EFFECTS OF MIDDLE EAR PRESSURE COMPENSATION ON EVOKED OTOACOUSTIC EMISSIONS AND POWER ABSORBANCE IN ADULTS

by

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Abstract

This study investigated the impact of positive and negative middle ear pressure (MEP) on evoked otoacoustic emissions (EOAEs) both distortion-product OAEs (1.5 to 8 kHz) and transient evoked OAEs (1 to 5 kHz), as well as wideband acoustic immittance measures of power absorbance (PA) in a normal-hearing young adult population between the ages of 18 and 35. The effectiveness was evaluated, of testing at ambient compared to a compensated pressure level corresponding to participants' tympanic peak pressure. Outcome measures were analyzed considering factors of gender, ethnicity, frequency, and MEP magnitude. For each participant, testing was conducted at a natural state MEP and at a MEP level induced by either the Toynbee or Valsalva maneuver. Titan Suite by Interacoustics was used to collect all measures and is the only commercially available system for assessing EOAEs at a compensated pressure level. One-hundred and four participants (67 female and 37 male, providing 208 ears) were recruited for testing. EOAE absolute amplitude and PA varied significantly as a function of test frequency and across test pressure conditions. Significant differences in PA and EOAE measures were observed between gender and ethnic groups. Mean PA magnitude at frequencies ≤4 kHz was significantly greater testing at peak compared to the ambient pressure in the presence of MEP deviating from 0 daPa. EOAE amplitude was similar between the post-maneuver (induced MEP) condition and baseline measures when assessed at peak pressure. Frequency-dependent changes in PA magnitude with alterations in MEP and ear canal pressure were linked to frequency-dependent changes in EOAE amplitude. Results of this study suggest clinical benefit for a more accurate assessment of middle ear status and cochlear integrity for patients with abnormal MEP when EOAE are assessed at a compensated pressure level. This study provided a database of PA measures over a range of MEPs measured at both ambient and tympanic peak pressure.

Preface

The following research was conducted for the completion of a thesis project as partial fulfillment of the requirements for the degree of Master of Science in the Faculty of Graduate and Postdoctoral Studies of the University of British Columbia. This study titled, Effects of Middle Ear Pressure Compensation on Evoked Otoacoustic Emissions and Power Absorbance in Adults, was approved by the University of British Columbia Clinical Research Ethics Board (UBC CREB) as an independent study. This study's associated UBC CREB certificate number is H15-03494. The principal investigator was Dr. Navid Shahnaz and Rae Riddler as the co-investigator. Identification and design of the research project as well as the analysis of all research related data was a collaborative process between the principal investigator Dr. Shahnaz and myself as the co-investigator. All related data and outcome measures were collected by me (co-investigator), along with the writing contained in this manuscript. There are neither sponsoring agencies nor any conflicts of interest to disclose. All equipment and devices used for this research project belonged to the UBC School of Audiology and Speech Sciences and the school's associated Middle Ear Lab run by associate professor Dr. Navid Shahnaz.

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List of Abbreviations

OAE – Otoacoustic Emission

EOAE – Evoked Otoacoustic Emission

TEOAE – Transient Evoked Otoacoustic Emission

DPOAE – Distortion-product Otoacoustic Emission

MEP – Middle Ear Pressure

NMEP – Negative Middle Ear Pressure

PMEP – Positive Middle Ear Pressure

PA – Power Absorbance

ER – Energy Reflectance

TPP – Tympanometric Peak Pressure

Hz – Hertz

dB HL – decibels Hearing Level

dB SPL – decibels Sound Pressure Level

mmho – Acoustic milliohm

ml – milliliters

CI – Confidence Interval

daPa – decapascal (1 decapascal = 10 pascal)

HSD – Honestly significant difference

ANOVA – Analysis of Variance

3D-WBT – 3-dimensional Wideband Tympanometry

L_1/L_2 – Sound level for the primary (L_1) and secondary (L_2) of DPOAE stimulus pure-tones

f_1/f_2 – Primary (f_1) and secondary (f_2) frequencies for DPOAE stimulus pure-tones

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Sincerely,
Rae Jean Riddler

Chapter 1: Introduction

Standard audiological assessments use a test battery approach to assess outer, middle, and inner ear status as well as general peripheral hearing function. Conventional measures include immittance testing via single frequency tympanometry, acoustic reflex assessments, evaluation of otoacoustic emissions (OAEs), determination of hearing thresholds through pure-tone audiometry, determination of speech recognition thresholds (SRT), and word recognition scores (WRS). OAE assessments have only recently been incorporated into the clinical test battery, but have been used with increasing popularity since the first demonstrated discovery of OAEs in 1978 (Kemp, 1978). An even more recent introduction into clinical practice has been wideband acoustic immittance providing wideband tympanometry and measures of wideband power absorbance (PA) and power reflectance (PR) as means to assess middle ear status.

OAE measures are most often used as an indicator of cochlear health primarily at the level of outer hair cells but OAEs also have the potential to be used as an indicator of middle ear status as these measures are reliant on the transmission of sound through the middle ear space (Avan, Buki, Maat, Dordain, & Wit, 2000; Plinkert, Bootz, & Vossieck, 1994). Various abnormalities of the middle ear will impact OAE measurements to differing degrees. Including OAEs into the audiological diagnostic test battery in combination with middle ear immittance measures, can lead to the use of OAEs as a means of differential diagnosis for pathology of cochlear origin such as sensorineural hearing loss or pathologies attributable to the middle ear such as otitis media and negative pressure (Schairer, Morrison, Szewczyk, & Fowler, 2011). Collecting OAE measurements without compensating for abnormal MEP has been documented to increase the number of false positives when using OAEs for hearing screening purposes or as a diagnostic indicator, providing inconclusive or false information regarding cochlear health (Trine, Hirsch, & Margolis, 1993). Measuring OAEs while compensating for abnormal MEP has shown to improve OAEs levels resulting in higher pass rates (Hof, Dijk, Chenault, & Anteunis, 2005b).

1.1 Evoked Otoacoustic Emissions; Elementary Review

During an audiological assessment cochlear health at the level of outer hair cells can be assessed non-invasively by measuring the evoked otoacoustic emissions (EOAE). EOAEs indicate the physiological response of the cochlea, thought to reflect the magnitude of outer hair cell (OHC) function, and the physical integrity of the cochlea in response to presented acoustic stimuli (Thompson, Henin, & Long, 2015). The term 'evoked' indicates that these emissions are elicited by a stimulus, in the case of EOAEs, this is an acoustic stimulus presented to the external ear canal. Presentation of a single evoking stimulus tone generates a stimulus frequency otoacoustic emission (SFOAE) that requires the use of narrow-band frequency analysis for its separation from background noise (Fay, Manley, & Popper, 2008). There are also spontaneous otoacoustic emissions (SOAEs), which require no evoking stimulus and can also be measured through the use of narrowband frequency analysis (Fay et al., 2008). Common clinical measures of EOAEs are distortion-product otoacoustic emissions (DPOAE) and transient evoked otoacoustic emissions (TEOAEs), which are routinely used to detect or screen for hearing loss and investigate cochlear health. For the purpose of this thesis, the remainder of the discussion will focus on DPOAE and TEOAEs.

Initial research attributed OAEs to the nonlinear distortion response of the OHCs as the sole source for all types of OAEs and classification of OAE types was based on the stimulus used to elicit these responses. Later findings suggested that the OAE response was comprised of multiple mechanisms and would be better classified based on the primary response components (Shera & Guinan, 1999). The initial research described EOAEs as the product of an electromotile response attributable to the non-linear properties of the cochlea when healthy and normally functioning stereocilia of the OHCs are stimulated (Kemp, 2002; Ramos et al., 2013). This electromotile response is an active process providing the basis for the cochlear amplifier. The cochlear amplifier acts to augment the vibrational energy of the basilar membrane (BM) for the traveling wave at its peak and thus enhancing frequency resolution and hearing sensitivity, especially for low-level stimuli. The OAEs are primarily a result of the electromotile response of the cochlear OHCs while the inner hair cells contribute only a small percent to the overall emission strength (Aidan, Lestang, & Bonfils, 1997). When the stereocilia of the OHCs are stimulated, the cell body of the OHCs contracts by prestin molecular responses, altering the length and width of the OHC body (Fay et al., 2008). The electromotile response of the OHCs to an eliciting stimulus is measured as an acoustic response (i.e. OAEs) in the outer ear canal. Vibrations transmitted backward from the cochlea, propagate through the middle ear cavity putting the tympanic membrane (TM) into motion. The TM is set into motion by the backward traveling elicited energy response after the cochlear fluid is set into motion by the evoking stimulus (Kemp, 2002). Movement of the TM creates pressure fluctuations within the external ear canal that can be recorded by a sensitive microphone. The nonlinear distortion from the cochlear amplifier is characterized as emissions that resemble the envelope of the stimulus traveling wave and are termed as wave-fixed emissions (Shera & Guinan, 1999). A second OAE generating mechanism is termed a place-fixed emission and is thought to be the result of traveling wave dispersions created by impedance perturbations as the traveling wave moves along the BM (Shera & Guinan, 1999). These place-fixed emissions are linear reflections opposed to the OHC created non-linear emissions. In addition, reflections created from the energy transmission through the middle ear cavity and standing waves created within the outer canal further complicate the measured emission response in the outer ear canal (Fay et al., 2008). Shera and Guinan (1999) argue that the classification of various OAEs should be based on the generating mechanisms, either linear or nonlinear mechanisms, rather than on the stimuli (or lack of stimuli in cases of SOAEs) that elicit these responses. For both the wave-fixed and place-fixed emissions, a backward traveling wave results that are detected as an OAE in the external canal but the generating mechanism for these emissions differ (Shera & Guinan, 1999; Knight & Kemp, 2000). This classification based on generating mechanism taxonomy for DPOAEs and TEOAEs is not completely straight-forward. In reality, both DPOAEs and TEOAEs are likely composed of a combination of emissions from multiple generating mechanisms with the presentation level and properties of the stimulus influencing the mechanism responsible for the most prevalent emission component (Shera & Guinan, 1999; Yates & Withnell, 1999). Figure 1 is adapted from Shera and Guinan (1999) which presents a classification system for different types of OAEs with taxonomy based on the mechanism generating the OAE. See the following sections (1.1) and (1.2) for separate detailed discussions of DPOAEs and TEOAEs. A taxonomy based on linear and nonlinear generating mechanisms also accounts for differences in phase properties for the classically defined DPOAE and TEOAE measurements. However, to limit the scope of this manuscript to material related to the study presented, the concept of emission phase and stimulus phase will not be explored further.

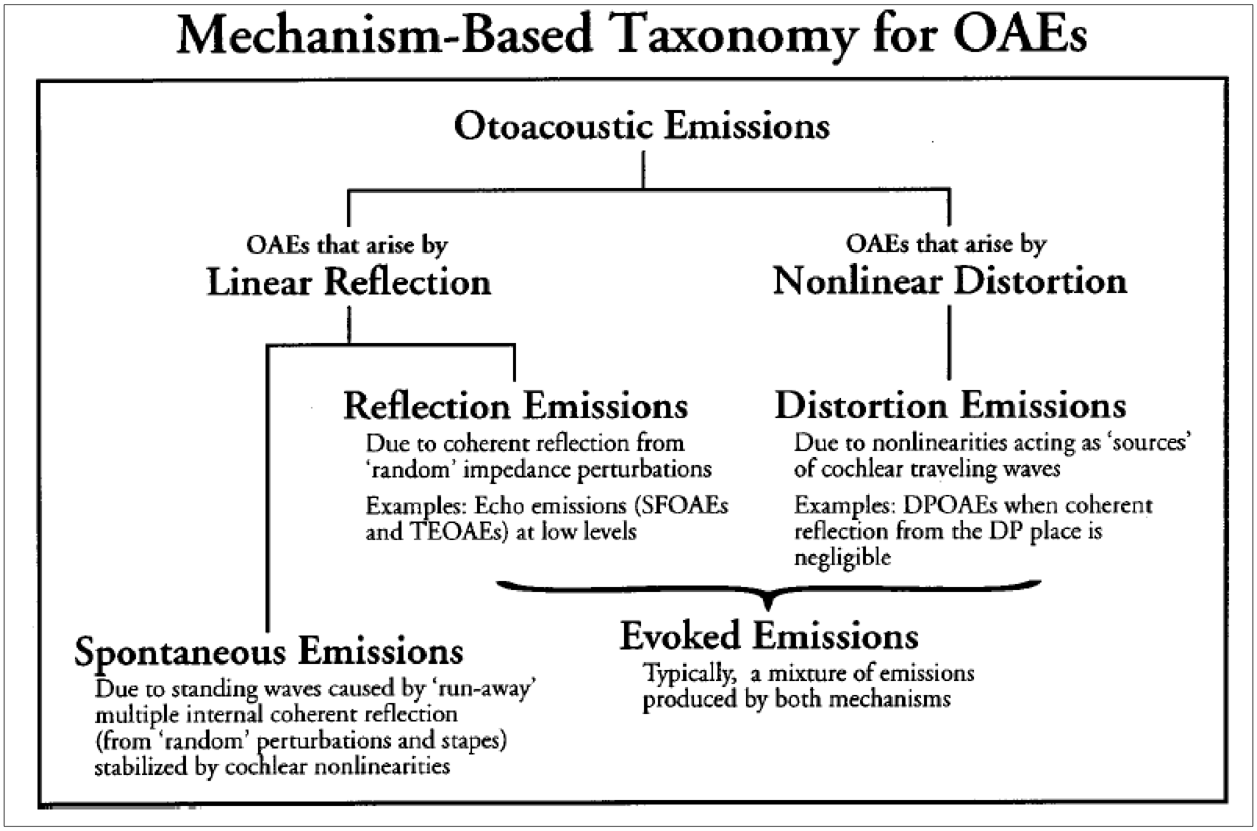


Figure 1: A proposed taxonomy for otoacoustic emissions based on the primary generating mechanism rather than the originally proposed classification based on the stimulus type used to evoke the emissions. The figure is adapted from Shera and Guinan (1999) text: "Evoked Otoacoustic Emissions Arise by Two Fundamentally Different Mechanism: A Taxonomy for mammalian OAEs." This classification of OAEs mark transient evoked and distortion-product evoked OAEs as separated evoked emission categories but generated by different mechanisms (Shera & Guinan, 1999).

The distortion and reflection component model proposed by Shera and Guinan (1999) is widely believed to be, at least in part, an accurate description of EOAEs. However, subsequent studies have proposed a more complex mechanism. Martin, Stagner, Chung and Lonsbury-Martin (2011) demonstrated that humans in addition to other laboratory animals have DPOAE measures consisting of components generated by mechanisms not accounted for by the Shera and Guinan (1999) model. Contrary to this two-source model by Shera & Guinan (1999), research using interference tones has provided evidence for additional DPOAE generators, specifically basal to the f_2 primary tone. Martin, Stagner and Lonsbury-Martin (2010) contend that basally generated DPOAE components contribute to the overall DPOAE measure and that rather than a two-generator model, DPOAEs are a result of a more distributed and complex process. They argue that either enhancement or suppression of the resulting DPOAE is dependent on the phase interaction between the basal and f_2 component. These basally generated DPOAE components have been shown to have both linear and distortion-like properties, particularly regarding phase patterns, as both distortion and reflection like characteristics have been noted (Martin et al., 2011). Martin, Stagner, and Lonsbury-Martin (2013) examined the DPOAE response in a time domain to determine the waveform components and their origins. In their 2013 study, Martin et al. describe the potential multiple wave-like interactions that occur between apparent travelling waves, which are thought to originate from both the f_2 location and locations basal to the f_2 position. Martin et al. (2010) suggest that a more accurate indication of cochlear integrity may be realized by using what they term as augmented DP-grams. These augmented displays of DPOAE measures provide a picture of the emission generators specifically basal to the f_2 location by introducing an interference tone 1/3-octave above the f_2 stimulus. Refer to Martin et al. (2010) for further discussion concerning ADP-grams and their potential clinical application.

For normal hearing adults with non-pathological inner, middle, and outer ear status, an EOAE response is expected to be present with an amplitude magnitude between -10 to +30 dB SPL

(Ramos, Kristensen, & Beck, 2013). For clinical application, both DPOAE and TEOAE measures have benefits and limitations. DPOAEs provide information about cochlear integrity over a wide range of test frequencies but with reduced sensitivity to minor non-pathological conditions of the cochlea, allowing DPOAEs to be assessed even in individuals with moderate sensorineural hearing losses dependent on both the type and presentation level of the eliciting stimulus (Kemp, 2002). For an individual presenting with normal middle ear status, if TEOAEs are absent but DPOAEs are clinically present, this is an indication of sensorineural hearing loss mild to moderate in degree (Kemp, 2002). The EOAE response is dependent on the stimulus type and amplitude, with a positive correlation observed between stimulus amplitude and EOAE level (Knight & Kemp, 2000; Plinkert et al., 1994). Assessment of EOAEs provides an objective and non-invasive means to quantify the response of the cochlear amplifier providing an estimate of cochlear integrity and an indication of auditory sensitivity (Kemp, 2002). The use of EOAEs clinically is not intended to replace the conventional pure-tone audiogram, but rather act as a compliment to the test battery for diagnostic audiology. The clinical use of EOAEs is widespread. For example, EOAE measures can provide a means to screen for hearing loss (i.e. newborn hearing programs), monitor for minor changes to the cochlea over time as is done for ototoxic monitoring, identify potential cases of pseudohypacusis and testing of EOAEs is used diagnostically to help in the identification of conditions such as Auditory Neuropathy Spectrum Disorder.

1.1.1 Distortion-product Otoacoustic Emissions

DPOAEs are produced by a healthy and relatively normal functioning cochlea (in the absence of middle ear pathology), when a specific acoustic signal of determined presentation level and frequency components are presented to the external ear canal. Historically, DPOAEs were thought to be produced due to the non-linear properties of the cochlea alone. It is now thought that DPOAEs are a result of more complex and multiple involved mechanisms. The recorded DPOAE response in humans is generated by at least two mechanisms, providing a composite DPOAE containing both place-fixed and wave-fixed components (Knight & Kemp, 2000). Some studies have also provided evidence of additional basally generated complex emission components (Martin et al., 2010; Martin et al., 2011). Referencing the two-source model, the linear reflection component termed the place-fixed component is characterized by physical properties and abnormalities of the cochlear structure, particularly along the BM. The wave-fixed component is the primary component of DPOAEs and is the initial emission source at the location on the BM of f_2, attributable to the non-linear mechanism of the OHCs (Knight & Kemp, 2000; Fay et al., 2008). When presented with two pure tones (f_1 and f_2) separated by a common ratio of 1.22, a third tone termed the cubic difference tone is produced due to the intermodulation of the two primary tones within the cochlea (Avan et al., 2000; Kemp, 2002). The non-linear properties of the cochlea cause the interference (i.e. intermodulation) of f_1 and f_2 producing the distortion product (cubic difference tone) that was not present in the initial stimuli. The cubic difference tone can be determined or specifically selected for by specifying the frequency components of the presented stimuli. This distortion-product third tone occurs at the frequency calculated by the equation, $2f_1$-f_2 which represents the cochlear response at the characteristic frequency point of $2f_1$-f_2 along the BM (Kemp, 2002). Emissions are present at both frequencies corresponding to locations along the BM that are higher and lower relative to primary tones, for example at $3f_1$-$2f_2$, $2f_1$-f_2, and $2f_2$-f_1. Although the cochlea generates multiple DPOAEs in response to the two simultaneously presented pure tones, the DPOAE produced on the BM closest to the f_2 is usually of clinical interest; the amplitude of the DPOAE corresponding to the $2f_1$-f_2 is referenced as an indicator of cochlear function of the f_2 frequency position (Torre, Cruickshanks, Nondahl, & Wiley, 2003). The non-linear mechanical distortion along the BM generates a backward traveling wave that is propagated by fluid motion towards the oval and round windows. The two primary pure tones can also cause overlapping traveling waves along the BM and this overlap creates additional energy that summates at a characteristic place along the BM (different from that of f_1 and f_2): Resulting is the linear reflection component of the emission (Thompson, Long, & Henin, 2013). An acoustic filter is needed for DPOAE recordings to remove the primary tones from the recordings and just measure the distortion-product (i.e. the acoustic emission of interest). Narrowband filtering is applied to extract the desired DPOAE signal, which is most commonly a frequency corresponding to $2f_1$-$f_{2,}$ from the surrounding noise. This noise is background noise identified at frequency bands located at f_1-$N(f_2$-$f_1)$ and $f_2 + N(f_2$-$f_1)$ surrounding the emission frequency of interest, with N representing an integer value larger than one (Fay et al., 2008). It is necessary to identify the interfering noise bands, to determine the emission level ($2f_1$-f_2) above this noise floor. The amplitude of DPOAE measurements is influenced by the level separation and frequency ratio of the two eliciting primary tones (Abdala, 1996). To generate a more robust response for DPOAE measures, a frequency ratio (f_2/f_1) of 1.22 and a 10 dB presentation level separation ($L_1>L_2$) between the primary tone stimuli is often implemented: A 65/55 dB or 75/65 dB difference for the primary tone levels is most commonly used (Abdala, 1996; Thompson et al., 2013; Thompson et al., 2015). The level of the primary tones influences the level of the DPOAE, with emission level increasing with increasing stimulus presentation level (Zwicker, 1983; Fay et al., 2008). If the stimulus frequencies are separated above this ratio of 1.22 then a drop in OAE amplitude is expected, and if the stimuli frequencies are closer together, then the phenomenon of beating is likely to occur (Abdala, 1996). The DPOAE response recorded by a probe placed in the external ear canal reflects the oscillatory pressure waveform produced by the tympanic membrane from the backward propagating waveform originating from the cochlea. This recorded response is a composite DPOAE consisting primarily of the distortion-product emission generated in the f_2 region along the BM producing a direct backward traveling wave, but this response also contains linear reflection components from reflector sources (Knight & Kemp, 2000). Alterations in the stimulus parameters such as presentation level and frequency separation of the evoking stimulus as well as subject-specific characteristics can influence the ratio of nonlinear distortion to linear reflection components of the recorded composite DPOAE (Fay et al., 2008). Early work by Gaskill and Brown (1990) exploring the use of DPOAEs as a clinical objective measure to indicate cochlear function, found that with optimal frequency separation of 1.22 the DPOAE absolute amplitude level were commonly found below 30 dB and although consistent for within-subject repeated measures, there was significant DPOAE level variation across frequencies for between-subject comparisons.

Recent work by Thompson, Henin and Long (2013) and Thompson, Long and Henin (2015) has investigated the impact of the two emission components (linear reflections and non-linear distortion products) on DPOAE related outcome measures. In a study of eight subjects in which negative MEP was induced, Thompson et al. (2013) found that by extracting the linear reflection component (i.e. noise interfering with the distortion-product) from the overall DPOAE, they were able to reduce the variance of data and allow for more specified analysis of the nonlinear component thereby providing an improved estimate of the effect of NMEP on DPOAEs. By separating the components of the composite OAE, this may provide insight into the micromechanics of the inner ear and possibly provide new tools for screening and diagnostic use of OAEs (Thompson et al., 2015).

1.1.2 Transient Evoked Otoacoustic Emissions

In the late 1970's, TEOAEs were the first discovered OAE (Kemp, 1978). Both wideband and frequency-limited stimuli such as a tone-burst stimulus can be used to elicit TEOAEs. Evoking TEAOEs is usually accomplished by presenting a short duration acoustic click either with linear or non-linear properties, although non-linear click stimuli are more commonly used to reduce stimulus artifacts. The pressure changes measured in the external ear canal representing a composite TEOAE is a complex oscillating response; work by Yates (1997, as cited in Fay et al., 2008) concludes that TEOAEs contain two response components, stimulus frequency, and a distortion-product response. As stated earlier, the type of OAE is categorized based on the response generating mechanism, which in the case of TEOAEs is primarily the linear coherent reflection component (Shera & Guinan, 1999). The reflected emissions are produced by linear reflections from the forward propagating traveling wave along the BM contacting areas of increased impedance. Such perturbations along the BM could include the orientation and number of OHCs as well as any structural abnormalities within the cochlea (Fay et al., 2008). Reflection emissions show properties of level-dependent amplification for both forward traveling and backward emitted responses due to the function of the OHCs especially in response to stimuli presented at higher intensity levels (Shera & Guinan, 1999). When lower level TEOAE stimuli are used, the resulting composite emission is predominately due to the linear reflection components. Although the OHC are thought to not be the primary source of TEOAEs, the actions of the cochlear amplifier can influence the wave properties of the reflection emissions thus, TEOAEs can indicate changes in OHC function and structure (Shera & Guinan, 1999).

Like DPOAEs, TEOAE responses are prone to noise interference. This short duration acoustic stimulus is presented repeatedly and the emitted signal of interest is extracted from the total emission (signal and noise) by means of synchronous averaging. TEOAE recording times can vary between seconds to minutes, with typical stimulus repetition rates between 50 to 100 presentations per second (Kemp, 2002). Click stimuli excite a wide range along the cochlear BM creating a time delay in the evoked responses at characteristic frequency points as the eliciting traveling wave moves base to apex along the BM. The evoked emission response thus has frequency components emerging at different times which Kemp (1978) termed frequency dispersion. This emitted complex signal requires frequency analysis to extract the cochlear emission from the stimulus frequency components (Fay et al., 2008). In order to derive frequency specific information from the TEOAE response measures, the elicited response must be separated into frequency bands to indicate the response from various portions along the BM. The resulting TEOAE spectra are highly influenced by the filter properties and recording window times selected. A recording window is set to remove the stimulus artifacts from the initial time portion of the TEOAE recording. However, this cut-off time for artifact removal must be carefully selected in order to avoid removing high-frequency energy emissions from characteristically high-frequency portions of the BM (Kemp, 1978). The stimulus presentation level should also be selected with caution as growth functions for TEOAE level as a function of stimulus presentation level show saturation responses at higher stimulus levels: It is common to see saturation of TEOAE responses to stimulus levels between 50 to 80 dB SPL (Zwicker, 1983). TEOAE are generally tested over a reduced frequency range in comparison to DPOAE and have the clinical advantage of being more sensitive to cochlear pathology in a frequency specific manner (Kemp, 2002). The basis for clinical application of TEOAE is that the component frequencies of the response and the corresponding emission strength reflect the physiological status of the cochlea at characteristic frequency positions along BM (Yates & Withnell, 1999). TEOAEs are even more sensitive to cochlear irregularities than are DPOAEs, since unlike DPOAEs the TEOAE response is typically comprised of predominately the linear reflection component, which can be influenced by cochlear perturbations or properties basal or apical to the point along the BM most associated with the stimulus frequency or point of distortion-product generation. Typical responses for TEOAEs are strongest between 1000 to 4000 Hz (Kemp, 2002). Specifically for TEOAEs less than 4000 Hz, weak responses of less than 3 dB SPL are expected in most normal hearing healthy adult populations with children showing larger amplitudes even at higher frequencies around 6000 to 7000 Hz (Kemp, 2002). TEOAE compared to DPOAEs are more susceptible to changes in the emission response in the presence of small cochlear changes. If hearing thresholds determined by pure-tone audiometry are >20-30 dB HL (Kemp, 2002) or some researchers suggest >35 dB nHL (Ramos et al., 2013) then TEOAE responses are expected to be absent at the corresponding frequencies.

1.1.3 Auditory Pathway of Eliciting Stimuli and Otoacoustic Emissions

The middle ear system has characteristic resonance properties allowing acoustic signals of a particular frequency to pass more effectively through the middle. Under conditions of ambient MEP the auditory pathway is frequency selective, with frequencies between 1 to 4 kHz being selectively enhanced. Acoustic stimuli presented to the outer ear canal as pressure waves first passes through the external auditory meatus to the tympanic membrane (TM). In a typical healthy system, there is equal pressure on either side of the TM, causing the TM to vibrate maximally in response to the pressure waves (Ibraheem, 2014). There is an energy transfer via the TM and propagation of the now mechanical energy occurs through the air-filled middle ear cavity via the ossicular chain in an oscillatory motion (Kemp, 1978). The ossicular chain is comprised of three middle ear bones, the malleus, incus, and stapes which function to improve the impedance mismatch experienced when the sound energy is transferred between mediums (Ibraheem, 2014). The malleus makes contact with the TM for the first step in energy transfer, from acoustic to mechanical energy. The malleus is connected to the incus, which is connected proximally to the stapes. The foot plate of the stapes contacts the cochlear oval window and the stimulus is further dampened as energy is passed through to the fluid-filled cochlea. The frequency and amplitude of the stimulus sound wave directly dictate the movement of the stapes footplate and will be altered by changes to the middle ear mechanical system (i.e. ossicular chain) (Ibraheem, 2014). This transfer of energy from the stapes to inner ear cochlea represents a change in medium through which the energy must flow. The pathway from the outer to the middle ear and then to the fluid filled cochlea creates an impedance mismatch. This mismatch is from the outer ear canal air medium to the mechanical energy flow transfer between the ossicular bones to the endocochlear fluid. By the ossicular chain acting as a type of lever system and the area difference that exists between the TM and the round window, the acoustic signals are enhanced by the transmission pathway to limit the energy lost by the impedance mismatch between mediums. Within the cochlea, an apparent traveling wave through a fluid medium instantly disperses the stimulus energy throughout the BM from base to apex. The fluid within the cochlea is set into motion by applied force on the oval window by the moving stapes footplate. This cochlear fluid is non-compressible but is able to move due to the thin malleable membrane covering the round window. The proper transmission of the originally acoustic signal from the outer to inner ear requires an unobstructed and properly functioning middle ear mechanical system. For OAEs to be elicited and the emission response to be recorded in the outer ear canal, the forward (evoking stimulus) and backward (emission response) propagation of sound energy must be relatively unimpeded.

Optimal EOAE assessment occurs when the middle ear pressure is equivalent to environmental pressure, allowing maximal vibration of the TM. The middle ear acts as a closed, relatively rigid chamber in which the air pressure is regulated. When a situation of negative pressure develops within the cavity, the TM becomes retracted which affects the transmission of acoustic energy between the outer and middle ear cavities. The cellular lining of the middle ear cavity is partly responsible for maintaining a resting ambient pressure through air and gas absorption which occurs in a bidirectional manner (Elner, 1972). If the middle ear cavity remains closed (unventilated) for a long enough period of time, the air within the middle ear cavity is absorbed by the surrounding cells lining the walls of the cavity and is exchanged with an extravascular fluid (Elner, 1972). For example, such circumstances arise for patients with Eustachian tube dysfunction where the accumulation of the extravascular fluid leads to a state of serous otitis. In cases of a normally functioning Eustachian tube and middle ear, the absorbed gas is replaced by air flowing into the middle ear cavity via the open Eustachian tube and the MEP remains equivalent to ambient pressure. A study investigating the amount of gas absorption by the ME lining for normal healthy individuals showed the surround middle ear tissues absorbs 28.1 to 47.4 microliters per hour (Elner, 1972). Gas diffusion can also occur across an intact TM, but the diffusion is minimal, amounting to 0.5 to 1.0% of the volume that passes through the Eustachian tube within a 24 hour time period (Elner, 1972). For the study presented in this manuscript, the gas exchange via the middle ear cavity lining and across the TM will not be considered as influencing variables, as the diffusion amount would be diminutive over the time period of data collection within this study. Refer to the introduction section (6.1) for a discussion of the Eustachian tube function and maintenance of middle ear ambient pressure.

1.2 Assessments of Otoacoustic Emissions

Research investigating the effects of abnormal MEP on clinical tests such as OAEs and power absorbance is still in a preliminary stage. This is especially salient with regards to research replication, relating research findings to clinical application, and differences in findings between studies using various test instruments and testing protocol. Past research, investigating the effect of abnormal MEP on OAE related outcome measures, used clinically available instrumentation that could not compensate for an individual’s MEP. Although, custom made devices developed by some researchers were able to compensate for the middle ear pressure through the use of modified environmental set-ups or external pressure controlling devices. With the advent of the new Titan platform by Interacoustics, now it has been possible to measure EOAEs at both ambient pressure and a peak pressure level corresponding to an estimate of an individual’s middle ear pressure; however, there are no conclusive data on the impact of this adjustment clinically on EOAE measures of absolute amplitude and noise level or its impact on PA magnitude. Thus, a major objective of my thesis was to determine the impact of this adjustment on EOAEs and PA.

1.2.1 Impact of Abnormal Middle Ear Pressure on Otoacoustic Emissions

Clinical testing methods for measuring EOAEs are currently conducted with the pressure within the ear canal being roughly equivalent to ambient environmental pressure. Multiple studies have demonstrated that the absolute amplitude measures of EOAEs, for both DPOAE and TEOAEs, are attenuated in the presence of abnormal middle ear pressure (Prieve, Calandruccio, Fitzgerald, Mazevski, & Georgantas, 2008; Sun & Shaver, 2009). Consistently, multiple studies have demonstrated the presence of negative or positive MEP reduces the OAE level on average by 5-10 dB (Fay et al., 2008; Avan et al., 2000). The presence of negative or positive MEP increases the stiffness of the ME system, resulting in the compression of the ossicular chain and changes to the TM position thus, leading to increased impedance through the system affecting both forward and backward traveling signals. In the case of a patient presenting with negative middle ear pressure (NMEP), the positioning of the tympanic membrane is altered so that it is retracted inwards, causing pressure to be applied to the middle ear ossicular chain (Thompson et al., 2013). It is common in both adult and pediatric clinical populations for patients to present with NMEP, as a pressure change often occurs with middle ear infections, Eustachian tube dysfunction, and is often associated with the common cold causing congestion (Marshall, Heller, & Westhusin, 1997). Positive middle ear pressure due to pathology is not as common as NMEP, but can occur in cases of acute otitis media and also results in the change in TM position

(Onusko, 2004). In order to compensate for this change in impedance, it has been suggested that the pressure gradient (i.e. equilibrium point) across the TM can be altered by changing the pressure within the external ear canal allowing for an increase in acoustic energy flow through the TM and along the ossicular chain to the cochlea.

There are various opinions by clinicians and researchers regarding the magnitude of MEP considered to be within a clinically normal range for both adult and pediatric populations. However, it is not debated that the normal MEP has a mean of 0 daPa. Some researchers state normal MEP associated with a type A Jerger tympanogram for adults is -100 to +50 daPa (Jerger, Jerger, & Mauldin, 1972), whereas others are more conservative, stating a normal range between -50 to +50 daPa (British Society of Audiology, 1986; Shanks & Shohet, 2009) or from -150 to +25 daPa (Duffey, 2007). Although MEP ranging between -31 to -65 daPa falls within a normal range by most classification standards, this degree of NMEP has been shown to significantly impact the magnitude of EOAEs (Marshall, Heller, & Westhusin, 1997). A study conducted by Avan et al. (2000) with a sample of five normal-hearing subjects, showed a significant decrease in DPOAE level even with only +40 daPa of MEP and for some trials, as low as +20 daPa. Research by Thompson et al. (2015) examining the impact of NMEP on DPOAE magnitude for twenty-six normal hearing subjects had multiple significant outcomes; (1) the degree of NMEP induced was correlated to the observed change in DPOAE amplitude for NMEP ranging from -65 to -324 daPa, and (2) NMEP significantly altered the level of the DPOAE composite response (i.e. emissions generated by all mechanisms) as well as the emission component levels for all frequencies assessed (500 to 4000 Hz). Thompson et al. (2015) indicated the greatest observed change in DPOAE amplitude comparing the normal MEP to

NMEP conditions was a change of 12 dB (NMEP -324 daPa) and smallest amplitude difference of 0.1 dB (MEP -129 daPa). On average for all subjects, there was an average decrease in DPOAE magnitude of 4.4 dB (SD=4.68) in the NMEP uncompensated test condition, with the greatest differences observed for the low frequencies test region (f_2: 891 to 1122 Hz). They also note the observed changes were most significant for the generator component of the composite DPOAE (i.e. the distortion-product emission). This study also investigated the impact of NMEP on the level of the f_1 primary tone magnitude, finding the f_1 signal reaching the cochlea was attenuated for the low test frequencies but enhanced for the mid to high frequencies. These changes were attributed to the impact of NMEP on the TM resonance properties and middle ear transfer function; the NMEP impeded the transmission of the f_1 signal past the TM and through the ME cavity (Thompson et al., 2015). Similarly, for TEOAE measures, Marshall et al.(1997) showed that in conditions of NMEP (as little as -35 to -65 daPa), it was not possible to obtain a flat stimulus spectrum. These effects on the stimulus spectrum increased with increasing abnormal MEP with changes >10 dB observed for specific frequencies.

1.2.2 Testing at Ambient versus a Compensated Peak Pressure

Otoacoustic emissions can be measured with the pressure in the external ear canal being equivalent to the surrounding ambient pressure or at peak pressure. Peak pressure indicates a pressure value corresponding to the pressure of the middle ear space determined by immittance testing. For single frequency tympanometry, pressure is commonly swept across a pressure range from positive to negative and a pressure corresponding to maximum admittance is indicated. The pressure point allowing maximum admittance (minimum impedance) corresponds to an estimate of the middle ear pressure and it is called tympanometric peak pressure (TPP). When EOAEs are measured at a TPP, this can be referred to as measuring EOAEs at peak pressure level or in other words, at a compensated pressure level. Past research has shown EOAEs, both DPOAEs and TEOAEs, collected at a peak pressure results in increased emission amplitude (Hof, Anteunis, Chenault, & van Dijk, 2005a; Sun & Shaver, 2009). It should be noted that the transfer function properties of the middle ear and the effect of compensating for abnormal middle ear pressure is frequency dependent (Schmuziger, Hauser, & Probst, 1996). Testing under a condition of compensated MEP has been shown to increase OAE amplitudes for mid and low frequencies with a trend for decreased amplitudes in the higher frequency range (Sun & Shaver, 2009). When testing at an uncompensated ambient pressure, high-frequency emissions are attenuated less than those of low-frequency EOAEs (Trine, Hirsch, & Margolis, 1993). Previous studies indicate the need to compensate for changes in MEP to achieve accurate clinical EOAEs. Continued research is needed for further examination of these effects, especially for DPOAEs, using larger sample sizes, testing over a wider frequency range (Sun & Shaver, 2009), and under various abnormal MEP magnitude conditions.

Measuring EOAEs at higher frequencies has particular clinical implication given that frequencies above about 2.5 kHz tend to be most important for long-term monitoring of hearing loss such as in cases of repeat noise exposure and ototoxic monitoring (Marshall et al., 1997). Repeat measures of EOAEs for the detection of acoustic ototoxicity, especially for patients receiving aminoglycosides, is common clinical practice. Monitoring through means of repeat EOAE measures provides a relatively quick and reliable method that presents signs of hearing loss sooner than would be shown by conventional behavioral audiometry (Constantinescu et al., 2009). To obtain reliable EOAE results at each monitoring appointment the patient's outer and middle ear should be comparable between appointments to allow for the measurements of EOAEs that can be compared between assessments. If a change in emission strength is observed from one assessment to the next, with tests recorded at differing degrees of MEP, then the difference in EOAE amplitude cannot be confidently attributed to ototoxicity but could be accounted for by the presence of uncompensated abnormal MEP. In a study of 12 children receiving a single cycle of cisplatin-infusion of 50 mg/m^2, on average TEOAE amplitude at 4 kHz and DPOAE absolute amplitude for test frequencies ≥3 kHz was found to be significantly reduced post-treatment (Stavroulaki, Apostolopoulos, Segas, Tsakanikos, & Adamopoulos, 2001). The difference in DPOAE absolute amplitude pre- versus post-infusion was 5, 5.3, 10.1, and 9.3 dB SPL for f_2 frequencies 3.1, 4, 5, and 6.3 kHz. In a study of 223 adult patients with testicular cancer, the reduction in DPOAE amplitude level was shown to be dose dependent. This study found that for a cisplatin doses above 400 mg/m^2 both the low and high frequencies were impacted (Biro et al., 2006). The greatest difference in DPOAE amplitude between the control group and patient group was for those patients presenting with symptomatic ototoxicity: For frequencies 0.75, 1, 1.5, 2, 3, 4 ,6, and 8 kHz an absolute amplitude difference of 1.83, 3.78, 5.38, 5.98, 8.25, 10.88, 7.62, and 10.17 dB SPL, respectively, was observed. For this comparison between the control and patient groups, a significant differences was only indicated at ≥1 kHz. For patients receiving ≥7 cycles of cisplatin treatment, a DPOAE amplitude difference between the patient group mean and control group mean was 1.43, 0.48, 2.03, 2.33, 5.99, 7.08, 7.91, and 8.57 dB SPL but only differences at ≥4 kHz were significant.

Using the GSI 60 DPOAE system, Sun and Shaver (2009) investigated the effect of compensating for induced NMEP when testing DPOAEs between 600 to 8000 Hz on 16 normal hearing subjects. Consistent with past research, the results of this study showed the impact of NMEP on emission strength was highly variable across the frequency range (Thompson et al., 2013; Thompson et al., 2015). When testing in the uncompensated condition with NMEP ranging from -40 to -420 daPa, DPOAE level was reduced by 4 to 6 dB on average at 1000 Hz and, by 5 to 12 dB at 3000 Hz. There was no significant change in amplitude level between 2000 and 6000 Hz, and an increase in amplitude was seen at 8000 Hz (Sun & Shaver, 2009). When compensating for NMEP Sun and Shaver (2009) found the change in DPOAE (600 to 8000 Hz) amplitude was significantly corrected. Consistent with the conclusions by Thompson et al. (Thompson et al., 2015), between-subject variability for the effect of NMEP on DPOAE amplitude was highly variable, changing as a function of frequency and a significant trend was found in the uncompensated condition for the DPOAE level to decrease as the NMEP increased (Sun & Shaver, 2009).

Multiple studies have shown the improvement in TEOAE amplitude when testing under conditions of compensated abnormal MEP in a frequency-dependent manner (Hof et al., 2005a; Marshall et al., 1997). Work by Trine, Hirsch and Margolis (1993) assessed the impact of MEP on TEOAEs in the subject group ranging in age from 2.5 to 58 years, recording at both ambient and pressure levels corresponding to TPP estimates. This study used the Otodynmaics ILO88 system for a sample of fourteen ears with naturally occurring NMEP. Findings indicated low-frequency TEOAE amplitude decreased but high-frequency levels increased in the presence of uncompensated MEP (ranging from -100 to -310 daPa). When NMEP was compensated for, an average TEOAE level increase from 1.15 to 6.8 dB was observed when averaging across the click spectrum, for frequencies 500 to 2000 Hz. Contrary to the findings by Prieve et al. (2008)

testing a child population, Tine et al. (1993a) did not find a correlation between TEOAE amplitude and MEP magnitude. It was their conclusion that by equalizing the NMEP within the external ear canal, TEOAE amplitude is increased across the frequency spectrum but this was not significantly related to the magnitude of the NMEP induced (Trine et al., 1993).

1.2.3 Titan Suite by Interacoustics

Titan allows for the use of a single device that will effectively collect measures of wideband tympanometry, wideband absorbance, single frequency tympanometry, acoustic reflexes, as well as DPOAEs and TEOAEs at both ambient and peak pressure. The Titan system is able to compensate for an individual participant's specific middle ear pressure by altering the pressure generated within the outer ear canal to be equal in magnitude to the tympanic peak pressure. The TPP used as a reference for determining target pressure under peak test conditions can either be generated from a single frequency tympanogram or from a 3-dimensional wideband tympanogram (3D-WBT). For target pressure based on the 3D-WBT measures, the MEP estimate value is extracted from the wideband average tympanogram with different frequency ranges and calibration norms dependent on the age of the individual being tested. The test setup using a single device allows for the collection of these various measures in a single test run controlled by a pre-set automatic procedure (i.e. test sequence) while using the same probe tip and probe placement. This system eliminates the need to run multiple tests with various instruments and reduces confounding variable of altered probe placement between comparison measures. The option of obtaining measurements at either ambient or compensated pressure is available with Titan Suite for DPOAE, TEOAE, and wideband absorbance modules.

1.3 Acoustic Immittance - Tympanometry

The assessment of middle ear status is a necessary component of any audiological test battery. The normal propagation of acoustic stimuli from the stimulus source to the cochlear hair cells requires a relatively unobstructed pathway. Acoustic immittance is a broad term encompassing acoustic impedance, acoustic admittance, and all related components (Hunter & Shahnaz, 2013). The reciprocating measures of acoustic impedance and admittance indicate the quantity of acoustic energy and ease in which this energy can be transferred within a system, in the context of this manuscript the flow of acoustic energy into the middle ear cavity (Hunter & Shahnaz, 2013). The three elements of mass, stiffness, and friction dictate the admittance of acoustic energy from the outer to the middle ear, and ultimately the amount of energy received by the cochlea. If there is a shift from equilibrium for any of these three elements, such as to an abnormally mass dominated or stiffness dominated middle ear system, then the resulting admittance of acoustic energy is altered. Normal healthy adults present with a stiffness dominated middle ear system while infants have a middle ear dominated by mass elements (Hunter & Shahnaz, 2013). Based on these major differences in middle ear properties, tympanometric characteristics are widely different between adults and children, requiring separate test parameters and age-matched norms.

1.3.1 Single Frequency Tympanometry

Conventionally, a single frequency tympanogram using a 226 Hz probe tone has been used as a measurement of admittance to assess tympanic membrane (TM) and middle ear status. A measurement of admittance is graphed as an admittance value in mmho or milliliters against an x-axis of pressure (typically in daPa). This graph is generating by presenting an acoustic stimulus (ex. single frequency tone) while sweeping the pressure within the ear canal in either a negative to positive or a positive to negative start to stop pressure direction. Two components, namely acoustic conductance and acoustic susceptance contribute to the admittance value (Hunter & Shahnaz, 2013). From a single tympanogram, estimates of tympanic peak pressure (TPP), tympanometric width (TW), static acoustic admittance (Y_{tm}), and equivalent ear canal volume (V_{ea}) are derived. In order to determine an estimate corresponding to the admittance for the TM and middle ear cavity alone, the admittance corresponding to the portion of the external ear canal from the end of the measurement probe to the TM must be excluded from the admittance estimate (Fowler & Shanks, 2002). When the measurement of V_{ea} is subtracted from the overall estimate of admittance at the peak (TPP), an estimate of just the TM and middle ear is provided, shown as Y_{tm} (Fowler & Shanks, 2002). These measurements obtained from a single frequency tympanogram have clinical relevance with associated normative data. For example, an abnormal TW estimate and sharp tympanometric peak can be suggestive of middle ear pathology (Beers, Shahnaz, Westerberg, & Kozak, 2010) and specific tympanometric shaped responses can indicate a hyper-compliant TM, a perforated TM, or the presence of occluding cerumen between the probe and TM. For a conventional single frequency tympanogram, a pressure sweep is used to determine the point of greatest admittance. This peak admittance corresponds to a point when the pressure is equivalent on both sides of the TM, representing the TPP value (Kenny et al., 2011). The TPP provides an estimate of the pressure within the middle ear cavity and can also be used as an indicator of middle ear pathology or Eustachian tube dysfunction. A shift of the tympanogram peak to the right of the center point (0 daPa position) indicates an estimate of positive MEP and a shift left of center indicates NMEP. A single peak indicates normal TM response to a pressure change within the ear canal. Although single frequency tympanometry is a highly utilized tool in clinical audiology providing an estimate of admittance magnitude, it is limited in its use for identification of certain pathologies. For example, Shahnaz and Polka (1997) compared conventional single frequency to multifrequency tympanometric measures to distinguish otosclerotic (n=28 patients) from normal (n=62 participants) ears. They found that overall, the test parameters associated with the conventional 226 Hz tympanometric measure could not distinguish otosclerotic from normal ears greater than chance level. The conventional tympanometric measurement of TPP for the estimate of MEP is also limited in its precision. Variations of elastic and viscous properties of an individuals' middle ear system (tympanic membrane and middle ear cavity) contribute to inaccuracies of MEP estimates. Measures of TPP are also influenced by test parameters such as sweeping pressure direction, number of consecutively assessed tympanometric measures, and pump speed (Shanks & Shohet, 2009). Single frequency tympanograms can provide an overestimate of MEP on the range of 30 to 70 daPa, which is particularly overestimated when the actual middle ear volume is small (Eliachar & Norman, 1974 as cited in Shanks & Shohet, 2009). However, studies have shown conventional tympanometry as an accurate means to determine MEP with sensitivity and specificity to detect middle ear fluid (Gaihede, Lambertsen, Bramstoft, Kamarauskas, & Fogh, 2000). Conventional 226 Hz tympanometric measures continue to be widely used clinically, despite more refined test measures and instrumentation options being commercially available and despite alternative test options having been shown to provide increased test sensitivity and specificity for diagnostic audiology. The use of a single frequency tympanogram over more advanced and newer assessment measures to assess middle ear status persists in part due to constraints such as clinician access to equipment, clinician competency, test time, training demands, and due to its proven usefulness in providing quick and relatively reliable measures of high clinical relevance such as of ear canal volume, MEP, and tympanic membrane status (Hunter & Shahnaz, 2013).

