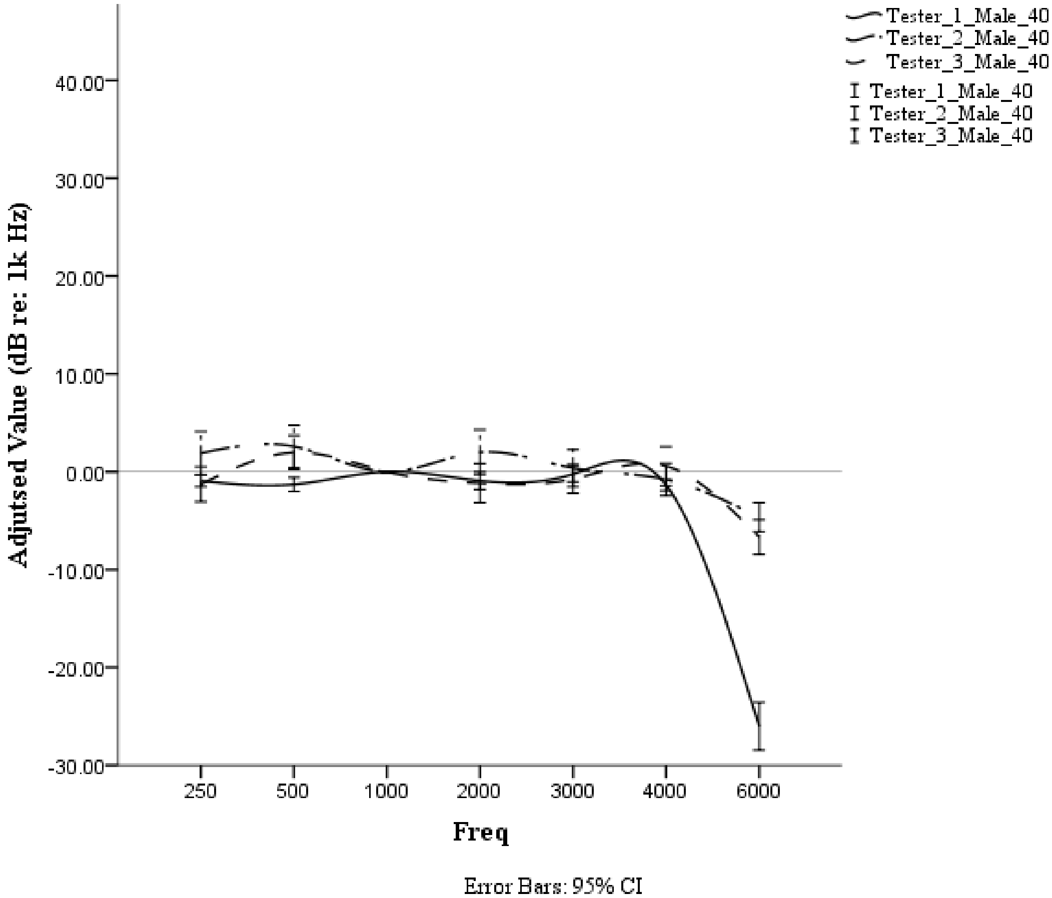


Figure 22. Adjusted mean values for all male participants separated by testers for all bone conduction conditions with a 1000 Hz reference set 40 dB HL.

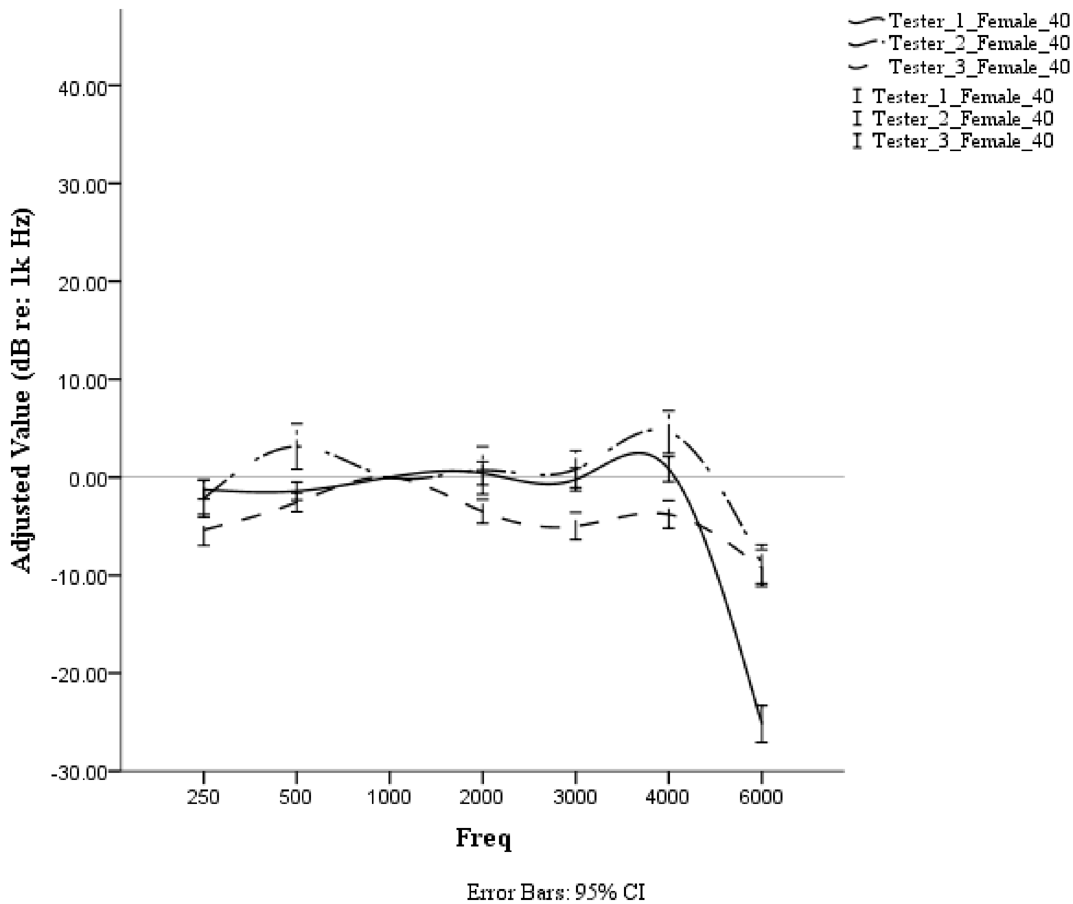


Figure 23. Adjusted mean values for all female participants separated by testers for all bone conduction conditions with a 1000 Hz reference set 40 dB HL.

and by 5-7 dB when compared to tester three. Tester three had lower values at 250, 2000, and 3000 Hz by 2-5 dB when compared to testers one and two.