1.3.2 Wideband Acoustic Immittance – Tympanometry

Wideband Acoustic Immittance (WAI) has the advantage over single frequency tympanometry of providing a broadened measure of middle ear status by evaluating the middle ear properties over a wide range of test frequencies (Robinson, Thompson, & Allen, 2016). Using a short duration click stimulus or pure tone stimuli presented simultaneously, WAI provides a comprehensive evaluation of middle ear function. The term WAI refers to measures of energy or power absorbance, reflectance, energy admittance, and conductance. The consensus statement from the Eriksholm workshop on wideband absorbance measures identified current shortcomings of WAI techniques and avenues for future research from both a clinical and research perspective. A few of the points the Consensus Statement outlined were the need for (1) refined and consistent use of WAI related terminology; (2) research needs such as increased normative databases, more studies investigating the sensitivity and specificity of WAI in detecting pathologies, as well as research focused on temporal aspects of WAI, and (3) considerations for future training plans regarding the implementation and interpretation of WAI measures into clinical practice (Feeney et al., 2013).

Wideband tympanometry (WBT) is characterized as a WAI measure with the basis of delivering a pressure sweep within the closed external ear canal. With WBT, air pressure sweeps over a specified range for a single measure, generating a three-dimensional wideband tympanogram (3D-WBT) for all probe tone frequencies. Wideband tympanometry is a method of assessing TM and middle ear status by measuring average absorbance as a function of pressure and frequency, with a typical frequency range between 226 to 8000 Hz (Beers et al., 2010). For the Titan Suite module, once the 3D-WBT measure is complete the system automatically derives absorbance at ambient and peak pressure, tympanograms at multiple single frequencies, resonant frequency, equivalent ear canal volume, and a wideband averaged tympanogram. A wideband average tympanogram displays an absorbance average across a wide range of frequencies, plotted as a function of air pressure. With the Titan IMP440 module, wideband tympanograms show frequency-averaged power absorbance as a function of pressure, with the sampling frequency range spanning 375 to 2000 Hz for adults. Although, the sampling range for the overall 3D-WBT measure is set at 226 to 8000 Hz. Response measures available with conventional single frequency tympanometry are also available such as estimates of TM compliance, TPP, and tympanometric width. An estimate of middle ear pressure is generated by the 3D-WBT. The MEP reflects the peak pressure (pressure point indicating the highest energy admittance) from the wideband averaged tympanogram with averaging limited to a maximum frequency of 2000 Hz. Past studies have demonstrated the usefulness of WAI tympanometry in distinguishing amongst various types of middle ear pathology in children (Beers et al., 2010) and adults (Ibraheem, 2014; Shahnaz, Longridge, & Bell, 2009).

1.3.3 Wideband Acoustic Immittance - Calibration

In order to quantify the percentage of acoustic energy that is either reflected back into the canal or absorbed by the middle ear, calibration of the equipment and stimuli must be meticulously performed. A common calibration technique and one used for Titan WAI module calibration is based on acoustic measures conducted using a set of simulation cavities to calculate Thevenin source impedance measures. With this calibration technique, pressure measurements are done within a minimum of two rigid calibration tubes of known diameter and length that are intended to simulate the human ear canal. Thevenin parameters and the pressure associated with the WAI measurement probe transducers are determined. The involved computer program is able to compare the characteristics of the pressure waves within the calibration tubes to generate a chi-square calculation (Jaffer, 2016). A click stimulus is presented to the calibration tubes and the system measures the incident waveform as a function of frequency and the source reflectance. The chi-square value provides an estimate of the energy that is lost in the system during the calibration measure and the RMS provides an indication of how similar the calibration is to the referenced model of sound propagation. Successful calibration requires the chi-square value (a goodness of fit estimate) to be close to a value of one with the root-mean-square (RMS) value close to 0.00 (Jaffer, 2016). Once these two parameters are known, they can be applied for real ear measurements. When the acoustic stimulus is presented to a real ear canal, a measure of the acoustic energy absorbed by the middle ear is estimated, providing a measure of power absorbance.

1.4 Power Absorbance and Energy Reflectance

When an acoustic stimulus is presented within the closed space between the probe tip and the TM, some of the energy is absorbed by the middle ear to be transferred to the inner ear, but a portion of energy is reflected at the level of the TM back along this pathway to the ear canal. Additionally, not all the energy is transferred through the TM and altered to fluid energy within the cochlea, but is either absorbed within the middle ear cavity or reflected back through the ossicular chain of the middle ear to the external canal. Assessing middle ear function over a wide frequency range, measures of wideband reflectance (or alternatively, wideband absorbance) keeps the pressure within the canal constant. The measurement of energy reflectance represents a ratio of reflected energy to incident sound energy (Hunter & Shahnaz, 2013). These measures of ER and PA are not as reliant on the probe placement within the ear canal as are single frequency or multifrequency tympanometric measurements, especially for higher frequency stimulus components: Unlike conventional tympanometric measures, WAI does not require the estimation of equivalent ear canal volume to estimate static admittance and WAI is less susceptible to interference from standing waves (Jaffer, 2016).Wideband measures of ER and PA are useful assessment for identification of various middle ear pathologies and are a superior approach to diagnostic audiology compared to the conventional single frequency tympanogram (Feeney, Grant, & Marryott, 2003; Hunter & Shahnaz, 2013; Sun, 2016). In addition to absorbance magnitude information, WAI measures also contain a measurement extracting the temporal aspect of the acoustic stimulus interaction with the middle ear and within the ear canal. This temporal measure can be referred to as the pressure reflectance phase or phase angle value (Feeney et al., 2013). This reflectance phase angle indicates the frequency response of sound wave propagation within the ear canal (Jaffer, 2016). Unlike PA magnitude, reflectance phase angle is influenced by the distance of the probe tip end to the TM (Rosowski et al., 2012). It has been suggested that assessing phase angle with wideband acoustic measures may be useful in the identification of acoustic leaks or inadequate ear canal probe insertion such as a shallow insertion (Mimosa Acoustics 2012 as cited in Jaffer, 2016). Measures of power absorbance can be plotted as a linear magnitude value 0 to 1, with 1 representing a situation in which all energy has been absorbed by the middle ear system and 0 reflecting all the presented energy was reflected (Shahnaz & Bork, 2006). Power absorbance magnitude is plotted as a function of frequency (typically 250 to 8000 Hz). There is a direct relationship between energy reflectance and power absorbance: Power absorbance is equal to one minus the total power reflectance (Kenny, 2011).

1.4.1 Clinical Application of Power Absorbance and Energy Reflectance

To investigate the integrity of the cochlea for regions corresponding to characteristic frequencies by means of EOAE testing, it would be advantageous to supply a consistent and equal excitation stimulus across the range of test frequencies (Keefe & Schairer, 2011). However, for EOAE testing in which the eliciting acoustic stimulus is presented by a probe positioned in the external ear canal, the sound intensity level and sound pressure level changes in a frequency dependent manner as the forward propagating stimulus is transferred from the outer to middle and then to the inner ear. The stimulus acoustic energy is altered due to the acoustic transfer function of the auditory pathway. Primarily, these transfer functions alter the admittance and reflectance from the external ear canal along the ossicular chain to the oval and round window. The magnitude of the stimulus power reaching the cochlea is equivalent to the amount of power absorbed by the middle ear subtracting the degree of loss through the middle ear system (Keefe & Schairer, 2011). To achieve an equivalent transfer of excitation energy to the cochlea, an equivalent absorbance of sound energy into the middle ear is needed for all frequencies. When there is MEP deviating from ambient (0 daPa), this changes the physical state of the TM, increasing the stiffness and impedance through the middle ear system and leading to a decrease in power absorbance (increased energy reflectance). The WAI measure of power absorbance can be used to assess middle ear status and aid in the assessment and interpretation of EOAE measures.

1.4.2 Power Absorbance with Normal Middle Ear Status

For estimates of static wideband energy reflectance in normal adult subjects, energy reflectance (ER) decreases with increasing frequency to a minimum around 4000 Hz (Burns, Harrison, Bulen, & Keefe, 1993) similar trends have also been observed for pediatric populations with a slight shift in frequency for minimum ER (Beers et al., 2010). Based on adult normative data, measures of wideband energy reflectance show the greatest energy reflectance at low frequencies with some reduction in reflectance for mid frequencies (between 1 to 4 kHz) and an increased reflectance at higher frequencies (Shahnaz & Bork, 2006; Rosowski et al., 2012). The difference in power absorbance measures as a function of frequency has been observed between ethnic groups. Findings by Shahnaz and Bork (2006) show a PA maxima around 1500 Hz and 4000 Hz for a Caucasian participant group, but the Chinese participants had a single PA maximum at 4000 Hz. Findings by Kenny (2011) showed contradicting results, with both ethnic groups indicating a two frequency PA peak. A recent study using the Titan Suite found for a young healthy adult population of Turkish ethnicity, female participants had significantly higher measures of PA within the range of 3100 to 6900 Hz compared to male participants (Polat, Baş, Hayır, Bulut, & Ataş, 2015).

A study by Keefe and Schairer (2011) tested a participant group of normal hearing subjects at frequencies 220 to 8000 Hz to investigate the change in presented acoustic stimulus energy within the ear canal. It was demonstrated that the acoustic transfer function contributed to differences observed between forward and incident pressure levels. Findings include: (i) a larger pressure level was observed for the forward propagating stimulus compared to the incident pressure for frequencies less than 0.77 Hz, (ii) the incident and forward pressure level differed less than 4 dB for frequencies 0.7 to 8 kHz, and (iii) for frequencies above 5 kHz, the forward pressure level was greater than the incident level for 90% of participants. This same study also showed the transfer function phase between the forward and total pressure changes as a function of frequency. These findings showed a minimum level of the forward traveling energy for low frequencies with a peak in energy around 4.3 kHz rolling off in energy towards 8 kHz (Keefe & Schairer, 2011). A study employing similar test procedures by Keefe and Abdala (2007) showed comparable findings but with a peak forward travelling energy of about 12 dB at 3.3 kHz (as cited in Keefe & Schairer, 2011). These measures are related to the estimate of conductance, with conductance levels reflecting the difference between the presented sound pressure and the absorbed power. Keefe and Schairer (2011) concluded that estimates of power absorbance for individual subjects could help with calibration of acoustic stimuli for improved audiological assessments such as OAEs.

1.4.3 Effects of Negative Middle Ear Pressure on Power Absorbance

For measures of wideband absorbance in the presence of abnormal MEP, there is a general observation for absorbance magnitude to decrease for frequencies <2000 Hz and for a combination of absorbance increases and decreases to occur between 2000 to 8000 Hz dependent on the pathology (ex. otitis media, perforated TM, NMEP, or PMEP)(Sun & Shaver, 2009). In a study of 78 children with normal MEP and 64 children with abnormal MEP, Beers et al. (2010) found a significant difference in energy reflectance between Chinese and Caucasian participants, with the Chinese group having a lower mean ER for mid frequencies. They also showed a significant difference in mean ER comparing pediatric to adult normative ER data. For the group presenting with abnormal MEP, there was a significant difference observed in mean ER between all conditions of varying abnormal MEP magnitude and in comparison to the middle ear effusion group.

Recently published work by Sun (2016b) provides a data set of WAI tympanometric measures for a sample of 84 normal hearing young adults. This study used a computer-based wideband tympanogram (WBT) research system from Interacoustics in conjunction with a Titan probe assembly and REFLWIN WBT software (see published journal for instrument details, (Sun, 2016b). Energy absorbance plotted as absorbance magnitude as a function of frequency 250 to 8000 Hz showed for 84 averaged measures run at ambient pressure, the mean energy absorbance increases in magnitude from 250 to a single peak maximum around 4000 Hz then slopes down at higher frequencies. There was a trend observed for more variability in response shape at higher frequencies. The pressure within the ear canal was set to +200 daPa and -300 daPa. The change in mean energy absorbance for the positive and negative pressure test conditions followed a similar pattern for the mid to low frequencies but differed in peak morphology and magnitude change roughly ≥4000 Hz. The -300 daPa condition showed a greater reduction in energy absorbance compared to the +200 daPa condition at >1000 Hz. Both abnormal pressure condition displayed an increase in absorbance compared to the ambient test condition at >4000 Hz. This study did not investigate interactions between outcome measures and factors of gender or ethnicity. Similar findings were seen in a study by Robinson, Thompson and Allen (Robinson et al., 2016) that found for a sample of eight ears with induced NMEP, absorbance was significantly reduced in the presence of uncompensated NMEP for the frequency range 800 to 2000 Hz and a small increase in absorbance was observed above 4000 Hz.

In a study by Kenny (2011) using the REFLWIN Interacoustics Wideband Reflectance machine, outcome measures of energy reflectance were compared between the two test conditions of static (ambient pressure) and dynamic pressure. The dynamic pressure refers to a pressure created by a pump to alter to test pressure within the ear canal, similar to how tympanometry uses a pump to sweep a pressure range (Jaffer, 2016). Findings from this study showed (i) significantly lower PA resulted for both Caucasian and Chinese participants at low test frequencies in the ambient compared to peak pressure test condition and (ii) for the static test condition, Caucasian participants had higher PA magnitude at frequencies 4000 to 5000 Hz (Kenny, 2011). These results are consistent with previous findings by Liu et al. (2008) (as cited in Kenny, 2011). The Kenny (2011) study showed significant interactions for the outcome measure of PA between gender and ethnic groups as a function frequency, with Chinese female participants having a higher PA for high frequencies compared to Caucasian females. These findings were consistent with those from a study by Shaw (2009), finding the Caucasian compared to Chinese participant group had a higher PA mean in the dynamic pressure condition but both ethnic groups showed overall increase mean PA in the dynamic compared to static pressure condition (as cited in Jaffer, 2016).

Ibraheem (2014) investigated the effect of NMEP on energy reflectance for a sample of three adult participants presenting with Eustachian tube dysfunction (ETD) and associated negative MEP estimates between -155 to -318 daPa. Results from this study showed the ETD participants had high ER for the low to mid test frequencies and this change in ER magnitude was pressure dependent. The frequency at which ER began to decrease was also found to be dependent on the degree of NMEP. The participant with the largest estimated NMEP of -318 daPa showed increased ER up to 4 kHz. However, contrary to other research (Robinson et al., 2016) this study by Ibraheem (2014) found a significant difference in ER magnitude between the control and ETD groups only at 250 Hz.

1.5 Normative Data

Another clinical occurrence with EOAE and power absorbance measures is to reference a patient's responses to normative data. Normative data is most commonly based on a participant sample representing a normal hearing and healthy population with pure-tone thresholds within a normal sensitivity range and absent of middle or inner ear pathology. For normative data to be useful clinically, the test patient must share characteristics of the test population on which the norms are based. For example, if a patient presents with abnormal MEP at the time of testing, their EOAE are likely to be outside the clinically acceptable range of normal when referencing age-matched normative data. However, if a process is available to allow for the compensation of the abnormal MEP providing an accurate indication of cochlear function despite the NMEP, and the measured OAEs then fall within the clinically normal range, then would be advantageous from a clinical perspective. The magnitude of EOAE amplitude change between assessing EOAEs at ambient versus a compensating peak pressure would need to be assessed in a control group in order to determine if the two test pressure options provide similar values when testing the same population on which norms would be based. Normative data is commonly displayed as a range of values, and measurements falling outside the 5th to 95th percentile of this normative data can be considered distinct from the normal population on which the norms were based (Feeney, et al., 2003). To determine the clinical significance of assessing EOAEs according to two different test protocols, one option over the other should provide increased diagnostic value (improved sensitivity and specificity). For example, consider the clinical scenario of assessing EOAEs with the goal to determine accurate cochlear status, for a patient presenting with abnormal MEP and the option to run the test measures at ambient versus peak pressure. It would be of clinical relevance to know first if the present abnormal MEP results in EOAE amplitude changes to a degree significant enough to cause the resulting EOAE measurement values to fall outside the normative data range of normal. Next, it would be pertinent to the clinician to know if assessing the EOAEs at peak pressure compared to the conventional ambient pressure would result in improved assessment outcomes. In other words, would testing at peak pressure in comparison to ambient pressure alter the test outcome substantially enough to result in the EOAE values falling within a range of normal (ex. within the 5th and 95th percentile range). Additionally, it would be of clinical interest to know at which magnitude of MEP, testing at peak versus ambient would result in a change in clinical judgment between normal/abnormal (pass/refer or present/absent).

1.5.1 Otoacoustic Emission Signal-to-Noise Ratio

In most clinical settings a signal-to-noise ratio (SNR) is used to determine the clinical presence or absence of OAEs. A SNR criteria for a pass or refer indication is often set with the standard clinical acceptance of a 3 to 6 dB separation between the signal and noise levels with differences for DPOAE and TEOAE measures (Ramos et al., 2013; Sun & Shaver, 2009). The impact of noise level on determining OAE presence or absence is most impactful for low test frequencies for both TE and DPOAE measures. Torre, Cruickshanks, Nondahl and Wiley (2003) testing a population of older adults (48 to 92 years of age), investigate the change of noise level in relation to DPOAE level for frequencies 1000 to 8000 Hz. The objective of their study was to determine

DPOAE noise and level response characteristics for an older sample population and evaluate how specific the conventional SNR are in differentiating hearing levels for this particular population. Findings indicated a mean noise level of 0 dB SPL at 2000 Hz, -15 dB SPL at 4000 Hz, -20 dB SPL at 8000 Hz and an overlap between noise and DPOAE level at 1000 Hz (Torre et al., 2003). In conclusion, Torre et al. (2003) indicated the potential need for frequency specific DPOAE level and SNR criteria at least in an older test population. There is a move towards referencing normative data to determine OAE presence or absence rather than a SNR criterion in clinical settings (Ramos et al., 2013). This shift is facilitated by the continued use of OAE in the clinical settings and the growing body of scientific research providing instrument specific and population specific normative data.

Research by Ramos et al. (2013) aimed to develop a normative data set for the Titan DPOAE440 module. This study looked at the DPOAE response from 500 to 8000 Hz (corresponding to f_2 frequencies) for 20 female and 19 male ears in a normal hearing population. Results indicate mean noise floor levels change as a function of frequency and between genders. This study proposed a categorization method where a patient's DPOAE response can be considered present, absent or abnormal based on the combination of an SNR criteria and DPOAE amplitude response referenced to a DPOAE amplitude normative data set (Ramos et al., 2013). A study by Sun and Shaver (2009) examining the impact of negative MEP on DPOAE amplitude, showed no significant change in noise level with induced NMEP (ranging from -40 to -420 daPa) for 22 human ears. Similarly for a test population of children 3 to 39 months of age, Prieve et al. (2008) found mean TEOAE levels were lower as TPP became more negative but there was no significant change in noise level as a function of frequency or MEP magnitude.

1.5.2 Participant Characteristics - Gender and Ethnic Effects

The development of gender and ethnic-specific normative data sets would allow for a more accurate assessment of whether a patient presents with clinically normal or pathological findings, by more accurately being able to assign test outcome measures within or outside a clinically defined normal range. In addition to ethnic, gender, and age-specific normative data sets, norms considering body size and other personal characteristics such as skull size may be warranted for certain test measures such as EOAEs, and admittance related measures (ex. power absorbance or energy reflectance) (Beers et al., 2010; Mazlan, Kei, Ya, Yusof, Saim, & Zhoa, 2015; Shahnaz & Bork, 2006; Sun, 2016; Wan & Wong, 2002).

1.5.2.1 Acoustic Immittance Measures - Participant Characteristics

Between-subject factors of ethnicity and gender have been shown to significantly impact certain middle ear measurements such as wideband energy reflectance and absorbance magnitude (Shahnaz, Feeney, & Schairer, 2013). Research by Shahnaz et al. (2013) indicate that ethnicity may be an influencing variable on middle ear measures possibly due to differences in individual participants' outer and middle ear properties, which may be attributed to body size and ear canal volume disparities. Shahnaz et al. (2013) suggest the use of ethnic-specific and age-matched norms (especially in cases of suspected middle ear pathology such as otosclerosis), and indicate the need further investigations into the correlation between body-size indices and WAI measures. Findings from Shahnaz and Bork (2006) suggest that when comparing outcome measures of wideband energy reflectance between Caucasian females and Chinese males, the effect of ethnicity is no longer a significantly impacting factor. It was suggested that the similarity in body size between comparison groups accounted for the comparable reflectance measures.

Research by Wan and Wong (2002) suggests possible differences in Eustachian tube functionality for various ethnic groups could explain the differences observed in tympanic peak pressure between Chinese and Caucasian participants. Similarly, research by Shahnaz and Bork (2006) showed the effect of ethnicity was an influencing factor for the comparison of multiple tympanometric assessments. The Caucasian participant group showed greater values of static admittance (Y_{tm}), narrower tympanic width (TW), more centered tympanic peak pressure (TPP), and larger equivalent ear canal volumes (V_{ea}) when compared to Chinese participants (Shahnaz & Davies, 2006). However, when considering between-subject factors of gender and ethnicity for measures of a 226 Hz tympanogram, Chinese males and Caucasian females showed comparable values for estimates of Y_{tm}, TW, TPP, and V_{ea} (Shahnaz & Davies, 2006). It was proposed in the discussion by Shahnaz and Davies (2006), that the similarity between Caucasian females and Chinese males could be attributable to these groups having comparable body-mass indices. This argument supports the idea that body size may be a primary source of differences observed amongst individuals and could be used as an indicator of response patterns when considering measures reliant on middle ear mechano-acoustic properties (Shahnaz & Davies, 2006).

1.5.2.2 Otoacoustic Emissions – Participant Characteristics

Some studies comparing the emission strength between gender groups have shown significant differences in emission amplitude, with female subjects having a greater response especially for mid to low frequencies and the differences being more robust for TEOAE compared to DPOAE measures (Dunckley & Dreisbach, 2004; Dieler, Shehata-Dieler, Klagges, & Moser, 1999; McFadden, Martin, Stagner, & Maloney, 2009). Various reasons have been proposed to explain the OAE level differences observed between gender groups; (1) differences in middle ear properties (Dunckley & Dreisbach, 2004; Kemp, 2002) and ear canal volume (Shahnaz, 2008) between gender groups could account for changes in sound transfer functions altering the forward and backward transmission of stimulus signals and OAEs; (2) increased prevalence of spontaneous OAEs have been found in females compared to male subjects, which could impact the level and phase of the emissions signals (Dunckley & Dreisbach, 2004; McFadden et al., 2009); and (3) difference in hormone levels (Dunckley & Dreisbach, 2004) and blood type have also been explored as possible explanations for OAE amplitude differences observed between subject groups (Chow, McPherson, & Fuente, 2016). A study by Aidan, Lestang, Avan and Bonfils (1997) tested 1164 ears of healthy normal hearing neonates finding that the click-evoked TEOAE magnitude varied significantly between genders with males having average emission strength of 21.4 dB SPL compared to females with 22.1 dB SPL. This same study found that 98% of neonates tested showed present TEOAEs between the frequency range of 500 to 5000 Hz using a 3 dB SNR criteria. However, there are contradicting studies showing no significant difference between genders such as the study conducted by Dunckley and Dreisbach (2004) that found no significant DPOAE amplitude differences for frequencies <8000 Hz between normal hearing adult male (n=17) and female (n=20) participants. This study by Dunckley and Dreisbach (2004) also found no difference in DPOAE between test ears right versus left, consistent with past research investigating ear specific OAE level differences (Dieler et al., 1999).

Differences in OAE strength has also been noted between ethnic groups. A study by Shahnaz (2008) investigated the effect of gender and ethnicity on characteristics of TEOAEs for a sample of 81 Chinese and 81 Caucasian normal hearing subjects using the clinical ILO-292 Analyzer by Otodynamnics. Results of this study showed when collapsing across ethnicities, females had significantly higher TEOAE amplitude compared to males with mean noise level being comparable between groups and consistent across frequencies 1000 to 4000 Hz. For the comparison of TEOAE amplitude collapsing across genders, the Chinese group had significantly larger TEOAE amplitude compared to Caucasians (Shahnaz, 2008). The difference in middle ear transmission properties, cochlear originating differences, as well as the factor of body size contributing to variations in ear canal volume and middle ear cavity size, were proposed as possible sources for the observed TEOAE amplitude differences between gender and ethnic groups (Shahnaz, 2008).

1.6 Eustachian Tube

Along the superior-anterior portion of the middle ear cavity, an opening exists to the Eustachian tube (Kenny, 2011). Normal Eustachian tube function is needed to maintain normal MEP. The muscles surrounding the Eustachian tube can be contracted and relaxed through various mechanisms, such as yawning, swallowing, or for some individual mandibular movements, altering the airflow along the tube. Abnormal positive or negative pressure can be created within the middle ear cavity through manipulation of the surrounding Eustachian tube muscles.

1.6.1 Eustachian Tube Function

The Eustachian tube forms a connection between the middle ear and the nasopharynx with the primary function of equalizing pressure between the middle ear cavity and the external environment. The Eustachian tube also functions as a duct along which middle ear sections can be drained and provides a route for nasopharyngeal secretions to drain protecting the middle ear cavity from a buildup of these fluids (Bluestone, 1983). When swallowing, the tensor veli palatine muscle is engaged which changes the diameter of the tube and subsequently alters the flow of air along the Eustachian tube (Bluestone, 1983). For healthy individuals which normal Eustachian tube function and middle ear status, periodic swallowing causes the intermittent opening and closing of the Eustachian tube maintaining a close to ambient pressure within the middle ear cavity (Bluestone, 1983). The Toynbee and Valsalva maneuvers are used to create abnormal pressure within the middle ear cavity by controlling the air-flow through the nasopharyngeal and middle ear spaces with manipulation of the muscles surrounding the Eustachian tube. Both these maneuvers are routinely being used clinically to assess the Eustachian tube function. For both maneuvers, the pressure change can be relieved when an individual, swallows, yawns, sneezes, or in some cases through movement of their mandible (Elner, Ingelstedt, & Ivarsson, 1971).

1.6.2 Induction of Abnormal Middle Ear Pressure - Toynbee Maneuver

To induce negative MEP via the Toynbee maneuver, the participant closes his or her mouth while pinching both sides of their nose firmly while swallowing (Thompson et al., 2015). Having participants swallow opens the Eustachian tube allowing air to flow out of the middle ear cavity due to the negative pressure created within the nasopharyngeal space during the swallowing motion. The pressure change created within the nasopharynx during swallowing typically creates as pressure wave with an initial positive and a following negative phase, with the Eustachian tube completing an open and closing cycle during the negative phase (Elner, Ingelstedt, & Ivarsson, 1971). A study by Elner et al. (1971) indicated 74 out of 79 participants (79%) were able to induce negative MEP with the standard Toynbee maneuver. This same study also found that the use of water during the swallowing motion did not improve the outcome of the maneuver and that some participants were able to create positive rather than negative MEP via the Toynbee maneuver (Elner et al., 1971). In past studies investigating the effect of middle ear pressure on OAEs, mean tympanic peak pressures ranging from -65 to -324 daPa has been achieved using the Toynbee maneuver in normal hearing adults with suspected normal middle ear and Eustachian tube function (Thompson et al., 2015). Similarly, in work by Sun and Shaver (2009), negative pressure was induced ranging from -40 to -420 daPa using the Toynbee maneuver in participants with no middle ear pathology. A negative MEP of -50 daPa or lower is considered as a commonly elicited pressure value as supported by past studies when using the Toynbee maneuver (Marshall et al., 1997; Prieve et al., 2008).

1.6.3 Induction of Abnormal Middle Ear Pressure - Valsalva Maneuver

A condition of positive middle ear pressure can be induced by means of the Valsalva maneuver, by having a participant close their mouth and pinch his or her nose while exhaling as if blowing up a balloon. By obstructing the mouth and nostrils, positive pressure builds to a point forcing open the Eustachian tube and the buildup of positive pressure can escape into the middle ear cavity being trapped once the Eustachian tube narrows (Kenny, 2011). It is not uncommon for the unexpected pressure (negative rather than positive MEP) to be created with the Valsalva maneuver (Kenny, 2011; Williams, 1975). The same study by Elner et al. (1971) shows for 101 individuals, 86% were successful in inducing positive MEP via the Valsalva maneuver, with all individuals creating pressure exceeding +30 cm H_20.

1.7 Study Objectives

The study presented in the following manuscript will focus on outcome measures of absolute EOAE amplitude and noise level as well as PA magnitude in the context of natural state middle ear pressure (MEP) and induced MEP test conditions. The impact of MEP magnitude on these outcome measures (PA and EOAEs) will be explored as well as the potential ways in which these effects can be mitigated. The primary objective of the following research is to demonstrate the impact of assessing EOAEs and PA under two pressure conditions by altering the pressure within the external ear canal. The first is testing at an ambient pressure equivalent to the surrounding air pressure (conventional approach to EOAE assessment). The second pressure condition is a compensated test pressure condition in which the pressure within the external canal between the probe tip and tympanic membrane corresponds in magnitude to a participants' tympanic peak pressure (TPP). The abnormal MEP test condition will require participants to induce either negative or positive MEP by means of the Toynbee and Valsalva maneuvers. The purpose of analyzing PA is to investigate if (1) PA magnitude is altered significantly with a change in MEP and with pressure compensation, and (2) if alterations to the response pattern of PA could be used to predict changes to EOAE outcomes measures. With this study design, participants will serve as their own control group by providing outcome measures to both the non-maneuver and post-maneuver test conditions for both EOAE and PA measures. The current study will investigate outcome measures from a larger sample of normal hearing participants between the ages of 18 to 35. A collection of both EOAE and PA will be done using a single test system, Titan Suite, by Interacoustics.

The absolute EOAE amplitude measures for both TEOAEs and DPOAEs are predicted to decrease as the degree of negative or positive middle ear pressure shifts from baseline (MEP centered on 0 daPa), when testing under an ambient test pressure condition. For participants tested under the abnormal induced MEP condition (positive or negative), we predict that compensating for abnormal pressure by testing at TPP will show absolute EOAE amplitude values approximating those measured in the baseline test condition. It is also expected that the change in EOAE absolute amplitude between test conditions will be dependent on test frequency. The trend for absolute amplitude measures for TEOAEs and DPOAEs to be more robust when compensating for abnormal MEP is predicted to be present for all ethnic groups and genders included in this study. As a control measure, it will be examined whether absolute EOAE amplitude and noise level measurements from the non-maneuver condition under ambient and peak test pressure conditions are comparable. Testing under a condition of compensated MEP in the post-maneuver test condition (induced NMEP and PMEP) we predict there will be (1) an increase in PA for the mid and low frequencies, (2) a trend for decreased PA in the higher frequency range (approximately ≥4000 Hz), and (3) a shift in peak PA to a higher frequency point. It is expected that the change in PA magnitude, as predicted with EOAE amplitude, will be dependent on the magnitude of abnormal MEP.

It is hoped that the information obtained from this study will help refine the clinical use of EOAEs to produce a more accurate statement of cochlear function even when patients present at the time of testing with middle ear pathology such NMEP.

Chapter 2: Methods

2.1 Participants

Approval from the University of British Columbia Clinical Research Ethics Board (UBC CREB) was obtained prior to distribution of all participant recruitment material and prior to contact with all potential participants. This study complied with the requirements of the UBC CREB for the entirety of the study using only board approved documentation such as participant consent forms.

2.1.1 Participant Recruitment & Description

A convenience sample of participants for this study was recruited by means of information posters distributed on bulletin boards throughout the University of British Columbia campus and on student forums with permission of moderators. A total of 104 individuals met with an experimenter to contribute to this study. Of the original 104, there were 93 participants (60 females and 33 males) meeting all inclusion and exclusion criteria for at least one ear. Of the 60 female participants, otoacoustic emission data was analyzed from 115 ears and 60 ears from the 33 male participants. In total, 175 different test ears were included in this study. Refer to Table 1 for a description of why participants were excluded from the final data analysis or did not meet inclusion and exclusion criteria. The 93 included participants ranged in age from 18 to 35 years with the mean being 24 years of age. A sample size of n=110 individual DPOAE recordings from n=48 different participants contributed to each DPOAE related test condition. A sample size of n=97 TEOAE measures from n=45 individual participants contributed to each test condition. A sample size of n=210 power absorbance measures were obtained from n=93 individual participants. All participants were presented with a small monetary honorarium of ten dollars and a copy of their audiogram for their involvement in this study.

		Both Ears Excluded		**One Ear Excluded**	
		Male	Female	Male	Female
Earliest Stage at which Exclusion Occurred	**Case History**	2			
	Otoscopy		4		1
	Immittance	1		1	
	Pure Tone Thresholds	1	1	2	2
	Acoustic Reflexes		1	3	2
	Technical Errors		1		1

Table 1: Summary of excluded test ears (n=34 total) from the final data analyses.

2.1.2 Classification of Ethnicity

At the time of case history taking, it was explained to participants that studies involving humans routinely collect information on ethnic origin as well as other characteristics of individuals that may influence how people respond to different clinical procedures and that may affect various test measures and analyses. Participants were informed that providing information on ethnic origin is completely voluntary. Ethnicity was determined through self-reporting with the aid of a list of ethnicities as options provided on the case history form. There were seven options provided; Chinese, Caucasian, Indian, Aboriginal, Middle Eastern, Other, and Mixed. The options provided and description of each ethnic group was consistent with past studies investigating the effect of ethnicity on various middle ear measures including power absorbance (Jaffer, 2016). Classification of Chinese includes Canadian or Chinese born participants whose parents have lineage from mainland China, Hong Kong, or Taiwan with no distinguishable foreign descent. The Caucasian group was comprised of participants of European descent with light pigmentation of the skin, not identifying as Chinese, South/East/West Asian, Aboriginal, Arab, Black, Filipino, and Hispanic (Statistics Canada, 2004 as cited by Jaffer, 2016; Shriver et al., 1997). The Indian group was comprised of Canadian and Indian-born participants whose parents were from the South Asian country of India with no distinguishable foreign descent. Participants identifying with the Middle Eastern or West Asian classification of ethnicity were defined based on the Statistics Canada 2004 classification of ethnic origins of Afghan, Armenian, Iranian, Israeli, Turk, Georgian, Pashtun, and Azerbaijani (as cited in Jaffer, 2016). The category of ethnicity titled as Other was defined as participants with ethnic lineage other than Caucasian, Indian, Chinese, Aboriginal, or Middle Eastern. If participants selected the Other category, they were asked to voluntarily specify the ethnic background with which they most accurately identify with. A classification of mixed was provided for those participants who identified with two or more ethnic heritages. The final pool of participants (n=93) consisted of people identifying with 16 different ethnicities. In order to group participants into categories with sample sizes approachable for statistical analysis, all participants were at the stage of data extraction categorized into only three ethnic groups; Caucasian, Asian, and Other. Participants who self-reported identifying as Filipino, Malaysian, Korean, Singaporean, Indonesian, Vietnamese, Bruneian, and Chinese were grouped under the category Asian. Participants identifying as Caucasian remained in the category labeled as Caucasian. All remaining participants (other, Indian, Aboriginal/First Nations, Middle Eastern, Mixed, Latino, or African) were grouped into the ethnic category of Other.

2.1.3 Inclusion and Exclusion criteria

Participants were included in the study if they met the following criteria: (i) between 18 to 35 years of age; (ii) free of any history of severe head trauma or concussions; (iii) no hearing loss as defined by having pure-tone thresholds no worse than 20 dB HL at octaves between 250 to 8000 Hz, and no air-bone gaps greater than 10 dB HL between 500 to 4000 Hz; (iv) no gross outer or middle ear abnormalities or pathology visible by otoscopy including partially or fully occluding cerumen); (v) no history of or current perforations of the tympanic membrane; (vi) normal middle ear status as determined by a middle ear analysis test battery and (vi) no current middle ear infections. The middle ear analysis test battery consisted of acoustic immittance and ipsilateral acoustic reflex measures. For participants to be included in the study, it was required that immittance measures indicate values within a clinically normal range for compliance (0.3 to 1.4 mmho) and ear canal volume (0.6 cc to 1.5 cc) as well as show a classic Jerger type A tympanometric response shape (Margolis & Heller, 1987). A 3D wideband tympanogram (3D-WBT) and a conventional 226 Hz tympanogram were both used as assessment measures for normal middle ear status. Furthermore, for the assessment of normal middle ear function, it was required participants have present ipsilateral acoustic reflexes to stimuli presented ≤100 dB HL in response to pure-tones of 500 Hz, 1000 Hz, and 2000 Hz and to broad band noise (BBN). For an ipsilateral acoustic reflex response to be considered present, a deflection value response criterion of ≥0.3 ml and a characteristically normal response shape and amplitude growth was set. All participants were required to be fluent in the English language as they needed to be able to follow instruction on test protocol during testing. English as a second language participants whose first language was Farsi or Mandarin/Cantonese could be accommodated as available research assistants were fluent in the previously mentioned languages; however, English as second language participants were still required to have functional knowledge of the English language.

2.2 Instrumentation

2.2.1 Otoscopy and Audiometry

Cursory otoscopic examinations were performed using a Welch Allyn clinical otoscope with Welch Allyn Universal disposal otoscope specula, adult size 4.25 mm. Pure tone audiometry was conducted using an Otometrics Madsen Astera[2] audiometer with calibration done according to ANSI standards (S3.6.1989) prior to the start of data collection of the same year. A biological listening check was performed prior to testing every participant. Adult or pediatric sized Etymotic Research (ER) 3A insert earphones were used for obtaining pure tone thresholds for air-conduction stimuli and a RadioEar B-81 bone oscillator was used to obtain pure tone bone-conduction thresholds. Pure-tone audiometry was conducted in an audiometric sound-treated booth.

2.2.2 3D-Wideband Tympanometry, Wideband Absorbance, Single Frequency Tympanometry, Ipsilateral Acoustic Reflexes, and Otoacoustic Emissions

Wideband acoustic immittance, absorbance measures, conventional 226 Hz probe tone tympanometry, assessment of ipsilateral acoustic reflexes, and evoked otoacoustic emission measurements were all performed using a single test system, Titan Suite, by Interacoustics. The Titan has the ability to be used as a standalone hand-held test unit. However, for this study, the Titan interfaced with various software modules; Impedance and Wideband Tympanometry

(IMP440/BT440), Distortion Product Otoacoustic Emissions (DPOAE44), Transient Evoked Otoacoustic Emissions (TEOAE440). In order to use the Titan device in a research capacity, the following components were required: (i) IBM compatible laptop computer, (ii) Otoaccess software, (iii) Titan hand-held unit with associated cradle, and (iv) Probe with extension cable and pre-amplifier. The OtoAccess software used for this study was a research version 1.1.2. The Titan Suite (version 3.2.2) was launched from the OtoAccess program for testing in a completely personal computer controlled mode. Since the completion of data collection for this study, a newer version of Titan software (version 3.3.0) has been released by Interacoustics. All test data was stored on the test computer and in OtoAccess.

The Titan with IMP440 module Impedance System was used for electroacoustic test measures; 3D tympanometry, wideband absorbance, conventional 226 Hz tympanometry, and ipsilateral acoustic reflexes. The 3D wideband tympanometry measure provides three tabs for viewing test data; (1) 3D Graph, (2) Tympanograms, and (3) Absorbances. The first tab, 3D Graph, displays a 3-dimensional measure of absorbance as a function of both pressure and frequency. The Tympanograms tab shows compliance measures as a function of pressure, which can be customized to display various response measures such as individual 226 Hz and 1000 Hz single frequency tympanograms as well as a Wideband Tympanogram. The individual tympanometric measures within the Tympanogram tab were retrieved from the 3D measurement. The last tab, Absorbances, shows a pair of power absorbance measures as a function of frequency, with one measure taken at ambient and the other at peak pressure. Within each tab, there are multiple viewing options available and ways in which the user can interact with the data. For example, under the Tympanograms tab, the tympanograms can be viewed showing acoustic admittance, conductance, or susceptance measures either compensated or uncompensated for equivalent ear canal volume estimates. Estimates of ear canal volume, compliance, peak pressure, and resonance frequency are available. These same viewing options are also available for the stand-alone conventional 226 Hz tympanometry measure. There is a setting option to have Titan conduct single frequency tympanograms at various test frequencies; for this study, only the 226 Hz tympanogram was of interest.

For distortion-product otoacoustic emission (DPOAE) measures and transient evoked otoacoustic emission (TEOAE) measures, the Titan DPOAE440 module and TEOAE440 module were used.

Titan requires the use of system specific disposable probe tips for all immittance and OAE related measures. Disposable mushroom shaped ear tips were used. On average, 8mm to 15mm tips were adequate for a complete seal for most participants.

2.2.3 Calibration

The Titan probe unit is the piece that contains the calibration data for the probe stimuli for DPOAE and TEOAE signals. Pressure sensor calibration data, safety valve and hardware calibration data are all stored on the Titan handle unit. For this study, rather than the clinical extension cable, the Titan Preamplifier was used, which contains the pressure sensor related calibration data. For DPOAE and TEOAE measures, calibration was performed according to IEC 60318-4 using the IEC 711 ear simulator coupler. The probe stimuli L_1 and L_2 for DPOAE measures are calibrated separately in SPL values and the TEOAE probe stimuli are calibrated in peSPL (Interacoustics Titan Suite User Manual). Calibration for all pieces used for testing and the associated calibration required for the various test measures were performed at the start of data collection: Calibration for both TEOAE and DPOAE measures was done by the manufacturer prior to data collection, at the time the system was sent in for annual service maintenance. However, at the beginning of every test day, calibration was done for the wideband acoustic immittance module. Calibration software for Titan Suite was installed on the laptop computer used to run the OtoAccess program. Calibration was accomplished by using calibration tubes and a 9 mm mushroom ear tips provided by Interacoustics. A large diameter long tube is used first for calibration: A graphical display of the measured click and resulting reflections in the tube are displayed on the computer screen. Second, the large diameter short tube is used for calibration with a resulting absorbance versus frequency graph, reflecting an incident waveform against frequency and the calculated source reflectance. Chi-square and RMS values are provided with an indication if calibration was successful or requires a re-attempt. The limit for the large diameter tubing was set at an RMS maximum of 0.015. A calibration attempt is accepted if the chi-square value is <1.00.

2.2.4 Protocol Settings & Test Parameters

For 3-dimensional wideband tympanometry (3D-WBT), a pump speed was selected for automated tympanometric measures; a pump speed of medium (200 daPa/sec) was used. The start and stop pressure range were set at +300 ad -400 daPa. The default age category was set to the Adult option. For each participant, their correct age was entered into the patient information tab to ensure the Titan Suite selected the appropriate test settings and calibration values. A short duration click stimulus is used for the 3D-WBT measure. The 3D tympanogram was displayed as a plot of an absorbance magnitude (0 to 100%) across the test frequency range (250 to 8000 Hz) and as a function of air pressure (-400 to +300 daPa). The absorbance measures extracted from the 3D-WBT recording were displayed as an absorbance magnitude 0 to 100% across a frequency range 250 to 8000 Hz. Both the absorbance parameter at ambient and peak pressure are displayed on the same graph. The target pressure for absorbance measures at peak pressure are based on the MEP estimate from the WB averaged tympanogram generated from the 3D-WBT measure. From the 3D-WBT measurement, a single frequency tympanogram at 226 Hz and 1000 Hz as well as a WB tympanogram averaged across 375 to 2000 Hz were made available.

The stand-alone Wideband Absorbance measure (independent from the 3D-WBT measure), was set to record at ambient pressure. The absorbance measures were plotted as absorbance magnitude (0 to 100%) a function of pressure (-600 daPa to +300 daPa).

For the conventional 226 Hz tympanogram, the start and stop pressure was set at +300 daPa and -400 daPa, sweeping in a positive to negative direction. An automatic normal setting was selected corresponding to a high pump speed, which causes the pump to slow to a low pump speed when reaching the peak of the tympanogram.

For ipsilateral acoustic reflexes to stimuli of 500 Hz, 1000 Hz, 2000 Hz, and a BBN, a reflex growth parameter with an automatic stop option was selected, rather than a fixed intensities parameter option. A reflex stimulus of WBN has a frequency spectrum of 400 to 12000 Hz. A sensitive threshold criterion of 0.03 ml was selected with a start to stop level range from 70 dB to 100 dB in 5 dB level increments.

For this study, test protocol was set up in a manner which allowed the test measures under the IIMP440 module tab to be run in an automatic continuum. For example, once the experimenter was ready to begin collection of the first test measure, the start button was selected and the Titan automatically went through the pre-selected test modules until completion; starting with 3D-WBT, WB Absorbance, Conventional 226 Hz tympanogram, and lastly, the Ipsilateral Acoustic Reflex measures. The examiner was then required to manually select the desired OAE tab.

For DPOAE measurements, eight test frequencies (f_2) were selected (1500, 2000, 2500, 3000, 4000, 5000, 6000, and 8000 Hz) for recording under the DP-Gram test option. Parameters were selected to have DPOAE assessed for a fixed time of 10 seconds at each test frequency (total DPOAE test time of 80 seconds). No other stopping criteria were selected. All test parameter options under the stop criteria, DP criteria, and DP reliability tabs within the protocol customization window were not selected. A fixed time approach to DPOAE measurements of 10 seconds per test frequency was selected for this study to contribute to test procedure consistency between participants. In order to use noise level as an outcome measure, a similar sample for all participants independent of pass or stop criterion was selected. The DP level (dB SPL), noise level (dB SPL), and signal-to-noise ratio for all recordings were measured. The main distortion product for DPOAE measures is expected at the frequency of $2f_2\text{-}f_1$. In order to generate a more robust response for DPOAE measures, a frequency ratio (f_2/f_1) of 1.22 and a 10 dB presentation level separation ($L_1>L_2$) between the primary tone stimuli was implemented. A 65/55 dB difference for the primary tone levels was set. If the stimulus frequencies were separated above this ratio of 1.22 then a drop in OAE amplitude was expected, and if the stimuli frequencies are closer together, then the phenomenon of beating was likely to occur (Abdala, 1996). The 'acceptable noise-level off' option was selected. During the recording of DPOAEs, Titan is constantly monitoring the probe status and by means of the probe microphone it monitors the stimuli tolerance levels.

The TEOAE measurements consisted of five test frequencies, presented as frequency bands; (1) 0.5 to 1.5 kHz, (2) 1.5 to 2.5 kHz, (3) 2.5 to 3.5 kHz, (4) 2.5 to 4.5 kHz, and (5) 4.5 to 5.5 kHz. The five test frequencies were displayed in the data extraction files corresponding to frequency points 0.87, 1.94, 2.96, 3.97, and 4.97 kHz. For ease of representation, the five test frequencies will be presented rounding up to the nearest thousand (representing the center bands) in hertz: TEOAE test frequencies are presented in this manuscript as 1, 2, 3, 4, and 5 kHz. A nonlinear click at a stimulus level of 83 dB peSPL was selected. In order to avoid artifact responses, a nonlinear click was selected over a linear click stimulus. The high-pass (HP) filter was set to the default of 450 Hz. As suggested by the manufacturer operation manual, a higher frequency filter setting would aid in eliminating low-frequency noise interference but may contribute to the attenuation of the low-frequency OAE response (Interacoustics Titan User Manual). Since low-frequency linear bands with center frequencies 1000 Hz and 2000 Hz were selected as test frequencies in this study, the default high-pass filter of 450 Hz was maintained. For TEOAE measures, the frequency bandwidth, signal level (TEOAE dB SPL), noise level (dB SPL), and signal-to-noise ratio are indicated for every recording. The TEOAE recordings were viewed in the 'original' view option. No stop criteria were selected: For both TEOAE recordings at ambient and peak pressure, a fixed test time of 60 seconds was selected. A total fixed for TEOAE measurements was selected to contribute to test procedure consistency between participants and to allow noise level to be used as an outcome measure. To obtain a similar sample for all participants independent of pass or stop criterion was selected, all options for TE criteria and stop criteria were deselected. The recording window was set at 4.0 ms to 22.0 ms, which defines the window that TEOAEs are analyzed within post presentation of the click stimulus. A rate of 45.5/sec was selected for stimulus presentation. Similar to DPOAE measures, the probe status and stimuli tolerance levels are monitored throughout recordings and the system will pause if measures are detected out of the acceptable range.

2.2.5 Titan Target Pressure for Otoacoustic Emission Measurements

The TEOAE440 and DPOAE440 modules allow for measurements to be collected at ambient pressure and a pressure corresponding to the participant’s tympanometric peak pressure (TPP). This target pressure for peak measures is determined by Titan referencing the last attempted impedance measure from the IMP440 module, which in this study was the conventional 226 Hz tympanogram. For Titan to reference this MEP estimate, the IMP440 module tab measures must be saved only after EOAE measurements are complete. By measuring EOAEs at a pressure corresponding to TPP, the presence of MEP is compensated for by Titan using the internal probe pump to generate an equal magnitude of pressure within the outer ear canal (the space between the tympanic membrane and the end of the test probe) with a set tolerance range of error. The tolerance levels for which Titan must maintain target pressure throughout a peak pressure recording differs for DPOEAE and TEOAE modules. The tolerance set for the pressure Titan establishes prior to the start of OAE recordings also differs for DP versus TE measures. Details concerning tolerance levels for DPOAE and TEOAE modules are presented in the discussion of Chapter 7. For both test options, there is one target pressure set. For test measures run at ambient pressure, the Titan uses the pump system to establish a pressure level within the sealed ear canal to within a specified tolerance level of ambient (0 daPa). Information regarding Titan pressure tolerance levels and the pump system was obtained through personal correspondence with Interacoustics (.J Huijnen, personal communication, November 11, 2016). To monitor the pressure within the sealed ear canal space, the Titan Suite uses the pressure sensors located in the test equipment device external to the ear canal (either the pre-amplifier box or the clinical shoulder box with extension cables). Therefore, for both EOAE measures at ambient and peak pressure, the system pump is used. When testing at a static pressure as with EOAEs, the pump speed must be slowed to avoid overshooting the target pressure. The settings for pump speed were designed in such a way to balance the need to maintain a reasonable pressure within a tolerance of target without creating oscillations around the target (overshooting then correcting for the overshoot). This setting of pump speed was balanced with the need to still compensate for pressure leaks during recordings (i.e. having to re-establish target pressure or maintain the pressure during leaks). Deviations from the target pressure are accepted within the tolerance range and the system is not specific enough to maintain test pressure within 1 daPa of the target.

2.3 Procedure

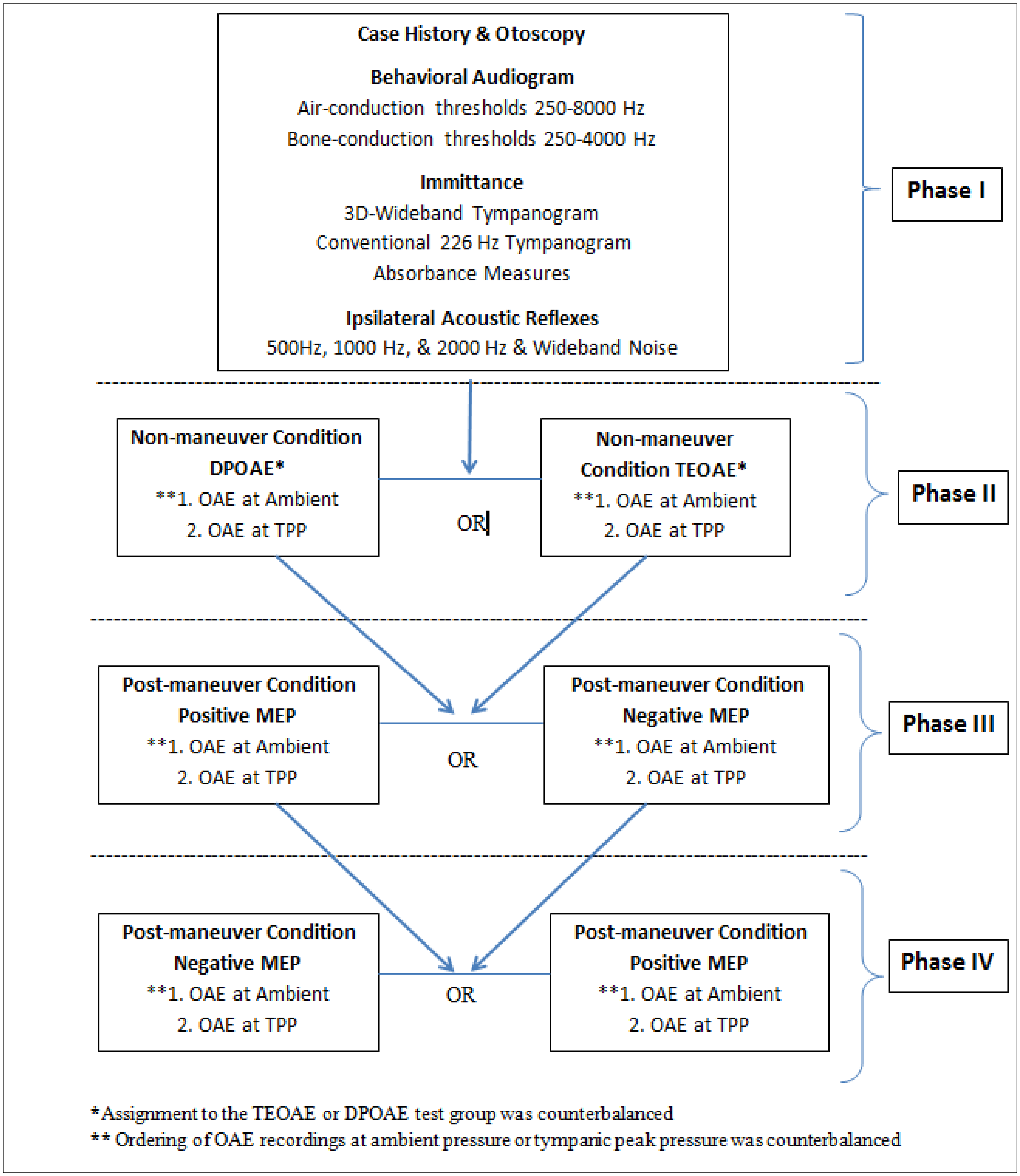
2.3.1 Procedure; Study Overview

Participants attended one test session about one hour in duration. All testing was carried out at the University of British Columbia (UBC) Woodward Instructional Resources Centre, the

location of the Middle Ear Lab of Dr. Navid Shahnaz, or at the School of Audiology and Speech Sciences located on the UBC Vancouver campus. Prior to undergoing the screening process or any further testing, participants were required to both read and sign the study's consent form. To maintain participant confidentiality, each participant was assigned a unique code known only to the researchers, and all information and outcome measures collected were identifiable only by this confidential code. Testing for the purpose of data collection was divided into two main parts. The first was testing at the participant's naturally occurring MEP (non-maneuver condition) and the second involved testing under a condition of either induced negative MEP (NMEP) or positive MEP (PMEP) termed in this manuscript as the post-maneuver test condition. The first part of testing combined test measures and assessments used to determine a participant's candidacy for inclusion in the study and as part of the study's intended data collection of outcome measures. The second portion of testing under induced abnormal MEP was solely for the purpose of study related data collection. Refer to
Figure 2 for an illustration of the four main test phases.

A daily biological listening check of the audiometer and associated equipment was performed prior to pure-tone testing. Daily calibration was conducted for the Titan Suite WB tympanometry module (see Calibration section for details). Prior to each test session, the Titan probe end was examined for debris buildup and abnormalities. The Titan cradle and connected extension cables were placed in proximity to the participant sitting position while minimizing all background noise and activity within the test environment. A daily biological test was performed on the co-investigator of the study for all Titan related test measures (IMP440, DPOAE440, and TEOAE440 test modules).

The study presented in this thesis has two main sets of testing. The first set of outcome measures (for both EOAE and PA measures) were conducted at a pressure corresponding to participants' naturally occurring MEP (roughly ambient pressure, centered on 0 daPa). The second assessment of EOAEs and PA were assessed under a condition of either induced negative or positive MEP. These two test conditions are termed the (1) non-maneuver test condition and (2) post-maneuver test condition. The Toynbee maneuver and Valsalva maneuver were employed to induce the abnormal MEP. For the purposes of this thesis and the content of the current manuscript, the term abnormal MEP will be used to refer to any deviation in MEP assessed in the post-maneuver condition from the baseline MEPs assessments in the non-maneuver condition. Although the term abnormal will be used, this does not necessarily imply that the magnitude of MEP being referenced is considered abnormal from a clinical perspective.



*Assignment to the TEOAE or DPOAE test group was counterbalanced
** Ordering of OAE recordings at ambient pressure or tympanic peak pressure was counterbalanced

Figure 2: Flow chart depicting the broadly described four phases of testing and the associated test components within each phase of the study.

2.3.2 Procedure; Phase I

Case history was completed to determine if participants met the study's preliminary inclusion criteria. Participant-specific information such as age, gender, ethnicity, and relevant medical history pertaining to the auditory vestibular system were recorded at the time of case history. For each prospective participant during the screening process, both ears were examined. If all inclusion criteria were met by only one ear and not the other ear, the participant was still eligible for further testing with unilateral data being collected. A cursory otoscopic examination of the outer ear canal and tympanic membrane was performed. Ear specific hearing thresholds were determined for air-conduction stimuli (250 to 8000 Hz) and bone-conduction stimuli (250 to 4000 Hz) in a sound treated test booth.

The remainder of the testing (immittance and EOAE testing) was conducted outside of the sound booth in the quiet lab room. The same seating location for testing was used for all participants. During testing, distractions and noise in the test environment was minimalized. For the remainder of the test session, participants were asked to sit in a cushioned chair with arm rests, having their feet planted on the floor in order to avoid movement during testing. Participants were encouraged to find a comfortable position sitting upright and looking forward. They were asked to remain as still as possible during the collection of test measurements. Sitting position was controlled for, as posture changes such as the orientation of a participant's head have been suggested to alter EAOE and middle ear related measurements (Buiki et al., 2000 as cited in Avan et al., 2000). At this point in testing, all participants were again reminded that their involvement in this study was completely voluntary, and they could stop testing at any point.

Consistent for all participants, a deep probe insertion within the ear canal for an air tight probe seal was obtained for immittance and EOAE measures. For some participants, the use of Otoferm cream was necessary for seal improvement. For a single test ear, the probe placement was not altered between test measures. If a probe leak was detected during testing or the probe managed to come loose from the participants' ear canal, a more appropriate probe size was selected and testing for that ear was restarted. Participants were explained that there would be pauses throughout the collection of test measures and they would be informed when so they could ask questions. They were encouraged to refrain from moving their body position, talking, coughing, sneezing, or swallowing excessively during the collection of test measures.

Immittance measures consisting of 3D-WB tympanometry, Wideband Absorbance, conventional 226 Hz tympanometry, and ipsilateral acoustic reflexes were conducted under the IMP440 module test tab (refer to Methods section for details of test parameters). At this stage of testing, if a participant did not meet inclusion criteria the next test ear was assessed. If the immittance, absorbance and reflex measures for the ear being tested qualified the participant for further testing (referencing the pre-set inclusion and exclusion criteria), then the next phase of testing commenced.

2.3.3 Procedure; Phase II

Phase II of testing consisted primarily of EOAE measures at both ambient and tympanic peak pressure, with the participants' MEP at a natural (baseline) pressure state. Phase II can be considered the non-maneuver test condition. With the intention of avoiding order effects, it was counterbalanced which EOAE condition (TEOAEs or DPOAEs) each participant would experience as well as in what order the peak pressure or ambient pressure test condition was implemented. Within either the DPOAE440 or TEOAE440 module tab, the option of running at ambient versus peak pressure was manually selected for and the OAE measures only began once the start button was selected. At the start of the EOAE recordings, the probe status was monitored by the examiner. If the probe signal indicated a poor probe seal, the recording was stopped and probe fit was reassessed requiring the retesting of immittance measures from phase I. During the recording of EOAEs, the Titan provides multiple indicators for probe status such as the color indicator light at the end of the probe piece at the external portion of the participant's ear canal. There is also a colored probe fit indicator bar available on the test screen, and a warning pop-up window that will appear on the test screen if the system has been paused due to an unresolvable leak or if stimulus or noise levels are detected outside tolerance.

Although Titan monitors the probe status automatically to maintain quality control throughout measurements, the probe status can also be manually checked via the probe check graph of sound pressure level (dB SPL) versus frequency. By recommendation of the manufacturer, viewing the low-frequency portion of the probe check graph provides the best indicator of probe status: A flat frequency response between 200 to 8000 Hz is an ideal response to a broadband click stimulus (Interacoustics Titan User Manual). This manual probe check graph was available on the test screen for TEOAE measures but required toggling between window options for DPOAE measures.

Once the start button was selected, for DPOAE recordings the total fixed test time was 80 seconds and for TEOAEs it was 60 seconds. These fixed times were extended if the test system detected a probe leak, noise levels exceeded tolerance, or the pump system had to re-establish appropriate test pressure. If the test probe came unsealed from the participant’s ear canal or a leak status was detected that could only be resolved with examiner interference, then testing was stopped and the immittance measures (3D-WBT, WB Absorbance, and the conventional 226 Hz tympanogram) in phase I were again, re-assessed. If testing of the first EOAE measurement (either at ambient or peak pressure) was completed without incident, the examiner then immediately selected the opposing pressure option and began recording of the second measurement. Recordings were manually stopped if at any point during either EOAE recording (ambient or peak), the participant spoke, coughed, sneezed, or yawned. Immittance measures from phase I were again, re-assessed to ensure the participant had not altered their MEP and testing continued again from this stage. Once both test pressure conditions were completed (OAEs at ambient and peak) successfully, all participant data was saved. This marked the end of the non-maneuver test condition and participants were able to ask questions and alter their MEP (by example, drinking water, blowing their nose, or coughing). However, participants were still encouraged to remain relatively motionless during the transition from phase II to III as to not disturb the probe placement within their ear canal.

2.3.4 Procedure; Phase III

Phase III of testing represents the post-maneuver test condition in which participants were asked to induce and maintain abnormal MEP throughout the test measures. Any degree of pressure induced by either the Valsalva or Toynbee maneuver was accepted. With the Toynbee maneuver, it was expected that most participants would generate negative MEP. Participants were asked to close their mouth while pinching his or her nose and swallow one to three times (Thompson et al., 2015). Water bottles were available for participants if they wished to try the Toynbee maneuver by swallowing sips of water with their nose pinched (Kenny, 2011). Inducing positive MEP was attempted by the Valsalva maneuver: The participant was asked to close their mouth and pinch tightly his or her nose while exhaling as if blowing up a balloon. It was explained to participants that both these maneuvers are routinely being used clinically to assess the Eustachian tube function. Picture illustrations with written instruction for each maneuver were available for participants to reference before attempting the maneuver. Participants were asked to try to maintain the induced MEP for roughly 100 seconds for the DPOAE test condition and for about 80 seconds in the TEOAE condition (time estimates include the time required to complete all test within the post-maneuver condition). Maintaining the induced MEP would be accomplished by having participants refrain from talking, swallowing, sneezing, yawning, or making any unnecessary movements of their mouth or head. In past studies investigating the effect of MEP on EOAEs, mean tympanic peak pressures ranging from -65 to -324 daPa were achieved using the Toynbee maneuver in normal hearing adults (Thompson et al., 2015). Similarly, in work by Sun and Shaver (2009), negative pressure was induced ranging from -40 to -420 daPa using the Toynbee maneuver in participants with no middle ear pathology. Participants were asked if they had any questions or concerns prior to attempting the maneuver or if they would like a demonstration of the maneuver by the examiner. Practice trials were allowed if requested by participants. It was by observation of the examiner that greater success for participants to maintain the induced MEP throughout the post-maneuver condition was obtained if a clear explanation of the test condition was provided. For example, participants were given a brief explanation of why the MEP was being created with both maneuvers, with the explanation facilitated by use of a visual diagram of the Eustachian tube and middle ear anatomy.

It was also explained the importance of maintaining the pressure for as long as possible throughout the recording time. A timer was available for participants if they wished to monitor the time throughout the post-maneuver condition. Once the basis of inducing abnormal MEP was explained, a subset of participants indicated they could generate abnormal MEP by other maneuvers such as yawning. If this subset of participants were successful in inducing abnormal MEP by their unique chosen maneuver, these pressure changes were accepted. After the participant had completed a pressure inducing maneuver the 3D-WBT, WB Absorbance, and conventional 226 Hz tympanogram were recorded.

Whether the ear being tested fell into the Toynbee or Valsalva maneuver test condition was determined by counterbalancing. The same EOAE condition (DP or TE) the participant experienced in phase II was consistent with phase III. Again, the order of test pressure condition (peak versus ambient) was pre-determined by counterbalancing. The same OAE test parameters from phase II applied to phase III as well as the same approach to monitoring for probe seal issues and saving of data between test measures. Testing in phase II and III differed with respect to post-EOAE recording assessments. After EOAEs were assessed at ambient and peak test pressure in the post-maneuver test condition, a conventional 226 Hz tympanogram was conducted.

Once all test measures were complete, participants were informed they could relieve the induced MEP by swallowing, yawning, coughing, talking aloud, or taking a drink of water. Participants were reassured that their MEP had returned to baseline, confirmed by a post-release conventional

226 Hz tympanogram. For some participants, multiple attempts were required to release the abnormal MEP.

2.3.5 Procedure; Phase IV

If timing allowed during the assessment, participants were tested as per phase IV protocol. Phase IV was done following the end of phase III prior to changing test ears. Participants attempted the pressure inducing maneuver (either Toynbee or Valsalva) that they had not attempted in phase III. The same EOAE condition (DP or TE) that the participant experienced in phase II and III was kept consistent for phase IV. The order of test pressure condition (peak versus ambient) was in the opposite test order from that determined by counterbalancing in phase III. The same test approach from impedance measures to post-release tympanograms as explained in the procedure section for phase III also applied to the phase IV test condition.

Once testing was completed for the first ear, the same steps were followed for the participant's second test ear. The pre-amplifier clip and extension cable were switched to the shoulder closest to the new test ear. The same EOAE test category (DP or TEP) was assigned to the second test ear. The same test pressure condition sequence was also followed. The difference between test ears was the maneuver category into which the second test ear was assigned; for phase III of testing of the second ear, the maneuver category (Toynbee or Valsalva) was opposite from that used in phase III of testing for the first ear.

2.4 Counterbalancing Test Conditions

As stated in the procedure description for test phases II to IV, the order in which ambient versus peak EOAE measurements was recorded for both the non-maneuver condition and post-maneuver condition was counterbalanced. A given participant was tested using one of four possible predetermined test sequences. All possible test sequences are depicted in Table 2.

		Sequence A	**Sequence B**	**Sequence C**	**Sequence D**
Test Condition	**Non-maneuver**	1. Ambient 2. Peak	1. Ambient 2. Peak	1. Peak 2. Ambient	1. Peak 2. Ambient
	Post-maneuver	1. Ambient 2. Peak	1.Peak 2. Ambient	1. Ambient 2. Peak	1. Peak 2. Ambient

Table 2: Test sequence options for counterbalanced EOAE measurements assessed at peak and ambient test pressure conditions within each maneuver condition (non-maneuver and post-maneuver).

The purpose of counterbalancing was to avoid test ordering as a confounding variable. Participants were first tested in the non-maneuver condition with MEP being recorded as the participants' natural MEP, which was presumed to remain stable pre- versus post-recording of EOAE measures. The abnormal MEP generated by participants (mainly through either the Valsalva or Toynbee maneuver) in the post-maneuver condition was determined by a conventional 226 Hz tympanogram immediately followed by testing EOAEs at ambient and peak pressures. Countering balancing the test pressure conditions was particularly important in the post-maneuver condition: The induced abnormal MEP was not expected to be perfectly stable throughout EOAE measurements. If a participant's MEP varied either during the collection of

EOAEs or between measurements at ambient and peak pressure, this would alter the target pressure needed for ideal compensation of TPP. The test system would be either over or under compensating for a given participants' MEP. In order to assess a participants' ability to maintain the induced MEP, the post-EOAE recording tympanogram was collected. A 226 Hz tympanometric measure was selected to be consistent with the type of MEP assessment used pre-recoding for determining target pressure during compensated EOAE measures. Although it would be valuable information to have an indication of MEP between EOAE measures at ambient and peak pressure, a tympanometric measure was not conducted between these two test conditions. It was determined at the study design stage that introducing a pause for such a measure would introduce a time delay during which the induced abnormal MEP could diminish or completely return to baseline. The time required to collect the immittance measures, as well as EOAE measures at both ambient and peak pressure during which participants were asked to maintain the induced MEP was challenging enough for the average participant.

In addition to counterbalancing the test order of test pressure condition (ambient versus peak), the first tested ear (right or left) and EOAE condition (DP or TE) were also counterbalanced. It was also counterbalanced between participants, into which maneuver category (Toynbee or Valsalva) each test ear was assigned. It was the researchers' aim to have an equivalent sample size for the DPOAE and TEOAE analysis with equal post-maneuver condition contributing measures under positive and negative MEP conditions.

2.5 Data analysis

2.5.1 Otoacoustic Emissions Outcome Measures

All statistical analyses for this study were performed using a program titled Statistica, version 13.0.0.4 by Dell Inc. (Dell Inc. 2015, Dell Statistica software.dell.com). A mixed model analysis of variance (ANVOA) approach was used to analyze the effects of gender, ethnicity, test ear, frequency, test maneuver condition (non-maneuver versus post-maneuver), and test pressure condition (ambient versus peak) on DPOAE and TEOAE outcome measures. In this model, both absolute amplitude and noise level were independently investigated outcome measures. Data for each measurement separated into four test conditions in a repeated measures design to determine under which test condition the greatest absolute amplitude and lowest noise level resulted. Outcome measures were analyzed as two-test condition comparisons and as a summary comparison between the four main test conditions (non-maneuver ambient, non-maneuver peak, post-maneuver peak, and post-maneuver ambient). There were six possible combinations for paired-condition comparisons (refer to Table 3) and if all the possible combinations were analyzed, this would provide 24 basic comparisons for a single outcome measure for DPOAE and TEOAE data separated based on positive and negative post-maneuver MEP. This sum of 24 comparisons does not even account for additional analyses involving between and within participant factor interactions. Due to the immense number of possible analyses, it was determined the most appropriate and efficient display of data would be achieved by combining the OAE data associated with both the negative and positive induced MEP pressure conditions. All DPOAE and TEOAE related outcome measures were analyzed in five parts: (1) non-maneuver ambient versus post-maneuver ambient, (2) non-maneuver ambient versus post-maneuver peak, (3) non-maneuver ambient versus non-maneuver peak, (4) post-maneuver ambient versus post-maneuver peak, and (5) four test condition comparison.

OAE Test Condition Comparison Possibilities (DPOAE or TEOAE)				
	Non-maneuver Condition		**Post-maneuver Condition (Positive or Negative MEP)**	
Test Pressure Condition	Ambient $_1$	Peak $_1$	Ambient $_2$	Peak $_2$
Possible Pair-wise Test Condition Comparisons	DPOAE (+): A_1:P_1, A_1:A_2, A_1:P_2, A_2:P_1, A_2:P_2, P_1:P_2 DPOAE (-): A_1:P_1, A_1:A_2, A_1:P_2, A_2:P_1, A_2:P_2, P_1:P_2 TEOAE (+): A_1:P_1, A_1:A_2, A_1:P_2, A_2:P_1, A_2:P_2, P_1:P_2 TEOAE (-): A_1:P_1, A_1:A_2, A_1:P_2, A_2:P_1, A_2:P_2, P_1:P_2			

Table 3: Illustration of the possible two-test condition comparisons

Between-subject factors of gender (x2), ethnicity (x3), and test ear (x2) were included in the statistical design to determine if significant absolute amplitude or noise level differences existed between the various ethnic and gender groups or between right and left test ears. Test frequency (x5 TEOAE, x8 DPOAE), and test condition (non-maneuver versus post-maneuver, ambient versus peak, x2) were treated as within-subject factors. The factor of test ear was treated as a within-subject factor because it was assumed to be different between the ears even though it was for the same participant subject, therefore begin treated as an individual measure. Our analysis did not show a significant difference with test ear as a factor so it was not further investigated and was removed as an explicit factor from all analyses.

For discussion purposes, absolute amplitude and noise level were also analyzed using a mixed ANOVA approach including the above mentioned within- and between-subject factors of gender, ethnicity, frequency, test maneuver condition, and test pressure condition but a new between-subject factor was introduced into the analysis, absolute MEP magnitude (x5 categories). These analyses including the new factor were focused on only four test condition comparisons.

For the various ANOVA analyses, the statistical significance indicator, p-value, and F-test value and associated degree of freedom are provided. For this study, a value of $p < .05$ was set as the criteria for significance. The degree of freedom (df) value is an indicator of the sample size or the number of independent data points contributing to the larger sample. This df value influences the F distribution. The F-test value represents the ratio of two variances (the variation between samples relative to the variation observed within a sample group) (Winter, September 21 2011). A large F ratio indicates the group means at least for one pair-wise mean comparison is not equal. Since variance measures are an indication of the degree of dispersion of data from the mean, a larger degree of dispersion is represented by a larger variance value (Winter, September 21 2011). For cases of low variability between group means, suggesting overlap or close groups means, a low F-value results. A high F-value results when there is greater separation between group means and the variability between group means is large (always referencing the within group degree of dispersion [i.e. variability]). A high F-value is usually associated with the rejection of the null hypothesis (no significant difference between groups being compared) implying group means are not equal (Winter, September 21 2011). In this manuscript, statistics values will be presented in the format [F(X, Y)=Z, p=.W]. The ‘X’ and ‘Y’ values represent the df. The resulting F-test value is symbolized as ‘Z’. The p-value ‘W’ provides an indication or probability value of how likely it was to have an outcome with the F value of ‘Z’ (lower p values indicate a less likely outcome). In short, a lower p-value and greater F-value are often favorable when a difference between group means is anticipated.

In order to avoid inflated Type I errors (increased chance of rejecting the null hypothesis incorrectly, ‘false positives’), a Greenhouse-Geisser (G-G) correction was performed for all OAE outcome measures (Abdi, 2010). All interactions showing significance with the mixed model ANOVA multivariate approach remained significant after the G-G correction. If an interaction was found not significant with the standard degrees of freedom approach (general linear model for a mixed ANOVA), then it would remain non-significant following a G-G correction (Abdi, 2010). The G-G correction factor is considered a highly conservative approach to adjusting the univariate test degrees of freedom.

The ANOVA may provide a finding that the interaction between two test factors was significant, but this only indicates that a minimum of one pair-wise comparison within the larger analysis was found to be significant. In order to determine the pattern of significance between all the group means, a post-hoc analysis was needed. In conjunction with the mixed ANOVA approach, post-hoc analyses were conducted using the Tukey-Kramer formula. This post-hoc test selection is particularly appropriate for the analyses involving comparison groups within this study that have unequal sample sizes, for example gender comparisons, as the Tukey method is very conservative when dealing with unequal sample sizes (Smith, 1971). Tukey’s honest significant difference (HSD) test essentially is a way to compare the mean value for one test group to another test group to determine if a significant difference greater than the suggested standard error exists: It applies all pairwise comparisons for all groups incorporated into the analysis from a conservative statistical approach (Abdi, 2010). When multiple comparisons are being performed between many test factors, a Tukey's HSD test approach is a means to reduce the number of Type I errors (Linton & Harder, 2007).

2.5.2 Supporting Analyses for Otoacoustic Emission Outcome Measures

A paired t-test for dependent samples was used to perform various comparisons between repeated measures: (1) The comparison between MEP estimates from the conventional 226 Hz tympanogram pre- versus post-EOAE recording in the post-maneuver condition, (2) the comparison between MEP estimates from the 3D-WBT to the conventional 226 Hz tympanogram for both non-maneuver and post-maneuver conditions, and for (3) the comparison between the target pressure for EOAE measures at peak pressure and the estimated pressure level maintained by Titan throughout these recordings. All comparisons were presented in this manuscript as Box and Whisker plots. Refer to Chapter 7 for a discussion of these three comparisons.

2.5.3 Between-subject Factor of Middle Ear Pressure Magnitude

For discussion purposes, the EOAE data was further analyzed with a between-subject factor of absolute MEP magnitude (five categories A to E). In order to compare non-maneuver to post-maneuver measurements across a factor of MEP, the difference in MEP between the two conditions was determined and termed as an absolute shift in MEP. All measures were categorized based on the change in MEP magnitude between the non-maneuver condition and the MEP induced in the post-maneuver condition. The tympanic peak pressure for both conditions was determined by the estimated MEP from the conventional 226 Hz tympanograms collected prior to EOAE measurements. This MEP difference was categorized A to E with each category signifying a range in absolute MEP differences (summarized in Table 4). The same coding system of absolute MEP ranges (A to E) in Table 4 was also applied to the individual MEP estimate for within test condition comparisons (for example, post-maneuver ambient versus peak). Again, the MEP referenced for coding was the estimate from the conventional 226 Hz tympanograms collected prior to EOAE measurements. Rather than a pressure range representing a shift in pressure, the categories A to E represent the absolute pressure present (or induced) within a single test condition.

	Category of Absolute MEP Magnitude				
	A	**B**	**C**	**D**	**E**
Category Description	0 to 10 daPa	11 to 25 daPa	26 to 50 daPa	51 to 99 daPa	≥100 daPa

Table 4: Description of absolute middle ear pressure (MEP) magnitude categories A to E. Codes (A to E) are applicable to both EOAE and power absorbance measures for between test condition (non-maneuver versus post-maneuver) comparisons representing MEP shift magnitudes or as absolute MEP magnitudes for within test maneuver condition (non-maneuver or post-maneuver) comparisons.

2.5.4 Power Absorbance

The source of absorbance data was the 3D-WBT. From a single measure extracted from the 3D-WBT, data corresponds to both an absorbance measure tested at a setting of ambient pressure and TPP. These absorbance measures are available for extraction from the saved Titan participant files. The MEP estimates used for the PA measures referenced the estimated value from the 3D-WBT, which is derived from the wideband averaged tympanogram plotted across a range of 226 Hz to 8000 Hz.

Only participants meeting all inclusion and exclusion criteria for the one ear in question had their data included in the final absorbance measure database. In this study, for a single participant when considering only one test ear, there are minimally four different absorbance measures available for examination. On average only two measures were conducted for each ear; one 3D-WBT during the non-maneuver condition (ambient and peak) and the second in the post-maneuver condition (ambient and peak). For some participants (n=35), there is associated absorbance measures for both the negative and positive induced MEP conditions (providing absorbance measures for all six test groups). A total of n=70 absorbance measures (n=35 NMEP, 35 PMEP) out of the total 210 measures were from the participants contributing to both the negative and positive absorbance measures. The six possible test conditions for a single test ear are presented in Table 5: (1) Non-maneuver test condition at ambient, (2) non-maneuver test condition at peak, (3) post-maneuver PMEP test condition at ambient, (4) post-maneuver PMEP test condition at peak, (5) post-maneuver NMEP test condition at ambient and (6) post-maneuver NMEP test condition at peak.

3D-WBT Power Absorbance Measures		
Test Ear (Left or Right)	**Test Condition**	**Power Absorbance Test Pressure**
	Non-maneuver	Ambient
		Peak
	Post-maneuver Positive MEP	Ambient
		Peak
	Post-maneuver Negative MEP	Ambient
		Peak

Table 5: Possible test conditions for power absorbance measures for a single test ear.

A mixed model ANOVA approach was used to investing the significance of factor main effects and interactions between factors. All graphs displaying absolute absorbance magnitude are scaled from (0.0 to 1.0). The ANVOAs considered factors of gender (x2), ethnicity (x3), center frequency (x16), test condition (non-maneuver versus post-maneuver and ambient versus peak, x2), and absolute MEP magnitude (x5 categories). In addition to the mixed ANOVA analyses, a G-G correction was performed. Post-hoc analyses via Tukey's HSD tests were also utilized to confirm significance (or lack of) between test factors and comparison groups. A significance criterion of $p < .05$ was set for all analyses. For this analysis, similar to OAE analyses, there were four main test comparisons; (1) non-maneuver ambient, (2) non-maneuver peak, (3) post-maneuver ambient, and the (4) post-maneuver peak test condition.

From the raw data files, PA values are represented across a frequency range from 226 to 8000 Hz and are available in step sizes corresponding to 107 frequency points. In order to avoid inflated Type I errors (avoid interactions being significant by chance) the number of the frequency points used in the final analysis was reduced to 16 center frequencies using 1/3 octaves averaging. The referenced center frequencies and corresponding frequency bands are as follows (in hertz, Hz): 250 (222.7-280.6), 315 (280.6-353.6) 400 (356.6-445.4), 500 (445.4-561.2), 630 (561.2-707.1), 800 (707.1-890.9), 1000 (890.9-1122.5), 1250 (1122.5-1414.2), 1600 (1414.2-1781.8), 2000 (1781.8-2244.9), 2500 (2244.9-2828.4), 3150 (2828.4-3563.6), 4000 (3563.6-4489.8), 5000 (4489.8-5656.9), 6300 (5656.9-7127.2), 8000 (7127.2-8979.7).

The raw absorbance measures were not separated based on whether or not the associated EOAEs were from DPOAE or TEOAE test conditions. In order to condense the negative and positive MEP associated absorbance data into a graphical format that was more accessible to the reader, the MEP was coded based on an absolute MEP value. This provided five categories A to E: A (0 to 10 daPa), B (11 to 25 daPa), C (26 to 50 daPa), D (51 to 99 daPa), and E (≥100 daPa). The categories A to E were used in two forms. The first was based on absolute MEP referencing the 3D-WBT MEP estimate for the post-maneuver or non-maneuver conditions. This absolute MEP was used for comparisons of absorbance measures within test conditions (ie. non-maneuver ambient versus peak). The second way coding system was used was for between test condition comparisons (i.e. non-maneuver ambient versus post-maneuver peak): An absolute MEP shift magnitude was determined by taking the difference between the post-maneuver MEP estimate from the non-maneuver MEP estimate. Both these MEP coding systems were used for the OAE analyses.

2.5.5 Middle Ear Pressure Estimates for the Associated OAE Measures

For the DP- and TE-OAE non-maneuver and post-maneuver test conditions, the associated MEP values were evaluated. A range of estimates and an absolute mean for each condition was determined. All MEP estimates that had associated EOAE measures included in the final analysis of EOAE outcome measures were converted into absolute MEP values. The variation in estimates of the absolute mean was determined as a 2 standard deviation (SD) calculation. The lower and upper bounds of the 2SD value were used to quantify the amount of variation in natural MEP for the non-maneuver condition, which served as a baseline measure. The number of estimates falling outside this 2SD range was tallied. The objective of the post-maneuver condition was for participants to generate the largest degree of abnormal MEP as possible and thus, the largest possible absolute shift in MEP between the condition non-maneuver and post-maneuver conditions. Therefore, a higher MEP estimate and a greater number of samples exceeding the upper SD boundary were advantageous. The DPOAE associated evaluations of MEP estimates are found in Table 6, and the TEOAE measures in Table 7. All MEP estimates in Table 6 and Table 7 referenced the conventional 226 Hz tympanogram, with the rationale being that this was the MEP estimation method from which Titan based the target pressure for EOAEs measured at peak pressure.

	DPOAE Associated Measures of MEP Estimates		
	Non-maneuver Condition (n=110)	**Post-maneuver Condition** (n=110)	**MEP Shift; Non & Post-maneuver Difference in MEP** (n=110)
MEP Range (not absolute)	-33 to +53 daPa	-145 to +280 daPa	---
Absolute MEP Range	0 to 53 daPa	6 to 280 daPa	0 to 291 daPa
Mean Absolute MEP	10.57 daPa	64.43 daPa	63.45 daPa
1 SD from |mean|	8.58 daPa	49.24 daPa	52.51 daPa
2 SD from |mean|	17.17 daPa	98.49 daPa	105.03 daPa
Upper Bound of 2 SD	27.74 daPa	162.92 daPa	168.48 daPa
Lower Bound of 2 SD	-6.59 daPa	-34.06 daPa	-41.57 daPa
Number of samples outside 2SD range, upper boundary	5	5	6

Table 6: Evaluations of DPOAE associated middle ear pressure (MEP) estimates. Non-maneuver and post-maneuver MEP estimates were from the conventional 226 Hz tympanograms conducted pre-EOAE recording. Standard deviations (SD) were based on the calculated absolute mean (|mean|) MEP values.

	TEOAE Associated Measures of MEP Estimates		
	Non-maneuver Condition (n=97)	**Post-maneuver Condition** (n=97)	**MEP Shift; Non & Post-maneuver Difference in MEP** (n=97)
Non Absolute MEP Range	-56 to +106 daPa	-174 to +199 daPa	---
Absolute MEP Range	0 to 106 daPa	5 to 199 daPa	1 to 227 daPa
Mean Absolute MEP	10.55 daPa	64.79 daPa	60.64 daPa
1 SD from |mean|	13.57 daPa	45.68 daPa	49.81 daPa
2 SD from |mean|	27.14 daPa	91.36 daPa	99.63 daPa
Upper Bound of 2 SD	37.69 daPa	156.16 daPa	160.27 daPa
Lower Bound of 2 SD	-16.60 daPa	-26.57 daPa	-38.99 daPa
Number of samples outside 2SD range, upper boundary	2	5	5

Table 7: Evaluations of TEOAE associated middle ear pressure (MEP) estimates. Non-maneuver and post-maneuver MEP estimates were from the conventional 226 Hz tympanograms conducted pre-EOAE recordings. Standard deviations (SD) were based on the calculated absolute mean (|mean|) MEP values.

2.5.6 Middle Ear Pressure Estimates for the Associated Absorbance Measures

For the power absorbance (PA) measures in the non-maneuver and post-maneuver test conditions, the associated MEP estimates were evaluated in a similar manner as was done for the

OAE related MEP estimates. A range of estimates and an absolute mean for each condition was determined. All MEP estimates that had associated PA measures included in the final analysis of absorbance magnitude were converted into absolute values. The variation in estimates of the absolute mean was determined as a 2 standard deviation (SD) calculation. The lower and upper bounds of the 2SD value were important for quantifying the amount of variation in natural MEP for the non-maneuver condition, which served as a baseline measure. For the post-maneuver condition and the MEP shift calculations (used for between test maneuver condition comparisons), the samples falling outside the 2SD range did so due to the upper boundary. The number of estimates falling outside this 2SD range was tallied. For the post-maneuver test condition, a higher value MEP estimate and a greater number of samples exceeding the upper SD boundary was advantageous. All MEP estimates in Table 8 referenced the 3D-wideband tympanogram, with the rationale being that this was the MEP estimation method from which Titan based the target pressure for PA measured at peak pressure.

	Power Absorbance Associated Measures of MEP Estimates		
	Non-maneuver Condition (n=210)	**Post-maneuver Condition** (n=210)	**MEP Shift; Non & Post-maneuver Difference in MEP** (n=210)
MEP Range (not absolute)	-57 to +102 daPa	-199 to +276 daPa	---
Absolute MEP Range	0 to 102 daPa	0 to 276 daPa	0 to 266 daPa
Mean Absolute MEP	10.95 daPa	65.29 daPa	55.16 daPa
1 SD from |mean|	11.09 daPa	49.49 daPa	50.06 daPa
2 SD from |mean|	22.18 daPa	98.99 daPa	100.13 daPa
Upper Bound of 2 SD	33.13 daPa	154.15 daPa	165.41 daPa
Number of samples outside 2SD range upper boundary	5	11	13

Table 8: Evaluations of power absorbance associated middle ear pressure (MEP) estimates. Non-maneuver and post-maneuver MEP estimates were from the 3D-Wideband tympanogram. Standard deviations (SD) were based on the calculated absolute mean MEP (|mean|) values.

Chapter 3: Results; Distortion-product Otoacoustic Emissions

Chapter 3 is divided into five main sections: (3.1) non-maneuver ambient and post-maneuver ambient test conditions; (3.2) non-maneuver ambient and post-maneuver peak test conditions; (3.3) non-maneuver ambient versus peak test conditions; (3.4) post-maneuver ambient versus peak test conditions; (3.5) four test condition comparison. For sections 3.1 through 3.5, findings for mixed model ANOVAs considering factors of gender (x2), frequency (x8), ethnicity (x3), and test condition (x2) are presented as two subsections for outcome measures of absolute amplitude and noise level. For ease of interpreting the data, the results and discussion sections have been combined in a way by providing a third subsection titled: Further Investigations; Middle Ear Pressure Magnitude. This third subsection provides analyses exploring the factor of absolute MEP magnitude in relation to DPOAE outcome measures of absolute amplitude and noise level explored in the first two subsections. Refer to Chapter 6 Discussion section for a combined comprehensive discussion of DPOAE and TEOAE findings.

3.1 Non-maneuver Ambient and Post-maneuver Ambient Test Conditions

The main effect for the following analyses was the comparison between the non-maneuver ambient and post-maneuver ambient test conditions for the outcome measures of DPOAE absolute amplitude and noise level. This comparison between test conditions is illustrated in Table 9. For the overall findings of significance for absolute amplitude and noise level measures, refer to the respective tables in Appendix B Statistical Analysis section Table 176 and Table 177. A sample size of n=110 individual DPOAE recordings from n=48 different participants contributed to each test condition. Referencing the conventional 226 Hz tympanogram, the mean absolute MEP estimate for the non-maneuver condition was 10.57 daPa (range: 0 to 53 daPa), and for the post-maneuver condition measures it was an absolute mean of 64.43 daPa (range: 6 to 280 daPa). The mean absolute MEP shift between test conditions was determined to be 63.45 daPa (range: 0 to 291 daPa).

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	Peak	**Ambient**	Peak

Table 9: Shaded boxes represent the test conditions under comparison.

3.1.1 Absolute Amplitude

The main effect of test condition [F(1, 106)= 26.3879, p=.00000] was significant: The mean absolute amplitude of the non-maneuver ambient compared to the post-maneuver ambient test condition was significantly different with the analysis collapsed across factors of gender, frequency, and ethnicity. Refer to the DPOAE four test condition comparison section 3.5 Figure 13, for a graphical display of the main effect of the factor of test condition. A mean absolute amplitude difference of 1.36 dB SPL was observed between the test conditions, with the non-maneuver ambient condition having the greater DPOAE amplitude (refer to Table 10 for descriptive statistics).

Test Condition	Mean DPOAE Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	8.01	1.04	5.95	10.1	110
Post-maneuver, Ambient	6.64	1.25	4.15	9.1	110

Table 10: Comparison of mean DPOAE absolute amplitude between non-maneuver ambient and post-maneuver ambient test conditions. The analysis was collapsed across factors of ethnicity, gender, and frequency. Current effect: [F(1, 106)=26.388, p=.00000].

The main effect of gender [F(1, 106)=0.3442, p=.5587] was not significant nor was the interaction between gender and test condition [F(1, 106)=0.4924, p=.484383]. The interaction between frequency and gender [F(7, 742)=1.3719, p=.214037] was also not significant. This indicates the variation in absolute DPOAE amplitude between test conditions as well as across the range of test frequencies (1500 to 8000 Hz) does not differ between male and female participants. The main effect of ethnicity [F(2, 106)=0.3822, p=.6833] was not significant. The interaction between ethnicity and test condition [F(2, 106)=0.3093, p=.734619] was also not significant, indicating the variation in absolute amplitude shown between test conditions did not differ for Caucasian, Asian, or Other participants.

The interaction between frequency and ethnicity was significant [F(14, 742)=4.9433, p=.00000] and the main effect of frequency [F(7, 742)=115.8156, p=.0000] was significant. A finding of significance for the interaction of ethnicity and frequency demonstrates that the variation in absolute amplitude observed across frequencies differed for the Caucasian (n=43), Asian (n=46), and Other (n=21) participants. As displayed in Figure 3, a similar trend in DPOAE amplitude is observed for the three ethnic groups across the range of test frequencies (1500 to 8000 Hz). From the peak amplitude occurring between 5000 to 6000 Hz, there is a decrease in amplitude to a minimum mean amplitude observed at mid frequencies 2500 to 3000 Hz and at the highest test frequency of 8000 Hz. The analysis was collapsed across factors of test condition (non-maneuver ambient and post-maneuver ambient) and gender. Refer to Appendix A, Table 117 for values of mean amplitude, standard error, and 95% confidence intervals. A post-hoc analysis indicated a significant difference in DPOAE amplitude between Caucasians and Asians only at 8 kHz and between Caucasians and Others at 8 kHz. No significant difference was observed between Asians and Others at any of the eight test frequencies.

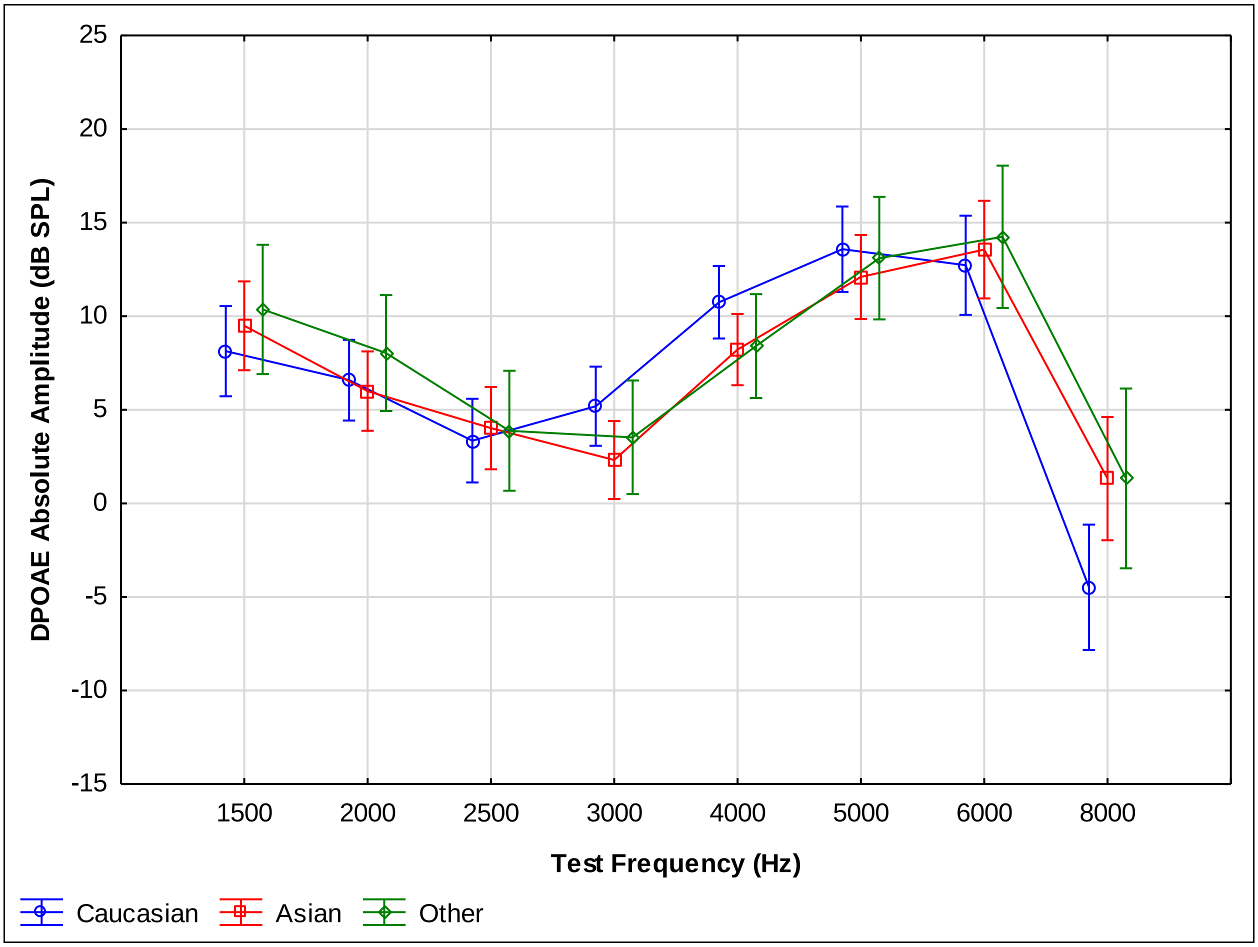


Figure 3: Comparison of mean DPOAE absolute amplitude across ethnic groups as a function of frequency. The analysis was collapsed across factors of test condition (non-maneuver ambient and post-maneuver ambient) and gender. Vertical bars denote the 95th percent confidence intervals. Current effect: [F(14, 742)= 4.9433, p=.00000].

A finding of significance [F(7, 742)=2.3882, p=.02026] was seen for the interaction of test condition and frequency. This interaction shows the absolute amplitude difference between test conditions does differ depending on the test frequency. Figure 4 shows the maximum mean absolute amplitude difference between test conditions is at the mid frequency range between ≥2500 Hz and <6000 Hz. This analysis was collapsed across factors of ethnicity and gender. Mean amplitude, standard error, and CIs can be found in Table 11. The mean DPOAE absolute amplitude values are greater for the non-maneuver ambient condition than the post-maneuver ambient condition when comparing at all eight test frequencies. Reference Appendix A Table 118 for the post-hoc descriptive statistics. A Tukey’s HSD test indicated that the difference in absolute DPOAE amplitude observed between test conditions was, in fact, significant at all eight test frequency (1500 to 8000 Hz), with the exception of 2000 Hz.

Test Condition	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1500	10.2	0.59	9.1	11.4	110
Post-maneuver, Ambient	1500	8.4	0.59	7.3	9.6	110
Non-maneuver, Ambient	2000	7.2	0.56	6.1	8.3	110
Post-maneuver, Ambient	2000	6.5	0.51	5.5	7.5	110
Non-maneuver, Ambient	2500	4.4	0.53	3.3	5.4	110
Post-maneuver, Ambient	2500	3.1	0.59	2.0	4.3	110

Test Condition	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	3000	4.5	0.47	3.6	5.5	110
Post-maneuver, Ambient	3000	2.8	0.59	1.6	4.0	110
Non-maneuver, Ambient	4000	9.8	0.46	8.9	10.7	110
Post-maneuver, Ambient	4000	8.4	0.54	7.3	9.5	110
Non-maneuver, Ambient	5000	14.0	0.50	13.0	15.0	110
Post-maneuver, Ambient	5000	11.8	0.67	10.5	13.2	110
Non-maneuver, Ambient	6000	14.0	0.62	12.7	15.2	110
Post-maneuver, Ambient	6000	13.1	0.68	11.7	14.4	110
Non-maneuver, Ambient	8000	-0.1	0.74	-1.6	1.3	110
Post-maneuver, Ambient	8000	-1.1	0.90	-2.9	0.7	110

Table 11: DPOAE mean absolute amplitude comparison between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of frequency. The analysis was collapsed across factors of ethnicity and gender. Shaded rows distinguish the data associated with the post-maneuver ambient from non-maneuver ambient test condition. Current effect: [F(7, 742)=2.3882, p=.02026].