Figure 24 illustrates a comparison, separated by tester, between male participants averaged across all bone conduction conditions determined with 1000 Hz reference set to20 dB HL. Examination of the figure indicates that tester one had lower values at 250, 500, and 2000 Hz by approximately 2-5 dB when compared to testers two and three. At 3000 Hz, tester one was lower by approximately 10 dB when compared to tester two and by approximately 2 dB when compared to tester three. Tester two was higher at 500 Hz by approximately 2-5 dB and lower by approximately 5-7 dB at 6000 hz when compared to testers one and three.

Figure 25 illustrates a comparison, separated by tester, between female participants averaged across all bone conduction conditions determined with 1000 Hz reference set to 20 dB HL. Examination of figure 25 indicates that tester one was highest at 6000 Hz and tester two was the highest while tester three was the lowest at 3000 HZ. Tester two was higher at 3000 Hz by approximately 5 db when compared to tester one and by approximately 10 dB when compared to tester three. Tester two was lower at 2000 Hz by approximately 2-4 dB at 2000 Hz and 5-7 dB at 4000 Hz when compared to testers one and two.

Statistical analyses were conducted using the SPSS program version 21. The outputs from these analyses are provided in table format throughout this chapter and are summarized in the text.

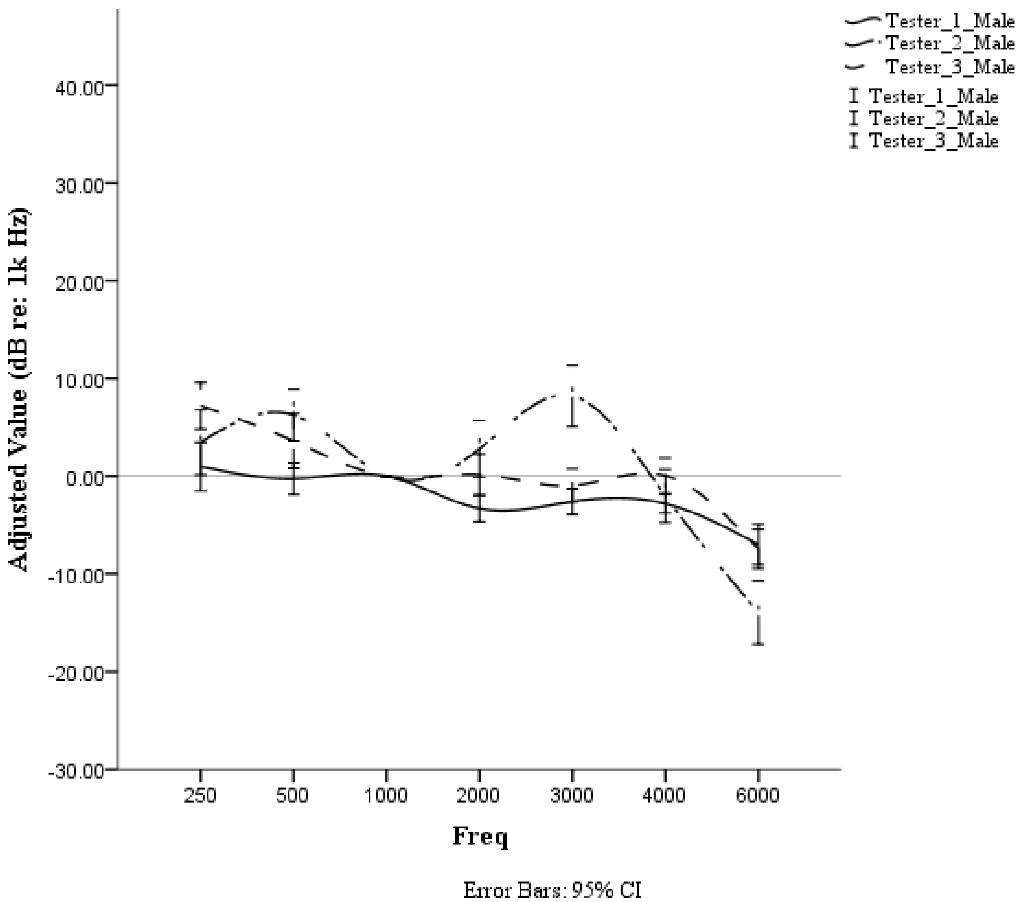


*Figure 24. A*djusted mean values for all male participants separated by testers for all bone conduction conditions with a 1000 Hz reference set 20 dB HL.