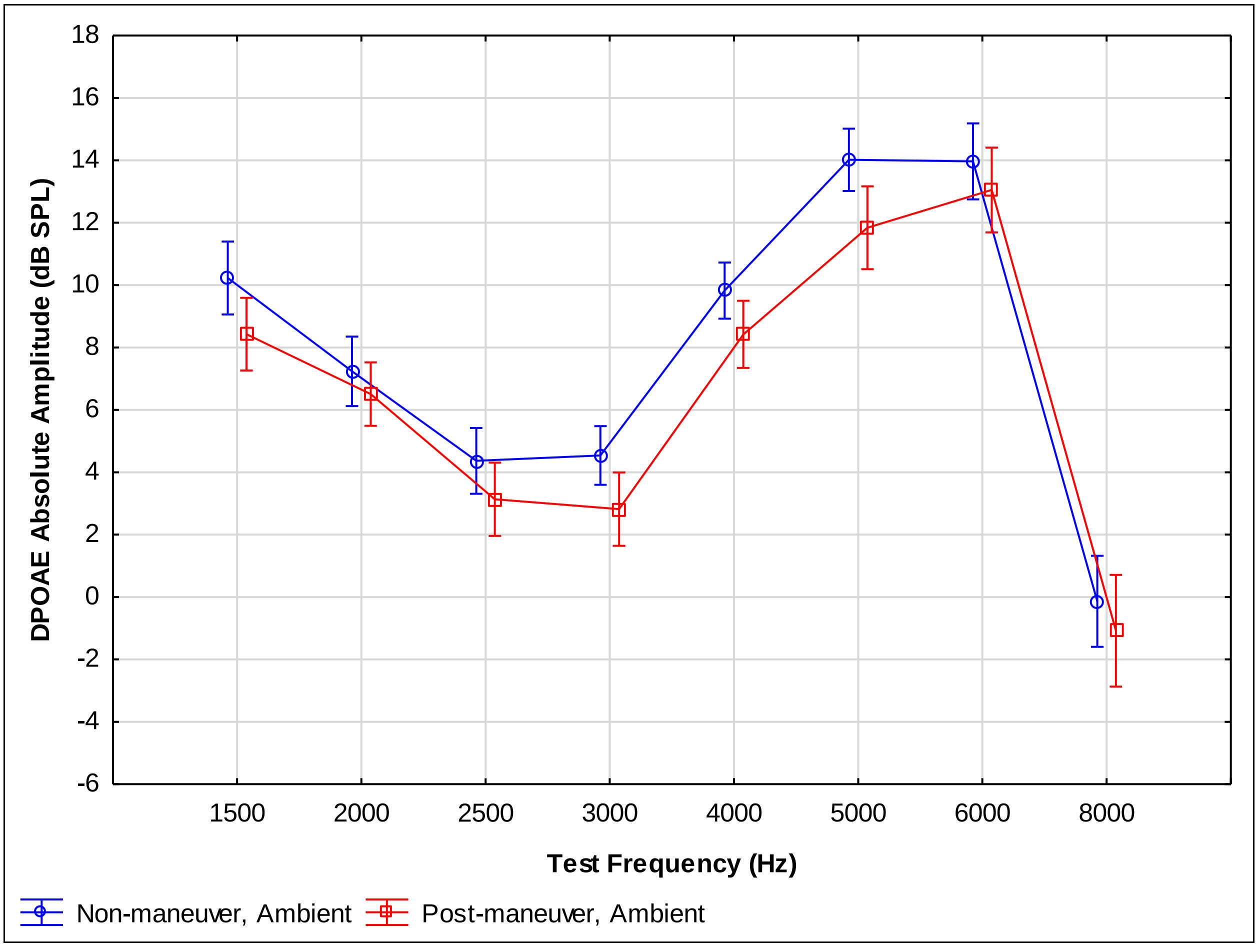


Figure 4: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of frequency. The analysis was collapsed across factors of ethnicity and gender. Vertical bars denote the 95th percent confidence intervals. Current effect: [F(7, 742)=2.3882, p=.02026].

3.1.2 Noise Level

For measures of DPOAE noise level, the main effects of gender [F(1, 106)=0.31184 p=.57773] and ethnicity [F(2, 106)=0.56729 p=.56877] were not significant. The main effect of test condition [F(1, 106)=0.08970 p=.76515] was not significant; noise level did not differ significantly when testing at ambient pressure in either the presence or absence of abnormal middle ear pressure. A graphical illustration of this test conditions comparison can be seen in section 3.5 Figure 13 for the four test condition comparison of mean DPOAE noise level.

Test Condition	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	-22.37	0.45	-23.26	-21.48	110
Post-maneuver, Ambient	-22.44	0.66	-23.75	-21.13	110

Table 12: Comparison of mean DPOAE noise level between the non-maneuver ambient and post-maneuver ambient test conditions. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 106)=0.08970, p=.76515].

Higher-order interactions for DPOAE noise level measures between factors of frequency, gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver ambient), were all found non-significant. The only finding of significance was the main effect of frequency [F(7, 742)=31.183, p=.00000]. Mean DPOAE noise level varied significantly across the eight test frequencies (1500 to 8000 Hz) when the analysis was collapsed across factors of test condition, gender, and ethnicity. Refer to Table 13 for measures of mean noise level, confidence intervals, and standard error. The highest mean noise level was measured at 1500 and 6000 Hz. A minimum mean noise level was seen at 3000 Hz (refer to Figure 5). The pattern observed for mean noise level plotted across frequencies (1500 to 8000 Hz) was comparable to the configuration observed for mean absolute amplitude displayed as a function of frequency in Figure 4.

Frequency (Hz)	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
1500	-19.28	0.439	-20.15	-18.41	110
2000	-22.34	1.126	-24.57	-20.11	110
2500	-23.66	0.447	-24.54	-22.77	110
3000	-24.89	0.443	-25.77	-24.01	110
4000	-24.18	0.165	-24.50	-23.85	110
5000	-22.04	0.161	-22.36	-21.72	110
6000	-20.22	0.362	-20.94	-19.50	110
8000	-22.64	0.129	-22.89	-22.38	110

Table 13: Descriptive statistics of mean DPOAE noise level comparison across test frequencies. The analysis was collapsed across factors of test condition (non-maneuver ambient versus post-maneuver ambient), ethnicity, and gender. Current effect: [F(7, 742)=31.183, p=.00000].

3.1.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of DPOAE absolute amplitude and noise level measures considering factors of test conditions, gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 178 and Table 179.

Figure 5 shows a significant finding of mean DPOAE absolute amplitude difference between the non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute MEP shift magnitude [F(4, 102)=5.9182, p=.00025]. This analysis was collapsed across factors of gender, ethnicity, and frequency. To further explore this finding, a Tukey's HSD test was performed. The results of the post-hoc analysis indicated a significant difference between the two test conditions only at the absolute MEP shift category E (≥100 daPa shift). A significant difference was found within the post-maneuver ambient condition between categories E:B, and E:D but not for E:C and E:A. Refer to Appendix A Table 119 for full post-hoc test results. Although not statistically significant for all category comparisons, a trend was observed for the measured DPOAE absolute amplitude to decrease with an increase in absolute MEP shift magnitude. The lowest mean amplitude was measured in the post-maneuver condition for category E (4.25 dB SPL), which corresponds to the MEP shift of the greatest magnitude (absolute MEP ≥100 daPa). Table 14 contains details of CIs, standard error, sample size, and mean absolute DPOAE amplitude.

|MEP| Shift (daPa)	**Test Condition (ambient pressure)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0-10)	Non-maneuver,	6.82	2.84	1.19	12.42	13
A (0-10)	Post-maneuver,	6.86	3.30	0.32	13.40	13
B (11-25)	Non-maneuver,	9.26	2.78	3.74	14.77	14
B (11-25)	Post-maneuver,	9.03	3.23	2.61	15.44	14
C (26-50)	Non-maneuver,	7.40	1.96	3.51	11.28	27
C (26-50)	Post-maneuver,	6.35	2.28	1.83	10.87	27
D (51-99)	Non-maneuver,	8.98	1.91	5.18	12.77	31
D (51-99)	Post-maneuver,	7.71	2.22	3.30	12.12	31
E (>99)	Non-maneuver,	7.51	2.08	3.39	11.63	25
E (>99)	Post-maneuver,	4.25	2.41	-0.54	9.03	25

Table 14: Descriptive statistics for mean DPOAE absolute amplitude comparison between the non-maneuver ambient and post-maneuver ambient test conditions, as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)=5.9182, p=.00025].

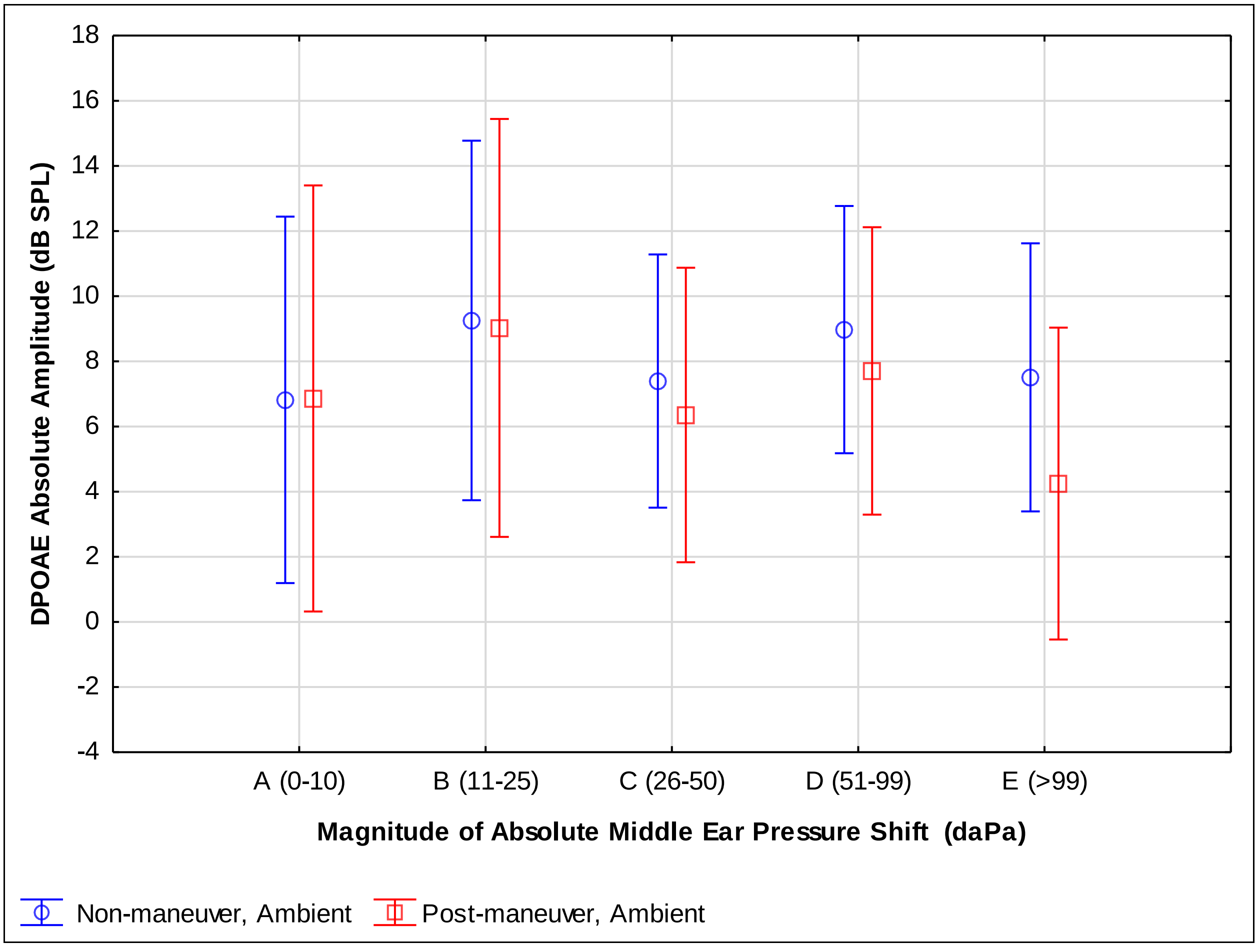


Figure 5: Mean DPOAE absolute amplitude comparison between the non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute middle ear pressure (MEP) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency.

Vertical bars denote the 95th percent confidence interval at each MEP shift category. Current effect: [F(4, 102)=5.9182, p=.00025].

An overall finding of non-significance was determined when comparing the mean noise level between the non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute MEP shift magnitude [F(4, 102)=1.1712 p=.32800]. Refer to Appendix A Table 120 for descriptive statistics.

3.2 Non-maneuver Ambient and Post-maneuver Peak Test Conditions

The following analyses represent the comparison, illustrated in Table 15, between the non-maneuver ambient condition and the post-maneuver peak test condition for outcome measures of DPOAE absolute amplitude and noise level (refer to Appendix B, Table 180 and Table 182, for the overall findings of significance). A G-G correction was performed, the results of which confirmed all findings of significance (refer to Appendix B, Table 181). Each test condition had a sample size of n=110 with DPOAE measures from n=48 individuals participants. The mean absolute MEP for the non-maneuver condition was 10.57 daPa (range: 0 to 53 daPa) and for the post-maneuver condition, it was 64.43 daPa (range: 6 to 280 daPa). The mean absolute MEP shift between test conditions was determined to be 63.45 daPa (range: 0 to 291 daPa).

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	Peak	Ambient	**Peak**

Table 15: Shaded boxes represent the test conditions under comparison.

3.2.1 Absolute Amplitude

The main effect of test condition [F(1, 106)= 16.7227, p=.00008] was significant: A significant difference in mean absolute amplitude was observed when comparing the non-maneuver ambient to the post-maneuver peak test condition measures, collapsing across factors of gender, frequency, and ethnicity. Refer to the four test condition comparison section 3.5 for a graphical representation of this finding, Figure 13. The post-maneuver peak condition had a lower mean amplitude value, with a mean absolute amplitude difference of 0.76 dB SPL between the two test conditions (refer to Table 16).

Test Condition	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	8.01	1.04	5.95	10.06	110
Post-maneuver, Peak	7.25	1.21	4.85	9.64	110

Table 16: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of ethnicity, gender, and frequency. Range in confidence is represented by ±95% confidence intervals. Current effect: [F(1, 106)=16.723, p=.00008].

The main effects of gender [F(1, 106)= 0.2101, p=.6476] and ethnicity [F(2, 106)=0.1342, p=.8745] were not significant. Interactions between gender and test condition [F(1, 106)=0.2370, p=.6274], ethnicity and test condition [F(2, 106)= 2.7224, p=.07031], as well as the interaction between frequency and gender [F(7, 742)= 1.4931, p=.16630] were also not significant.

The main effect of frequency [F(7, 742)=116.7839 p=.00000] was significant. Displayed in Figure 6, the interaction of frequency and ethnicity was significant [F(14, 742)=5.1555, p=.00000]. This interaction demonstrates that the variation in absolute amplitude across the range of test frequencies differed for Caucasian (n=43), Asian (n=46), and Other (n=21) participants. The analysis was collapsed across factors of test condition (non-maneuver and post-maneuver ambient) and gender. As illustrated in Figure 6, a comparable trend in DPOAE amplitude is observed for the three ethnic groups across test frequencies (1500 to 8000 Hz). The same pattern is also observed for the comparison of non-maneuver-ambient versus post-maneuver ambient test conditions as a function of frequency (displayed in the above section, in Figure 4). Figure 6 shows a similar DPOAE amplitude/frequency response is shown for all ethnic groups; the highest amplitude is observed between 5000 to 6000 Hz, dropping to a minimum mean DPOAE amplitude at 8000 Hz. Refer to Appendix A, Table 121 for measures of mean amplitude, standard error, and 95% CIs. A post-hoc analysis was conducted for the interaction between factors of frequency and ethnicity with the analysis collapsed across factors of gender and test condition (non-maneuver ambient versus post-maneuver peak). A Tukey’s HSD test showed no significant difference in absolute DPOAE amplitude between Caucasians and Others at any of the test frequencies, nor between Asians and Others. A significant difference was seen between the Caucasian and Asian groups at only one test frequency, 8 kHz.

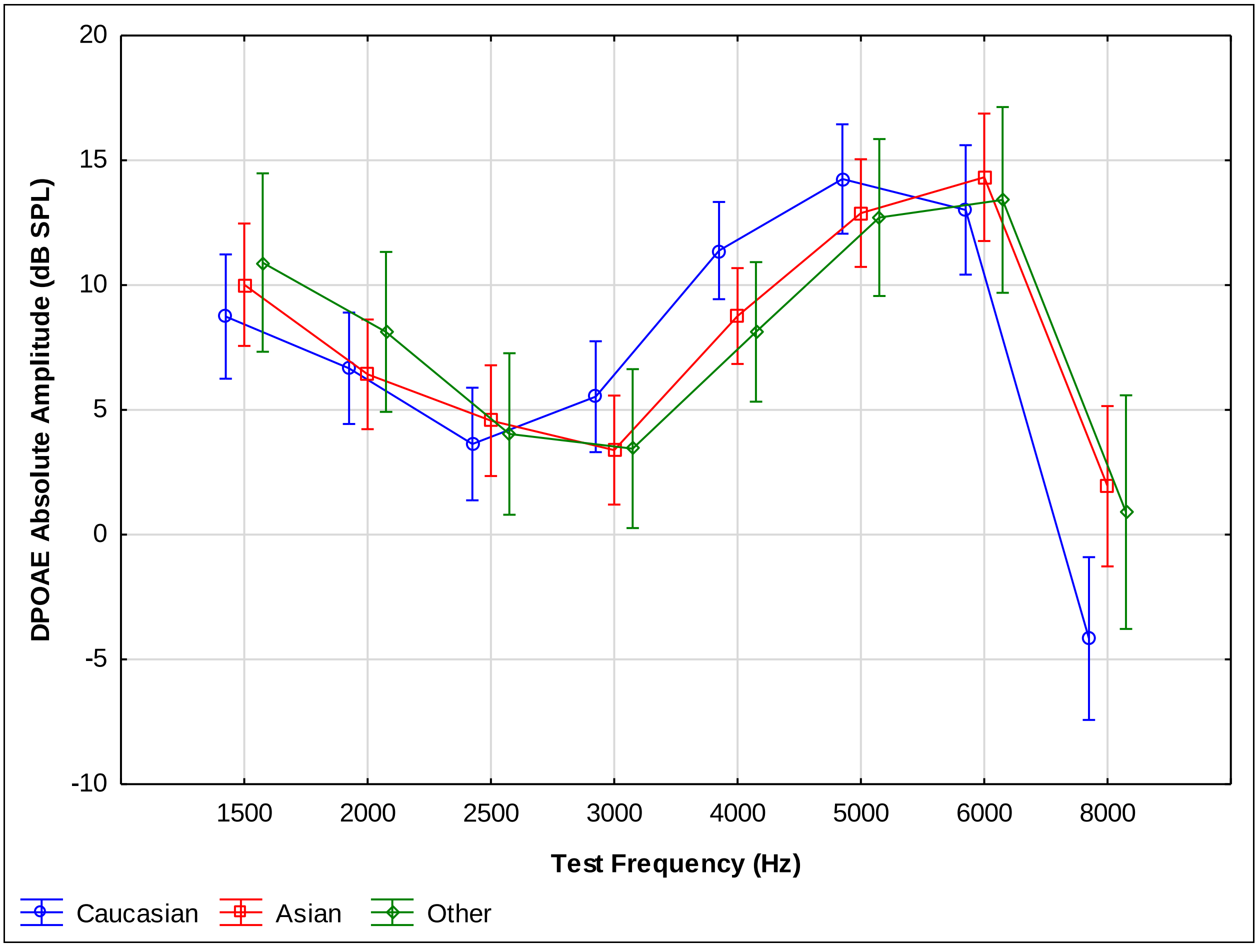


Figure 6: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function frequency. The analysis was collapsed across factors of test condition (non-maneuver ambient and post-maneuver peak) and gender. Vertical bars denote the 95th percent confidence intervals. Current effect: [F(14, 742)=5.1555, p=.00000].

The interaction between test condition and frequency was not significant [F(7, 742)=1.7185, p=.10144], with the analysis collapsed across factors of ethnicity and gender. This finding indicates that the variation in absolute amplitude for DPOAE measures across the range of test frequencies did not differ between the two test conditions (non-maneuver ambient versus post-maneuver peak). Measures of mean amplitude, standard error, and CIs for this interaction are shown in Appendix A in Table 122 with a graphical display of this interaction shown in Figure 67 also in Appendix A.

3.2.2 Noise Level

For the outcome measure of noise level, the main effect of test condition [F(1, 106)= 0.63803, p=.42621] was not significant. The mean noise level for the non-maneuver ambient test condition was -22.37 dB SPL and -22.23 dB SPL for the post-maneuver peak condition; a non-significant difference of 0.14 dB SPL was shown between test conditions. Table 17 presents descriptive statistics for the main effect comparison between test conditions. For the noise level comparison between non-maneuver ambient and post-maneuver ambient test conditions, the mean noise level was less favorable (more positive in value).). Refer to Figure 15 in section 3.5 for a graphical representation of the four test condition comparison of mean noise level.

Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	-22.37	0.45	-23.26	-21.48	110
Post-maneuver, Peak	-22.23	0.57	-23.37	-21.09	110

Table 17: Descriptive statistics from the comparison of mean DPOAE noise level as a function of test condition (non-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 102)=0.63803 p=.42621].

Main effects of gender [F(1, 106)=2.5481, p=.11340] and ethnicity [F(2, 106)=0.78441, p=.45902] were not significant. Interactions between test condition and gender [F(1, 106)=0.14990, p=.69941], test condition and ethnicity [F(2, 106)=2.1364, p=.12314], frequency and gender [F(7, 742)=1.0305, p=.40804], frequency and ethnicity [F(7, 742)=0.99141, p=.46002] were also not significant. The variation in noise level across the test conditions and between test frequencies does not differ significantly between gender or ethnic groups.

For the analyses involving test conditions non-maneuver ambient and post-maneuver peak for the outcome measures of noise level, the only finding of significance was for the main effect of frequency [F(7, 742)=80.181, p=0.00000]. The maximum noise level was detected at the lowest test frequency of 1500 Hz and the minimum noise level was at 3000 Hz (refer to Table 18 for descriptive statistics). The main effect of frequency is displayed in Figure 7. The pattern of mean noise level plotted as a function of frequency (Figure 7) is similar to the pattern observed for mean absolute amplitude plotted as a function of frequency in Figure 6 and in Figure 67 found in Appendix A.

Test Frequency (Hz)	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1500	-19.22	0.42	-20.06	-18.38	110
2000	-21.77	0.46	-22.67	-20.86	110
2500	-23.97	0.31	-24.58	-23.36	110
3000	-25.11	0.25	-25.61	-24.61	110
4000	-24.10	0.17	-24.43	-23.77	110
5000	-21.58	0.55	-22.66	-20.50	110
6000	-19.93	0.52	-20.96	-18.90	110
8000	-22.72	0.14	-22.99	-22.45	110

Table 18: Mean DPOAE noise level as a function of test frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver peak). Current effect: [F(7, 742)=80.181, p=.0000].

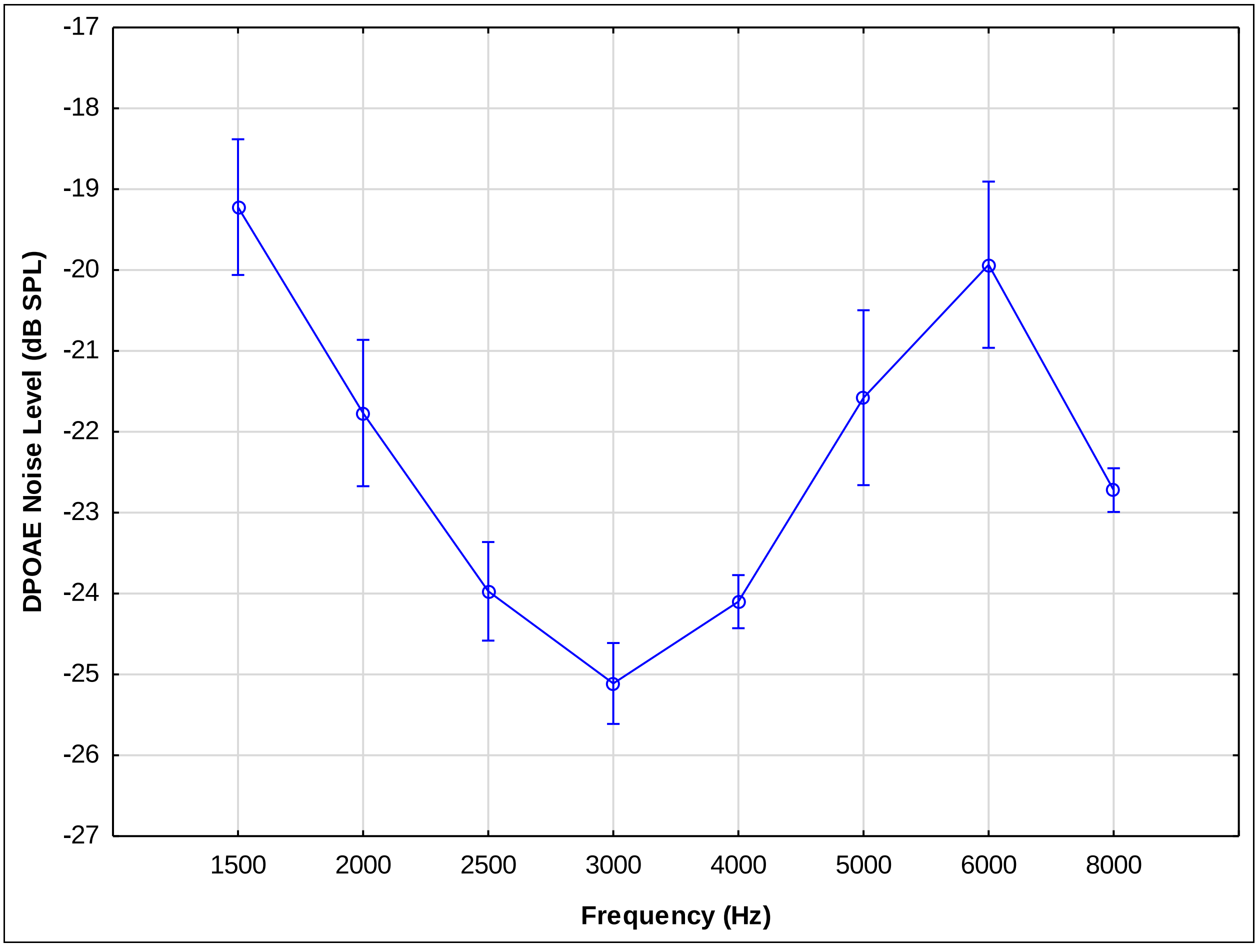


Figure 7: Mean DPOAE noise level as a function of test frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver peak). Vertical bars denote 95th percent confidence intervals. Current effect: [F(7, 742)=80.181, p=.0000].

3.2.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of DPOAE absolute amplitude and noise level measures considering factors of test condition (non-maneuver ambient versus post-maneuver peak), gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 183 and Table 184.

Figure 8 displays the significant interaction for DPOAE absolute amplitude measure comparisons between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute MEP shift magnitude [F(4, 102)= 3.6144, p=.00850]. The analysis was collapsed across other factors of gender, ethnicity, and frequency. Descriptive statistics are shown in Table 19. A post-hoc analysis revealed that for the absolute MEP shift categories A, B, C, and D there was no significant difference in mean absolute amplitude between non-maneuver ambient and post-maneuver peak conditions. The only MEP shift category that indicated a significant difference between test conditions was category E (absolute MEP shift ≥100 daPa). Refer to Appendix A Table 123 for post-hoc analysis descriptive statistics.

|MEP| Shift Magnitude (daPa)	Test Condition	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	6.82	2.84	1.19	12.4	13
A (0 to 10)	Post-maneuver, Peak	6.96	3.25	0.50	13.4	13
B (11 to 25)	Non-maneuver, Ambient	9.26	2.78	3.74	14.8	14
B (11 to 25)	Post-maneuver, Peak	8.65	3.19	2.32	15.0	14
C (26 to 50)	Non-maneuver, Ambient	7.39	1.96	3.51	11.3	27

|MEP| Shift Magnitude (daPa)	**Test Condition**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
C (26 to 50)	Post-maneuver, Peak	6.55	2.25	2.09	11.0	27
D (51 to 99)	Non-maneuver, Ambient	8.97	1.91	5.18	12.8	31
D (51 to 99)	Post-maneuver, Peak	8.70	2.19	4.34	13.1	31
E (>99)	Non-maneuver, Ambient	7.51	2.08	3.39	11.6	25
E (>99)	Post-maneuver, Peak	5.72	2.38	0.99	10.4	25

Table 19: Comparison of DPOAE absolute amplitude between non-maneuver ambient and post-maneuver peak test conditions as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)=3.6144, p=.00850].

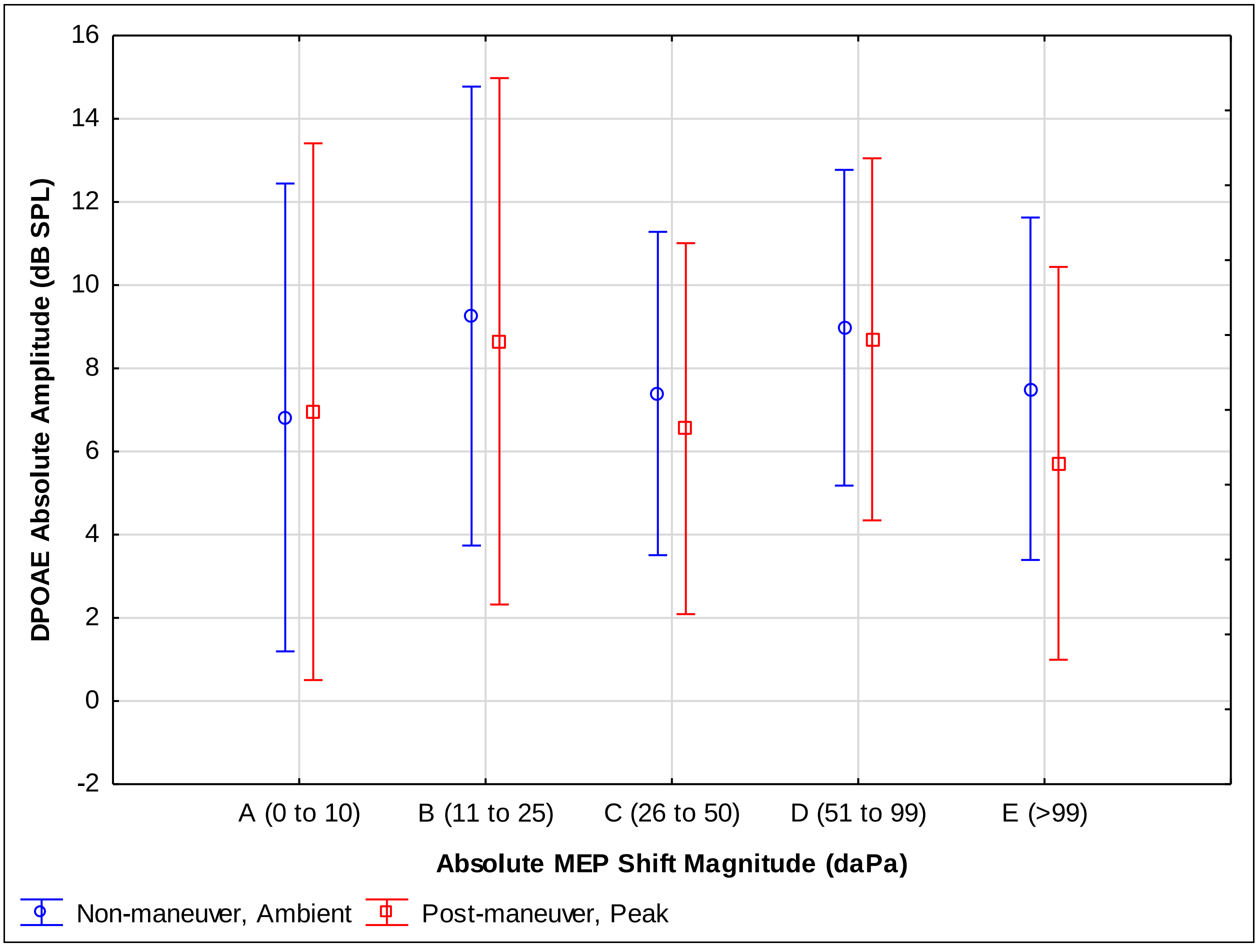


Figure 8: DPOAE absolute amplitude comparison between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude (categories A to E). The analysis was collapsed across factors of ethnicity, frequency, and gender. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 102)=3.6144, p=.00850].

For the outcome measure of noise level, the interaction of test condition (non-maneuver ambient versus post-maneuver peak) and absolute MEP shift magnitude was not significant [F(4, 102)=1.9389, p=.10964]. Table 124 in Appendix A shows the descriptive statistics for this interaction.

3.3 Non-maneuver Ambient and Non-maneuver Peak Test Conditions

The following analyses examined the comparison between the non-maneuver ambient and non-maneuver peak test conditions for outcome measures of DPOAE absolute amplitude and noise level (comparison illustrated in Table 20). Refer to Appendix B Table 185 and Table 186 for the overall findings of significance for both absolute amplitude and noise level measures, respectively. A G-G test was performed, the results of which confirmed all findings of significance. Referencing the conventional 226 Hz tympanogram estimates, the mean absolute MEP associated with the DPOAE recordings was 10.57 daPa (range 0 to 53 daPa) (refer to methods section Table 6). There was a sample size of n=110 DPOAE measures from n=48 individual participants contributing to each test condition.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	**Peak**	Ambient	Peak

Table 20: Shaded boxes represent the test conditions under comparison.

3.3.1 Absolute Amplitude

The main effect of test condition [F(1, 106)=.48047, p=.48972] was not significant: No significant difference in mean absolute amplitude was seen between the two non-maneuver test conditions (refer to Table 21). This analysis was collapsed across factors of gender, ethnicity, and frequency. Refer to section 3.5 Figure 13 for a four test condition comparison of DPOAE absolute amplitude.

Test Condition	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	8.01	1.04	5.95	10.06	110
Non-maneuver, Peak	8.09	1.07	5.97	10.22	110

Table 21: Descriptive statistics for the comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 106)=.48047, p=.48972].

The main effect of gender [F(1, 106)=0.2194, p=.640467], as well as the interaction of gender and test condition [F(1, 106)=0.4232, p=.516740], were not significant. The interaction of gender and frequency [F(1, 106)=1.3791, p=.210930] was not significant, showing that the variation in absolute amplitude across the range of test frequencies did not vary between male and female participants. All higher-order interactions involving the factor of gender into the analysis were not significant.

The main effect of ethnicity [F(2, 101)=0.1603, p=.852068] was not significant, nor was the interaction between test condition and ethnicity [F(2, 106)=0.7471, p=.476219]. The main effect of frequency was found to be significant [F(7, 742)=122.2514, p=.00000]. The interaction between frequency and ethnicity [F(14, 742)=4.9305, p=.00000] was significant. This finding of significance implies that the variation in absolute amplitude seen across the frequency range

(1500 to 8000 Hz) does differ between the three ethnicity groups; Caucasians (n=43), Asians (46), and Others (21). The same pattern in absolute amplitude plotted against test frequency was seen for all three ethnicity groups (Figure 9). This response pattern mirrors that of DPOAE amplitude as a function of frequency (1500 to 8000 Hz) for the main effect of frequency (graphical illustration for the main effect of frequency was not included in this manuscript). The significant interaction between ethnicity and frequency was analyzed collapsing across factors of gender and test condition (non-maneuver ambient versus peak), the descriptive statistics for which can be found in Appendix A Table 125. Post-hoc analysis revealed a significant difference in mean DPOAE amplitude between Caucasians and Asians at only 8 kHz. No significant difference in DPOAE amplitude was observed between Caucasians and Others at any test frequency or between Asians and Others at any frequency (1500 to 8000 Hz). Although not significant, a trend was observed for the mean absolute amplitude for the Caucasian group to be greater than Others and Asians at mid test frequencies 3000, 4000, and 5000 Hz. The mean DPOAE amplitude values for the Other and Asian participants at each test frequency were comparable, relative to the Caucasian group.

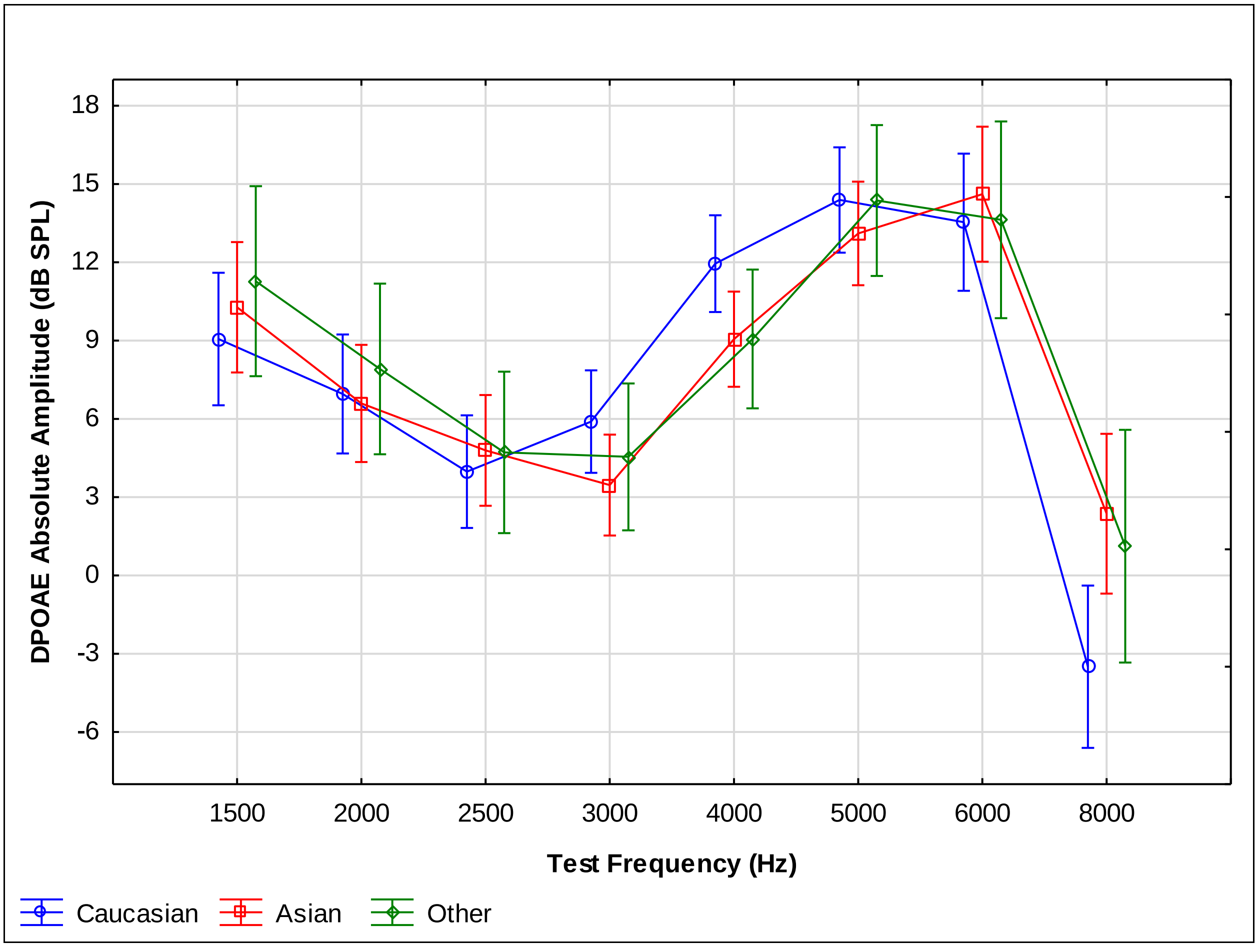


Figure 9: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and test condition (non-maneuver ambient versus non-maneuver peak). Vertical bars denote 95th percent confidence intervals. Current effect: [F(14, 742)=4.9305, p=.00000].

Although the variation in absolute amplitude across frequency differed for ethnic groups, the interaction of test condition and ethnicity was not significant [F(2, 106)=.74709, p=.47622]. Appendix A Table 126 contains the descriptive statistics for the analysis of the interaction between test condition and ethnicity, which was collapsed across factors of gender and frequency.

The interaction between test condition and frequency was not significant [F(7, 742)=0.7447, p=.66832]. This demonstrates that the variation seen in absolute amplitude across frequencies did not differ significantly between the non-maneuver ambient and non-maneuver peak test conditions (see Appendix A Table 127 for associated descriptive statistics). A graphical display of this non-significant interaction can be found in Appendix A Figure 68, which shows the comparable mean amplitude between test conditions 15000 to 8000 Hz. For the outcome measure of absolute DPOAE amplitude, the plotted interaction of test condition and frequency shows the same configuration as that seen for the main effect of frequency and the interaction of frequency and ethnicity.

3.3.2 Noise Level

The main effect of test condition [F(1, 106)=.37809, p=.53994] was not significant: There was no significant difference in mean noise level between the non-maneuver test conditions (ambient versus peak). Refer to section 3.5 for graphical representation of the comparison between the four test conditions for the outcome measure of the noise level. This analysis was collapsed across factors of gender, ethnicity, and frequency. Refer to Appendix A Table 128 for associated descriptive statistics.

The main effect of frequency was significant [F(7, 742)=84.207, p=.0000]. The pattern in noise level across the frequency range of 1500 to 8000 Hz is the same as that seen in when collapsing across non-maneuver ambient and post-maneuver peak test conditions in Figure 7.

Test Frequency (Hz)	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1500	-19.24	0.48	-20.19	-18.30	110
2000	-21.88	0.43	-22.72	-21.03	110
2500	-23.61	0.61	-24.81	-22.40	110
3000	-25.12	0.31	-25.73	-24.50	110
4000	-23.93	0.40	-24.71	-23.14	110
5000	-21.93	0.34	-22.61	-21.25	110
6000	-20.11	0.36	-20.83	-19.39	110
8000	-22.64	0.15	-22.94	-22.33	110

Table 22: Mean DPOAE noise level as a function of test frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus non-maneuver peak). Current effect: [F(7, 742)=84.207, p=.0000].

The main effect of gender [F(1, 106)=4.2280, p=.4222)] was not significant. The male participant group (n=46 DPOAE measures) had a mean noise level of -22.72 dB SPL and the female group (n= 64 DPOAE measures) a mean noise level of -21.89 dB SPL. Refer to Appendix A Table 129 for further descriptive statistics.

The main effect of ethnicity [F(2, 106)=2.0515, p=.13362)] was not significant. The interaction between gender and test condition [F(1, 106)=3.7121, p=.05670] was not significant (refer to

Appendix A Table 130 for descriptive statistics). As well, the interaction between ethnicity and test condition [F(2, 106)=2.3121, p=.10403] was not found to be significant (refer to Appendix A Table 131 for descriptive statistics). These non-significant findings indicate that the variation in noise level observed between test conditions did not differ between female and male participants as well as between Caucasian, Asian, and Other participants.

3.3.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of DPOAE absolute amplitude and noise level measures considering factors of test conditions, gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 187 and Table 188.

The main effect of absolute MEP magnitude category was significant [F(3, 103)=3.4740, p=.01878]. As absolute MEP increases, there is a corresponding decrease in mean DPOAE absolute amplitude (refer to Table 23). The same response pattern is reflected in the analysis for the interaction between factors of test condition (non-maneuver ambient versus peak) and absolute MEP magnitude (refer to Appendix A Table 132). A large difference in mean absolute amplitude is seen between categories A, B, and C compared to the most extreme absolute MEP magnitude condition labeled as category D (|MEP|= 51 to 99 daPa). Note the small sample size (n=1) seen in category D. A small sample size in this category was sought after because having participants with a MEP centered on ambient pressure (0 daPa) was ideal for the non-maneuver ‘baseline’ condition. There were in total five categories of absolute MEP (A to E), no participants fell into category E (MEP ≥100 daPa) for the non-maneuver test condition.

|MEP| Magnitude (daPa)	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	7.88	0.47	6.9	8.82	58
B (11 to 25)	8.59	0.53	7.5	9.64	47
C (26 to 50)	5.37	1.80	1.8	8.94	4
D (51 to 99)	-1.32	3.54	-8.3	5.70	1

Table 23: Comparison of mean DPOAE absolute amplitude across categories of absolute middle ear pressure (|MEP|) magnitude. The analysis was collapsed across factors of gender, ethnicity, frequency, and test condition (non-maneuver ambient versus peak). Current effect: [F(3, 103)=3.4740, p=.01878].

The interaction between test condition and absolute MEP magnitude [F(3, 103)=2.4526, p=.06753] was not significant. Refer to Appendix A Table 132 for mean DPOAE amplitude values. Although the overall interaction was not significant, a trend was observed for the mean absolute DPOAE amplitude for both test conditions (non-maneuver ambient and peak), to decrease with increasing absolute MEP magnitude. This trend should be interpreted with caution, as there was a very small sample size of only n=4 for category C and n=1 in category D.

The main effect of absolute MEP magnitude category for noise level was significant [F(3, 103)=5.2443, p=.00208]: The mean noise level increased in magnitude (more positive in value) as the degree of absolute MEP increased. This same response pattern is seen for the interaction of test condition and absolute MEP magnitude. Again, for the non-maneuver test condition analyses, note the small samples sizes in categories C and D (refer to Table 24).

|MEP| Magnitude (daPa)	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	-22.11	0.26	-22.62	-21.60	58
B (11 to 25)	-22.70	0.29	-23.27	-22.13	47
C (26 to 50)	-21.88	0.98	-23.82	-19.94	4
D (51 to 99)	-15.41	1.92	-19.22	-11.59	1

Table 24: Comparison of mean DPOAE noise level across categories of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, frequency, and test condition (non-maneuver ambient versus peak). Current effect: [F(3, 103)= 5.2443, p=.00208].

The interaction between test condition and absolute MEP magnitude was not significant [F(3, 103)=2.1822, p=.09462]. Refer to Appendix A Table 133 for descriptive statistics and again, note the small sample size in categories C (n=4) and D (n=1).

3.4 Post-maneuver Ambient and Post-maneuver Peak Test Conditions

The following analyses were for the comparison between the post-maneuver ambient and the post-maneuver peak test conditions for the outcome measures of DPOAE absolute amplitude and noise level (comparison illustrated in Table 25). There were n=110 individual DPOAE recordings contributing to both post-maneuver test conditions from a total of 48 individual participants. Overall statistical findings involving either DPOAE absolute amplitude or noise level can be found in Appendix B Table 189 and Table 191, respectively. The mean absolute MEP associated with the post-maneuver condition DPOAE measures was 64.43 daPa with a range of absolute MEP estimates from 6 to 280 daPa.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	Ambient	Peak	**Ambient**	**Peak**

Table 25: Shaded boxes represent the test conditions under comparison.

3.4.1 Absolute Amplitude

The main effect of comparing mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) was significant [F(1, 106)=9.6368, p=.00245]. This finding indicates that there was a significant difference in the measure of absolute amplitude between the test conditions when collapsing the analysis across factors of gender, ethnicity, and frequency. The post-maneuver peak condition had a 0.61 dB SPL greater mean absolute amplitude value than the ambient test condition. Table 26 contains the descriptive statistics for the main effect of test condition, including means, standard error, and ±95% CIs. Refer to section 3.5, Figure 13, for a graphical display of mean absolute amplitude between the four test pressure conditions.

Test Condition	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Post-maneuver, Ambient	6.64	1.25	4.15	9.13	110
Post-maneuver, Peak	7.25	1.21	4.85	9.64	110

Table 26: Descriptive statistics for the comparison of mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 106)=9.6368, p=.00245].

The main effect of gender [F(1, 106)=0.4078, p=.524478] was not significant. The interaction between gender and test condition [F(1, 106)=.2422, p=.623647)] was not significant implying that the variation in mean absolute amplitude between test conditions did not differ between male and female participants. Similarly, the interaction between gender and frequency [F(7, 742)=1.4730, p=.173557] was not significant, showing that the magnitude of variation in absolute amplitude across frequency (1500 to 8000 Hz) did not differ between male and female participants.

The main effect of ethnicity [F(2, 106)=0.1777, p=.837454] was not significant. However, the interaction between test condition (post-maneuver ambient versus peak) and ethnicity for absolute amplitude was found to be significant [F(2, 106)= 4.8358, p=.00978]. Following a Greenhouse-Geisser correction, the interaction between test condition and ethnicity remained significant (refer to Appendix A, Table 190). Table 27 shows the mean DPOAE absolute amplitude values corresponding to each test condition and ethnic group. Figure 10 shows mean absolute DPOAE amplitude being greater in the peak compared to the ambient test condition only for the Caucasian (n=43) and Asian (n=46) groups, but not for the Other (n=21) ethnic group. A post-hoc analysis was conducted by means of a Tukey's HSD test. The results indicated a significant difference only within the ethnic group having the largest sample size, the Asian group: A significant difference was found when comparing the mean DPOAE absolute amplitude between the two test conditions. Although the mean amplitude was greater in the peak rather than the ambient test condition for the Caucasian group and vice-versa for the Others group, neither of these differences were not statistically significant. Refer to Table 28 for results of the post-hoc analysis.

Ethnicity	**Test Condition**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	Post-maneuver, Ambient	6.20	1.90	2.44	10.0	43
Caucasian	Post-maneuver, Peak	7.01	1.83	3.39	10.6	43
Asian	Post-maneuver, Ambient	6.37	1.87	2.66	10.1	46
Asian	Post-maneuver, Peak	7.69	1.80	4.12	11.3	46
Other	Post-maneuver, Ambient	7.35	2.72	1.96	12.7	21
Other	Post-maneuver, Peak	7.04	2.62	1.85	12.2	21

Table 27: Comparison of mean DPOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Others) as a function of test condition (post-maneuver ambient versus peak). The analysis was collapsed across factors of gender and frequency. Current effect: [F(2, 106)= 4.8358, p=.00978].

Tukey HSD test; Pooled MSE = 18.313, df = 117.25							
Ethnicity	**Test Condition**	**{1} 6.27**	**{2} 7.06**	**{3} 6.47**	**{4} 7.76**	**{5} 7.25**	**{6} 6.97**
Caucasian	Post-maneuver, Ambient		0.09	1.00	0.57	0.96	0.99
Caucasian	Post-maneuver, Peak	0.09		0.99	0.97	1.00	1.00
Asian	Post-maneuver, Ambient	1.00	0.99		**0.00**	0.98	1.00
Asian	Post-maneuver, Peak	0.57	0.97	**0.00**		1.00	0.98
Other	Post-maneuver, Ambient	0.96	1.00	0.98	1.00		0.99
Other	Post-maneuver, Peak	0.99	1.00	1.00	0.98	0.99	

Table 28: Tukey's HSD test results for the comparison of DPOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Other) as a function of test condition (post-maneuver

ambient versus peak). Shaded values indicate inter-ethnic group comparisons. Bolded values indicate significance (p<.05).

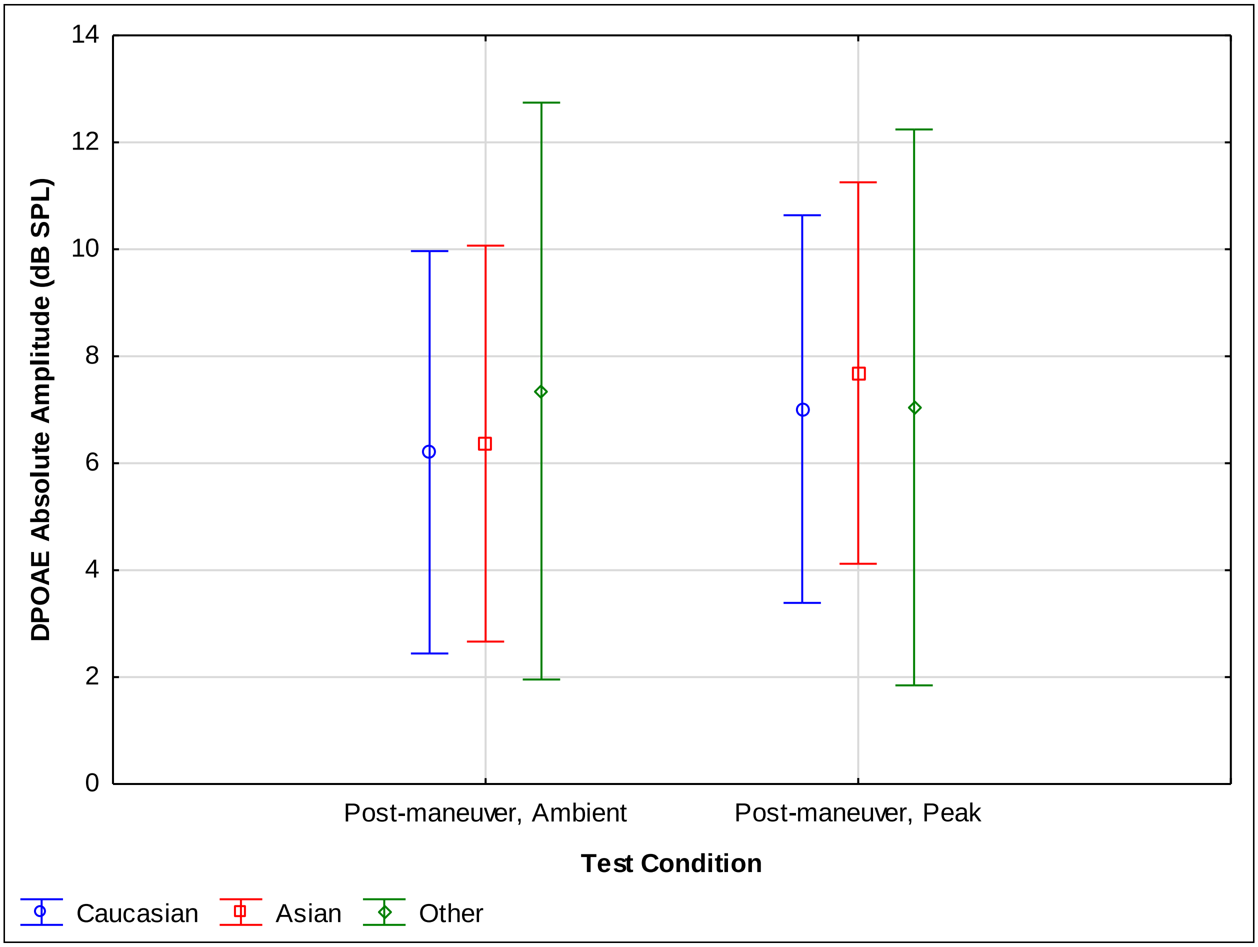


Figure 10: Comparison of mean DPOAE absolute amplitude among ethnic groups (Caucasian, Asian, Other) and between test conditions (post-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of gender and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(2, 106)=4.8358, p=.00978].

For the outcome measure of absolute amplitude, the main effect of frequency [F(7, 742)=104.2530, p=.00000] was significant. The interaction between ethnicity and frequency (1500 to 8000 Hz) was also significant [F(14, 742)=5.1343, p=.00000] and remained significant following a G-G correction. The descriptive statistics (absolute amplitude means, standard error, and confidence intervals) associated with the analysis of the interaction between frequency and ethnicity can be found in Appendix A Table 134. This analysis was collapsed across factors of gender and test condition (post-maneuver ambient and peak). The interaction between frequency and ethnicity shows that the magnitude of variation in absolute amplitude across the frequency range (1500 to 8000 Hz) does differ between Caucasian, Asians, and Others. As can be seen in Figure 11, the pattern of absolute amplitude across test frequencies is similar between the Asian and Other ethnic groups, with the Caucasian group having a visually different amplitude pattern across the frequency range. Based on the mean absolute amplitude values at each test frequency, the Caucasian group had on average a higher mean values for frequencies between 3000 to 5000 Hz compared to Asian and Other participants. The Asian and Other group had greater mean absolute amplitude values at the highest (6000 to 8000 Hz) and lowest (1500 to 2000 Hz) test frequencies compared to the Caucasian group. In order to determine if the differences between ethnic groups at certain test frequencies were in fact significant, a post-hoc analysis was conducted. Tukey’s HSD test results indicated a significant difference in absolute amplitude between the Caucasian group compared to both the Asian and Other group at only one test frequency, 8000 Hz. There were no significant differences found between the Asian and Other group when comparing absolute amplitude means at any of the eight test frequencies. Refer to Appendix A Table 135 for the Tukey’s HSD descriptive statistics.

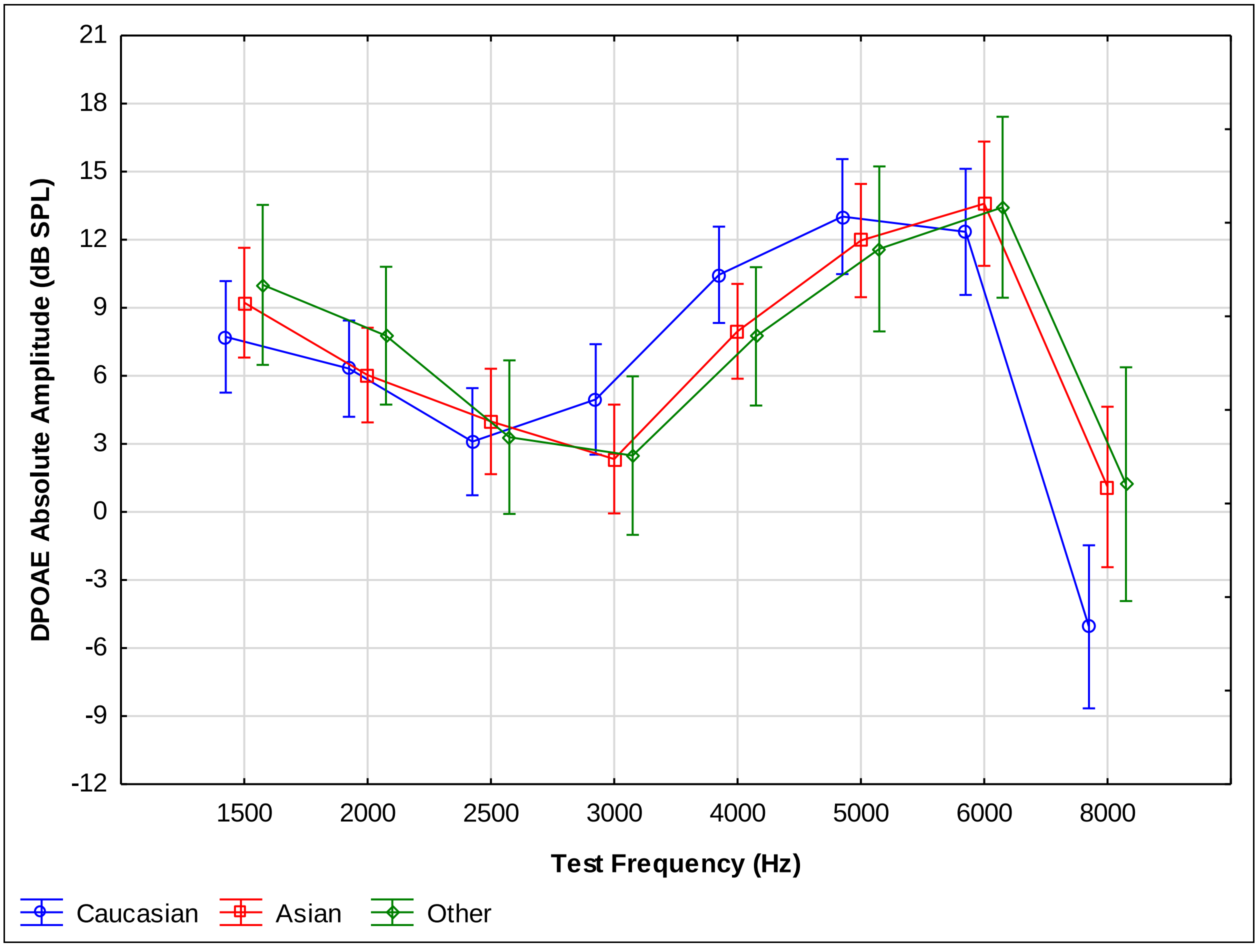


Figure 11: Mean DPOAE absolute amplitude comparison between ethnic groups (Caucasian, Asia, and Other) as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and test condition (post-maneuver ambient versus peak). Vertical bars denote 95th percent confidence intervals. Current effect: [F(14, 742)=5.1343, p=.00000].

The interaction between test condition (post-maneuver ambient versus peak) and frequency was not significant [F(7, 742)=1.2104, p=.29435]. However, the same overall trend in absolute amplitude across the frequency range can be seen for both test conditions. There is a peak in absolute amplitude at 1500 and 6000 Hz with amplitude drops at 2500 to 3000 Hz and at 8000 Hz. Although the overall interaction between factors was not significant, the mean DPOAE absolute amplitude for the post-maneuver peak condition measures was greater than the ambient test condition measures at all eight test frequencies (ranging from 1500 to 8000 Hz). The associated mean amplitude values and descriptive statistics can be found in Appendix A, Table 136.

3.4.2 Noise Level

The main effect of gender [F(1, 106)=0.82, p=.367031] and the main effect of ethnicity [F(2, 106)=0.64, p=.529107) were not significant. These findings indicate that the between-participants factors, gender, and ethnicity, do not have a statistically significant impact on mean noise level during DPOAE recordings. Interactions between test condition and gender [F(1, 106)=2.28, p=.133681] as well as test condition and ethnicity [F(2, 106)=0.73, p=.483048] were also not significant, signifying that the between-participant factors did not significantly impact the mean noise levels when comparing between test conditions (post-maneuver ambient versus peak).

The main effect for the comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus peak) was not significant [F(1, 106)=1.0856, p=.29983]. This finding indicates that there was no significant difference in the measure of noise level between the test conditions when collapsing the analysis across factors of gender, ethnicity, and frequency. Although not significant, the post-maneuver peak (-22.15 dB SPL) compared to the ambient (-22.44 dB SPL) condition had a higher mean noise level. Table 29 contains the main effect descriptive statistics, including mean noise levels, standard error, and ±95% CIs.

Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Post-maneuver, Ambient	-22.44	0.66	-23.75	-21.13	110
Post-maneuver, Peak	-22.15	0.65	-23.44	-20.86	110

Table 29: Comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 106)=1.0856, p=.29983].

The only finding of significance regarding the outcome measure of noise level was the main effect of frequency [F(7, 742)=28.762, p=0.0000]. The descriptive statistics are provided in Table 30. The same response pattern was observed for mean DPOAE noise level plotted as a function of frequency (ranging between 1500 to 8000 Hz), when plotting (1) the main effect of frequency collapsing across the non-maneuver ambient and post-maneuver peak test conditions and (2) when plotting both noise level as a function of frequency responses separately for the two test conditions. The highest noise level value was observed for the lowest test frequency (1500 Hz) sloping to a minimum in noise level around 3000 Hz to 4000 Hz. An increase in DPOAE noise level was seen for frequencies between 5000 to 8000 Hz. Higher-order interactions between factors of frequency and gender, ethnicity, or test pressure condition were not found to be significant.

Test Frequency (Hz)	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
1500	-19.05	0.45	-19.95	-18.16	110
2000	-22.18	1.16	-24.47	-19.89	110
2500	-23.77	0.41	-24.58	-22.96	110

Test Frequency (Hz)	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
3000	-25.16	0.42	-26.00	-24.33	110
4000	-24.10	0.17	-24.43	-23.77	110
5000	-21.48	0.55	-22.57	-20.40	110
6000	-20.09	0.54	-21.17	-19.01	110
8000	-22.52	0.34	-23.19	-21.86	110

Table 30: Comparison of mean DPOAE noise level as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (post-maneuver ambient versus peak). Current effect: [F(7, 742)=28.762, p=0.0000].

3.4.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of DPOAE absolute amplitude and noise level measures considering factors of test conditions, gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 192 and Table 193.

The interaction between test condition (post-maneuver ambient versus peak) and absolute MEP magnitude [F(4, 102)=2.8410, p=.02797] was significant. The mean absolute amplitude for each category (A to E) is shown in Table 31. A small sample size in category A is expected. Since this was the post-maneuver test condition, the majority of participants were tested at elevated (either negative or positive direction) MEP. For the DPOAE condition, only n=6 participants and in the TEOAE condition for the same interaction, n=3 participants could not generate a change in MEP from their baseline non-maneuver condition state. The absolute MEP categories C (n=29), D (n=35) and E (n=22) show a greater mean absolute amplitude in the post-maneuver peak condition than the ambient condition. These differences were only significant for categories D and E (refer to Append A Table 137 for Tukey's HSD descriptive statistics).

|MEP| Magnitude (daPa)	Test Condition	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Post-maneuver, Ambient	6.95	4.88	-2.73	16.64	6
A (0 to 10)	Post-maneuver, Peak	6.67	4.84	-2.93	16.28	6
B (11 to 25)	Post-maneuver, Ambient	7.55	2.86	1.88	13.21	18
B (11 to 25)	Post-maneuver, Peak	7.36	2.83	1.74	12.98	18
C (26 to 50)	Post-maneuver, Ambient	7.94	2.19	3.60	12.28	29
C (26 to 50)	Post-maneuver, Peak	8.18	2.17	3.87	12.49	29
D (51 to 99)	Post-maneuver, Ambient	6.83	2.14	2.59	11.07	35
D (51 to 99)	Post-maneuver, Peak	7.85	2.12	3.65	12.06	35
E (>99)	Post-maneuver, Ambient	3.68	2.56	-1.41	8.76	22
E (>99)	Post-maneuver, Peak	5.08	2.54	0.03	10.12	22

Table 31: Comparison of mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) as a function of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)=2.8410, p=.02797].

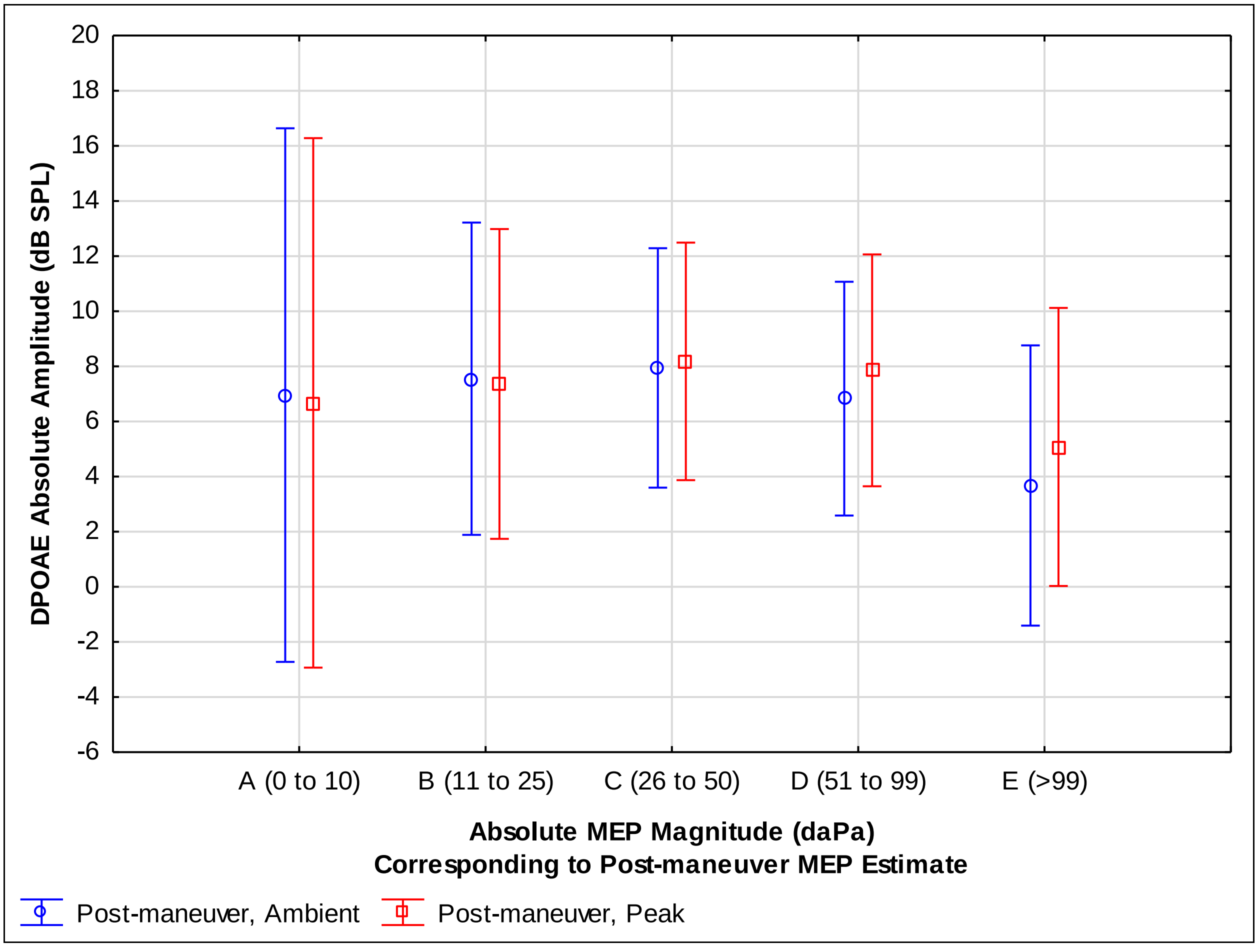


Figure 12: Comparison of mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (MEP) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 102)=2.8410, p=.02797].

The interaction between absolute MEP magnitude and test condition [F(4, 102)=.88142, p=.47791] for the outcome measure of noise level, was not significant. Refer to Appendix A Table 138 for descriptive statistics.

3.5 DPOAE Four Test Condition Comparison

Outcome measures of absolute DPOAE amplitude and DPOAE noise level were investigated comparing between all four test conditions. The statistical analysis summaries can be found in Appendix B Table 194 and Table 195 respectively. The test conditions included in the analyses are illustrated in Table 32. A sample size of n=110 DPOAE measures from n=48 participants contributed to each test condition. The mean absolute MEP associated with each test condition was determined; non-maneuver (10.57 daPa), and post-maneuver (64.43 daPa) test conditions. The mean absolute MEP shift between test conditions was determined to be 63.45 daPa.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	**Peak**	**Ambient**	**Peak**

Table 32: Shaded boxes represent the test conditions under comparison.

3.5.1 Absolute Amplitude

The main effects of test condition [F(3, 318)=21.828, p=.00000] was significant. Figure 13 shows the test conditions with the largest to smallest mean absolute amplitude was in the order of (1) non-maneuver peak (8.09 dB SPL), (2) non-maneuver Ambient (8.01 dB SPL), (3) post-maneuver peak (7.25 dB SPL), and then (4) post-maneuver ambient (6.64 dB SPL). This analysis was collapsed across factors of gender, ethnicity, and frequency. Descriptive statistics are presented in Table 33. A Tukey’s HSD analysis shows the mean DPOAE absolute amplitude between certain test conditions was significant (refer to Appendix A Table 139).

Test Condition	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	8.01	1.04	5.95	10.06	110
Non-maneuver Peak	8.09	1.07	5.97	10.22	110
Post-maneuver Peak	7.25	1.21	4.85	9.64	110
Post-maneuver Ambient	6.64	1.25	4.15	9.13	110

Table 33: Comparison of mean DPOAE absolute amplitude between the four test conditions. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 318)=21.828, p=.00000].

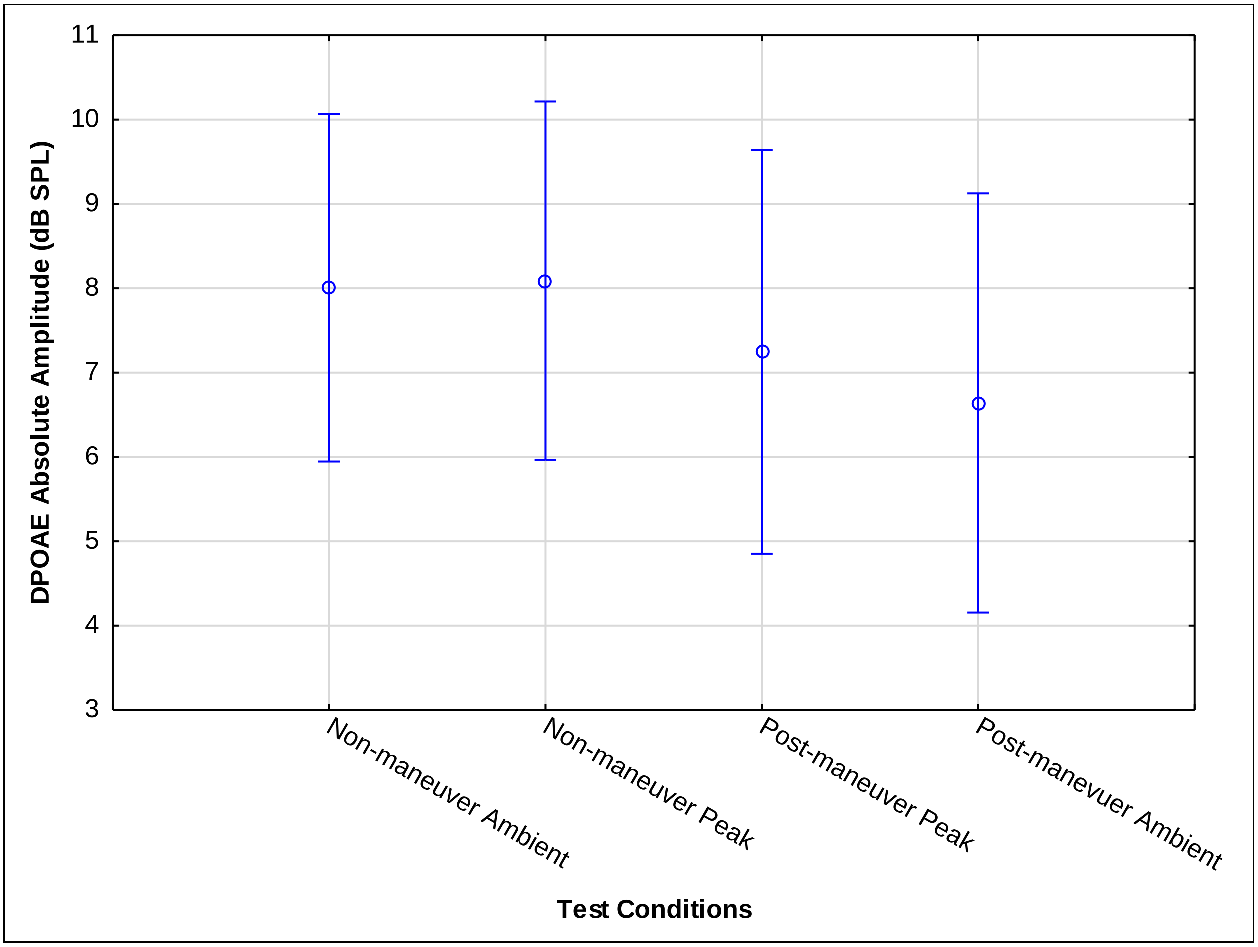


Figure 13: Comparison of mean DPOAE absolute amplitude between the four test conditions. The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 318)=21.828, p=.00000].

The main effect of gender [F(1, 106)=0.3314, p=.566074] and the interaction between gender and test condition (x4) [F(3, 318)=0.2716, p=.845833] were not significant. Although not significant, the male participants had on average lower mean amplitude values compared to female participants across all four test conditions. The main effect of ethnicity [F(2, 106)=0.1753, p=.839444] and the interaction between ethnicity and test condition (x4) [F(6, 318)=1.5758, p=.153553] were not significant. These findings indicate that the variation in DPOAE absolute amplitude observed between the four test conditions did not differ between gender groups, or between the three ethnic groups.

The main effect of frequency [F(7, 742)=121.1566, p=0.00000] was significant, with the analysis collapsed across factors of gender, ethnicity, and test condition (x4). This same pattern for the mean absolute amplitude to fluctuate in magnitude over the frequency range 1500 to 8000 Hz was also observed for the other analyses for two test condition comparisons. The interaction of frequency and gender [F(7, 742)=1.4675, p=.175586] was not significant. However, when collapsing the analysis across factors of gender and test condition (x4), the interaction between frequency and ethnicity [F(14, 742)=5.3114, p=.00000] was significant demonstrating that the variation in mean absolute DPOAE amplitude observed across frequencies did differ between the three ethnic groups. This significant interaction has already been illustrated in Figure 3, Figure 6, Figure 9, and Figure 11 for analyses collapsing across two test conditions. The Caucasian group (n=43) had greater mean amplitude values for the mid frequency range 3000 to 5000 Hz. The Asian (n=46) and Other (n=21) ethnic group had higher mean amplitude values for the low and high frequencies tested. Detailed mean values and associated descriptive statistics can be found in Appendix A Table 140. Post-hoc analysis indicated a significant difference in mean DPOAE amplitude between Caucasians and Asians at only one test frequency, 8 kHz and between Caucasians and Others at 8 kHz. No significant difference was found at any test frequency comparing the Asian and Other groups. Graphical display of this interaction is also included in the Discussion, section 6.3.1.

A higher-order interaction between test condition (x4) and frequency [F(21, 2226)=1.7589, p=.017796] was significant. This analysis was collapsed across factors of gender and ethnicity. Figure 14 illustrates the greatest difference in mean absolute amplitude between the four test conditions was for the mid test frequencies, 2500 to 5000 Hz. On average across frequencies 15000 to 8000 Hz, the non-maneuver ambient and peak test condition had the greatest mean amplitude, followed by the post-maneuver peak condition, and then the post-maneuver ambient had consistently from 1500 to 8000 Hz the lowest mean amplitude. Table 141 Appendix A contains the descriptive statistics associated with the interaction of frequency and test condition.

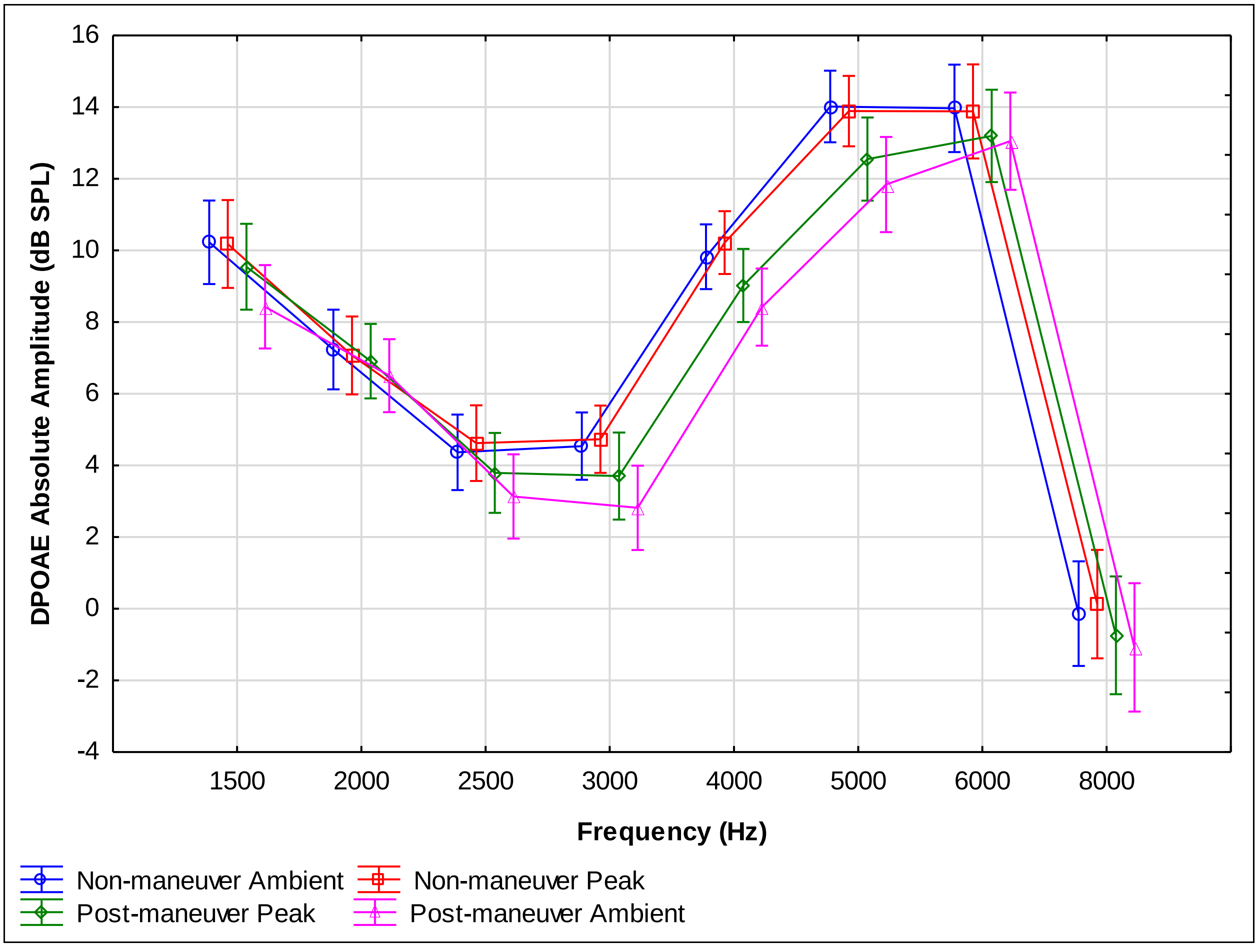


Figure 14: Comparison of mean DPOAE absolute amplitude between the four test conditions as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(21, 2226)=1.7589, p=.01780].

3.5.2 Noise Level

For the DPOAE outcome measure of noise level, the main effect of test condition [F(3, 318)=0.35194, p=.78777] was not significant. This analysis was collapsed across factors of gender, ethnicity, and frequency. The descriptive statistics are displayed in Table 34 and the interaction between test conditions is illustrated in Figure 15.

Test Condition	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	-22.37	0.45	-23.26	-21.48	110
Non-maneuver Peak	-22.24	0.80	-23.82	-20.66	110
Post-maneuver Peak	-22.23	0.57	-23.37	-21.09	110
Post-maneuver Ambient	-22.44	0.66	-23.75	-21.13	110

Table 34: Comparison of mean DPOAE noise level between test conditions (non-maneuver, post-maneuver, ambient, and peak pressure). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 318)= 0.35194, p=.78777].

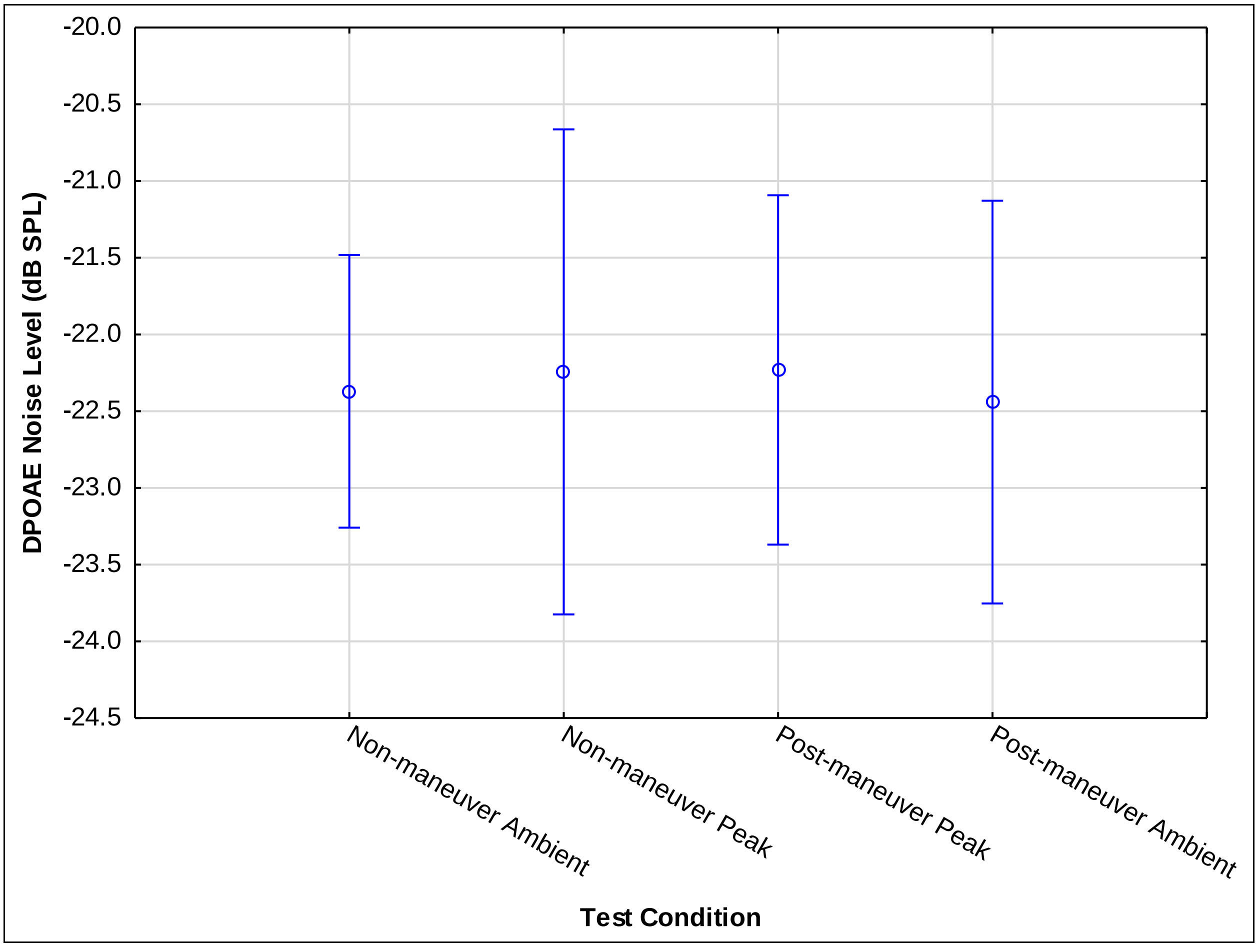


Figure 15: Comparison of mean DPOAE noise level between test conditions (non-maneuver, post-maneuver, ambient, and peak pressure). The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 318)= 0.35194, p=.78777].

The main effect of frequency [F(7, 742)=77.635, p=0.00000] was significant when collapsing the analysis across factors of test condition (x4), gender, and ethnicity. The same pattern observed in the previous discussed test condition comparisons: The pattern of noise level across the frequency range mirrors the pattern of DPOAE absolute amplitude. Refer to Table 35 for descriptive statistics for noise level across test frequencies 1500 to 8000 Hz. No higher-order interactions for noise level measures were found to be significant.

Frequency (Hz)	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
1500	-19.15	0.62	-20.38	-17.92	110
2000	-22.03	0.91	-23.84	-20.22	110
2500	-23.69	0.61	-24.89	-22.49	110
3000	-25.14	0.42	-25.97	-24.31	110
4000	-24.01	0.35	-24.70	-23.33	110
5000	-21.71	0.48	-22.65	-20.76	110
6000	-20.18	0.45	-21.08	-19.28	110
8000	-22.66	0.17	-23.00	-22.33	110

Table 35: Descriptive statistics of mean DPOAE noise level comparison across test frequencies. The analysis was collapsed across factors of test condition (x4), ethnicity, and gender. Current effect: [F(7, 742)=77.635, p=.00000].

3.5.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of DPOAE outcomes measures (absolute amplitude and noise level) considering factors of test conditions (non-maneuver, post-maneuver, ambient, and peak pressure), gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 196 and Table 197.

Figure 16 displays the significant interaction between test condition (x4) and absolute MEP shift magnitude [F(12, 306)=4.1300, p=.00001] for the outcome measure of absolute DPOAE amplitude. The same trend in absolute amplitude difference between test conditions shown in Figure 13 and Figure 14 is also observed across the absolute MEP shift categories A to E in Figure 16. There is greater separation between the non-maneuver and post-maneuver conditions at categories C to E, which represents the greater absolute MEP shift magnitudes. Descriptive statistics are shown in Table 36. A post-hoc analysis using a Tukey's HSD test approach indicated a significant difference in mean absolute amplitude between test conditions within absolute MEP categories D (51to 99 daPa) and E (≥100 daPa). The post-hoc analysis can be found in Appendix A Table 142. Figure 16 provides a summary illustration of the change in absolute DPOAE amplitude between test conditions (non-maneuver and post-maneuver) as the degree of absolute MEP increases. As the magnitude of abnormal MEP increases (from category A to E), there is an evident drop in the post-maneuver ambient response curve (representing DPOAE amplitude) and a slight reduction in the amplitude response curve for the post-maneuver peak condition in comparison to the non-maneuver test pressure conditions.

|MEP| Shift Magnitude (daPa)	**Test Condition**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Non-maneuver Ambient	6.82	2.84	1.19	12.44	13
A (0 to 10)	Non-maneuver Peak	7.26	2.94	1.44	13.09	13
A (0 to 10)	Post-maneuver Peak	6.96	3.25	0.50	13.41	13
A (0 to 10)	Post-maneuver Ambient	6.86	3.30	0.32	13.40	13
B (11 to 25)	Non-maneuver Ambient	9.26	2.78	3.74	14.77	14
B (11 to 25)	Non-maneuver Peak	9.11	2.88	3.40	14.83	14

|MEP| Shift Magnitude (daPa)	**Test Condition**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
B (11 to 25)	Post-maneuver Peak	8.65	3.19	2.32	14.98	14
B (11 to 25)	Post-maneuver Ambient	9.03	3.23	2.61	15.44	14
C (26 to 50)	Non-maneuver Ambient	7.39	1.96	3.51	11.28	27
C (26 to 50)	Non-maneuver Peak	7.51	2.03	3.48	11.53	27
C (26 to 50)	Post-maneuver Peak	6.55	2.25	2.09	11.01	27
C (26 to 50)	Post-maneuver Ambient	6.35	2.28	1.83	10.87	27
D (51 to 99)	Non-maneuver Ambient	8.97	1.91	5.18	12.77	31
D (51 to 99)	Non-maneuver Peak	9.15	1.98	5.22	13.08	31
D (51 to 99)	Post-maneuver Peak	8.70	2.19	4.34	13.05	31
D (51 to 99)	Post-maneuver Ambient	7.71	2.22	3.30	12.12	31
E(>99)	Non-maneuver Ambient	7.51	2.08	3.39	11.63	25
E(>99)	Non-maneuver Peak	7.38	2.15	3.12	11.65	25
E(>99)	Post-maneuver Peak	5.72	2.38	0.99	10.44	25
E(>99)	Post-maneuver Ambient	4.25	2.41	-0.54	9.03	25

Table 36: Comparison of DPOAE absolute amplitude between test conditions as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(12, 306)=4.1300, p=.00001].

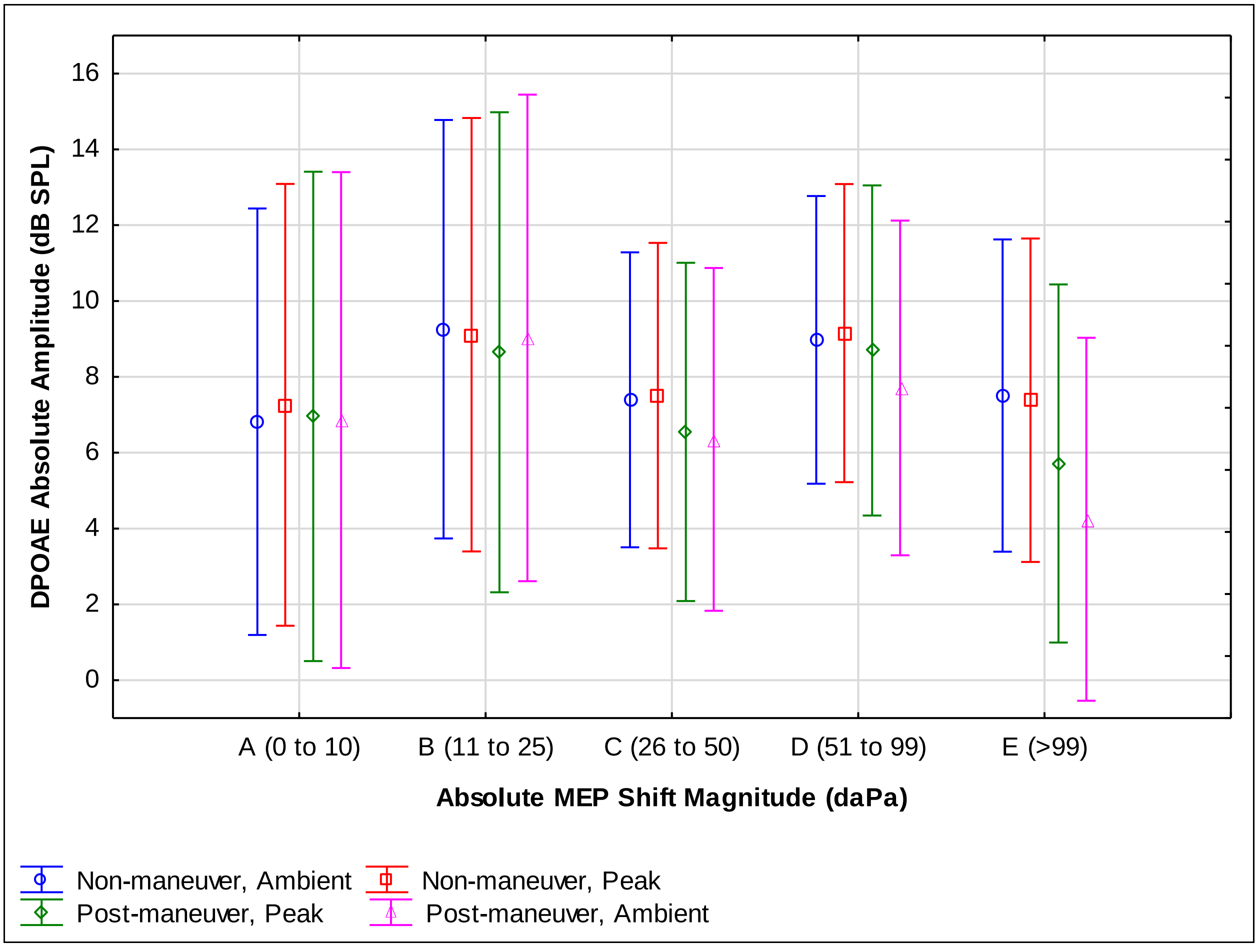


Figure 16: Comparison of DPOAE absolute amplitude between test conditions as a function of absolute middle ear pressure (|MEP|) shift magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(12, 306) =4.1300, p=.00001].

For the outcome measures of DPOAE noise level, the interaction between test condition (x4) and absolute MEP shift magnitude [F(12, 306)=0.68374, p=.76704] was not significant. The analysis was collapsed across factors of gender, ethnicity, and frequency. Descriptive statistics are shown in Appendix A, Table 143.

Chapter 4: Results; Transient Evoked Otoacoustic Emissions

The outline of Chapter 4 mirrors that presented in Chapter 3. Chapter 4 is divided into five main sections: (4.1) non-maneuver ambient and post-maneuver ambient test conditions; (4.2) non-maneuver ambient and post-maneuver peak test conditions; (4.3) non-maneuver ambient versus peak test conditions; (4.4) post-maneuver ambient versus peak test conditions; (4.5) four test condition comparison. Sections 4.1 through 4.5 present results for subsections investigating absolute amplitude and noise level outcome measures considering factors of gender (x2), frequency (x5), ethnicity (x3), and test condition (x2). The third subsection presents results for analyses exploring the factor of absolute MEP magnitude. Refer to Chapter 6 Discussion section for a combined comprehensive discussion of DPOAE and TEOAE findings.

4.1 Non-maneuver Ambient & Post-maneuver Ambient Test Conditions

Analyses were performed comparing the TEOAE mean absolute amplitude measures obtained from the non-maneuver ambient condition to those from the post-maneuver ambient condition. This comparison is illustrated in Table 37. Refer to Appendix B Table 198 and Table 199 and for the overall findings of significance for outcome measures of absolute amplitude and noise level, respectively. A sample size of n=97 TEOAE measures from n=45 individual participants contributed to each test condition. Referencing the conventional 226 Hz tympanograms, the mean absolute MEP estimate for the non-maneuver condition was 10.55 daPa (range: 0 to 106 daPa), and for the post-maneuver condition measures, it was an absolute mean of 64.479 daPa (range: 5 to 199 daPa). The mean absolute MEP shift between test conditions was 60.64 daPa (range: 1 to 227 daPa).

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	Peak	**Ambient**	Peak

Table 37: Shaded boxes represent the test conditions under comparison.

4.1.1 Absolute Amplitude

The main effect of test condition [F(1, 93)= 18.0160, p=.00005] was significant. As was found with the same analysis for the DPOAE data, the TEOAE data showed a significant difference in mean absolute amplitude for the comparison of non-maneuver ambient versus post-maneuver ambient test condition measures with the former having the greater amplitude mean. There was a mean absolute amplitude difference of 1.06 dB SPL between the two test conditions each having a sample size of n=97 (refer to Table 38). This analysis was collapsed across factors of gender, frequency, and ethnicity. As was seen with the same test condition comparison for the DPOAE data, the post-maneuver ambient condition (2.38 dB SPL) had a significantly lower mean absolute amplitude value compared to the non-maneuver ambient test condition (3.44 dB SPL). Refer to the four test condition comparison of absolute amplitude in section 4.5 Figure 18 for a graphical display of these findings.

Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	3.44	1.23	0.99	5.88	97
Post-maneuver, Ambient	2.38	1.32	-0.24	4.99	97

Table 38: Comparison of mean TEOAE absolute amplitude between non-maneuver ambient and post-maneuver ambient test conditions. The analysis was collapsed across all factors of ethnicity, gender, and frequency. Current effect: [F(1, 93)=18.016, p=.00005].

Interactions of test condition and gender [F(1, 93)=0.1366, p=.712568] as well as test condition and ethnicity [F(2, 93)= 1.0862, p=.341740] were not significant. The main effects of ethnicity [F(2, 93)=2.7715, p=.067744] was not significant. The same findings were observed for the comparable DPOAE data analyses.

The main effect of gender was found to be significant [F(1, 93)=5.8659, p=.017376], with male participants having an average absolute TEOAE amplitude 2.57 dB SPL lower than the female participant group. The female group average was 4.19 dB SPL (n=64) compared to the male participants with an average of 1.62 dB SPL (n=33) (refer to Table 39). Interactions between factors involving ethnicity or gender were not significant.

Gender	**TEOAE Mean Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	4.19	0.64	2.93	5.46	64
Male	1.62	0.88	-0.13	3.37	33

Table 39: Comparison of TEOAE absolute amplitude between gender groups. The analysis was collapsed across factors of ethnicity, frequency, and test condition (non-maneuver ambient and post-maneuver ambient). Current effect: F(1, 93)=5.8659, p=.01738].

Comparable to the equivalent comparison for the DPOAE data, the main effect of frequency [F(4, 372)= 212.5858, p=.00000] was significant and the interaction between frequency and gender [F(4, 372)= 1.5977, p=.174254] was not significant. There is a sloping decrease in absolute TEOAE amplitude starting at an amplitude maximum for test frequency 1000 Hz to a minimum mean amplitude observed at 5000 Hz. Refer to Table 40 for frequency-specific mean amplitude values. To avoid presentation of redundant findings, a figure for the main effect of frequency was not included in this manuscript; however, the visual trend in decreasing TEOAE amplitude with increasing frequency is shown in Figure 69 and Figure 70.

Test Frequency (Hz)	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1000	12.21	0.96	10.31	14.12	97
2000	7.11	0.78	5.56	8.67	97
3000	3.30	0.95	1.42	5.18	97
4000	-1.05	1.09	-3.21	1.11	97
5000	-7.04	1.24	-9.51	-4.57	97

Table 40: Comparison of mean TEOAE absolute amplitude between test frequencies (1000 to 5000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver ambient). Current effect: [F(4, 372)=212.59, p=.0000].

Unlike the DPOAE analysis, for the TEOAE recordings the interaction between factors of frequency and ethnicity [F(4, 372)= 0.7212, p=.672790] was not significant. The trend observed in absolute amplitude for the individual ethnic groups is the same between DPOAE and TEOAE measures: A peak in absolute EOAE amplitude occurs at the lowest test frequency 1000 Hz and slopes to a minimum at 5000 Hz. Even though the overall interaction between these two factors (ethnicity and frequency) was not significant, Caucasians (n=26) had on average the lowest amplitude, followed by the Asian group (n=48) with a slightly higher mean amplitude and the Other ethnic group (n=23) had the highest absolute amplitude across all test frequencies (refer to Appendix A Figure 69 for a graphical display of these findings). Table 144 in Appendix A contains descriptive statistics (mean amplitude, CIs, and standard error) for the interaction between frequency and ethnicity for TEOAE measures of absolute amplitude.

Again, unlike the DPOAE analysis, for TEOAE recordings the interaction of test condition (non-maneuver ambient versus post-maneuver ambient) and test frequency [F(4, 372)=1.3276, p=.259102] was not significant. A trend was observed for the non-maneuver ambient condition to have greater mean amplitudes at all frequencies (1000 to 5000 Hz) compared to the post-maneuver ambient condition. Refer to Appendix A Figure 70 for a graphical display of this interaction. The post-maneuver ambient test condition reflects the uncompensated condition with TEOAEs assessed in the presence of abnormal MEP. Mean absolute amplitude values can be found in Appendix A Table 145.

4.1.2 Noise Level

Analogous to the findings with DPOAE measures, for the TEOAE outcome measures of noise level, the main effects of gender [F(1, 93)=3.100 p=.081581] and ethnicity [F(2, 93)=0.574 p=.0.565429] were not significant. Comparable to the noise level DPOAE analysis, for TEOAE measures the interactions between test condition (non-maneuver ambient and post-maneuver ambient) and gender [F(1, 93)=0.015 p=.902417] as well as test condition and ethnicity [F(2, 93)=2.675 p=.074211] were not significant.

Unlike the DPOAE analysis, the main effect of test condition (non-maneuver ambient versus post-maneuver ambient) was significant [F(1, 93)=20.80, p=.039006]. A significant finding for test condition collapsed across factors of gender, ethnicity, and frequency indicates that the noise level did differ significantly when testing at an ambient pressure for conditions when the mean MEP was centered on 0 daPa compared to some degree of abnormal MEP associated with the post-maneuver condition. The absolute difference in mean noise level between the two test conditions is only 0.04 dB SPL, with the noise level being greater in the post-maneuver ambient (-10.32 dB SPL) compared to the non-maneuver ambient (-10.65 daPa) test condition. Refer to Table 41 for TEOAE related descriptive statistics.

Test Condition	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	-10.65	0.46	-11.56	-9.74	97
Post-maneuver, Ambient	-10.32	0.49	-11.29	-9.36	97

Table 41: Comparison of mean TEOAE noise level between the non-maneuver ambient and post-maneuver ambient test conditions. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=20.80, p=.039006].

Higher-order interactions for TEOAE noise level outcome measures between frequency, gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver ambient) were all found non-significant. Analogous to the DPOAE analysis for noise level, the only analysis of significance for measures of TEOAE noise level was for the main effect of frequency [F(4, 372)=128.964, p=.00000]. This analysis was collapsed across factors of test condition, gender, and ethnicity. Refer to Table 42 for descriptive statistics. For TEOAE measures mean noise level decreased as test frequency increased from 1000 to 5000 Hz: Noise level was greatest in magnitude at the lowest test frequency of 1000 Hz with an average of -4.88 dB SPL, sloping to a minimum of -15.51 dB SPL at the highest test frequency of 5000 Hz.

Test Frequency (Hz)	**Mean Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1000	-4.88	1.12	-7.11	-2.65	97
2000	-8.08	0.26	-8.59	-7.57	97
3000	-10.36	0.16	-10.69	-10.04	97
4000	-13.59	0.21	-14.00	-13.18	97
5000	-15.51	0.33	-16.17	-14.86	97

Table 42: TEOAE noise level as a function of test frequency (1000 to 5000 Hz). The analysis collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver ambient). Current effect: [F(4, 372)=128.96, p=.0000].

This effect of frequency on TEOAE noise level was further explored looking at the difference in noise level between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of frequency. This analysis was collapsed across factors of gender and ethnicity. The interaction between test condition and frequency [F(4, 372)=1.874, p=.114375] was not significant. Table 146 in Appendix A presents the associated descriptive statistics for this analysis. Again, a trend in noise level was observed: For both test conditions, mean noise level decreased as frequency increased.

4.1.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of TEOAE absolute amplitude and noise level measures considering factors of test conditions, gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B Table 200 and Table 201.

For the outcome measure of absolute TEOAE amplitude, the interaction between test condition and absolute MEP shift magnitude [F(4, 89)=1.1821, p=.32419] was not significant. This analysis was collapsed across factors of gender, ethnicity, and frequency. Although not statistically significant, mean absolute amplitude is larger in the non-maneuver ambient condition compared to the post-maneuver ambient condition for categories A to C (refer to Table 43). The greatest difference in amplitude is seen at category E, with a difference of 1.82 dB SPL between test conditions (non-maneuver ambient and post-maneuver ambient).

|MEP| Shift Magnitude (daPa)	Test Condition	TEOAE Mean Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	3.37	3.27	-3.1	9.9	12
A (0 to 10)	Post-maneuver, Ambient	2.61	3.46	-4.3	9.5	12
B (11 to 25)	Non-maneuver, Ambient	4.51	2.82	-1.1	10.1	18
B (11 to 25)	Post-maneuver, Ambient	4.11	2.99	-1.8	10.1	18
C (26 to 50)	Non-maneuver, Ambient	3.11	2.67	-2.2	8.4	18
C (26 to 50)	Post-maneuver, Ambient	2.50	2.83	-3.1	8.1	18
D (51 to 99)	Non-maneuver, Ambient	3.54	2.30	-1.0	8.1	30
D (51 to 99)	Post-maneuver, Ambient	2.25	2.44	-2.6	7.1	30
E (>99)	Non-maneuver, Ambient	2.84	2.63	-2.4	8.1	19

|MEP| Shift Magnitude (daPa)	Test Condition	TEOAE Mean Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
E (>99)	Post-maneuver, Ambient	1.02	2.78	-4.5	6.6	19

Table 43: Comparison of TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=1.1821, p=.32419].

The interaction between test condition (non-maneuver ambient versus post-maneuver ambient) and absolute MEP shift magnitude (A to E) magnitude [F(4, 89)=.57253, p=.68326] was not significant when considering the outcome measures of noise level. The analysis was collapsed across factors of gender, ethnicity, and frequency. Refer to the Appendix A Table 147 for descriptive statistics.

4.2 Non-maneuver Ambient and Post-maneuver Peak Test Conditions

The following are analyses for the comparison between the non-maneuver ambient condition and the post-maneuver peak test condition for outcome measures of TEOAE absolute amplitude and noise level (comparison illustrated in Table 44). Refer to Appendix B Table 202 and Table 203 for analysis summaries for absolute amplitude and noise level measures. A G-G test was performed, the results of which confirmed all findings of significance. Referencing the conventional 226 Hz tympanograms, the mean absolute MEP estimate for the non-maneuver condition was 10.55 daPa (range: 0 to 106 daPa), and for the post-maneuver condition measures, it was an absolute mean of 64.479 daPa (range: 5 to 199 daPa). A sample size of n=97 TEOAE measures from n=45 individual participants contributed to each test condition.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	Peak	Ambient	**Peak**

Table 44: Shaded boxes represent the test conditions under comparison.

4.2.1 Absolute Amplitude

Equivalent to DPOAE findings, the main effect of test condition (non-maneuver ambient versus post-maneuver peak) was significant [F(1, 93)=5.1724, p=.02525]. The analysis was collapsed across factors of gender, ethnicity, and frequency and the descriptive statistics associated are shown in Table 45. The mean absolute amplitude for the post-maneuver peak condition (3.03 dB SPL) was less than the non-maneuver ambient condition mean (3.44 dB SPL). This comparison is illustrated in four test condition comparison, Figure 18.

Test Condition	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**|CI| Spread**	**n**
Non-maneuver, Ambient	3.44	1.23	0.99	5.88	4.89	97
Post-maneuver, Peak	3.03	1.27	0.50	5.55	5.05	97

Table 45: Comparison of mean TEOAE absolute amplitude between non-maneuver ambient and post-maneuver peak test conditions. The analysis was collapsed across all factors of ethnicity, gender, and frequency. Current effect: [F(1, 93)=5.1724, p=.02525].

The main effect of ethnicity [F(2, 93)=2.8066 p=.065533], was not significant. The interactions between ethnicity and test condition [F(2, 93)=2.0299, p=.137125], as well as ethnicity and frequency [F(8, 372)=0.9247, p=.495870], were not significant. These findings imply that the variation in TEOAE absolute amplitude observed between test conditions (non-maneuver ambient and post-maneuver peak) as well as across the range of test frequencies (1000 to 5000 Hz) does not differ significantly between ethnic groups.

Although the main effect of test condition was found significant, the interaction between test condition (non-maneuver ambient versus post-maneuver peak) and frequency was not significant [F(4, 372)=0.8327, p=.505016]. Mean TEOAE absolute amplitude decreased in value with an increase in test frequency (1000 to 5000 Hz) for both test conditions. Values of mean absolute amplitude, 95% CI, and standard error for the interaction of test condition and frequency are shown in Table 148 found in Appendix A. A graphical display of this non-significant finding is shown in Appendix A, Figure 71.

For the outcome measure of TEOAE absolute amplitude, the main effect of gender was significant [F(1, 93)=5.5667 p=.020397] and the associated descriptive statistics are shown in Table 46. Although the male group had a lower mean absolute amplitude value compared to females for the DPOAE measures, the main effect of gender was not significant (unlike for TEOAEs). For this analysis of TEOAE measures, male participants (mean of 1.99 dB SPL) had on average significantly lower TEOAE absolute amplitude measures compared to female participants (mean of 4.48 dB SPL).

Gender	**TEOAE Mean Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	4.48	0.63	3.22	5.73	64
Male	1.99	0.87	0.25	3.73	33

Table 46: Comparison of mean TEOAE absolute amplitude between genders. The analysis was collapsed across factors of ethnicity, frequency, and test condition (non-maneuver ambient versus post-maneuver peak). Current effect: [F(1, 93)=5.5667, p=.02040].

The interaction between gender and frequency [F(4, 372)=2.3307, p=.055541] as well as gender and test condition [F(1, 93)=0.0005, p=.981785] were not significant (p>.05). These findings for TEOAE absolute amplitude are consistent with DPOAE findings. Both these findings of non-significance indicate that the variation in absolute amplitude across the range of test frequencies (1000 to 5000 Hz) for between test condition comparisons did not differ significantly for male (n=33) and female (n=64) participants. The interaction of gender and frequency is shown in Figure 72 of Appendix A with the associated descriptive statistics displayed in Table 149 also found in Appendix A. Although not significant at each frequency, a trend was observed for the mean TEOAE amplitude level to be consistently lower for male compared to female participants at all test frequencies 1000 to 5000 Hz).

4.2.2 Noise Level

The main effect of test condition [F(1, 93)= 1.055, p=.306909] for the outcome measure of TEAOE noise level, was not significant. Although not significant, the mean TEOAE noise level is less favorable (more positive in value) in the post-maneuver peak condition (refer to Table 47 for descriptive statistics). The mean noise level for the non-maneuver ambient test condition (n=97) was -10.65 dB SPL and it was -10.40 dB SPL for the post-maneuver peak condition (n=97), lending to a non-significant difference of 0.16 dB SPL. For the DPOAE measures, there was a non-significant difference of 0.63dB SPL between the test conditions. In section 4.5, Figure 77 displays the mean noise level for all four test conditions.

Test Condition	Mean TEOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	-10.65	0.46	-11.56	-9.73	97
Post-maneuver, Peak	-10.40	0.37	-11.13	-9.68	97

Table 47: Comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of frequency, gender, and ethnicity. Current effect: [F(1, 93)=1.0555, p=.30691].

Main effects of gender [F(1, 93)=1.591, p=.210296] and ethnicity [F(2, 93)=0.560, p=.572849] were not significant. Interactions between test condition and gender [F(1, 93)=1.760, p=.187932], test condition and ethnicity [F(2, 93)=0.107, p=.898976], frequency and gender [F(4, 372)=0.872, p=.481033], frequency and ethnicity [F(8, 372)=0.636, p=.747661] were also not significant. These findings of significance for TEOAE measures are analogous to the analyses for DPOAE noise level.

For the outcome measures of noise level, the main effect of frequency [F(4, 372)=295.17, p=0.0000] was significant. There was a consistent decrease in noise level with an increase in test frequency; the greatest mean noise level was identified at the lowest test frequency of 1000 Hz and the minimum noise level at 5000 Hz (refer to Table 48). The pattern of mean noise level plotted as a function of frequency is similar to the pattern observed for mean absolute amplitude plotted as a function of frequency in Figure 71 and Figure 72. This consistency in patterns between noise level and amplitude measures as a function of frequency was also seen for DPOAE analyses. This pattern is also consistent with the findings for the comparisons of TEOAE non-maneuver ambient versus post-maneuver ambient analysis of frequency and noise level.

Test Frequency (Hz)	**TEOAE Mean Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1000	-5.14	0.611	-6.35	-3.92	97
2000	-8.19	0.247	-8.69	-7.70	97
3000	-10.36	0.181	-10.72	-10.00	97
4000	-13.31	0.311	-13.93	-12.70	97
5000	-15.62	0.322	-16.26	-14.98	97

Table 48: Comparison of mean TEOAE noise level as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus post-maneuver peak). Current effect: [F(4, 372)=295.17, p=0.0000].

For the outcome measure of noise level, a finding of non-significance [F(4, 372)=.42861, p=.78798] was observed for the interaction between test condition (non-maneuver ambient and post-maneuver peak) and frequency. This analysis was collapsed across factors of ethnicity and gender. Refer to Appendix A Table 150 for descriptive statistics. This finding indicates that the variation in absolute amplitude for TEOAE measures across the range of test frequencies did not differ between the two test conditions (non-maneuver ambient versus post-maneuver peak). These findings of significance and non-significance are comparable between DPOAE and TEOAE measures.

4.2.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of TEOAE absolute amplitude and noise level measures considering factors of test conditions, gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 204 and Table 205.

For the outcome measure of absolute amplitude, the interaction of test condition (non-maneuver ambient versus post-maneuver peak) and absolute MEP shift magnitude which was found non-significant [F(4, 89)=1.9070, p=.11621]. Mean absolute amplitude values for each category and test conditions are shown in Table 151 in Appendix A. A graphical display of this interaction is shown in Appendix A, Figure 73.

For the outcome measure of noise level, the interaction of test condition (non-maneuver ambient versus post-maneuver peak) and absolute MEP shift magnitude is not significant [F(4, 89)=1.1058, p=.35886]. Refer to Appendix A Table 152 for descriptive statistics. A finding of non-significance was also seen for the same interaction with DPOAE measures.

4.3 Non-maneuver Ambient and Non-maneuver Peak Test Conditions

The following is the presentation of analyses for the comparison between the non-maneuver ambient and non-maneuver peak test conditions for outcome measures of TEOAE absolute amplitude and noise level (comparison illustrated in Table 49). Refer to Appendix B Table 206 and Table 207 for the overall findings of significance for both absolute amplitude and noise level measures, respectively. Based on the estimates from the conventional 226 Hz tympanogram, the absolute mean MEP estimate associated with the non-maneuver condition TEOAE measures (n=97 measures per test condition) was 10.55 daPa.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	**Peak**	Ambient	Peak

Table 49: Shaded boxes represent the test conditions under comparison.

4.3.1 Absolute Amplitude

Table 50 contains the descriptive statistics for the main effect of test condition [F(1, 93)=1.7906, p=.18412] which was not significant. The analysis was collapsed across factors of gender, ethnicity, and frequency (1000 to 5000 Hz). Refer to section 4.5 Figure 18 for a summarizing graphical representation of the mean TEOAE absolute amplitude between the four test conditions.

Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	3.44	1.23	0.99	5.88	97
Non-maneuver, Peak	3.60	1.20	1.22	5.98	97

Table 50: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=1.7906, p=.18412].

Unlike the equivalent analysis with DPOAE data, for the TEOAE absolute amplitude outcome measure, the main effect of ethnicity [F(2, 93)=4.2267, p=.01750] was significant. There was a significant difference in mean absolute amplitude measures between ethnic groups, collapsed across test conditions, frequency, and gender. Caucasians had the lowest mean value (1.74 dB SPL), followed by the Asian group (3.14 dB SPL). The Other group had the greatest mean amplitude value (5.68 dB SPL). Table 51 contains the descriptive statistics for this main effect analysis of ethnicity. Interactions between ethnicity and test condition [F(2, 93)=1.5288, p=.222201] and for the interaction between ethnicity and frequency [F(8, 372)=0.8553, p=.554562] were not significant.

Ethnicity	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n

Caucasian	1.74	0.96	-0.17	3.65	26
Asian	3.14	0.71	1.73	4.55	48
Other	5.68	1.01	3.67	7.70	23

Table 51: Comparison of mean TEOAE absolute amplitude between ethnic groups (Caucasians n=26, Asians n=48, and Others n=23). The analysis was collapsed across factors of test condition (non-maneuver ambient and non-maneuver peak), gender, and frequency. Current effect: [F(2, 93)=4.2267, p=.01750].

Although the interaction between ethnicity and test condition was not significant [F(2, 93)=1.5288, p=.22220], the Caucasian (n=26) group had on average for both test conditions, lower TEOAE absolute amplitude means compared to both Asian (n=48) and Other (n=23) participant groups (refer to Appendix A Table 153). The Other ethnic group showed the greatest mean TEOAE amplitude value for both test conditions. This analysis of the interaction between ethnicity and test condition was collapsed across factors of gender and frequency.

Unlike the equivalent analysis with DPOAE data, for the TEOAE absolute amplitude outcome measure the main effect of gender was significant [F(1, 93)=6.0662, p=.01562]. Parallel to the trend observed with the DPOAE analysis, for TEOAE associated data, the male participants had a lower mean absolute amplitude value compared to female participants. A difference of 2.54 dB SPL was seen between gender groups (Table 52 contains the descriptive statistics). The interaction between gender and test condition [F(1, 93)=0.2000, p=.655736] and the interaction between gender and frequency [F(4, 372)=2.0011, p=.093768] were not significant. These findings indicate that any variation in the absolute amplitude between test frequencies (1000 to 5000 Hz) and between test conditions did not differ between male and female participants.

Gender	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	4.79	0.62	3.56	6.02	64
Male	2.25	0.85	0.56	3.95	33

Table 52: Comparison of mean TEOAE absolute amplitude between genders (n=64 females and n=33 males). The analysis was collapsed across factors of ethnicity, frequency, and test condition (non-maneuver ambient versus peak). Current effect: [F(1, 93)=6.0662, p=.01562].

The main effect of frequency [F(4, 372)=246.6767, p=.00000] was significant: Absolute TEOAE amplitude decreased with an increase in test frequency (1000 to 5000 Hz). The same pattern for TEOAE amplitude plotted against frequency can be seen in Appendix A Figure 74, which illustrates the non-significant interaction between test condition and frequency [F(4, 372)=1.1826, p=.31800]. This shows that the variation in absolute amplitude observed across frequencies does not differ between test conditions (non-maneuver ambient and peak)). Although the interaction between these factors was not statistically significant, a trend was observed (as was seen for the same DPOAE analysis), for the mean TEOAE absolute amplitude to be greater in the peak pressure condition compared to the ambient condition for comparisons across test frequencies, with the exception of 3000 Hz. The mean amplitude values can be seen in Table 154 in Appendix A.

4.3.2 Noise Level

The main effect of test condition [F(1, 93)=.06362, p=.80143] collapsing the analysis across factors of gender, ethnicity, and frequency was not significant. The same finding of non-significance was seen for the comparable analysis with DPOAE measures. Table 53 contains the associated descriptive statistics for this main effect analysis. Refer to section 4.5 Figure 77 for the comparison of mean TEOAE noise level between the four test conditions.

Test Condition	Mean TEOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	|CI| Spread	n
Non-maneuver, Ambient	-10.6	0.46	-11.56	-9.73	1.83	97
Non-maneuver, Peak	-10.6	0.80	-12.13	-8.98	3.15	97

Table 53: Descriptive statistics for the comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=.06362, p=.80143].

The main effect of frequency was significant [F(4, 372)=92.219, p=0.0000]. There were n=97 TEOAE recordings for each of the five test frequencies (1000 to 5000 Hz). Table 54 contains descriptive statistics for this main effect analysis. The mean noise level decreased in magnitude (more negative in value) with an increase in frequency. This pattern is consistent with the findings for the comparisons of TEOAE non-maneuver ambient versus post-maneuver ambient analysis (section 4.1) for the interaction between frequency and noise level, as well as for test conditions non-maneuver ambient versus post-maneuver peak (section 4.2).

Test Frequency (Hz)	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1000	-4.96	0.62	-6.21	-3.72	97
2000	-8.15	0.30	-8.75	-7.55	97
3000	-10.28	0.25	-10.78	-9.77	97
4000	-13.17	0.38	-13.93	-12.42	97
5000	-16.44	1.23	-18.89	-13.99	97

Table 54: Comparison of mean TEOAE noise level between test frequencies (1000 to 5000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (non-maneuver ambient versus peak). Current effect: [F(4, 372)=92.219, p=.0000].

The interaction between test condition (non-maneuver ambient versus peak) and frequency was not significant [F(4, 372)=.56622, p=.68732]. This interaction followed the same pattern as was seen for the main effect of frequency: Noise level decreased as frequency increased. The descriptive statistics for this interaction analysis are displayed in Table 155 in Appendix A. Although the overall interaction was not significant, for frequencies 1000 to 4000 Hz, a trend was observed for the non-maneuver ambient compared to the peak pressure test condition to have a lower mean noise level.

For the outcome measures of noise level, the main effects of gender [F(1, 93)=3.532, p=.063330] and ethnicity [F(2, 93)=1.630, p=.201513] were not significant. These findings match the significance of findings for the same main effect analyses for DPOAE measures. Contrasting the findings for DPOAE measures, for the TEOAE measures the interaction between test condition and gender [F(1, 93)=0.215, p=.644133] was not significant nor was the interaction between test condition and ethnicity [F(2, 93)=1.623, p=.202855]. A high-order interaction of significance between test condition, frequency, and ethnicity was found for the DPOAE analysis but this specific interaction concerning TEOAE measures was not significant [F(8, 372)=1.487, p=.160006].

4.3.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of TEOAE absolute amplitude and noise level measures considering factors of test conditions (non-maneuver ambient and peak), gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B Table 208 and Table 209.

For TEOAE measures the main effect of absolute MEP magnitude category was not significant [F(4, 89)=0.40186, p=.806836]. The interaction between absolute MEP magnitude and test condition [F(4, 89)=2.3560, p=.05969] was not significant. Although not significant, there was a trend for the mean absolute amplitude to be larger for the peak compared to the ambient test condition at absolute MEP categories A to D (see Table 55). The small sample size in the test conditions corresponding to greater absolute MEP magnitude is not ideal from a statistical analysis standpoint but was sought after for testing in the non-maneuver condition.

|MEP| Magnitude (daPa)	Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	3.70	1.55	0.6	6.79	63
A (0 to 10)	Non-maneuver, Peak	3.92	1.50	0.9	6.91	63
B (11 to 25)	Non-maneuver, Ambient	2.57	2.24	-1.9	7.01	26

|MEP| Magnitude (daPa)	Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
B (11to 25)	Non-maneuver, Peak	2.81	2.17	-1.5	7.12	26
C (26 to 50)	Non-maneuver, Ambient	4.21	4.57	-4.9	13.29	6
C (26 to 50)	Non-maneuver, Peak	4.33	4.43	-4.5	13.13	6
D (51 to 99)	Non-maneuver, Ambient	6.06	11.29	-16.4	28.50	1
D (51 to 99)	Non-maneuver, Peak	7.83	10.94	-13.9	29.57	1
E (>99)	Non-maneuver, Ambient	3.95	11.33	-18.6	26.45	1
E (>99)	Non-maneuver, Peak	1.17	10.97	-20.6	22.98	1

Table 55: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=2.3560, p=.05969].

For the outcome measure of TEOAE noise level, the interaction between test condition and absolute MEP magnitude was significant [F(4, 89)=4.0118, p=.00488]. Descriptive statistics for this interaction are shown in Table 56. This finding of significance should be interpreted with caution due to the extremely small sample size in categories C to E. A Tukey's HSD test showed that for the comparison of mean TEOAE noise level between test conditions across categories of absolute MEP magnitude, only category C (MEP 26 to 50 daPa) showed significance (Appendix A, Table 157). This analysis was collapsed across factors of gender, ethnicity, and frequency. The same interaction for the DPOAE measures was found not to be significant.

|MEP| Magnitude (daPa)	Test Condition	Mean TEOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	-10.26	0.56	-11.38	-9.15	63
A (0 to 10)	Non-maneuver, Peak	-9.90	0.92	-11.73	-8.08	63
B (11 to 25)	Non-maneuver, Ambient	-11.44	0.81	-13.04	-9.84	26
B (11to 25)	Non-maneuver, Peak	-10.65	1.32	-13.28	-8.02	26
C (26 to 50)	Non-maneuver, Ambient	-10.69	1.65	-13.96	-7.42	6
C (26 to 50)	Non-maneuver, Peak	-15.38	2.70	-20.75	-10.02	6
D (51 to 99)	Non-maneuver, Ambient	-10.21	4.07	-18.30	-2.13	1
D (51 to 99)	Non-maneuver, Peak	-10.67	6.68	-23.94	2.60	1
E (>99)	Non-maneuver, Ambient	-11.34	4.08	-19.44	-3.23	1
E (>99)	Non-maneuver, Peak	-11.48	6.70	-24.79	1.83	1

Table 56: Comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=4.0118, p=.00488].

4.4 Post-maneuver Ambient and Post-maneuver Peak Test Conditions

The main effect for the following analyses was the comparison between the post-maneuver ambient and post-maneuver peak test conditions for the outcome measures of TEOAE absolute amplitude and noise level (comparison illustrated in Table 57). There were n=97 individual TEOAE recordings from n=45 participants contributing to both post-maneuver test conditions. The overall statistical findings from the mixed ANOVAs involving either TEOAE absolute amplitude or noise level can be found in Appendix B Table 210 and Table 212, respectively. A summary of a G-G analysis for absolute amplitude measures can be found in Appendix B Table 211. Referencing the conventional 226 Hz tympanograms, the mean absolute MEP estimate for the post-maneuver condition measures was 64.479 daPa (range: 5 to 199 daPa).

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	Ambient	Peak	**Ambient**	**Peak**

Table 57: Shaded boxes represent the test conditions under comparison.

4.4.1 Absolute Amplitude

The main effect of test condition was significant [F(1, 93)=8.4336, p=.00460], with the mean absolute amplitude being greater in the peak condition (3.03 dB SPL) compared to the ambient condition (2.38 dB SPL). This analysis was collapsed across factors of gender, ethnicity, and frequency. Table 58 contains the descriptive statistics for the main effect of the factor of test condition. Refer to the four test condition comparison in section 4.5 for TEOAE absolute amplitude, Figure 18.

Test Condition	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Post-maneuver, Ambient	2.38	1.32	-0.24	4.99	97
Post-maneuver, Peak	3.03	1.27	0.50	5.55	97

Table 58: Descriptive statistics for the comparison of mean TEOAE absolute amplitude between test conditions (post-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=8.4336, p=.00460].

The main effect of gender [F(1, 93)=5.6382, p=.01963] was significant indicating mean absolute amplitude differed between male and female participants. For the analysis collapsing across factors of ethnicity, frequency, and test condition, male participants (n=33) had a mean absolute amplitude of 1.41 dB SPL compared to the female (n=64) participant group having a mean of 3.99 dB SPL (refer to Table 59). This finding is unlike that from the DPOAE analysis, because although male participants had an overall lower mean DPOAE absolute amplitude compared to females, the difference between genders was not significant. Similar to the DPOAE analysis, for TEOAE measures the male participant group had a substantially smaller sample size compared to the female group lending to the larger range in confidence for male participants. The variation in absolute amplitude observed across the range of test frequencies (1000 to 5000 Hz) and between test conditions did not differ significantly between female and male participants: The interaction between gender and test condition [F(1, 93)=0.1564, p=.693443] and between gender and frequency [F(4, 372)=1.7167, p=.145567] were not significant.

Gender	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	3.99	0.65	2.69	5.28	64
Male	1.41	0.90	-0.37	3.20	33

Table 59: Comparison of mean TEOAE absolute amplitude between genders (n=64 females and n=33 males). The analysis was collapsed across factors of ethnicity, frequency, and test condition (post-maneuver ambient versus peak). Current effect:[F(1, 93)=5.6382, p=.01963].

The main effect of frequency [F(4, 372)=215.84, p=.0000] was significant. Presented in Table 60, the mean TEOAE absolute amplitude decreased in magnitude with an increase in frequency (1000 to 5000 Hz). This finding of significance for the main effect of frequency was consistent when the analysis was collapsed across any combination of test conditions and for all between test condition comparisons.

Test Frequency (Hz)	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
1000	11.97	0.97	10.04	13.91	97
2000	6.88	0.80	5.29	8.47	97
3000	2.96	0.98	1.02	4.90	97
4000	-1.14	1.09	-3.30	1.03	97
5000	-7.17	1.23	-9.61	-4.74	97

Table 60: Mean TEOAE absolute amplitude comparison between test frequencies (1000 to 5000 Hz). The analysis was collapsed across factors of gender, ethnicity, and test condition (post-maneuver ambient versus peak). Current effect:[F(4, 372)=215.84, p=.0000].

The interaction between frequency and ethnicity [F(8, 372)=0.6749, p=.713713] was not significant collapsing the analysis across factors of gender and test condition (post-maneuver ambient and peak). The interaction between ethnicity and test condition [F(2, 93)=0.0242, p=.976088] was also not significant with the analysis collapsed across factors of gender and frequency. The disparity in absolute amplitude observed across test frequencies and between test conditions did not significantly differ for Caucasian (n=26), Asian (n=48), and Other (n=23) participant groups. When the analysis was collapsed across factors of gender, frequency, and test condition (post-maneuver ambient versus peak), the main effect of ethnicity was also not significant [F(2, 93)=1.9659, p=.145807]. Unlike for the TEOAE analyses discussed above, the interaction of ethnicity and test condition, as well as ethnicity and frequency, were significant for DPOAE amplitude measures.

The interaction between frequency and test condition [F(4, 372)=.73760, p=.56679] was not significant. A graphical display of this interaction is shown in Figure 75 of Appendix A. This non-significant finding implies that the variation in amplitude across frequencies did not differ between the two test conditions (post-maneuver ambient and post-maneuver peak). The descriptive statistics are displayed in Table 61: The mean amplitude value is greater in the peak compared to the ambient test condition at each frequency comparison (1000 to 5000 Hz). Although the overall interaction was not significant for TEOAE measures, a trend was observed for the post-maneuver peak condition to have larger mean TEOAE absolute amplitudes at frequencies 1000 to 4000 Hz compared to the ambient pressure condition. The same comparison for DPOAE measures for the interaction between test condition and frequency was also not significant.

Test Condition	Frequency (Hz)	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Post-maneuver, Ambient	1000	11.49	1.01	9.48	13.50	97
Post-maneuver, Peak	1000	12.46	0.54	11.39	13.53	97
Post-maneuver, Ambient	2000	6.31	0.60	5.12	7.50	97
Post-maneuver, Peak	2000	7.46	0.60	6.27	8.64	97
Post-maneuver, Ambient	3000	2.69	0.69	1.32	4.07	97
Post-maneuver, Peak	3000	3.22	0.70	1.83	4.61	97
Post-maneuver, Ambient	4000	-1.37	0.79	-2.95	0.21	97
Post-maneuver, Peak	4000	-0.91	0.80	-2.49	0.68	97
Post-maneuver, Ambient	5000	-7.24	0.88	-8.98	-5.49	97
Post-maneuver, Peak	5000	-7.11	0.88	-8.85	-5.36	97

Table 61: Mean TEOAE absolute amplitude comparison between test conditions (post-maneuver ambient versus peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Shaded rows identify the post-maneuver peak test condition data. Current effect: [F(4, 372)=.73760, p=.56679].

4.4.2 Noise Level

Considering the outcome measure of TEOAE noise level, the main effect of gender [F(1, 93)=1.500, p=.223828] and the main effect of ethnicity [F(2, 93)=0.934, p=.396696) were not significant. The same outcome for the main effect of gender and ethnicity were also seen for the analyses of DPOAE noise level. For TEOAEs (comparable DPOAE findings), the interactions between test condition and gender [F(1, 93)=2.144, p=.146461] as well as test condition and ethnicity [F(2, 93)=1.808, p=.169619] were also not significant.

The main effect of test condition [F(1, 93)=.13100, p=.71822] was not significant. This analysis was collapsed across factors of gender, ethnicity, and frequency. The same comparison (post-maneuver ambient versus post-maneuver peak noise level) for DPOAE measures was also not significant. Refer to the four test condition comparison for TEOAE measures in section 4.5, Figure 77, for a graphical display of noise level between test conditions. Referencing Table 62, the post-maneuver peak condition (-10.40 dB SPL) had a lower mean noise level compared to the ambient condition (-10.32 dB SPL).

Test Condition	Mean TEOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Post-maneuver, Ambient	-10.32	0.49	-11.29	-9.36	97
Post-maneuver, Peak	-10.40	0.37	-11.13	-9.68	97

Table 62: Descriptive statistics for the comparison of mean TEOAE noise level between test conditions (post-maneuver ambient versus peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=.13100, p=.71822].

As was seen with the DPOAE measures, the only finding of significance regarding the outcome measure of TEOAE noise level was for the main effect of frequency [F(4, 372)=243.902, p=.00000]. The mean noise level decreased with an increase in frequency (1000 to 5000 Hz). The interaction between test condition (post-maneuver ambient versus peak) and frequency was not significant [F(4, 372)=0.582, p=.675933], showing that the variation in noise between frequencies did not differ between test conditions (refer to Appendix A Table 158). The pattern observed for noise level as a function of frequency (1000 to 5000 Hz) was comparable to the configuration observed for mean absolute amplitude as a function of frequency: Both mean noise level and TEOAE absolute amplitude decreased with increasing frequency.

4.4.3 Further Investigations; Middle Ear Pressure Magnitude

Appendix B, Table 213 and Table 214 contains the statistical analysis summaries involving the factor of absolute MEP magnitude for TEOAE post-maneuver ambient versus post-maneuver peak test condition comparisons of absolute amplitude and noise level.

For the outcome measure of TEOAE absolute amplitude, the interaction between test conditions (post-maneuver ambient versus peak) and absolute MEP magnitude was not significant [F(4, 89)=.42440, p=.79065]. This interaction analysis was collapsed across factors of gender, ethnicity, and frequency. The descriptive statistics are presented in Table 159 of Appendix A. There was a trend observed for the TEOAE categories B (n=16), C (n=29), D (n=35) and E (n=22) to have a greater mean absolute TEOAE amplitude in the post-maneuver peak condition compared to the ambient condition. This difference between test conditions is illustrated in Figure 76 found in Appendix A. This same trend was also observed for the analogous DPOAE analysis.

The high-order interaction between ethnicity, frequency, and test condition [F(16, 256)=1.0350, p=.418463] was significant when the analysis was collapsed across factors of gender and absolute MEP magnitude. From a visual analysis of Figure 17, Caucasians, Asians, and Others had a similar pattern for absolute amplitude plotted against the test frequency range: Absolute amplitude decreases with an increase in frequency. The Other group had on average higher absolute amplitude means 1000 to 5000 Hz compared to both Asians and Caucasians, while the Asian group had greater mean values compared to Caucasians. The differences in mean amplitude between ethnic groups grew with an increase in frequency from 1000 to 5000 Hz. The descriptive statistics associated with this interaction analysis can be found in Appendix A Table 160.

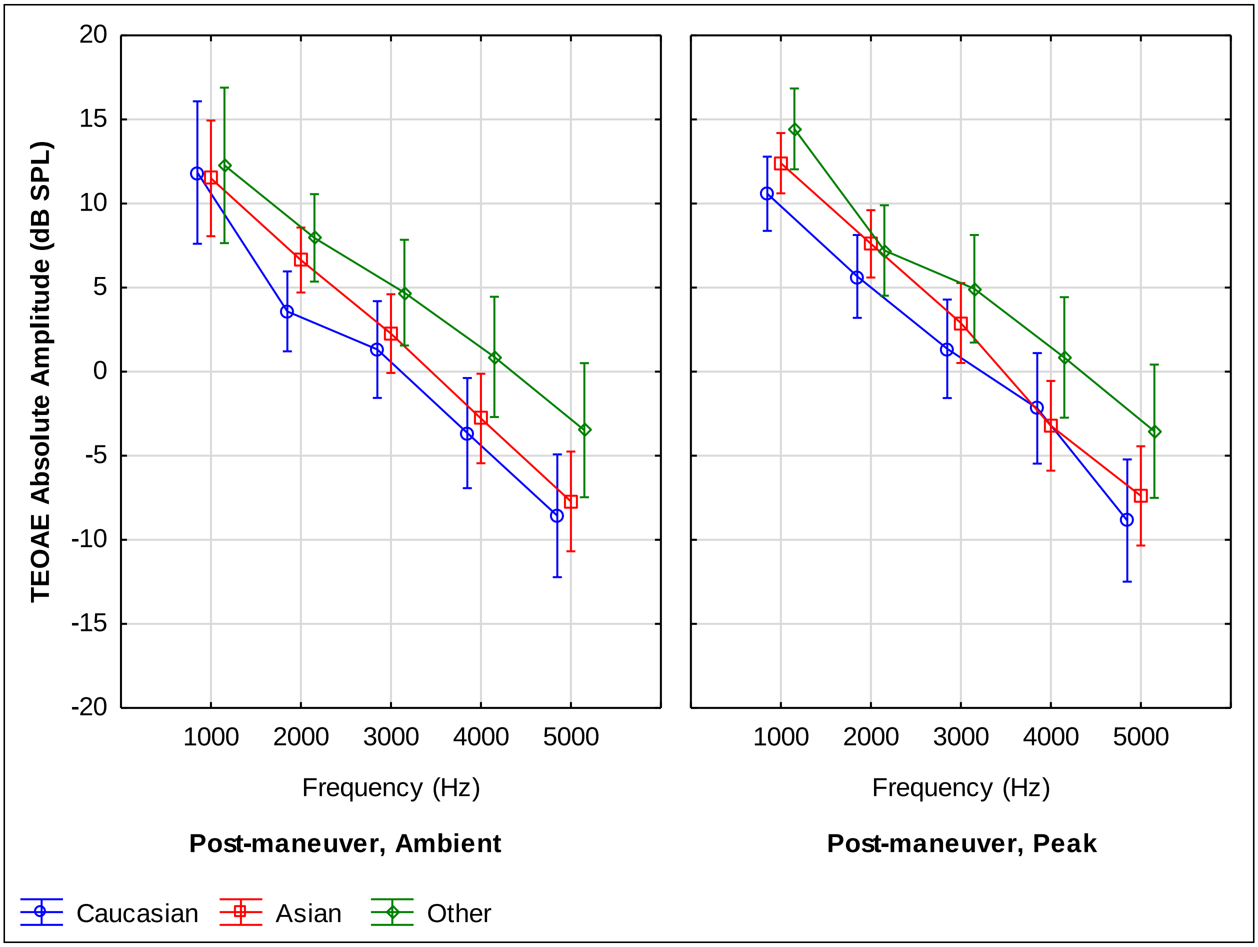


Figure 17: Comparison of TEOAE absolute amplitude between test conditions (post-maneuver ambient n=97 versus post-maneuver peak n=97) and ethnic groups, as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factor of gender and absolute MEP magnitude. Vertical bars denote 95th percent confidence intervals. Current effect: [F(8, 356)=2.0201, p=.04329].

For the outcome measure of TEOAE noise level, the interaction between test condition and absolute MEP magnitude [F(4, 89)=.38231, p=.82075] was not significant. This non-significant finding indicates that the variation in noise level between test conditions did not differ for the categories A to E. Descriptive statistics are presented in Appendix A Table 161.

4.5 TEOAE Four Test Condition Comparison

Outcome measures of absolute TEOAE amplitude and TEOAE noise level were investigated comparing all four test conditions (illustrated in Table 63). The statistical analysis summary for both outcomes measures can be found in Appendix B Table 215 and Table 216, respectively.

	Non-maneuver Condition		**Post-maneuver Condition**	
Test Pressure Condition	**Ambient**	**Peak**	**Ambient**	**Peak**

Table 63: Shaded boxes represent the test conditions under comparison.

4.5.1 Absolute Amplitude

The main effects of test condition **[**F(3, 279)=14.482, p=.00000] was significant. Figure 18 shows the test conditions with the largest to smallest mean absolute amplitude was in the order of (1) non-maneuver peak (3.60 dB SPL), (2) non-maneuver ambient (3.44 dB SPL), (3) post-maneuver peak (3.03 dB SPL), and then (4) post-maneuver ambient (2.38 dB SPL). The analysis for the main effect of test condition was done collapsing across factors of gender, ethnicity, and frequency. A Tukey's HSD analysis shows the mean absolute TEOAE amplitude between certain test conditions was significant (refer to Table 65 for descriptive statistics). This post-hoc analysis indicated the following results: (1) the difference between the two non-maneuver (ambient and peak) conditions was not significant, (2) the difference between the non-maneuver ambient and post-maneuver peak conditions was not significant, (3) the difference in absolute amplitude between the non-maneuver ambient and post-maneuver ambient conditions was significant and (4) a significant difference in absolute amplitude was seen for the comparison between the post-maneuver ambient and post-maneuver peak test conditions. The pattern of significance between test conditions differed for the TEOAE and DPOAE analyses when analyzing simultaneously across all four test conditions, rather than the two-test condition comparisons.

Test Condition	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	3.44	1.23	0.99	5.88	97
Non-maneuver, Peak	3.60	1.20	1.22	5.98	97
Post-maneuver, Peak	3.03	1.27	0.50	5.55	97
Post-maneuver, Ambient	2.38	1.32	-0.24	4.99	97

Table 64: Comparison of mean TEOAE absolute amplitude between the four test conditions (non-maneuver and post-maneuver). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 279)=14.482, p=.00000].

Cell No.	Tukey HSD test; Within MSE = 8.1535, df = 279.00				
	Test Condition	{1} 3.71	{2} 3.84	{3} 3.33	{4} 2.70
1	Non-maneuver, Ambient		0.90	0.16	**0.00**
2	Non-maneuver, Peak	0.90		**0.03**	**0.00**
3	Post-maneuver, Peak	0.16	**0.03**		**0.00**
4	Post-maneuver, Ambient	**0.00**	**0.00**	**0.00**	

Table 65: Tukey’s HSD analysis for the comparison of mean TEOAE absolute amplitude between four test conditions (n=97 samples for each test condition). The analysis was collapsed across factors of gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

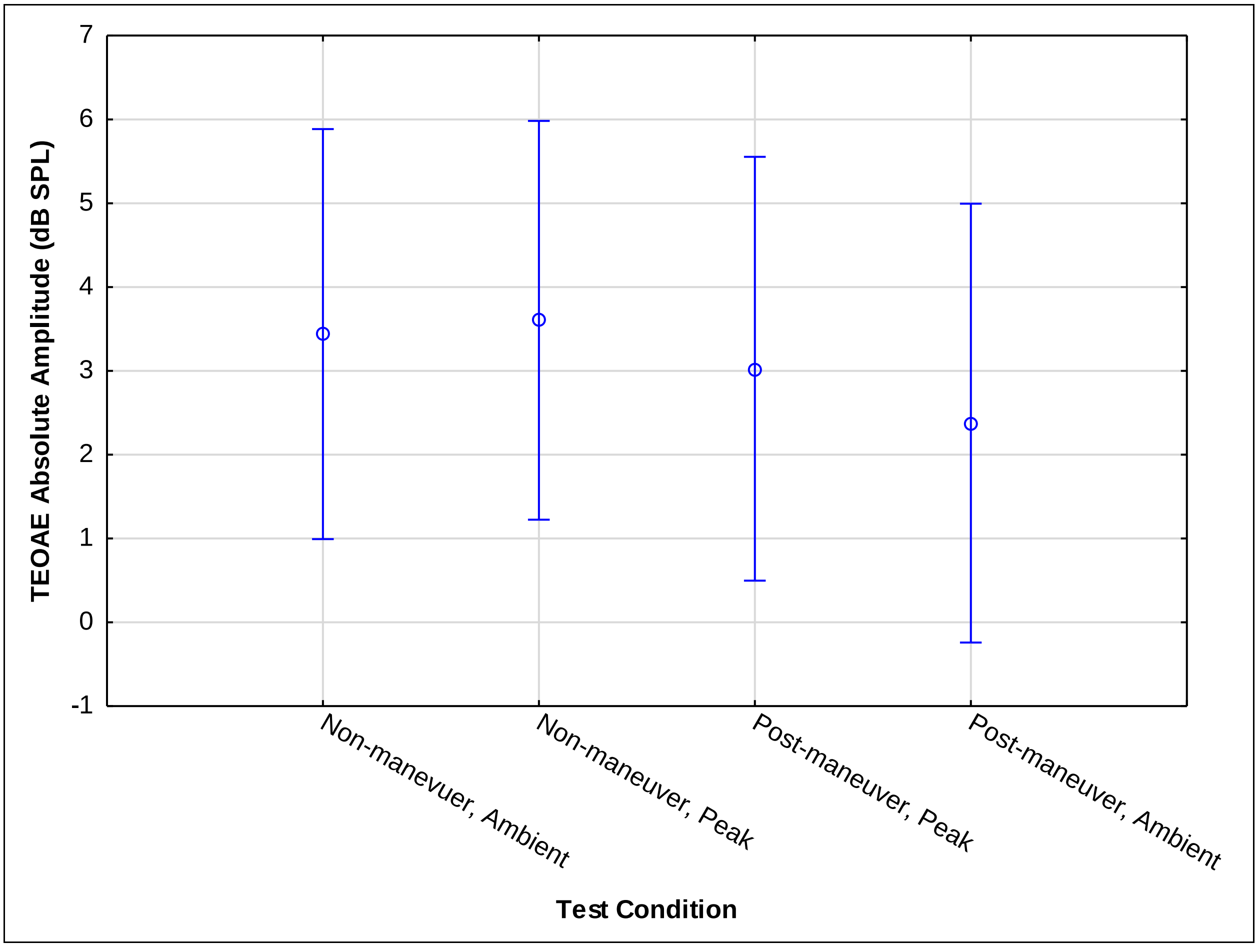


Figure 18: Comparison of mean TEOAE absolute amplitude between the four test conditions: (1) Non-maneuver Ambient (n=97), (2) Non-maneuver Peak (n=97), (3) Post-maneuver Peak (n=97), (4) Post-maneuver Ambient (n=97). The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 279)=14.482, p=.00000].