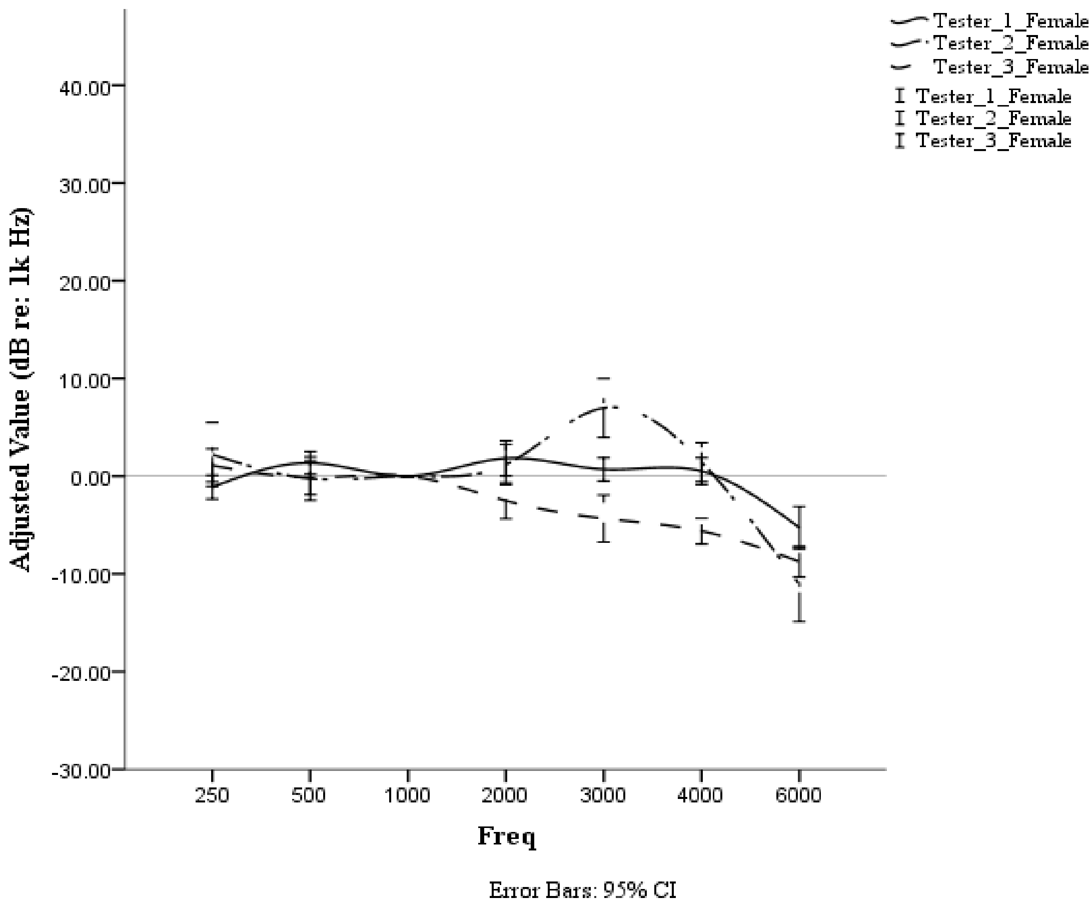


Figure 25. Adjusted mean values for all female participants separated by testers for all bone conduction conditions with a 1000 Hz reference set 20 dB HL.

A 2x2x7 repeated measures ANOVA was used to examine the differences between condition, placement, and frequency at 20 dB HL. The dependent variable is the adjusted mean values and the independent variables are frequency, condition, and placement. Mauchly's test (see Table 1) indicated that the assumption of sphericity had been violated, $X^2(20) = 101.420$, $p<.05$; therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (e=0.445). Table 2 lists the results of the analysis. In summary, there were no statistically significant differences for condition and placement, $F(1, 29)=1.977$, $p<.05$. Frequency was statistically significant $F(3.175,6) = 23.207$, $p<.05$, $w^2=0.023$ (Table 3).

A 2x2x7 repeated measures ANOVA was used to examine the differences between condition, placement, and frequency at 40 dB HL. The dependent variable is the adjusted mean values and the independent variables are frequency, condition, and placement. Mauchly's test (see Table 4) indicated that the assumption of sphericity had been violated, $X^2(20) = 150.480$, $p<.05$; therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (e=0.590). Table 5 and 6 lists the results of the analysis. In summary there were no statistically significant difference for condition and placement, $F(1,29)=26.049$, $p<.05$. Frequency was statistically significant $F(1.983,6) = 41.749$, $p<.05$, $w^2=0.004$.

A 2x2x2x7 repeated measures ANOVA was used to examine the differences between condition, intensity, placement, and frequency. The dependent variable is the adjusted mean values and the independent variables are frequency, condition, intensity and placement. Table 7, 8, and 9 list the results of the analysis. In summary, there were no statistically significant differences for condition and placement, $F(1,29)=13.339$, $p<.05$.

Table 1

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.
Frequency	.023	101.420	20	.000
Placement	1.000	.000	0	
Condition	1.000	.000	0	
Frequency*Placement	.116	57.726	20	.000
Frequency*Condition	.087	65.247	20	.000
Placement*Condition	1.000	.000	0	
Frequency*Placement*Condition	.098	62.269	20	.000

Table 2

Tests of Between-Subjects ANOVA

Source	Type III Sum of Squares	*df*	*Mean Square*	*F*	Sig.	Partial Eta Squared
Intercept	250.724	1	250.724	1.977	.170	.064
Error	3678.247	29	126.836			

Table 3

Test of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Frequency	*10337.311	6	1722.885	23.207	.000	.445
	+10337.311	2.836	3645.439	23.207	.000	.445
	×10337.311	3.175	3255.893	23.207	.000	.445
	•10337.311	1.000	10337.311	23.207	.000	.445
Error(Frequency)	*12917.530	174	74.239			
	+12917.530	82.235	157.081			
	×12917.530	92.074	140.296			
	•12917.530	29.000	445.432			
Placement	*56.753	1	56.753	1.531	.226	.050
	+56.753	1.000	56.753	1.531	.226	.050
	×56.753	1.000	56.753	1.531	.226	.050
	•56.753	1.000	56.753	1.531	.226	.050
Error(Placement)	*1074.742	29	37.060			
	+1074.742	29.000	37.060			
	×1074.742	29.000	37.060			
	•1074.742	29.000	37.060			
Condition	*19.458	1	19.458	.393	.536	.013
	+19.458	1.000	19.458	.393	.536	.013

	×19.458	1.000	19.458	.393	.536	.013
	•19.458	1.000	19.458	.393	.536	.013
Error(Condition)	*1437.538	29	49.570			
	+1437.538	29.000	49.570			
	×1437.538	29.000	49.570			
	•1437.538	29.000	49.570			
Frequency * Placement	*77.540	6	12.923	.716	.637	.024
	+77.540	3.388	22.889	.716	.561	.024
	×77.540	3.890	19.933	.716	.579	.024
	•77.540	1.000	77.540	.716	.404	.024
Error(Frequency*Placement)	*3141.802	174	18.056			
	+3141.802	98.243	31.980			
	×3141.802	112.808	27.851			
	•3141.802	29.000	108.338			
Frequency * Condition	*62.989	6	10.498	.577	.748	.020
	+62.989	3.378	18.649	.577	.651	.020
	×62.989	3.877	16.249	.577	.674	.020
	•62.989	1.000	62.989	.577	.453	.020
Error(Frequency*Condition)	*3163.460	174	18.181			
	+3163.460	97.949	32.297			
	×3163.460	112.420	28.140			
	•3163.460	29.000	109.085			

Placement * Condition	*10.483	1	10.483	.222	.641	.008
	+10.483	1.000	10.483	.222	.641	.008
	×10.483	1.000	10.483	.222	.641	.008
	•10.483	1.000	10.483	.222	.641	.008
Error(Placement*Condition)	*1370.161	29	47.247			
	+1370.161	29.000	47.247			
	×1370.161	29.000	47.247			
	•1370.161	29.000	47.247			
Frequency * Placement * Condition	*142.583	6	23.764	1.557	.162	.051
	+142.583	3.307	43.121	1.557	.201	.051
	×142.583	3.783	37.691	1.557	.194	.051
	•142.583	1.000	142.583	1.557	.222	.051
Error(Frequency*Placement*Condition)	*2655.106	174	15.259			
	+2655.106	95.889	27.689			
	×2655.106	109.704	24.202			
	•2655.106	29.000	91.555			

Note: Sphericity assumed is denoted with a * symbol, Greenhouse-Geisser is denoted with a + symbol, Huynh-Feldt is denoted with a × symbol, and Lower-bound is denoted with a • symbol.

Table 4

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*df*	Sig.
Frequency	.004	150.480	20	.000
Placement	1.000	.000	0	
Condition	1.000	.000	0	
Frequency*Placement	.391	25.130	20	.199
Frequency*Condition	.224	40.006	20	.005
Placement*Condition	1.000	.000	0	
Frequency*Placement*Condition	.389	25.284	20	.194

Table 5

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	*df*	*Mean Square*	*F*	Sig.	Partial Eta Squared
Intercept	3892.753	1	3892.753	26.049	.000	.473
Error	4333.823	29	149.442			

Table 6

Test of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Frequency	*17874.019	6	2979.003	41.749	.000	.590
	+17874.019	1.861	9607.070	41.749	.000	.590
	×17874.019	1.983	9014.029	41.749	.000	.590
	•17874.019	1.000	17874.019	41.749	.000	.590
Error(Frequency)	*12415.795	174	71.355			
	+12415.795	53.955	230.115			
	×12415.795	57.504	215.910			
	•12415.795	29.000	428.131			
Placement	*54.970	1	54.970	1.578	.219	.052
	+54.970	1.000	54.970	1.578	.219	.052
	×54.970	1.000	54.970	1.578	.219	.052
	•54.970	1.000	54.970	1.578	.219	.052
Error(Placement)	*1010.529	29	34.846			
	+1010.529	29.000	34.846			
	×1010.529	29.000	34.846			
	•1010.529	29.000	34.846			
Condition	*87.299	1	87.299	2.368	.135	.075

	+87.299	1.000	87.299	2.368	.135	.075
	×87.299	1.000	87.299	2.368	.135	.075
	●87.299	1.000	87.299	2.368	.135	.075
Error(Condition)	*1069.145	29	36.867			
	+1069.145	29.000	36.867			
	×1069.145	29.000	36.867			
	●1069.145	29.000	36.867			
Frequency * Placement	*32.089	6	5.348	.572	.752	.019
	+32.089	4.686	6.848	.572	.710	.019
	×32.089	5.699	5.630	.572	.744	.019
	●32.089	1.000	32.089	.572	.456	.019
Error(Frequency*Placement)	*1627.224	174	9.352			
	+1627.224	135.890	11.975			
	×1627.224	165.283	9.845			
	●1627.224	29.000	56.111			
Frequency * Condition	*94.006	6	15.668	1.764	.109	.057
	+94.006	3.881	24.225	1.764	.143	.057
	×94.006	4.555	20.639	1.764	.131	.057
	●94.006	1.000	94.006	1.764	.194	.057
Error(Frequency*Co	*1545.454	174	8.882			

ndition)	+1545.454	112.535	13.733			
	×1545.454	132.090	11.700			
	•1545.454	29.000	53.292			
Placement * Condition	*39.721	1	39.721	.995	.327	.033
	+39.721	1.000	39.721	.995	.327	.033
	×39.721	1.000	39.721	.995	.327	.033
	•39.721	1.000	39.721	.995	.327	.033
Error(Placement*Condition)	*1157.835	29	39.925			
	+1157.835	29.000	39.925			
	×1157.835	29.000	39.925			
	•1157.835	29.000	39.925			
Frequency * Placement * Condition	*36.908	6	6.151	.928	.476	.031
	+36.908	4.686	7.876	.928	.461	.031
	×36.908	5.699	6.476	.928	.473	.031
	•36.908	1.000	36.908	.928	.343	.031
Error(Frequency*Placement*Condition)	*1153.507	174	6.629			
	+1153.507	135.888	8.489			
	×1153.507	165.280	6.979			

•1153.507	29.000	39.776

Note: Sphericity assumed is denoted with a * symbol, Greenhouse-Geisser is denoted with a + symbol, Huynh-Feldt is denoted with a × symbol, and Lower-bound is denoted with a • symbol.