The main effect of gender [F(1, 93)=5.9836, p=.01632] was significant. For TEOAE measures, male participants (n=33, mean 1.83 dB SPL) had on average a lower mean absolute amplitude compared to female participants (n=64, 4.39 dB SPL) (refer to Table 66 for descriptive statistics). This finding of significance and female participants showing the greater mean EOAE amplitude is analogous to the findings for the DPOAE analysis.

Gender	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	4.39	0.63	3.14	5.64	64
Male	1.83	0.87	0.11	3.55	33

Table 66: Comparison of mean TEOAE absolute amplitude between gender groups (n=64 females and n=33 males). The analysis was collapsed across factors of ethnicity, frequency, and test condition (non-maneuver and post-maneuver, both ambient and peak pressure conditions). Current effect: [F(1, 93)=5.9836, p=.01632].

The interaction between gender and test condition (x4) for TEOAE measures, was not significant [F(3, 279)=.09445, p=.96306]. This demonstrates that the variation in absolute amplitude across test conditions did not differ between male and female participants. Figure 19 shows the pattern of absolute amplitude magnitude across test conditions is similar between gender groups and matched the pattern seen in Figure 18 for the main effect for the factor of test condition. Descriptive statistics are shown in Table 162 in Appendix A.

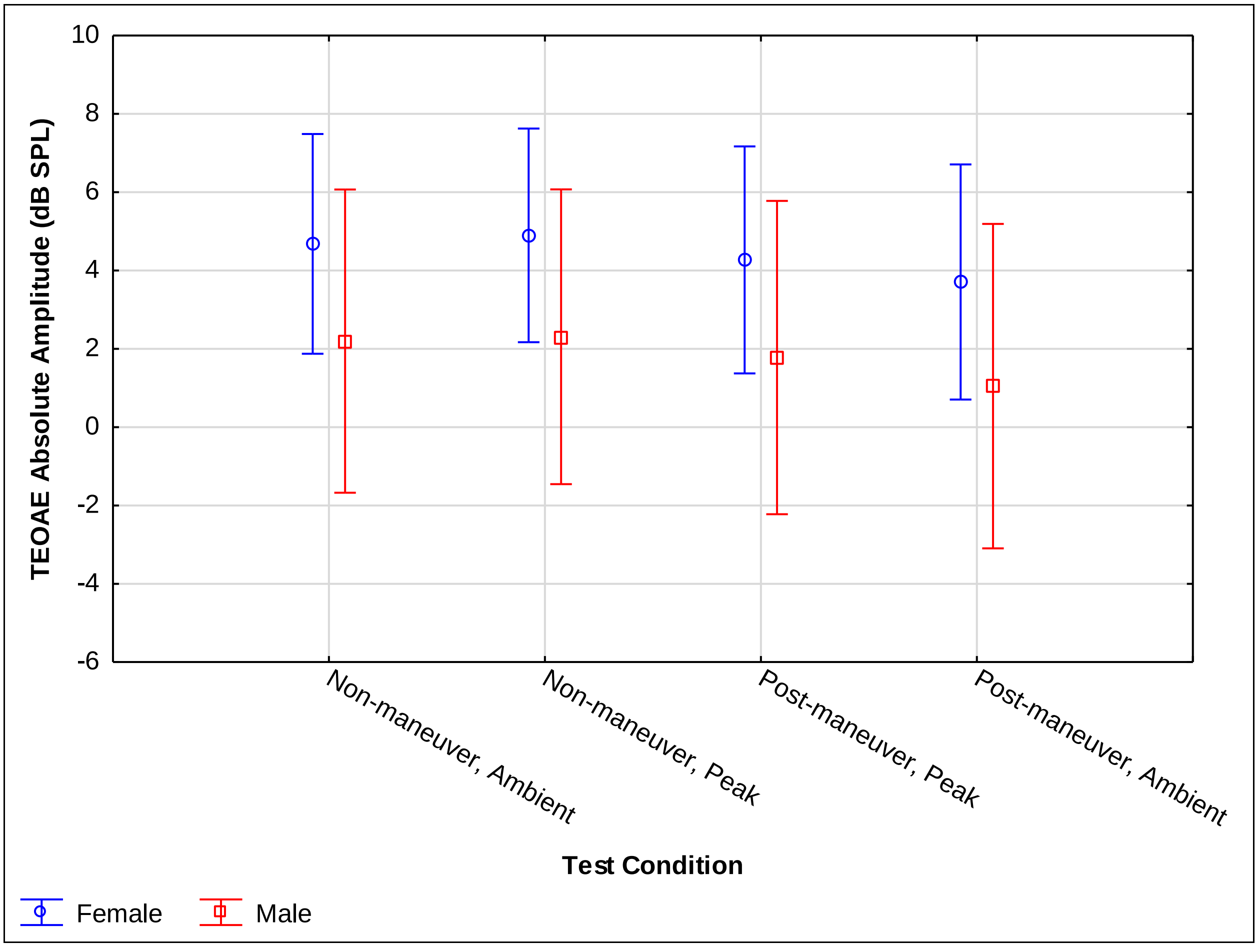


Figure 19: Comparison of mean TEOAE absolute amplitude between gender groups (n=64 females and n=33 males) as a function of test condition (x4, non-maneuver and post-maneuver). The analysis was collapsed across factors of ethnicity and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 279)=.09445, p=.96306].

Unlike the analysis for the DPOAE measures, for TEOAE measures the main effect of ethnicity [F(2, 93)=3.0301, p=.05311] was significant (refer to Table 67). The difference in absolute amplitude between ethnic groups reflects the configuration already shown in the two-way test condition comparisons: The Other group (n=26) had the largest mean amplitude, followed by the Asian group (n=48) and Caucasian group (n=23) had the smallest mean amplitude.

Ethnicity	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	1.57	0.98	-0.37	3.51	26
Asian	2.80	0.72	1.37	4.23	48
Other	4.96	1.03	2.92	7.01	23

Table 67: Comparison of mean TEOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Other). The analysis was collapsed across factors of gender, frequency, and test condition (non-maneuver and post-maneuver, both ambient and peak pressure). Current effect: [F(2, 93)=3.0301, p=.05311].

The interaction between ethnicity and test condition (x4) was not significant [F(6, 279)=1.7832, p=.10248]. This demonstrates the variation in absolute amplitude across test conditions did not differ for Caucasian, Asian, and Other participants. The pattern of absolute amplitude across test conditions is similar between ethnic groups and matched the pattern seen for the main effect of test condition. The descriptive statistics for the interaction of ethnicity and test condition are shown in Table 163 in Appendix A (graphical display of this analysis is in the Discussion, section 6.3.2). Similar to TEOAE data, DPOAE measures show no significant interaction between ethnicity and test condition with the same pattern in mean amplitude observed between ethnic groups (absolute EOAE amplitude in the order of Others > Asians > Caucasians).

The main effect of frequency [F(4, 372)=246.8823, p=.00000] was significant. Mean absolute amplitude decreased with an increase in frequency. The interactions between frequency and gender, as well as frequency and ethnicity, were not significant demonstrating that the variation in absolute amplitude observed across the test frequency range (1000 to 5000 Hz) did not vary between the three ethnic groups, or for male and female participants. These findings are consistent with those already explored with the two-way test condition comparisons.

Unlike the DPOAE analysis, the interaction between frequency and test condition [F(12, 1116)=1.0371, p=.41169] was not significant for TEOAE measures of absolute amplitude collapsing across factors of gender and ethnicity. This implies that the variation in amplitude observed across the test frequency range did not differ for the four test conditions. Figure 20 shows that at each of the five test frequencies, the mean absolute amplitude value is greatest in the test condition order of non-maneuver peak, non-maneuver ambient, post-maneuver peak, and then post-maneuver ambient. This is the same pattern observed in Figure 18 when the analysis was collapsed across the factor of frequency. A trend was observed for the difference in mean absolute amplitude between test conditions to be largest at frequencies 1000, 2000, and 3000 Hz. This trend was observed for the comparison between non-maneuver ambient, non-maneuver peak, and post-maneuver peak conditions compared to the post-maneuver ambient test condition. At test frequencies 4000 and 5000 Hz, there was less of a difference in absolute amplitude observed between test conditions. Descriptive statistics for the interaction between test condition (x4) and frequency are shown in in Table 164 Appendix A.

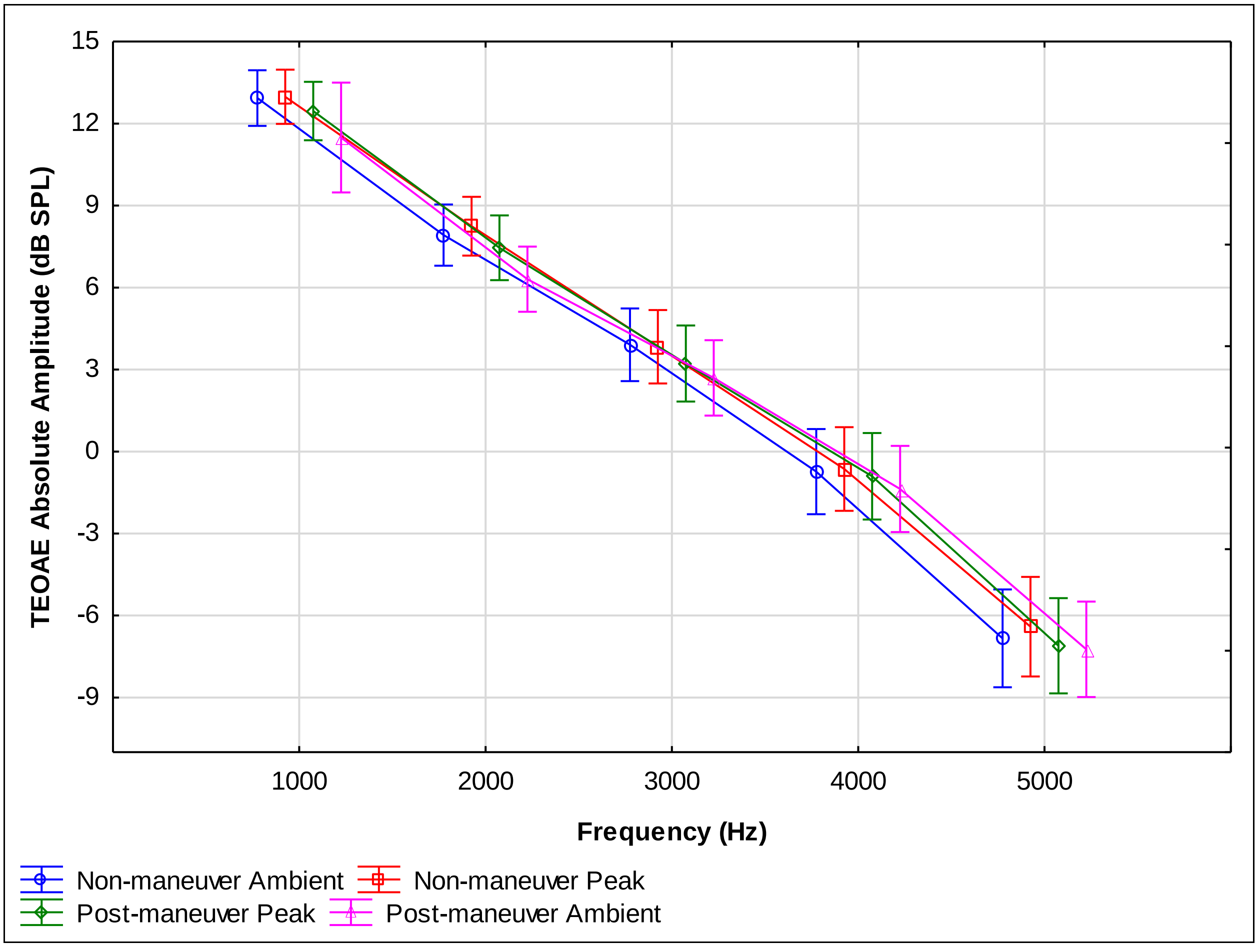


Figure 20: Comparison of mean TEOAE absolute amplitude between test conditions (x4, non-maneuver and post-maneuver) as a function of frequency (1000 to 5000 Hz). A sample size of n=97 TEOAE measures contributes to each test condition. The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(12, 1116)=1.0371, p=.41169].

4.5.2 Noise Level

The main effect of frequency was significant [F(4, 372)=205.84, p=.0000]. Noise level decreased with an increase in test frequency (1000 to 5000 Hz). The main effect of test condition [F(3, 279)=.46396, p=.70767] was not significant (refer to Appendix A Table 165). Displayed in Figure 77 in Appendix A, a trend was observed for the mean noise level to increase in the order of non-maneuver ambient, non-maneuver peak, post-maneuver peak, and post-maneuver ambient. This trend would imply that the presence of abnormal MEP increased the noise level as shown by the non-maneuver versus post-maneuver condition comparisons, but that the level of noise is slightly reduced when testing at peak pressure compared to ambient (post-maneuver peak versus ambient).

4.5.3 Further Investigations; Middle Ear Pressure Magnitude

A summary of the statistical analysis for the comparison of TEOAE absolute amplitude measures considering factors of test conditions (x4), gender, ethnicity, frequency, and absolute MEP magnitude can be found in Appendix B, Table 217. The four test conditions referenced are: non-maneuver and post-maneuver both ambient and peak pressure test conditions.

For TEOAE measures of noise level, the interaction between test condition (x4) and absolute MEP shift magnitude [F(12, 267)=1.6436, p=.07974] was not significant. For the outcome measure of absolute TEOAE amplitude, the interaction between test condition (x4) and absolute MEP shift magnitude [F(12, 267)=1.1628, p=.31017] was not significant (descriptive statistics are found in Table 166 in Appendix A). Figure 21 displays mean absolute amplitude within each MEP shift category decreasing in the test condition order of (1) non-maneuver peak, (2) non-maneuver ambient, (3) post-maneuver peak, and (4) post-maneuver ambient. This trend in magnitude between test conditions was not seen for category A. Sample sizes for the five categories are as follows: A (n= 12), B (n=18), C (n=18), D (n=30), E (n=19). A greater difference in absolute amplitude is seen between the test conditions as the degree of absolute MEP shift increases (A to E). Although the overall interaction between the factors of test condition and absolute MEP shift magnitude was not significant, the greatest difference in mean absolute amplitude was observed for categories D (|MEP| =51 to 99 daPa, a 1.29 dB SPL difference) and E (|MEP|= ≥100 daPa, a 1.82 dB SPL difference), for the comparison between the non-maneuver ambient and post-maneuver ambient test conditions. The greatest difference in absolute amplitude for the comparison between the post-maneuver ambient and peak test conditions was observed for categories B (0.93 dB SPL difference), D (0.8 dB SPL difference), and E (0.97 dB SPL difference).

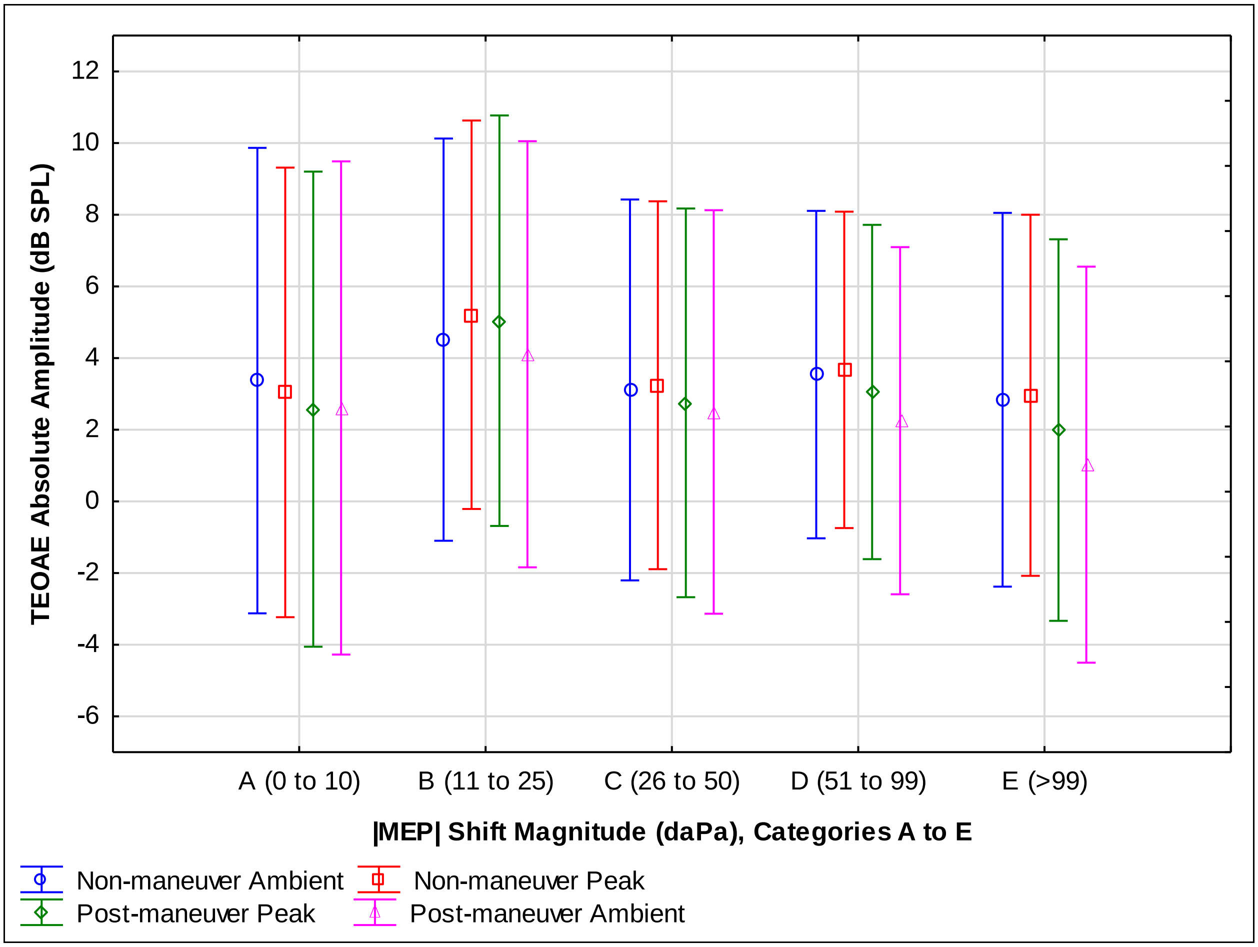


Figure 21: Comparison of mean TEOAE absolute amplitude between test conditions (x4, non-maneuver and post-maneuver) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Sample sizes for the five categories are as follows: A (n= 12), B (n=18), C (n=18), D (n=30), E (n=19). Current effect: [F(12, 267)=1.1628, p=.31017].

Chapter 5: Results; Power Absorbance

Power absorbance data has been presented in a two-test condition comparison format and a summarizing analysis of a four test condition comparison. Chapter 5 Power Absorbance (PA) data is presented in five main sections: (5.1) PA; Non-maneuver Ambient versus Post-maneuver Ambient Test Conditions, (5.2) PA; Non-maneuver Ambient versus Post-maneuver Peak Test Conditions, (5.3) PA; Non-maneuver Test Conditions, (5.4) PA; Post-maneuver Test Conditions, and (5.5) PA; Comparison between Four Test Conditions. For the n=210 PA measures included in the final analysis, the non-maneuver absolute MEP estimates based on the 3D-WBT are as follows: A (n=116), B (n=80), C (n=11), D (n=2), E (n=1). For post-maneuver absorbance measures the sample sizes for each absolute MEP magnitude category is A (n=15), B (n=36), C (n=52), D (n=61), E (n=46). When the absolute MEP shift magnitude (non-maneuver compared to post-maneuver MEP estimates) was determined, the sample sizes for each category altered slightly: A (n=29), B (n=30), C (n=48), D (n=57), E (n=46). The n=210 MEP estimates for the non-maneuver condition shows an absolute average of 10.95 daPa and an absolute average MEP of 65.29 daPa for the post-maneuver MEP estimates (refer to for a detailed presentation of MEP estimate related evaluations).

5.1 Power Absorbance; Non-maneuver Ambient and Post-maneuver Ambient Test Conditions

The test conditions in comparison for the following analyses are between the non-maneuver ambient and post-maneuver ambient test conditions (illustrated in Table 68). A summary of the statistical analysis for all main effects and interactions between factors is shown in Appendix B

Table 222. In order to compare the PA measures from the two different maneuver conditions (non-versus post-maneuver) the coding system reflecting the MEP difference between the two test conditions was used. The absolute difference values were categorized into five groups representing an absolute shift in MEP (daPa): A (0 to 10), B (11 to 25), C (26 to 50), D (51 to 99), and E (≥100). All interactions showing significance with the mixed ANOVA analyses remained significant after a G-G correction. The mean absolute MEP for the non-maneuver test condition was 10.95 daPa and for the post-maneuver peak condition it was estimated to be 65.29 daPa. The mean absolute MEP shift between test conditions was estimated to be 55.16 daPa (refer to Table 8 for PA related MEP evaluations). A sample size of n=210 power absorbance measures were obtained from n=93 individual participants.

	Test Condition	**Absorbance Test Pressure**
Test Ear (Left or Right)	**Non-maneuver**	**Ambient**
		Peak
	Post-maneuver (Absolute MEP)	**Ambient**
		Peak

Table 68: Shaded boxes represent test conditions under comparison in the following analyses

Test Condition

The main effect of test condition [F(1, 202)=360.35, p=.0000] was significant, and the descriptive statistics are shown in Table 69. Mean power absorbance magnitude is lower in the post-maneuver ambient condition (mean 0.35) compared to the non-maneuver ambient test condition (mean 0.42), when the analysis was collapsed across factors of gender ethnicity, frequency, and absolute MEP shift magnitude.

Test Condition	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	0.42	0.02	0.37	0.46	210
Post-maneuver, Ambient	0.35	0.02	0.31	0.40	210

Table 69: Post-maneuver ambient measures: Comparison of mean power absorbance (PA) magnitude between test conditions (non-maneuver ambient versus post-maneuver ambient). The analysis was collapsed across factors of gender, ethnicity, frequency, and absolute middle ear pressure shift magnitude. Current effect: [F(1, 202)=360.35, p=.0000].

Gender and Ethnicity

When collapsing the analyses across the factors of test condition (non-maneuver ambient and post-maneuver ambient), frequency, ethnicity, and absolute MEP shift magnitude the main effect of gender [F(1, 202)=7.117, p=.008256] was significant. The main effect of ethnicity [F(2, 202)=1.273, p=.282348] was not significant when collapsing the analysis across factors of gender, frequency, test condition, and absolute MEP shift magnitude. The interactions between test condition and ethnicity as well as between test condition and gender were not significant, indicating the variation in PA magnitude between test conditions did not differ for ethnic or gender groups.

Absolute Middle Ear Pressure Magnitude

Collapsing the analysis across factors of gender, ethnicity, test condition, and frequency the main effect of absolute MEP shift [F(4, 202)=5.206, p=.000519] was significant. The interaction between test condition (non-maneuver ambient versus post-maneuver ambient) and absolute MEP shift magnitude [F(4, 202)=63.256, p=.0000] was significant, indicating the variation in PA between test conditions does differ across different pressure magnitudes (A to E). Demonstrated in Table 70, mean PA magnitude is consistently lower for the post-maneuver ambient test condition compared to the non-maneuver ambient condition. A Tukey's HSD test shows a significant difference between the test conditions for categories C, D, and E. Figure 22 illustrates the trend that the magnitude difference between test conditions increases with an increase in absolute MEP shift magnitude (A to E).

|MEP| Shift (daPa)	**Test Condition**	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Non-maneuver, Ambient	0.42	0.06	0.31	0.53	29
A (0 to 10)	Post-maneuver, Ambient	0.41	0.05	0.30	0.51	29
B (11 to 25)	Non-maneuver, Ambient	0.41	0.06	0.29	0.52	30
B (11 to 25)	Post-maneuver, Ambient	0.38	0.05	0.28	0.49	30
C (26 to 50)	Non-maneuver, Ambient	0.42	0.05	0.33	0.51	48
C (26 to 50)	Post-maneuver, Ambient	0.38	0.04	0.29	0.46	48
D (51 to 99)	Non-maneuver, Ambient	0.41	0.04	0.33	0.49	57
D (51 to 99)	Post-maneuver, Ambient	0.32	0.04	0.24	0.40	57
E (>99)	Non-maneuver, Ambient	0.43	0.05	0.34	0.52	46
E (>99)	Post-maneuver, Ambient	0.28	0.04	0.19	0.36	46

Table 70: Comparison of power absorbance (PA) magnitude between non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute middle ear pressure (|MEP|) shift magnitude (A to E). The analysis was collapsed across frequency, gender, and ethnicity. Current effect: [F(4, 202)=63.256, p=.0000].

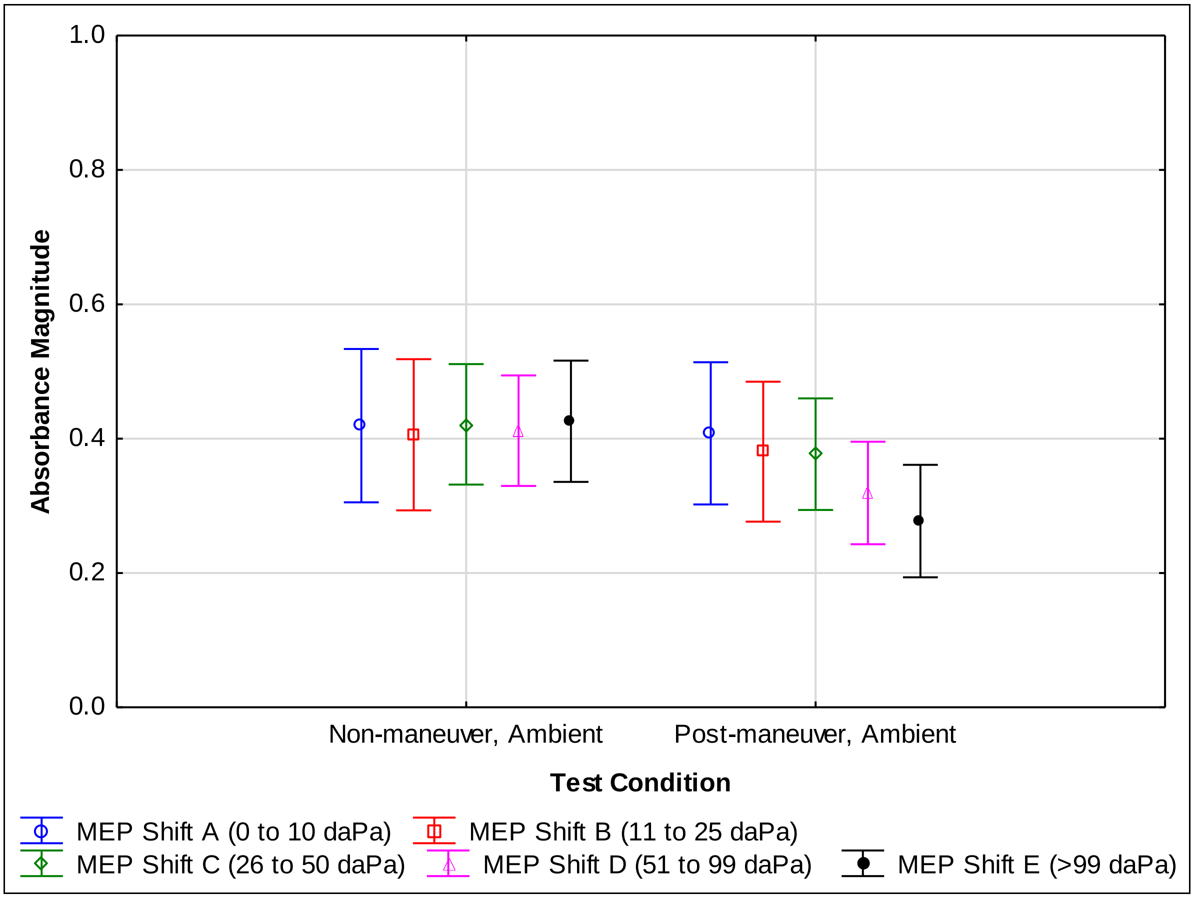


Figure 22: Comparison of power absorbance magnitude between non-maneuver ambient (n=210) and post-maneuver ambient (n=210) test conditions as a function of absolute middle ear pressure shift magnitude (A to E). The sample sizes for each category are as follows: A (n=29), B (n=30), C (n=48), D (n=57), and E (n=46). The analysis was collapsed across frequency, gender, and

ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 202)=63.256, p=.0000].

Higher-order Interactions

The main effect of frequency [F(15, 3030)=366.736, p=.00000] was significant. The interaction between frequency and gender [F(15, 3030)=5.387, p=.00000] was also significant. The interaction between frequency and gender as well as frequency and absolute MEP shift magnitude were also significant. The high-order interaction of test condition, frequency, and ethnicity [F(30, 3030)=4.651, p=.00000] was significant when collapsing the analysis across factors of gender and absolute MEP shift magnitude.

The difference in PA between the two test conditions was further explored with the interaction between test condition, frequency, and absolute MEP shift magnitude [F(60, 3030)=15.658, p=.0000]. This significant interaction is displayed in Figure 23 and the analysis was collapsed across factors of ethnicity and gender. There is a greater difference in mean PA magnitude as the magnitude of absolute MEP shift increases from categories A to E, particularly for center frequencies <4000 Hz. For both the right (non-maneuver) and left (post-maneuver) panels, the PA magnitude is greatest for category E (≥100 daPa) at center frequencies roughly ≥5000 Hz. This interaction is equivalent to the response observed for the post-maneuver ambient versus post-maneuver peak test condition comparison shown earlier in Figure 29. For the tail of the curve (roughly 3000 Hz and lower), there is an evident drop in PA magnitude in the presence of uncompensated abnormal MEP with the upper tail portion remaining relatively stable. Again, the peak portion of the curve shifts toward the higher frequency in the presence of uncompensated abnormal MEP (post-maneuver ambient condition), peaking around 4000 to 6000 Hz. A greater increase in abnormal MEP is observed by a more distinct shift in the curve peak to a higher frequency and with a greater reduction in PA magnitude for the low frequencies.

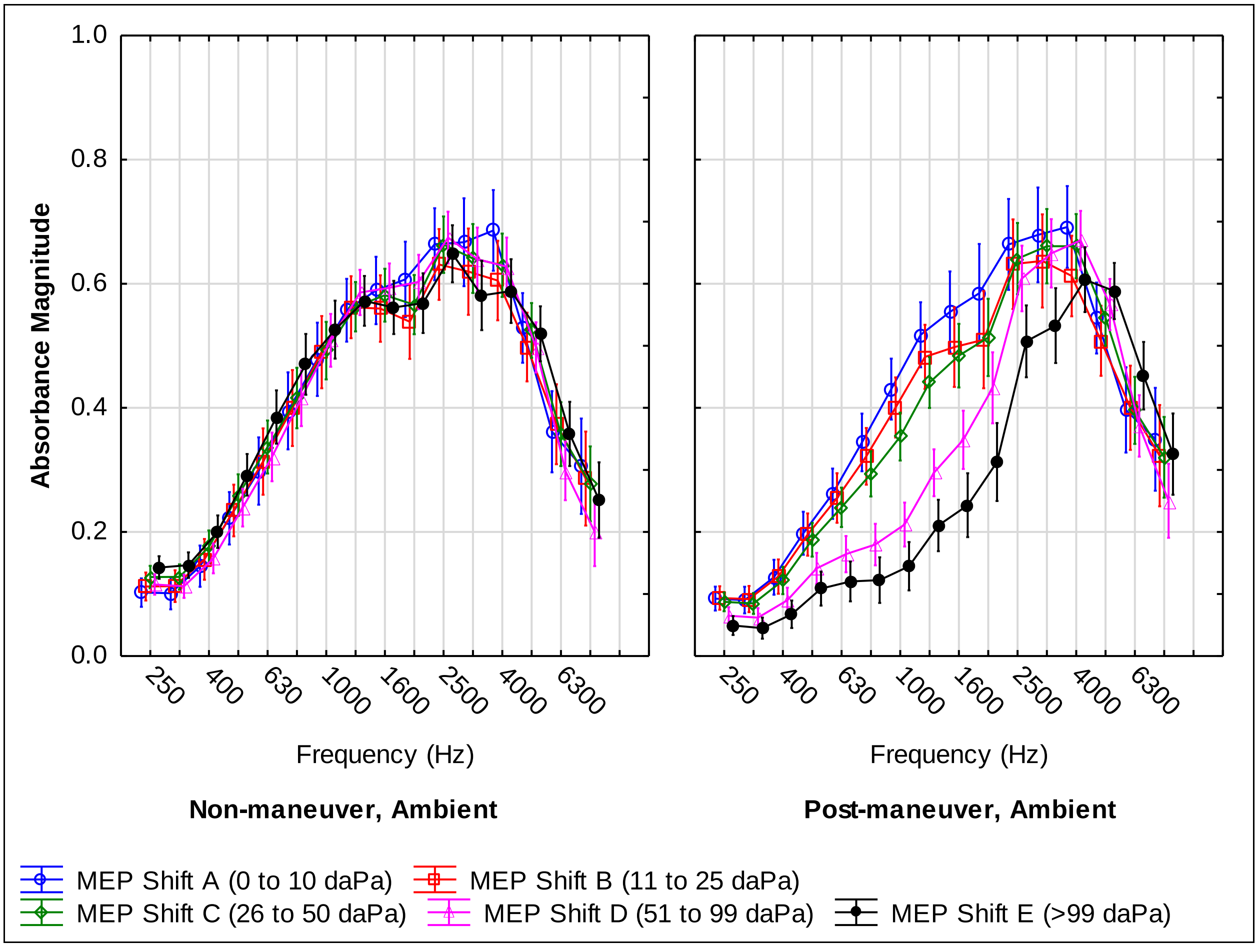


Figure 23: Comparison of power absorbance magnitude between non-maneuver ambient (n=210 samples) and post-maneuver ambient (n=210 samples) test conditions as a function of center frequency and absolute middle ear pressure (|MEP|) shift magnitude (A to E). The analysis was

collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(60, 3030)=15.658, p=.0000].

5.2 Power Absorbance; Non-maneuver Ambient and Post-maneuver Peak Test Conditions

The following results are for the comparison of non-maneuver ambient and post-maneuver peak test conditions (illustrated in Table 71). A summary of the statistical analysis are shown in Appendix B Table 223. All interactions showing significance with the mixed ANOVA analyses remained significant after a G-G correction. The mean absolute MEP for the non-maneuver test condition was 10.95 daPa and 65.29 daPa for the post-maneuver peak condition. The mean absolute MEP shift between test conditions was estimated to be 55.16 daPa (refer to Table 8 for PA related MEP evaluations). A sample size of n=210 PA measures from n=93 individual participants contributed to each test condition.

	Test Condition	**Absorbance Test Pressure**
Test Ear (Left or Right)	**Non-maneuver**	**Ambient**
		Peak
	Post-maneuver (Absolute MEP)	**Ambient**
		Peak

Table 71: Shaded boxes represent test conditions under comparison in the following analyses

Test Condition

The main effect of test condition [(F(1, 202)=2.453, p=.118881] was not significant, indicating mean PA magnitude for the non-maneuver ambient and post-maneuver peak test conditions were not significantly different (refer to Table 72). The interaction between test condition and gender, as well as test condition and ethnicity were not significant, showing the variation in PA magnitude between test conditions did not differ for ethnic or gender groups.

Test Condition	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	0.42	0.02	0.37	0.46	210
Post-maneuver Peak	0.42	0.02	0.37	0.47	210

Table 72: Comparison of power absorbance (PA) magnitude between test conditions (non-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factors of gender, ethnicity, frequency, and absolute middle ear pressure shift magnitude. Current effect: F(1, 202)=2.4528, p=.11888].

Absolute Middle Ear Pressure Magnitude

The main effect of absolute MEP shift magnitude was not significant when collapsing across factors of test condition, ethnicity, gender, and frequency. The interaction between test condition, and absolute MEP shift magnitude [F(4, 202)=1.766, p=.13706] was also not significant. These findings imply that the PA magnitude did not differ between test conditions when considering the degree of abnormal MEP. Table 73 contains the descriptive statistics for this interaction between test condition and absolute MEP shift magnitude.

|MEP| Shift Category	Test Condition	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10 daPa)	Non-maneuver, Ambient	0.42	0.06	0.31	0.53	29
A (0 to 10 daPa)	Post-maneuver, Peak	0.43	0.06	0.31	0.56	29
B (11 to 25 daPa)	Non-maneuver, Ambient	0.41	0.06	0.29	0.52	30
B (11 to 25 daPa)	Post-maneuver, Peak	0.41	0.06	0.29	0.53	30
C (26 to 50 daPa)	Non-maneuver, Ambient	0.42	0.05	0.33	0.51	48
C (26 to 50 daPa)	Post-maneuver, Peak	0.42	0.05	0.33	0.52	48
D (51 to 99 daPa)	Non-maneuver, Ambient	0.41	0.042	0.33	0.49	57
D (51 to 99 daPa)	Post-maneuver, Peak	0.41	0.04	0.33	0.50	57
E (>99 daPa)	Non-maneuver, Ambient	0.43	0.05	0.34	0.52	46
E (>99 daPa)	Post-maneuver, Peak	0.42	0.05	0.33	0.52	46

Table 73: Comparison of power absorbance (PA) magnitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 202)=1.7661, p=.13706].

Gender, Ethnicity, and Frequency

The main effect of ethnicity [F(2, 202)=2.202, p=.113196] was not significant. The main effect for both gender and frequency were significant. The interaction between gender and frequency [F(15, 3030)=5.410, p=.00000] as well as between ethnicity and frequency [F(30, 3030)=4.113, p=.00000] were also significant. These findings indicate that the variation in PA magnitude across the 16 1/3 octave frequencies did differ between the ethnic and gender groups. The interaction between test condition, frequency, and ethnicity [F(0, 3030)=0.80166, p=.76906] was not significant. This indicates that the variation in PA across the range of center frequencies (250 to 8000 Hz) as a function of test condition did not differ between the three ethnic groups (Caucasian, Asian, and Other).

The interaction between test condition and frequency [F(15, 3030)=37.202, p=.00000] was significant. This indicates that the variation in PA magnitude between test conditions does differ across the frequency range (250 to 8000 Hz). This interaction is displayed in Figure 24 (refer to Appendix A, Table 171 for descriptive statistics). The post-maneuver peak test condition had a greater mean PA magnitude value compared to the non-maneuver ambient test condition at center frequencies between the range of 250 to 1000 Hz and 6300 to 8000 Hz. A post-hoc analysis indicated a non-significant difference in PA magnitude between test conditions at center frequencies 250, 1000, 1250, and 5000 Hz.

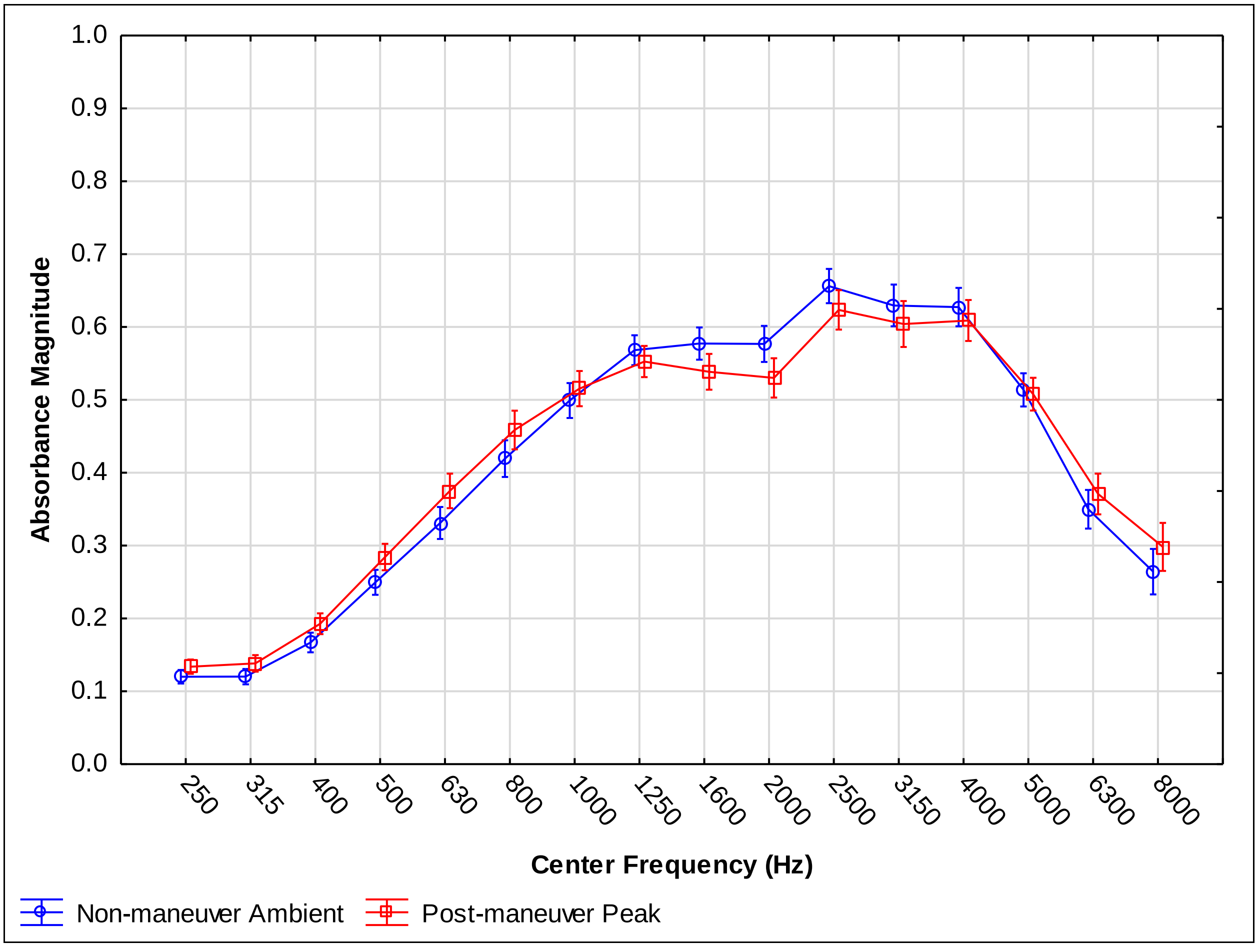


Figure 24: Comparison of power absorbance magnitude between non-maneuver ambient (n=210) and post-maneuver peak (n=210) test conditions as a function of center frequency (250 to 8000 Hz). The analysis was collapsed across factors of gender, ethnicity, and absolute middle ear pressure shift magnitude. Vertical bars denote 95th percent confidence intervals. Current effect: F(15, 3030)=37.202, p=0.0000.

Higher-order Interactions

Displayed in Figure 25 is the non-significant interaction between test condition (non-maneuver ambient versus post-maneuver peak), absolute MEP shift magnitude, and frequency [F(60, 3030)=0.84576, p=.79525]. This analysis was collapsed across factors of gender and ethnicity. The two test conditions both had the same sample size for each absolute MEP shift category; A (n=29), B (n=30), C (n=48), D (n=57), E (n=46). A trend is observed for the mid to low frequencies to be comparable in PA magnitude across |MEP| shift categories A to E for both test conditions. The PA magnitude curve for all categories in both test conditions show similar response shapes and peak absorbance occurs in roughly the same frequency range (about 2500 to 4000 Hz). This same interaction between test condition, absolute MEP shift magnitude, and frequency for measures in the non-maneuver ambient versus post-maneuver ambient test conditions (Figure 23) as well as with the post-maneuver ambient versus peak conditions (Figure 31) were significant.

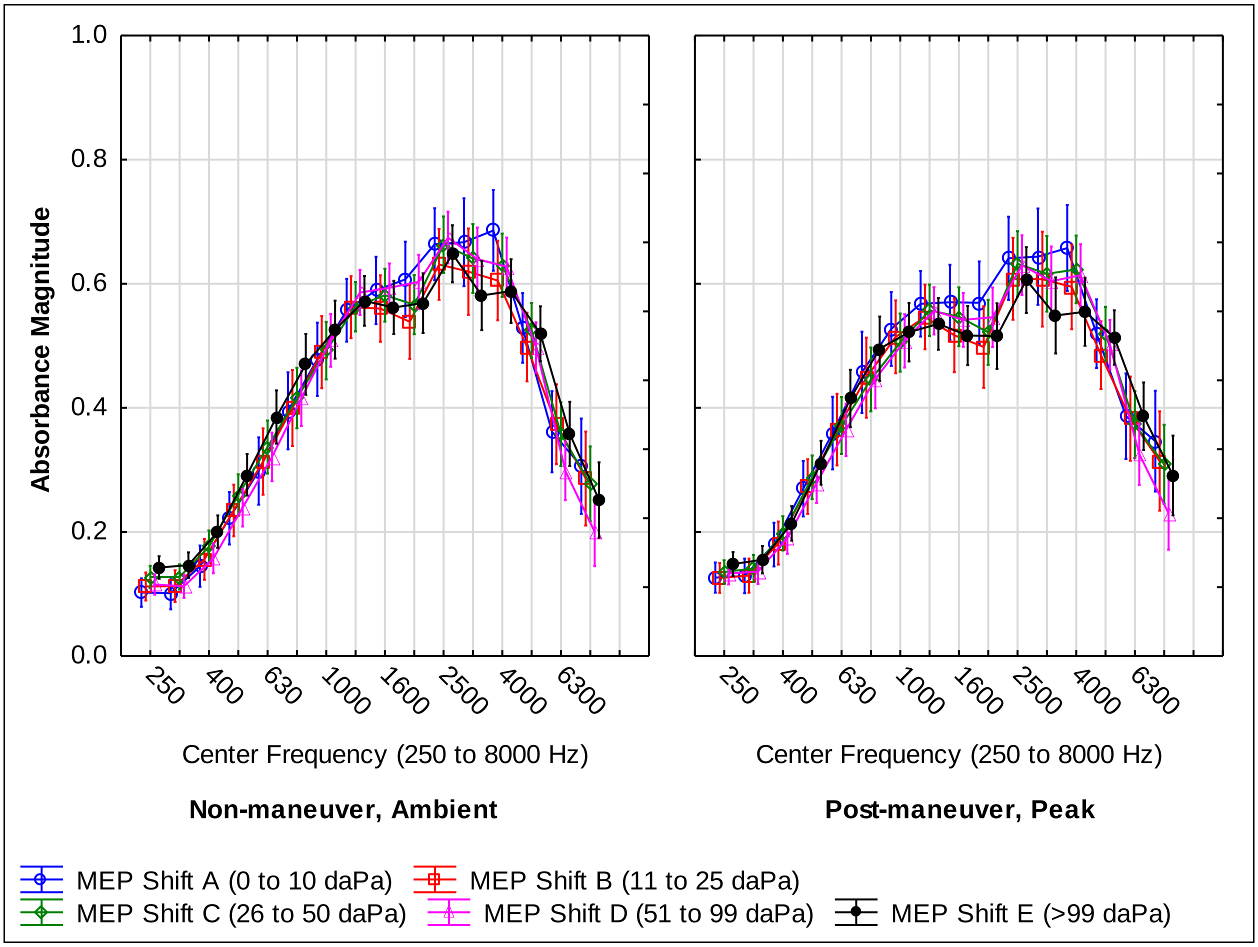


Figure 25: Comparison of power absorbance magnitude between test conditions (non-maneuver ambient n=210 versus post-maneuver peak n=210) as a function of center frequency (250 to 8000 Hz) and absolute middle ear pressure (|MEP|) shift magnitude (A to E). Sample sizes for each category are as follows: A (n=29), B (n=30), C (n=48), D (n=57), and E (n=46). The analysis was collapsed across factors of gender, and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(60, 3030)=0.8576, p=.79525].

5.3 Power Absorbance; Non-maneuver Test Conditions

Data for the following analyses were from the non-maneuver condition (illustrated in Table 74). A summary of the statistical findings can be found in Appendix B Table 221. The average absolute MEP estimate associated with the n=210 non-maneuver absorbance measures was 10.95 daPa (absolute range: 0 to 102 daPa). All interactions showing significance with the mixed ANOVA analyses remained significant after a G-G correction.

Test Ear (Left or Right)	**Test Condition**	**Absorbance Test Pressure**
	Non-maneuver	**Ambient**
		Peak
	Post-maneuver (Positive MEP & Negative MEP) Absolute MEP	Ambient
		Peak

Table 74: Shaded boxes represent test conditions under comparison in the following analyses.