Table 7

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	*DF*	Sig.
Intensity	1.000	.000	0	
Condition	1.000	.000	0	
Placement	1.000	.000	0	.000
Frequencies	.028	96.048	20	
Intensity*Condition	1.000	.000	0	
Intensity*Placement	1.000	.000	0	
Condition*Placement	1.000	.000	0	
Intensity*Condition*Placement	1.000	.000	0	
Intensity*Frequencies	.001	177.194	20	.000
Condition*Frequencies	.260	36.029	20	.016
Intensity*Condition*Frequencies	.194	43.851	20	.002
Placement*Frequencies	.176	46.568	20	.001
Intensity*Placement*Frequencies	.178	46.214	20	.001
Condition*Placement*Frequencies	.341	28.805	20	.094
Intensity*Condition*Placement*Frequencies	.133	54.030	20	.000

Table 8

Test of Between-Subjects Effects

Source	Type III Sum of Squares	*Df*	*Mean Square*	*F*	Sig.
Intercept	3059.669	1	3059.669	13.339	.001
Error	6651.908	29	229.376		

Table 9

Test of Within-Subjects ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intensity	*1083.808	1	1083.808	23.108	.000
	+1083.808	1.000	1083.808	23.108	.000
	×1083.808	1.000	1083.808	23.108	.000
	●1083.808	1.000	1083.808	23.108	.000
Error(Intensity)	*1360.162	29	46.902		
	+1360.162	29.000	46.902		
	×1360.162	29.000	46.902		
	●1360.162	29.000	46.902		
Condition	*3.830	1	3.830	.064	.803
	+3.830	1.000	3.830	.064	.803
	×3.830	1.000	3.830	.064	.803
	●3.830	1.000	3.830	.064	.803
Error(Condition)	*1745.401	29	60.186		
	+1745.401	29.000	60.186		
	×1745.401	29.000	60.186		
	●1745.401	29.000	60.186		
Placement	*2.608	1	2.608	.059	.810
	+2.608	1.000	2.608	.059	.810
	×2.608	1.000	2.608	.059	.810

	•2.608	1.000	2.608	.059	.810
Error(Placement)	*1279.855	29	44.133		
	+1279.855	29.000	44.133		
	×1279.855	29.000	44.133		
	•1279.855	29.000	44.133		
Frequencies	*26506.403	6	4417.734	54.157	.000
	+26506.403	3.201	8279.527	54.157	.000
	×26506.403	3.645	7271.415	54.157	.000
	•26506.403	1.000	26506.403	54.157	.000
Error(Frequencies)	*14193.656	174	81.573		
	+14193.656	92.842	152.880		
	×14193.656	105.713	134.266		
	•14193.656	29.000	489.436		
Intensity * Condition	*126.707	1	126.707	6.064	.020
	+126.707	1.000	126.707	6.064	.020
	×126.707	1.000	126.707	6.064	.020
	•126.707	1.000	126.707	6.064	.020
Error(Intensity*Condition)	*605.968	29	20.895		
	+605.968	29.000	20.895		
	×605.968	29.000	20.895		
	•605.968	29.000	20.895		
Intensity *	*146.413	1	146.413	5.245	.029

Placement	+146.413	1.000	146.413	5.245	.029
	×146.413	1.000	146.413	5.245	.029
	•146.413	1.000	146.413	5.245	.029
	*809.596	29	27.917		
Error(Intensity*Placement)	+809.596	29.000	27.917		
	×809.596	29.000	27.917		
	•809.596	29.000	27.917		
	*4.696	1	4.696	.078	.782
Condition * Placement	+4.696	1.000	4.696	.078	.782
	×4.696	1.000	4.696	.078	.782
	•4.696	1.000	4.696	.078	.782
	*1749.284	29	60.320		
Error(Condition*Placement)	+1749.284	29.000	60.320		
	×1749.284	29.000	60.320		
	•1749.284	29.000	60.320		
	*45.508	1	45.508	1.695	.203
Intensity * Condition * Placement	+45.508	1.000	45.508	1.695	.203
	×45.508	1.000	45.508	1.695	.203
	•45.508	1.000	45.508	1.695	.203
	*778.712	29	26.852		
Error(Intensity*Condition*Placement)	+778.712	29.000	26.852		
	×778.712	29.000	26.852		

	•778.712	29.000	26.852		
	*1704.927	6	284.155	4.438	.000
Intensity *	+1704.927	1.639	1039.922	4.438	.023
Frequencies	×1704.927	1.725	988.628	4.438	.021
	•1704.927	1.000	1704.927	4.438	.044
	*11139.668	174	64.021		
Error(Intensity*Freq	+11139.668	47.545	234.298		
uencies)	×11139.668	50.012	222.742		
	•11139.668	29.000	384.126		
	*53.139	6	8.857	.601	.729
Condition *	+53.139	3.898	13.632	.601	.658
Frequencies	×53.139	4.579	11.604	.601	.685
	•53.139	1.000	53.139	.601	.444
	*2564.002	174	14.736		
Error(Condition*Fre	+2564.002	113.049	22.680		
quencies)	×2564.002	132.798	19.307		
	•2564.002	29.000	88.414		
	*75.297	6	12.549	1.286	.266
Intensity *	+75.297	4.090	18.410	1.286	.279
Condition *	×75.297	4.846	15.539	1.286	.274
Frequencies	•75.297	1.000	75.297	1.286	.266
Error(Intensity*Con	*1698.099	174	9.759		

dition*Frequencies)	+1698.099	118.613	14.316		
	×1698.099	140.522	12.084		
	•1698.099	29.000	58.555		
Placement * Frequencies	*50.419	6	8.403	.433	.856
	+50.419	3.613	13.953	.433	.766
	×50.419	4.191	12.029	.433	.793
	•50.419	1.000	50.419	.433	.516
Error(Placement*Frequencies)	*3377.839	174	19.413		
	+3377.839	104.790	32.234		
	×3377.839	121.548	27.790		
	•3377.839	29.000	116.477		
Intensity * Placement * Frequencies	*26.690	6	4.448	.389	.885
	+26.690	3.783	7.056	.389	.806
	×26.690	4.421	6.037	.389	.834
	•26.690	1.000	26.690	.389	.538
Error(Intensity*Placement*Frequencies)	*1989.134	174	11.432		
	+1989.134	109.704	18.132		
	×1989.134	128.211	15.515		
	•1989.134	29.000	68.591		
Condition * Placement * Frequencies	*52.075	6	8.679	.687	.660
	+52.075	4.528	11.499	.687	.620
	×52.075	5.470	9.520	.687	.647

	•52.075	1.000	52.075	.687	.414
Error(Condition*Placement*Frequencies)	*2196.651	174	12.624		
	+2196.651	131.325	16.727		
	×2196.651	158.623	13.848		
	•2196.651	29.000	75.747		
Intensity * Condition * Placement * Frequencies	*127.416	6	21.236	2.292	.037
	+127.416	3.525	36.150	2.292	.072
	×127.416	4.072	31.290	2.292	.062
	•127.416	1.000	127.416	2.292	.141
Error(Intensity*Condition*Placement*Frequencies)	*1611.962	174	9.264		
	+1611.962	102.214	15.770		
	×1611.962	118.091	13.650		
	•1611.962	29.000	55.585		

Note: Sphericity assumed is denoted with a * symbol, Greenhouse-Geisser is denoted with a + symbol, Huynh-Feldt is denoted with a × symbol, and Lower-bound is denoted with a • symbol.

Chapter 5

Data Analysis and Discussion

Dependent t- tests were conducted at each frequency to compare the published ISO 2003 values for 40 dB to the means of the current soundfield values determined with a 1000 Hz reference set to 40 dB HL. The results showed that none mean values from the current soundfield study were statistically significant from the published ISO values for the soundfield at 40 dB SPL. Table 10 shows the *p* values that were <0.05.

Soundfield Equal Loudness Contours

Means of the current soundfield data and the published ISO 2003 values were compared to observe if there were any significant differences. Results showed no statistically significant differences between the means of the soundfield data from the current study and the published ISO 2003 values. The results from the current study were compared to the results from Pollack (1952). The procedures for both the studies were similar and the loudness values at the reference level of 40 dB HL closely matched except for 250 Hz. As seen in figure 2 the loudness value at 250 Hz for Pollack (1952) was higher than the value for 250 Hz in the current study. Also, the ISO 2003 values for 40 dB HL were higher at 250, 6000, and 8000 Hz when compared to the current soundfield study. In the mid frequencies from 500 Hz to 4000 Hz, the current soundfield results closely matched both ISO 2003 and Pollack (1952) values for 40 dB SPL. Pollack used a variety of filters to create different band width. The broader the band width is the more displacement on the basilar membrane. The band widths for the current study were different from the ones in Pollack (1952). This could explain the differences between the loudness values from the current study and the values from Pollack (1952). As mentioned before, the published ISO values were higher than the current soundfield study for 40 dB SPL. The published ISO

Table 10

T test results comparing ISO 2003 values for 40 dB SPL and soundfield data from the current study

Frequency	n	Mean	SD	t stat	t crit	df	*p* value	Sig
250	2	-0.705	7.85	-.12	12.7062047	1	0.92	No
500	2	1.7695	1.74	0.3	12.7062047	1	0.81	No
1000	2	0	0	0	12.7062047	1	1	No
2000	2	-2.015	1.72	-0.34	12.7062047	1	0.79	No
3000	2	0.39	5.49	0.06	12.7062047	1	0.96	No
4000	2	-3.7975	0.70	-0.64	12.7062047	1	0.64	No
6000	2	-4.751	1.34	-0.8	12.7062047	1	0.57	No
8000	2	5.7512	8.41	0.97	12.7062047	1	0.51	No

Note: Values rounded up to two decimal points.

values are based on pure tone loudness contours study conducted by Suzuki and Takeshima (2004). Again, the difference in stimuli could explain the differences between the two studies.

To further investigate the differences between the current soundfield study results and literature, the results from the current study were compared to the previous studies of Fletcher and Munson (1933), Churcher and King (1937), Zwicker and Feldtkeller (1955), Robinson and Dadson (1956), and Suzuki and Takeshima (2004). Again, all the above mentioned studies used pure tones as their stimuli. Figure 26 taken from Suzuki and Takeshima (2004) illustrates the equal loudness contours from previous studies and the current study. It was noted that the results from the current study closely matched Robinson and Dadson (1956) at almost all frequencies and closely approximated Fletcher and Munson (1933) Churcher and King (1937) and Suzuki and Takeshima (2004) in the mid and high frequencies. The loudness values from the current soundfield study at 250 Hz, 6000 Hz, and 8000 Hz were lower than Fletcher and Munson (1933) and Churcher and King (1937). The results of the current study were farthest from the results of Zwicker and Feldtkeller (1955). These differences could be attributed to the stimuli, and method of adjustment used by Zwicker and Feldtkeller (1955). Researchers in Zwicker and Feldtkeller (1955) used earphone and free field equalizer with two filters. The filters modified the stimuli and responses were therefore influenced creating a smoother curve. In addition, Zwicker and Feldtkeller (1955) used the Bekesy tracking method instead of method of adjustment. In this method the stimuli was constant and participant pressed a button to indicate when he or she felt that the loudness was equal. After multiple trials, the average of the responses was calculated for the loudness value. The Bekesy tracking method is known to be more variable due to its averaging process. This could also have caused the differences between the equal loudness

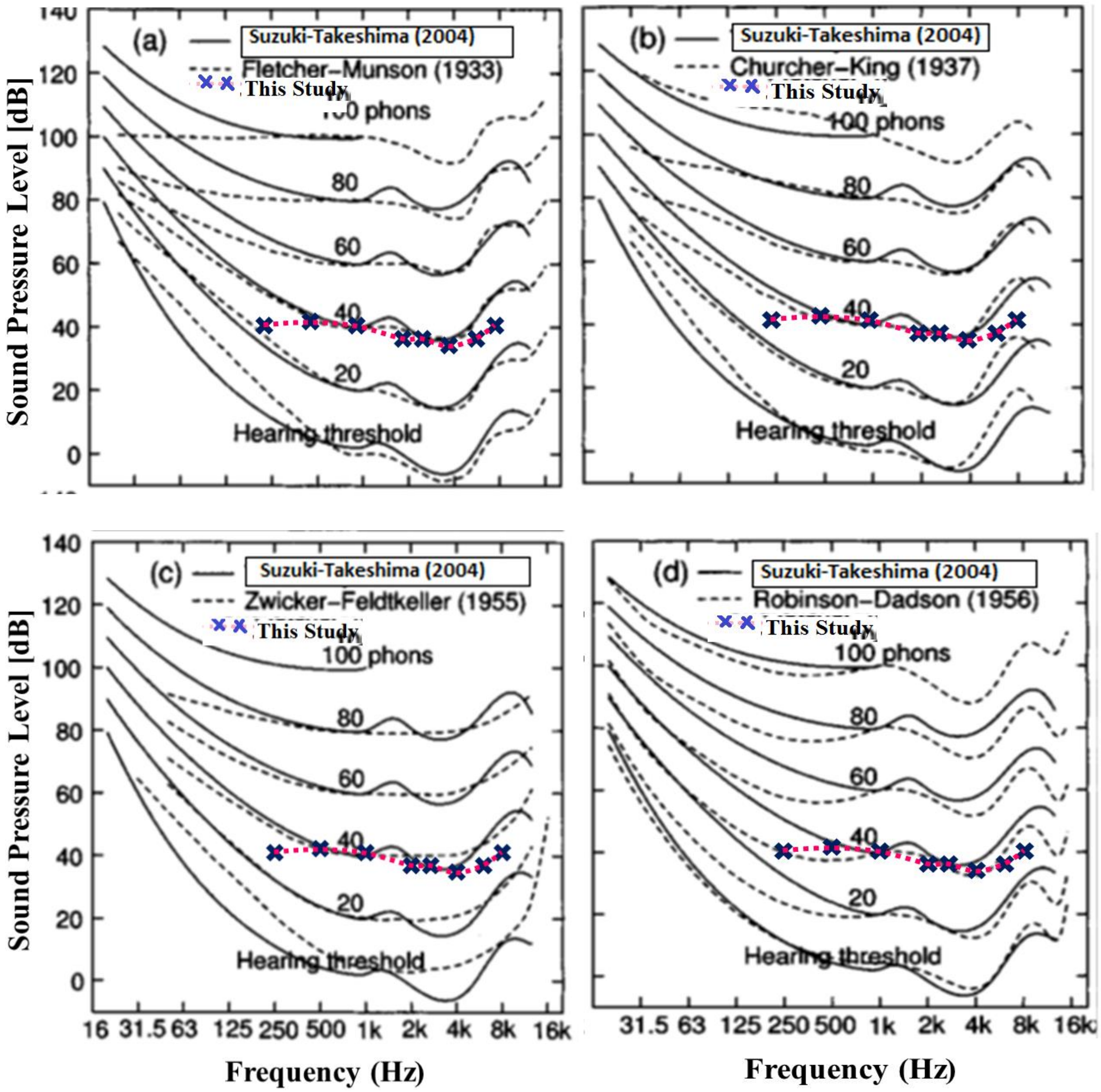


Figure 26. Soundfield equal loudness contours from the previous studies and the current study determined with a reference of 1000 Hz at 40 dB HL.

curves from the previous studies and the current study when compared to Zwicker and Feldtkeller (1955) (Suzuki & Takeshima, 2004).

Bone Conduction Equal Loudness Contours

Results from a 2x2x2x7 ANOVA showed that there were no statistically significant differences between the intensities, placements, and conditions. Overall all of bone conduction equal loudness contours measured in the current study closely matched established ISO 2003 values at 20 dB HL and 40 dB HL. As seen in figure 4 and 5 the loudness values at 250 Hz and 6000 Hz were lower than the published ISO 2003 values in all conditions, placements, and intensities. It could be that the high intensity added vibrotactile responses to the already high loudness perception at 250 Hz (Patrick et al., 2012). It was also noted that the bone conduction loudness values were slightly higher than the current soundfield study and the published ISO values at 20 and 40 dB SPL. This could because the clinically used RadioEar- B 71 bone vibrator is used to test 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. It is could be that the capacity of this particular bone vibrator does not include frequencies above 4000 Hz. This could also explain the non-linear trait seen at 6000 Hz with the bone vibrator and also the significant differences found.

Chapter 6

Summary and Conclusion

Results from this study indicated that the equal loudness contours for soundfield at reference level of 40 dB HL closely approximated the bone conduction equal loudness contour at the same intensity. Also, the ISO published values for 20 dB SPL were similar to the bone conduction loudness contours at the same intensity from the current study. Some differences were noted in the lower frequency of 250 Hz and the higher frequency of 6000 Hz, but were not statistically significant. Everyone perceives loudness differently which can result in variability of loudness values when compared to the previous studies. No statistically significant difference was observed between the placements, conditions, or intensities. Loudness is subjective and varies over frequencies. In the past loudness contours for soundfield have helped engineers develop and program traditional hearing aids. Similarly, bone conduction loudness contours can be critical while fitting bone anchored hearing aids in addition to other bone conduction communication systems.

Bone conduction transmission has been studied for decades; however, equal loudness contours for bone conduction have never been established. The results from this study will play a critical role in advancement of bone conduction communication systems like adding adaptive active noise control systems, determining better placement for the communications system without obstructing ears, and use of hearing protection with optimal communication. Future research should include a B81 vibrator, which has a wider frequency range, a larger output for frequencies below 1000 Hz, and less distortion at frequencies below 1000 Hz (Jasson, Hakkanson, Johannsen, & Tengstrand, 2013).

Appendix A

Institutional Review Board

TOWSON UNIVERSITY

APPROVAL NUMBER: 13-A053

Office of University Research Services

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

To: David Andreaggi
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Justin Buckingham, Member ALT

Date: Monday, April 15, 2013

RE: Application for Approval of Research Involving the Use of Human Participants

APPROVED APR 15 2013 TOWSON IRB

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Equal Loudness Contours for Bone Conduction and Sound Field Presentation of Frequency-Specific Stimuli at Four Intensity Levels

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: D. Emanuel
File

TOWSON UNIVERSITY

Date: Monday, April 15, 2013

NOTICE OF APPROVAL

TO: David Andreaggi **DEPT:** ASLD

PROJECT TITLE: *Equal Loudness Contours for Bone Conduction and Sound Field Presentation of Frequency-Specific Stimuli at Four Intensity Levels*

SPONSORING AGENCY:

APPROVAL NUMBER: 13-A053

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [✓] is not required of each participant

This protocol was first approved on: 15-Apr-2013
This research will be reviewed every year from the date of first approval.

Amy L Taylor for
Justin Buckingham, Member
Towson University Institutional Review Board

Appendix B

Instructions for the tasks

Soundfield to soundfield:

In this task, the goal is to have the two signals coming from the loudspeaker equal in loudness. The signals will alternate simultaneously. Your job is to notify the tester to turn up or turn down the intensity dial to adjust the volume of one signal, so that it is matching the other in loudness. When you think the signals are the same, notify the tester.

Soundfield to bone: I

In this task, the goal is to compare the loudness between the signal coming out of the speaker to the signal coming out of the bone vibrator which you are wearing on your head. Just like the previous task, both signals will be played simultaneously, alternating and you will indicate to the tester to increase or decrease the loudness of the signal from channel 2 and adjust the signal coming out of the bone vibrator so it is just as loud as the signal coming out of the speaker. For this task you will be using a method of adjustment technique. Just let me know when you feel that the bone stimuli are just as loud as the soundfield stimuli.

Bone-to-bone:

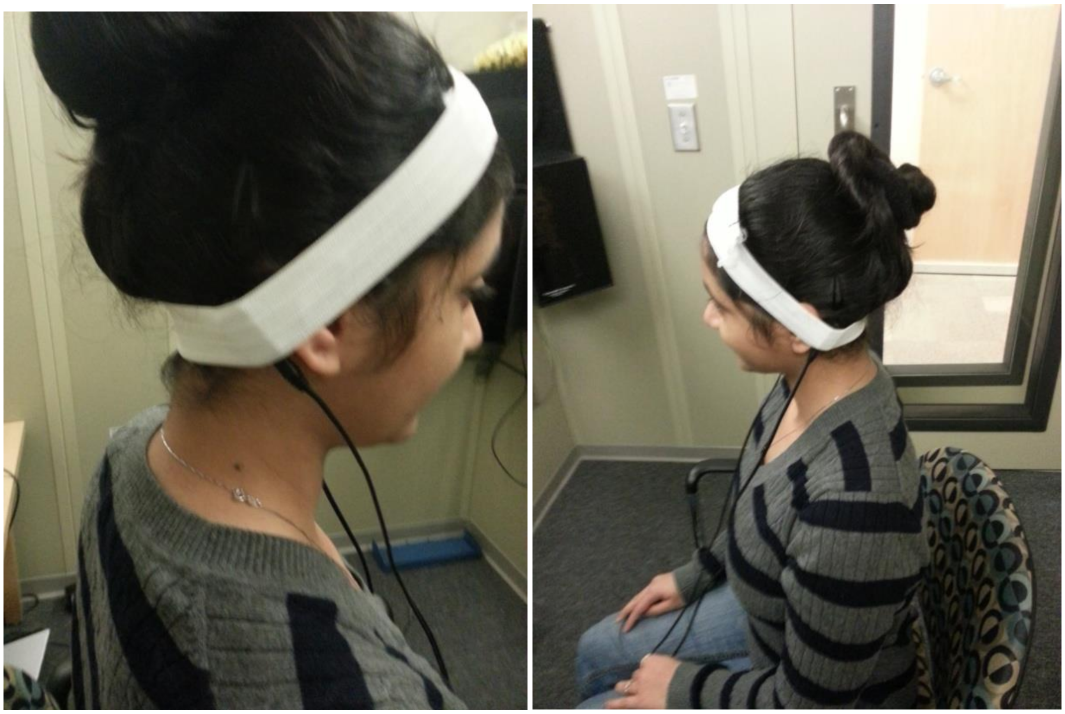
In this task, the goal is to compare the loudness between two signals coming out of each bone vibrator. Just like the previous task (soundfield-to-bone), both signals will be played simultaneously, alternating and you will have to indicate to the tester to increase or decrease the intensity of the signal in channel 2 and adjust

> the signal coming out of the bone vibrator so it is just as loud as the reference signal coming out of the other bone vibrator. For this task you will be using the previous method of adjustment technique to adjust the intensity of the bone vibrator stimulus.

Instructions were read to each participant before each task and were given time to digest the instructions and to ask questions.

Appendix C

Two Radio Ear B-71 bone vibrators attached with elastic and Velcro strips



Appendix D

RETFL and RETSPL Values

RETFL values	
Frequency	Values
250 Hz	24.5
500 Hz	15.5
1000 Hz	0
2000 Hz	-11.5
3000 Hz	-12.5
4000 Hz	-7
6000 Hz	-2.5
RETSPL values	
250 Hz	9
500 Hz	2
1000 Hz	0
2000 Hz	-3.7
3000 Hz	-8.2
4000 Hz	-7.8
6000 Hz	1.9
8000 Hz	10.2

References

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Curriculum Vitae

EDUCATION

Towson University: *Towson, MD* Aug. 2011-*Present*
Candidate for Doctorate of Audiology, May 2016

Towson University: *Towson, MD* Jan. 2009-May 2011
Bachelor of Science degree in Audiology and Speech Language Pathology, May 2011

Community College of Baltimore County: *Essex, MD* Aug 2005-Dec 2008
Associate of Arts in General Studies, May 2008

EXPERIENCE

Audiology Intern, Sept 2013-May 2014
ENTAA Care: Glen Burnie, MD
Performed comprehensive diagnostic audiology for pediatrics and adults
Performed cochlear implant candidacy testing and follow up mapping
Administered hearing aid evaluations; programmed, adjusted, modified, and dispensed hearing aids
Assessed dizziness using Electronystagmography (ENGs) and Vestibular Evoked Myogenic Potentials (VEMPs)
Evaluated retro-cochlear pathology via Auditory Brainstem Response (ABR) and Electrocochleography (Ecog) testing

Audiology Intern, May. 2013-Aug 2013
Johns Hopkins Medical Center at Bayview: Baltimore, MD

Performed comprehensive diagnostic audiology for pediatrics and adults
Administered hearing aid evaluations; programmed, adjusted, modified,and dispensed hearing aids

Audiology Intern, Feb 2012-Dec 2012
Towson University Speech, Language, and Hearing Center: Towson, MD
Performed comprehensive audiological evaluations
Administered hearing aid evaluations, programming, adjustments, modifications, and dispensed hearing aid
Produced professional clinical reports summarizing audiological evaluation results

EXTRACURRICULAR ACTIVITIES

Member of Student Academy of Audiology at Towson University (2010- Present)

SCHOLARSHIPS AND AWARDS

Recipient of the Army's College Qualified Leaders (CQL) Apprenticeship program