Gender

The main effect of gender [F(1, 202)=7.0546, p=.008537] was significant. Table 75 shows PA magnitude on average is greater for male participants (mean 0.413, n=79) compared to the mean absorbance (mean 0.384, n=131) for female participants, which was the same finding for the post-maneuver condition PA measures. The interaction between test pressure condition (ambient versus peak) and gender [F(1, 202)=0.1592, p=.690372] was not significant, indicating the variation in PA magnitude between test pressure conditions did not differ between female and male participants.

Gender	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Female	0.38	0.02	0.35	0.42	131
Male	0.41	0.02	0.37	0.45	79

Table 75: Non-maneuver condition measures: Comparison of power absorbance (PA) magnitude between gender groups (n=79 males and n=131 females). The analysis was collapsed across factors of ethnicity, frequency, absolute middle ear pressure magnitude, and test pressure (ambient versus peak). Current effect: [F(1, 202)=7.0546, p=.008537].

Test Pressure Condition

The main effect for the factor of test pressure condition [F(1, 202)=170.4860, p=.00000] for non-maneuver condition measures was significant. The mean PA magnitude for the ambient condition (mean 0.381) was less than that for the peak condition (mean 0.416) (refer to Table 76). The analysis was collapsed across factors of ethnicity, gender, frequency, and absolute MEP magnitude.

Test Pressure Condition	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Ambient	0.38	0.08	0.23	0.53	210
Peak	0.42	0.08	0.26	0.57	210

Table 76: Non-maneuver condition measures: Comparison of power absorbance (PA) magnitude between test pressure conditions (ambient versus peak). The analysis was collapsed across factors of ethnicity, gender, and absolute middle ear pressure magnitude (based on pre-maneuver 226 Hz tympanogram MEP estimates). Current effect: [F(1, 202)=170.4860, p=.00000].

There were two options for approaching data analysis, one was to use the categorical between-subject factor of absolute MEP shift magnitude and the other was to use the factor of absolute MEP magnitude. As described in the Methods section, the absolute MEP shift categorization involves the comparison of MEP between non-maneuver and post-maneuver test conditions. The categorization of absolute MEP is only references the MEP estimates within a single maneuver condition (i.e. either the non-maneuver or post-maneuver condition). When the main effect of test condition was analyzed collapsing across either the factor of absolute MEP shift magnitude (refer to Table 77) or the factor of absolute MEP magnitude, the mean PA magnitude value was altered slightly in magnitude. However, the significance of the analysis was equivalent for both approaches. The PA magnitude values presented in Table 78 are also found for the four-test condition comparison presented in section 5.5. Like the data presented in Table 78, the summary figure of the four test condition comparisons in section 5.5 had the analysis collapsed across the factor of absolute MEP shift magnitude. When analyzing just the mean PA magnitude values collapsing the analysis across between-subject factors, the mean PA magnitudes for both the peak and ambient test conditions reflect the values presented in Table 78.

Test Pressure Condition	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Ambient	0.42	0.02	0.37	0.46	210
Peak	0.43	0.02	0.38	0.47	210

Table 77: Non-maneuver condition measures: Comparison of power absorbance (PA) magnitude between test pressure conditions (ambient versus peak). The analysis was collapsed across factors of ethnicity, gender, and absolute middle ear pressure shift magnitude. Current effect: [F(1, 202)=77.746, p=.00000].

Frequency

The main effect of frequency [F(15, 3030)=28.6737, p=.00000] was significant. The interaction between frequency and gender [F(15, 3030)=6.3068, p=.00000] was significant and the interaction between frequency and ethnicity [F(30, 3030)=4.3183, p=.00000] was also significant. These findings indicate that the variation in PA magnitude across the range of center frequencies does differ between gender and ethnic groups. For the non-maneuver condition measures, the comparison of absorbance magnitude between gender groups as a function of center frequency was not graphically displayed as the pattern reflects that already shown for the post-maneuver condition measures in Figure 28.

The interaction between frequency and absolute MEP magnitude [F(60, 3030)=0.8354, p=.812809] was not significant and the main effect of absolute MEP magnitude [F(4, 202)=1.6996, p=.151484] was not significant. Since these PA measures were from the non-maneuver condition, there were very small sample sizes in the categories corresponding to greater MEP magnitudes. The categories had sample sizes of A (n=116), B (n=80), C (n=11), D (n=2), E (n=1). Given the small sample sizes, a non-significant finding between factors of MEP magnitude and frequency is not unexpected. Due to the majority of measures falling into the category A and B and the non-significant findings, the interaction between frequency, test condition, and absolute MEP magnitude [F(60, 3030)=26.7032, p=.00000] was not displayed graphically. The interaction of primary interest for the comparison of non-maneuver test pressure conditions (ambient and peak) is between the factors of frequency and test condition. For results pertaining to this interaction refer to the section below titled: Test Pressure Condition and Frequency.

Ethnicity

The main effect of ethnicity [F(2, 202)=2.4800, p=.086289] was not significant. The interaction between ethnicity and test pressure condition [F(2, 202)=3.0715, p=.048521] was significant (refer to Table 78). A Tukey’s HSD test confirms there was no significant difference between the three ethnic groups for PA magnitude when comparing within the ambient test condition nor when compared within the peak test condition (refer to Appendix A Table 168). However, there was a significant difference between the ambient and peak test conditions for each ethnic group. This interaction between ethnicity and test pressure condition is displayed in Figure 26: PA magnitude was consistently greater for the peak pressure condition compared to the ambient condition for all three ethnic groups.

Ethnicity	**Test Pressure Condition**	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	Ambient	0.39	0.08	0.23	0.55	70
Caucasian	Peak	0.43	0.08	0.26	0.59	70
Asian	Ambient	0.37	0.08	0.21	0.53	95
Asian	Peak	0.40	0.08	0.24	0.57	95

Ethnicity	Test Pressure Condition	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Other	Ambient	0.39	0.08	0.22	0.55	45
Other	Peak	0.42	0.09	0.25	0.59	45

Table 78: Non-maneuver condition measures: Comparison of mean power absorbance (PA) magnitude between ethnic groups and test pressure conditions (ambient versus peak). The analysis was collapsed across factors of frequency, gender, and absolute middle ear pressure magnitude. Current effect: [F(2, 202)=3.0715, p=.048521].

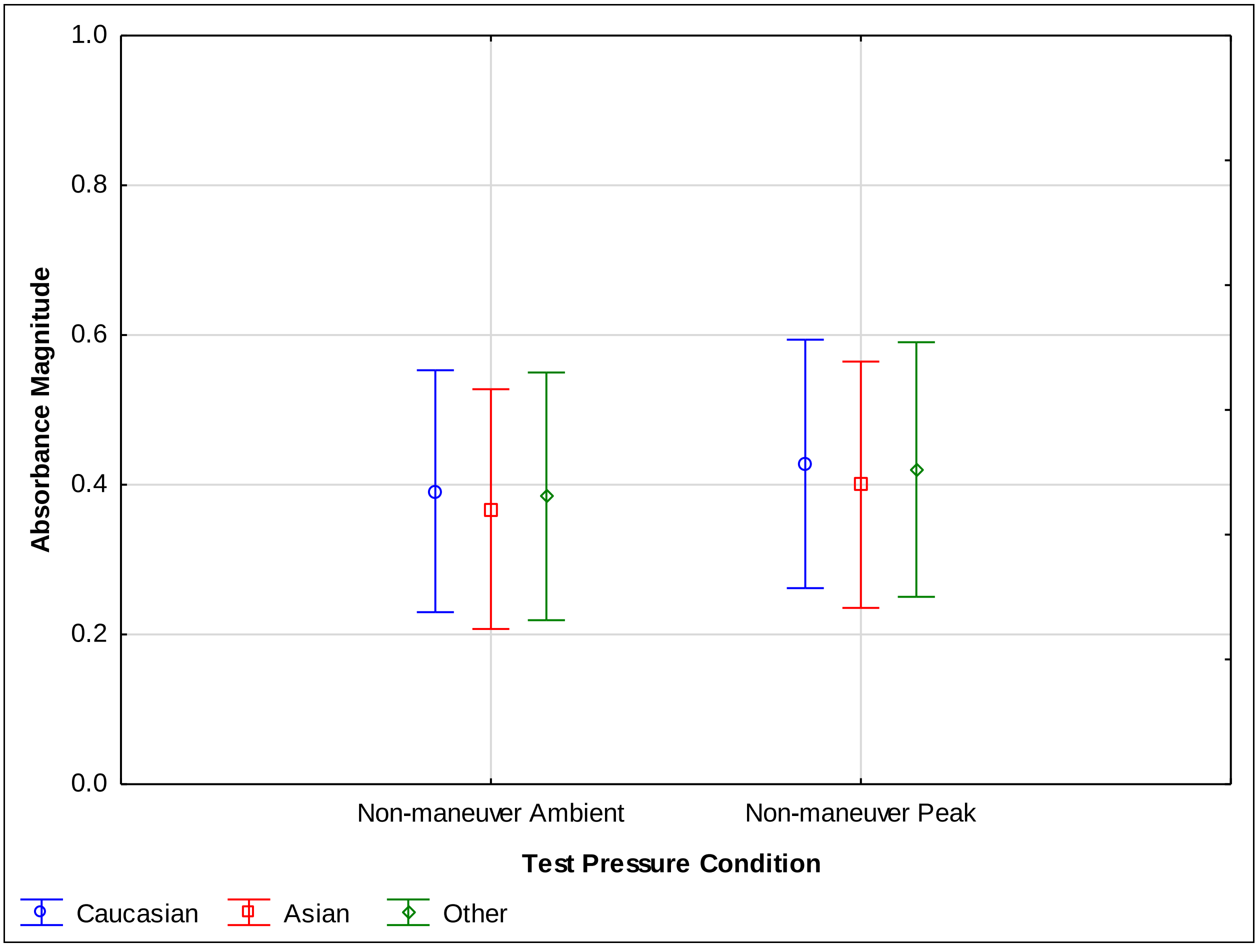


Figure 26: Non-maneuver condition measures: Comparison of mean power absorbance magnitude between ethnic groups and test pressure conditions (ambient versus peak). The analysis was collapsed across factors of frequency, gender, and absolute middle ear pressure magnitude. Sample sizes for Caucasians n=70, Asians n=95, and Others n=45 contributed to both test pressure conditions. Vertical bars denote 95th confidence intervals. Current effect: [F(2, 202)=3.0715, p=.048521].

Test Pressure Condition and Frequency

The interaction between test pressure condition (ambient versus peak) and absolute MEP magnitude [F(4, 202)=47.2529, p=.00000] was significant. The interaction between frequency and test pressure condition [F(15, 3030)=69.312, p=.00000] was also significant. Figure 27 displays the significant interaction between frequency and test pressure condition with descriptive statistics displayed in Table 79. The non-maneuver peak compared to the ambient pressure condition had a greater PA magnitude between the frequency range of 250 to 1600 Hz and at 2500 Hz. The ambient pressure condition had a greater PA magnitude at center frequencies between 3150 to 8000 Hz. The PA magnitude was equivalent between the test pressure conditions at 2000 Hz. Post-hoc analysis indicates a significant difference in mean PA magnitude at frequencies between the range of 250 to 1250 Hz with the peak pressure condition having the greater mean PA magnitude compared to the ambient condition. A significant difference in PA magnitude was also noted at frequencies between 4000 to 8000 Hz with the ambient pressure condition having the greater value. The peak and ambient conditions were equivalent in PA magnitude at frequencies of 2000 and 3150 Hz with the peak condition being significantly greater at 2500 Hz. No significant difference between test conditions was found at 1600, 6300, and 8000 Hz. Although not significant, the peak compared to ambient condition had the greater mean PA magnitude at 1600 Hz with the ambient condition being greater at 6300 and 8000 Hz.

Test Condition	**Center Frequency (Hz)**	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	250	0.10	0.02	0.07	0.13	210
Non-maneuver Peak	250	0.14	0.02	0.11	0.17	210
Non-maneuver Ambient	315	0.10	0.02	0.07	0.14	210
Non-maneuver Peak	315	0.14	0.02	0.11	0.18	210
Non-maneuver Ambient	400	0.14	0.02	0.10	0.19	210
Non-maneuver Peak	400	0.20	0.02	0.15	0.25	210
Non-maneuver Ambient	500	0.21	0.03	0.15	0.27	210
Non-maneuver Peak	500	0.29	0.03	0.23	0.35	210
Non-maneuver Ambient	630	0.26	0.04	0.19	0.34	210
Non-maneuver Peak	630	0.39	0.04	0.31	0.47	210
Non-maneuver Ambient	800	0.34	0.04	0.26	0.42	210
Non-maneuver Peak	800	0.49	0.04	0.41	0.58	210
Non-maneuver Ambient	1000	0.43	0.04	0.36	0.51	210
Non-maneuver Peak	1000	0.54	0.04	0.46	0.62	210
Non-maneuver Ambient	1250	0.52	0.03	0.45	0.58	210
Non-maneuver Peak	1250	0.56	0.03	0.50	0.62	210
Non-maneuver Ambient	1600	0.51	0.04	0.44	0.58	210
Non-maneuver Peak	1600	0.53	0.04	0.46	0.60	210
Non-maneuver Ambient	2000	0.50	0.04	0.42	0.58	210
Non-maneuver Peak	2000	0.50	0.04	0.42	0.58	210
Non-maneuver Ambient	2500	0.61	0.04	0.53	0.69	210
Non-maneuver Peak	2500	0.62	0.04	0.54	0.70	210
Non-maneuver Ambient	3150	0.61	0.05	0.52	0.71	210
Non-maneuver Peak	3150	0.61	0.05	0.51	0.70	210

Test Condition	Center Frequency (Hz)	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver Ambient	4000	0.64	0.05	0.55	0.73	210
Non-maneuver Peak	4000	0.62	0.05	0.53	0.71	210
Non-maneuver Ambient	5000	0.54	0.04	0.47	0.62	210
Non-maneuver Peak	5000	0.51	0.04	0.43	0.58	210
Non-maneuver Ambient	6300	0.36	0.05	0.27	0.45	210
Non-maneuver Peak	6300	0.34	0.05	0.25	0.43	210
Non-maneuver Ambient	8000	0.21	0.05	0.11	0.32	210
Non-maneuver Peak	8000	0.19	0.05	0.08	0.29	210

Table 79: Non-maneuver condition: Comparison of mean power absorbance (PA) magnitude between test pressure conditions (ambient versus peak) as a function of center frequency (250 to 8000 Hz). A sample size of n=210 PA measures contributed to each test pressure condition. The analysis was collapsed across factors of ethnicity, absolute middle ear pressure magnitude (referencing 226 Hz tympanogram MEP estimates from pre-maneuver condition), and gender. The shaded rows distinguish the non-maneuver peak pressure condition from the ambient data. Current effect: [F(15, 3030)=69.312, p=.00000].

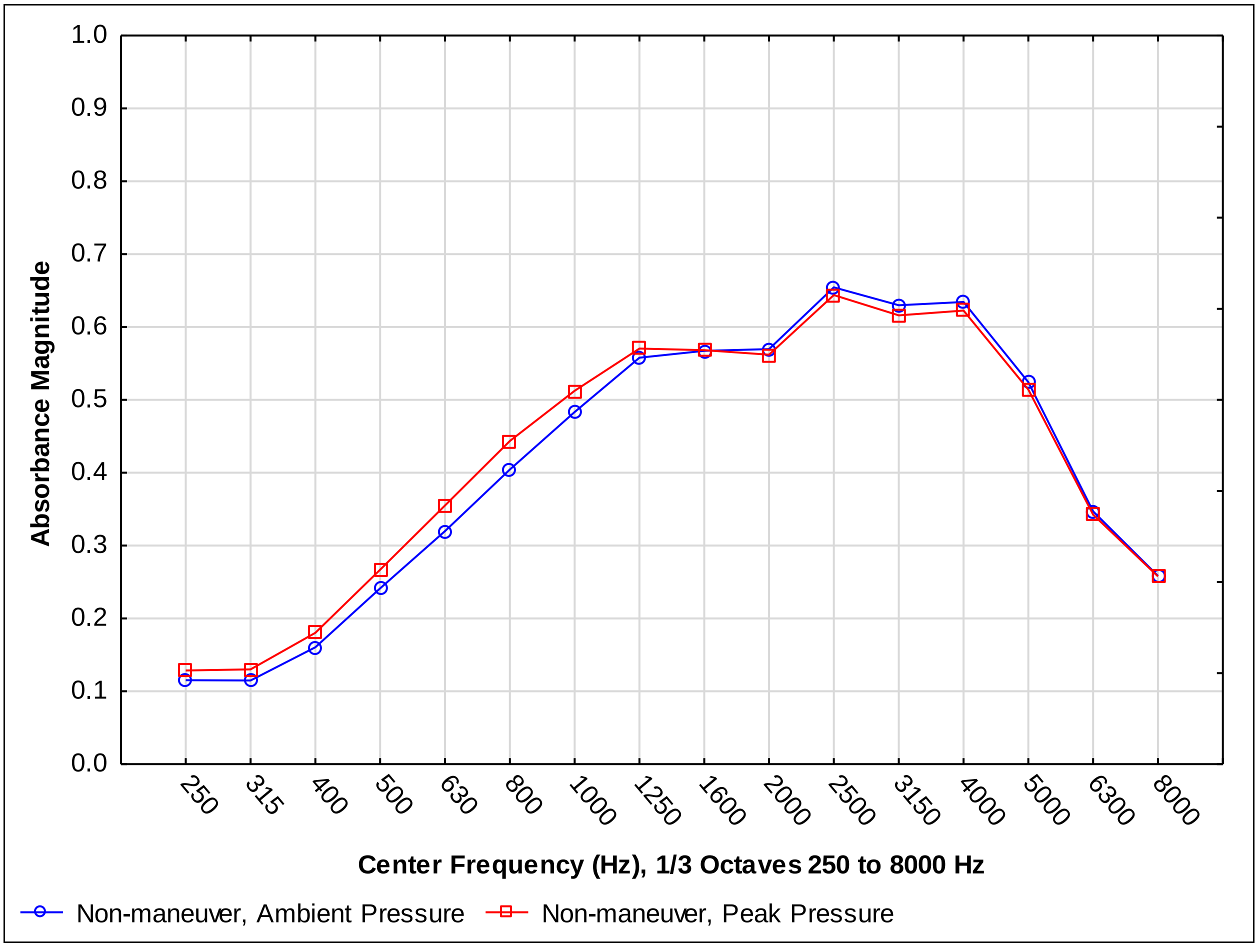


Figure 27: Non-maneuver condition: Comparison of mean power absorbance magnitude between test pressure conditions (ambient versus peak) as a function of center frequency (250 to 8000 Hz). The analysis was collapsed across factors of ethnicity, absolute middle ear pressure magnitude, and gender. Vertical bars denote 95th percent confidence intervals. Current effect: [F(15, 3030)=69.312, p=.00000].

The comparison of mean PA magnitude between test pressure conditions (ambient versus peak) as a function of frequency was also analyzed collapsing across factors of ethnicity, absolute MEP shift magnitude, and gender. This interaction was found to be significant [F(15, 3030)=62.754, p=.00000]. This specific interaction is in comparison to the analysis presented above in Table 79 and Figure 27 that collapsed across the factor of absolute MEP magnitude (referencing the pre-maneuver MEP estimates) rather than absolute MEP shift magnitude. Descriptive statistics as well as the 5th and 95th percentiles are included in Table 114. The figures associated with this interaction (Figure 62) and the descriptive data tables are presented in the PA Discussion section, Chapter 8, for the comparison against published PA normative data and discussion of clinical application of PA pressure compensation.

Higher-order Interactions

The interaction between test pressure condition, ethnicity, and frequency [F(30, 3030)=1.5022, p=.039097] was also significant. Then interaction between test pressure condition, frequency, and absolute MEP magnitude [F(60, 3030)=26.7032, p=.00000] was also significant. These findings indicate that the variation in PA magnitude between test pressure conditions (ambient versus peak) did differ between (i.) absolute MEP magnitude categories (although small sample sizes in categories C to E), (ii.) across center frequencies, and (iii.) between ethnic groups.

5.4 Power Absorbance; Post-maneuver Test Conditions

Data for the following analyses were from the post-maneuver condition measures (illustrated in Table 80). Refer to Appendix B, Table 220 for a summary of the mixed ANOVA statistical analysis. The average absolute MEP estimate associated with the n=210 post-maneuver absorbance measures was 65.98 daPa (absolute range: 0 to 276 daPa). All interactions showing significance with the mixed ANOVA analyses remained significant after a G-G correction.

Test Ear (Left or Right)	**Test Condition**	**Absorbance Test Pressure**
	Non-maneuver	Ambient
		Peak
	Post-maneuver (Positive MEP & Negative MEP) Absolute MEP	**Ambient**
		Peak

Table 80: Shaded boxes represent test conditions under comparison.

Test Pressure Condition

The main effect for the factor of test pressure condition (ambient versus peak) [F(1, 202)=405.52, p=.0000] was significant. The mean PA magnitude for the ambient condition (mean 0.35, n=210) was significantly lower than the peak test condition (mean 0.42, n=210). The analysis was collapsed across factors of ethnicity, gender, frequency, and absolute MEP magnitude. Descriptive statistics for the main effect of test pressure condition are shown in Table 81. Refer to section 5.5 Figure 32 for a comparison of mean absorbance across all four test conditions.

Test Pressure Condition	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Ambient	0.36	0.02	0.31	0.41	210
Peak	0.42	0.03	0.37	0.48	210

Table 81: Comparison of mean power absorbance (PA) magnitude between test pressure conditions (ambient versus peak) for post-maneuver absorbance measures. The analysis was collapsed across factors of gender, ethnicity, frequency, and absolute MEP magnitude. Current effect: [F(1, 202)=405.52, p=.0000].

The interaction between test pressure condition and gender [F(1, 202)=1.332, p=.249782] as well as the interaction between test pressure condition and ethnicity [F(2, 202)=2.628, p=.074713] were not significant. This demonstrates that the variation in PA magnitude observed between the post-maneuver peak and ambient test conditions does not differ for the three ethnic groups (Caucasians, Asians, and Others) nor does it differ significantly for genders (male versus female).

Gender

The main effect of gender [F(1, 202)=5.6581, p=.01831] was significant, the analysis was collapsed across factors of frequency, ethnicity, absolute MEP magnitude, and test pressure condition (ambient versus peak). The mean PA magnitude was found to be significantly greater for male participants (mean 0.40, n=79) compared to female participants (mean 0.37, n=131) (refer to Table 82).

Gender	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Female	0.37	0.00	0.36	0.39	131
Male	0.40	0.00	0.38	0.42	79

Table 82: Post-maneuver test condition measures: Comparison of mean power absorbance (PA) magnitude between genders (n=131 females and n=79 males). The analysis was collapsed across factors of frequency, absolute MEP magnitude, ethnicity, and test pressure condition (ambient versus peak). Current effect: [F(1, 202)=5.6581, p=.01831].

Frequency

The main effect of frequency [F(15, 3030)=240.721, p=.00000] was significant. The interaction between test condition and frequency [F(15, 3030)=122.01, p=.0000] was significant when collapsing the analysis across factors of gender, ethnicity, and absolute MEP magnitude. A post-hoc analysis indicated a significant difference between test conditions at all center frequencies with the exception of 1350 and 8000 Hz. The compensated test condition had the higher PA magnitude between frequencies 250 to 2500 Hz and the lower mean PA magnitude between the frequency range 3150 to 8000 Hz. Refer to the below graphical representation for higher-order interaction involving frequency, test condition, and absolute MEP magnitude.

The interaction between gender and frequency [F(15, 3030)=4.8016, p=.0000] was also significant, with the analysis collapsed across factors of test pressure (ambient versus peak), ethnicity, and absolute MEP magnitude. Post-hoc analysis shows a significant difference in mean PA magnitude between male and female participants at all center frequencies, with the exception of 2500 Hz. With the exception of frequencies 3150 Hz to 5000 Hz, across the center frequency range, male participants (n=79) had on average a greater measure of PA magnitude compared to female participants (n=131). The variation of PA magnitude across center frequencies is displayed in Figure 28. Descriptive statistics for the interaction of gender and frequency can be found in Appendix A, Table 167.

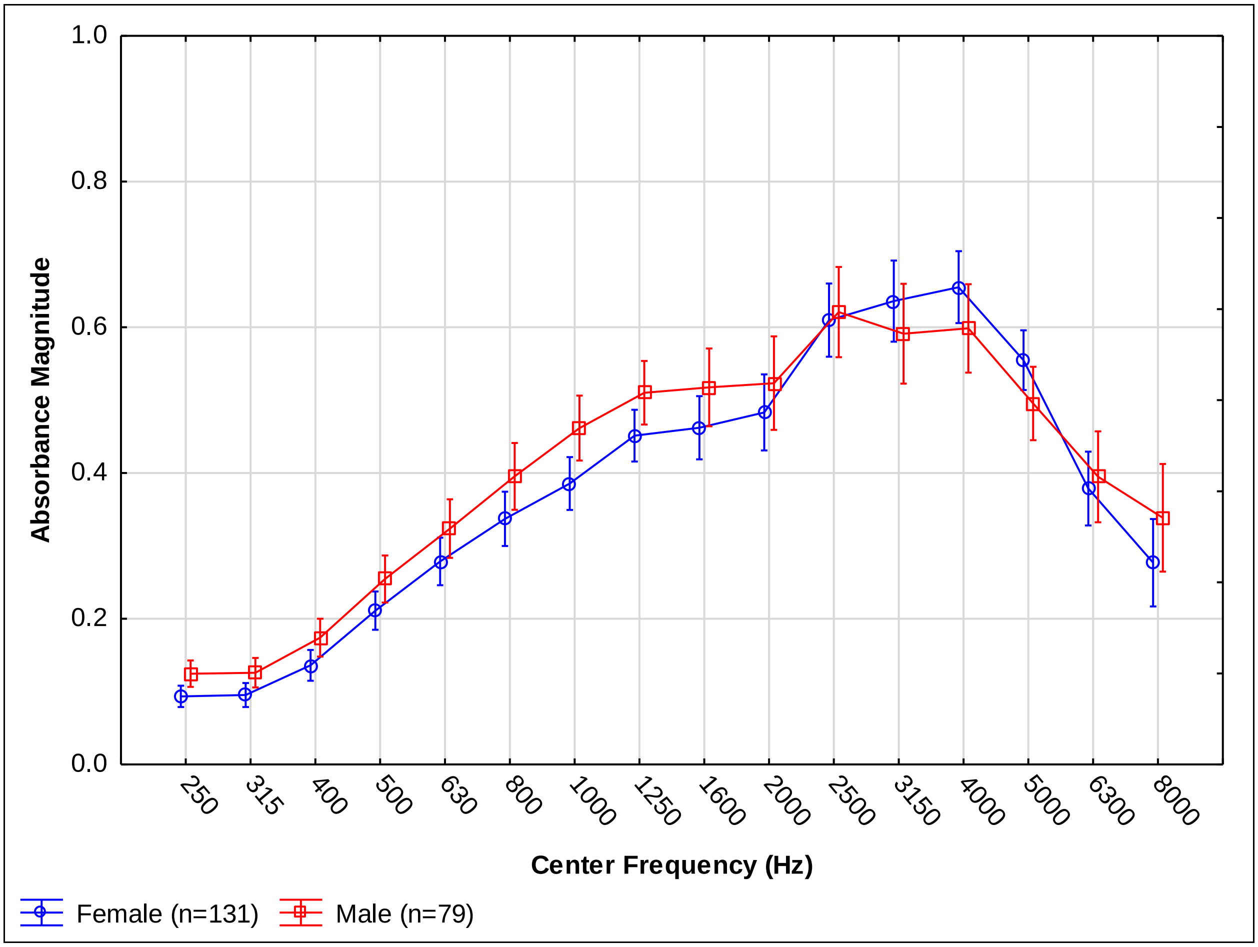


Figure 28: Post-maneuver condition: Comparison of mean power absorbance magnitude between gender groups (n=131 females and n=79 males) as a function of center frequency (250 to 8000 Hz). Analysis was collapsed across factors of ethnicity, absolute middle ear pressure (MEP) magnitude, and test pressure (ambient versus peak). Vertical bars denote 95th percent confidence intervals. Current effect: [F(15, 3030) =4.8016, p=.0000].

Ethnicity

The main effect of ethnicity [F(2, 202)=1.681, p=.188849] was not significant. However, the interaction between ethnicity and frequency [F(30, 3030)=3.710, p=.0000] was significant. A higher-order interaction between test pressure condition (ambient versus peak), frequency, and ethnicity [F(30, 3030)=4.371, p=.0000] was also significant. Participant data was categorized into three groups; Caucasian (n=70), Asian (n=95), and Other (n=45). Figure 29 shows the PA magnitude across the frequency range when comparing the ethnic groups for post-maneuver ambient and peak test conditions separately. This same response pattern was also seen in the interaction of absolute amplitude for DPOAE measures plotted as a function of frequency (refer to Figure 6 and Figure 11). For PA magnitude, a trend was observed in both the ambient and peak test pressure conditions: Mean PA was greatest for the Caucasian group for mid to low frequencies (250 to ~2500 Hz) and greater for the Asian and Other ethnic groups compared to Caucasians for the mid to high frequencies (3150 to 8000 Hz). A trend was also observed for PA magnitude in the ambient test condition, for absorbance to increase in magnitude from 250 Hz rising to about 4000 Hz, and then decreasing from the peak at 4000 Hz to a minimum at 8000 Hz. A similar trend was observed for the analyzed data in the peak test condition; absorbance magnitude rose from 250 Hz to a peak between 2500 to 4000 Hz and then decreased in a sloping manner to 8000 Hz. Referencing Figure 29, all three ethnic groups also share a similar response when comparing the PA curve shape between post-maneuver ambient and peak pressure conditions. For the tail of the curve (roughly 2500 Hz and lower), there is a noticeable drop in PA magnitude in the presence of uncompensated abnormal MEP. The upper tail portion of the curve and the peak of the curve remain relatively stable with respect to PA magnitude between test conditions. However, there is a slight indication that the peak portion of the curve shifts toward the higher frequency (right-ward) in the post-maneuver ambient condition (peaks at 4000 Hz) and then levels out across a wider frequency range for the peak test condition (2500 to 4000 Hz). A difference in the number of peaks is also observed when comparing the ambient to the peak pressure curves. The peak pressure condition response curve has two distinctive peaks for all three ethnic groups while the ambient test pressure condition response curves have a single more rounded peak response.

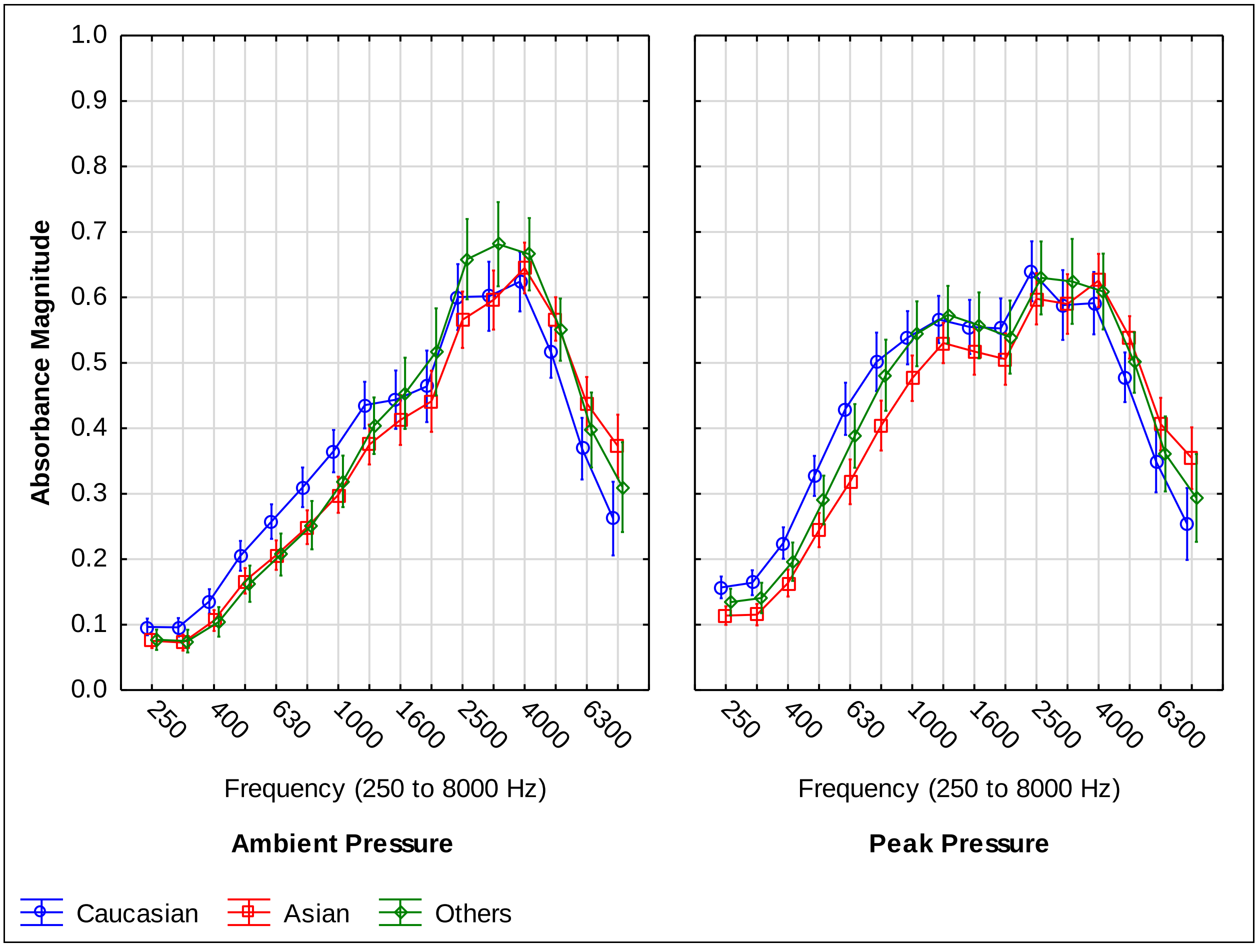


Figure 29: Post-maneuver condition measures: Comparison of mean power absorbance magnitude between test pressure conditions (ambient versus peak), center frequency (250 to 8000 Hz), and ethnicity. Sample sizes for the three ethnic groups were as follows: Caucasians (n=70), Asian (n=95), and Others (n=45). The analysis was collapsed across factors of gender and absolute middle ear pressure magnitude. Vertical bars denote 95th confidence intervals. Current effect: [F(30, 3030)=4.3710, p=.0000].

Absolute Middle Ear Pressure Magnitude

The main effect of absolute MEP magnitude [F(4, 202)=5.7877, p=.00020] was significant, indicating mean PA magnitude did differ across the five absolute MEP magnitude categories (A to E). The mean PA magnitude for each category is shown in Table 83. This analysis was done collapsing across factors of frequency, ethnicity, gender, and test pressure (ambient versus peak). A trend was evident for absorbance magnitude to decrease as absolute MEP increases, displayed as the downward slope in absorbance from categories A to E in Figure 30. A Tukey's HSD test results are shown in Table 84, these results indicate a significant difference in mean PA magnitude for comparisons between categories A:E, D:B, and E:B. The n=15 measures in the MEP magnitude category A (0 to 10 daPa), is a relatively smaller sample size. For the post-maneuver condition, the majority of participants were able to successfully induce abnormal MEP in this test condition, contributing to the larger sample sizes in categories B to E.

|MEP| Magnitude (daPa)	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	0.42	0.02	0.39	0.46	15
B (11 to 25)	0.42	0.01	0.39	0.44	36
C (26 to 50)	0.39	0.01	0.37	0.41	52
D (51 to 99)	0.37	0.01	0.35	0.39	61
E (≥100)	0.35	0.01	0.33	0.37	46

Table 83: Post-maneuver condition measures: Comparison of mean power absorbance (PA) magnitude between absolute middle ear pressure (|MEP|) magnitude categories (A to E). The analysis was collapsed across factors of test pressure (ambient versus peak), gender, ethnicity, and frequency. Current effect: [F(4, 202)=5.7877, p=.00020].

|MEP| Magnitude (daPa)	{1}.41	{2} .41	{3} .39	{4} .36	{5} .35
A (0 to 10)		1.00	0.72	0.12	**0.02**
B (11 to 25)	1.00		0.57	**0.02**	**0.00**
C (26 to 50)	0.72	0.57		0.43	0.07
D (51 to 99)	0.12	**0.02**	0.43		0.83
E (≥100)	**0.02**	**0.00**	0.07	0.83	

Table 84: Tukey's HSD test analysis for the comparison of mean power absorbance magnitude between absolute middle ear pressure (|MEP|) magnitude categories (A to E) for post-maneuver condition measures. Samples sizes for each category are as follows: A (n=15), B (n=36), C (n=52), D (n=61), and E (n=46). The analysis was collapsed across factors of test pressure (ambient versus peak), gender, ethnicity, and frequency. Bolded values indicate significance (p<.05). Current effect: [F(4, 202)=5.7877, p=.00020].

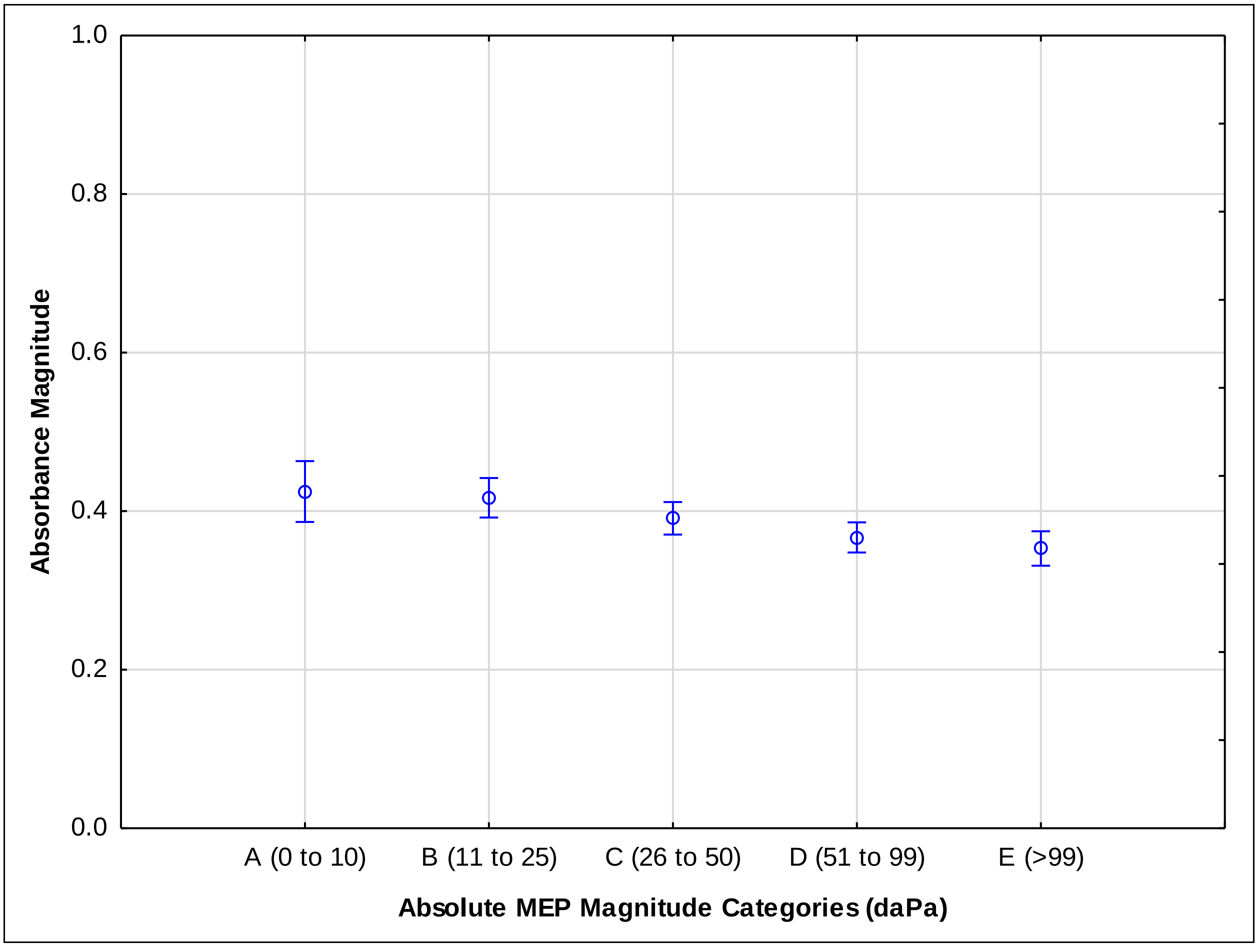


Figure 30: Post-maneuver condition measures: Comparison of mean absorbance magnitude between absolute middle ear pressure (MEP) magnitude categories (A to E). The analysis was collapsed across factors of test pressure (ambient versus peak), gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 202)=5.7877, p=.00020].

Absolute Middle ear Pressure Magnitude, Test Pressure Condition, and Frequency

The interaction between test pressure condition and absolute MEP magnitude [F(4, 202)=68.445, p=.00000] was significant, indicating that the variation in PA between ambient and peak conditions does vary between the various magnitude categories. The interaction between absolute MEP magnitude, test pressure condition (ambient versus peak), and center frequency [F(60, 3030)=16.268, p=.0000] was also significant. The analysis was collapsed across factors of gender and ethnicity. This interaction indicates that the variation in PA magnitude across the frequency range differs between the MEP magnitude categories and also between test pressure conditions. Figure 31 represents the post-maneuver condition PA measures plotted as a function of three factors; test pressure (ambient versus peak test conditions), center frequency, and absolute MEP magnitude. There were five categories of absolute MEP magnitude A (n=15), B (n=36), C (n=52), D (n=61), and E (n=46). The left panel of Figure 31 for the ambient pressure condition shows a significant difference in mean PA magnitude between the five MEP magnitude categories. For frequencies <4 kHz, PA magnitude decreased from categories A to E. There was overlap in PA magnitude for all five categories for the higher center frequencies roughly >4 kHz. The right panel of Figure 31 (testing at peak pressure) shows an apparent trend for PA to be similar in magnitude between the absolute MEP categories across the entire range of center frequencies (250 to 8000 Hz). Observed for both test conditions (ambient and peak analysis), category E (MEP of ≥100 daPa) corresponding to the largest absolute MEP magnitude, shows an enhanced PA magnitude compared to categories A to D for the higher center frequencies (≥5000 Hz). The trend in PA response across frequencies (Figure 31) suggests there is a greater change in PA magnitude observed for the mid to lower center frequencies in the presence of abnormal MEP. The peak of the curve also changes between the ambient and peak test conditions, most noticeably for categories D and E (similar trend as was observed in Figure 29).

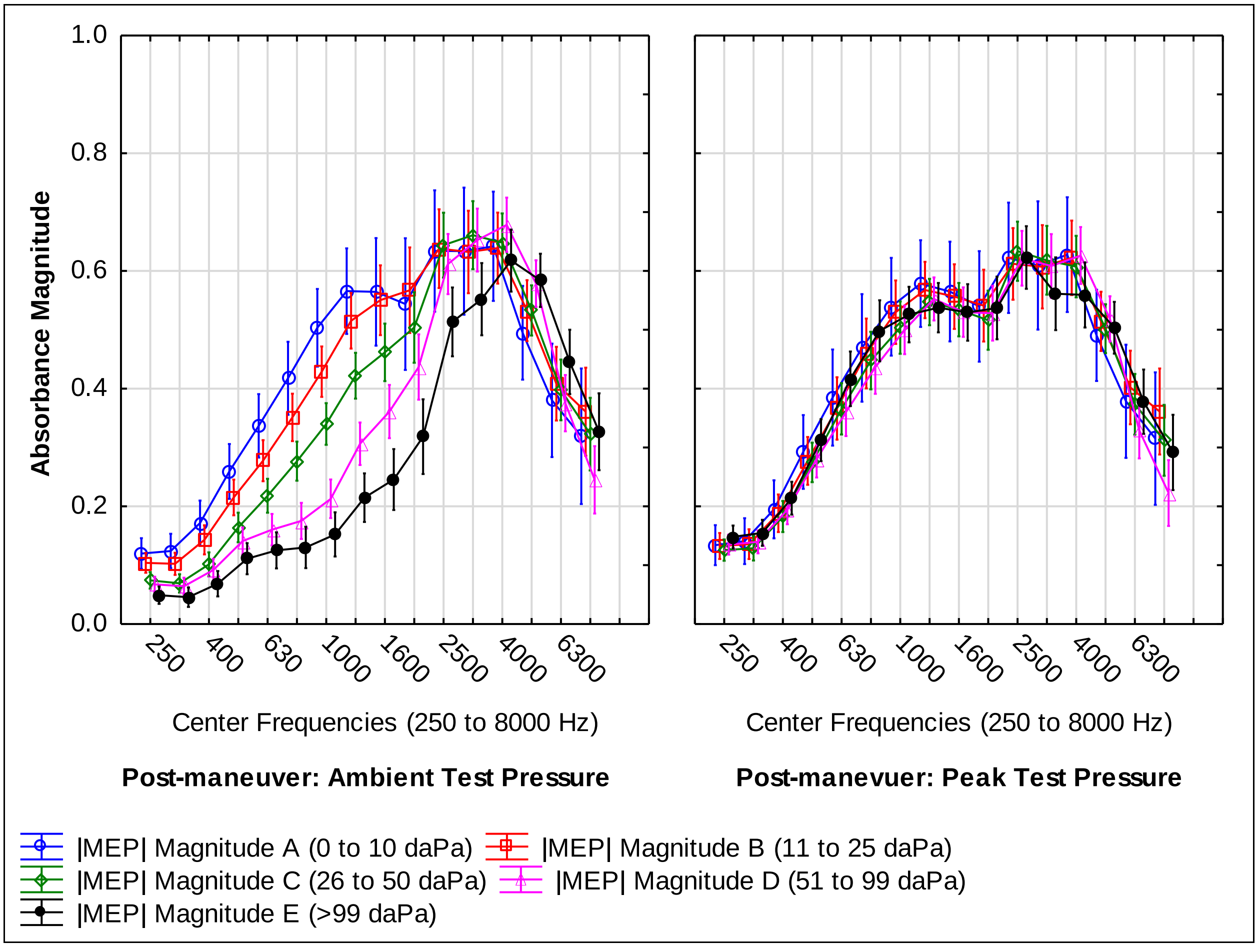


Figure 31: Post-maneuver condition measures: Comparison of mean power absorbance magnitude between test pressure conditions (ambient versus peak), frequency (250 to 8000 Hz), and absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(60, 3030)=16.268, p=.0000].

5.5 Power Absorbance; Comparison between Four Test Conditions

The following analyses incorporate absorbance measures from all four test conditions, non-maneuver ambient and post-maneuver for both ambient and peak pressure conditions (illustrated in Table 85). The factor of absolute MEP shift magnitude will be used for the following analyses. A summary of the statistical analysis for all main effects and interactions between factors is shown in Appendix B, Table 222. Refer to Table 8 for mean MEP estimates for each test condition. A sample size of n=210 PA measures from n=93 individual participants contributed to each of the four test conditions.

	Test Condition	**Absorbance Test Pressure**
Test Ear (Left or Right)	**Non-maneuver**	**Ambient**
		Peak
	Post-maneuver (Absolute MEP)	**Ambient**
		Peak

Table 85: Shaded boxes represent test conditions under comparison.

Test Pressure

The main effect of test condition [F(3, 606)=319.57, p=.0000] was significant. The non-maneuver peak test condition had the greatest mean PA magnitude (0.43); followed by the post-maneuver peak (0.42) and non-maneuver ambient (0.42) test conditions with equivalent PA magnitudes, and then the post-maneuver ambient test condition (0.35) had the lower PA magnitude. The analysis was collapsed across factors of gender, ethnicity, frequency, and absolute MEP shift magnitude (descriptive statistics are shown in Table 86). A post-hoc analysis showed a significant difference in PA magnitude when comparing the post-maneuver ambient condition to both non-maneuver test conditions and to the post-maneuver peak condition. A significant difference was also seen between the two non-maneuver test conditions. However, no significant difference was seen between both non-maneuver conditions and the post-maneuver peak test condition. Refer to Appendix A Table 169 for Tukey's HSD test results. The main effect of test condition is illustrated in Figure 32. In addition as further support, when the factor of absolute MEP shift magnitude is not considered in the analysis for the main effect of test condition (x4), no significant difference was found between the two non-maneuver test conditions [F(3, 618)=234.66, p=.0000], with all other interactions between test conditions not changing in significance.

Test Condition	**Mean PA Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	0.42	0.02	0.37	0.46	210
Non-maneuver, Peak	0.43	0.02	0.38	0.47	210
Post-maneuver, Ambient	0.35	0.02	0.31	0.40	210
Post-maneuver, Peak	0.42	0.02	0.37	0.47	210

Table 86: Comparison of power absorbance (PA) magnitude between test conditions (x4). The analysis was collapsed across factors of frequency, gender, ethnicity, and absolute middle ear pressure shift magnitude. Current effect: [F(3, 606)=319.57, p=.0000].

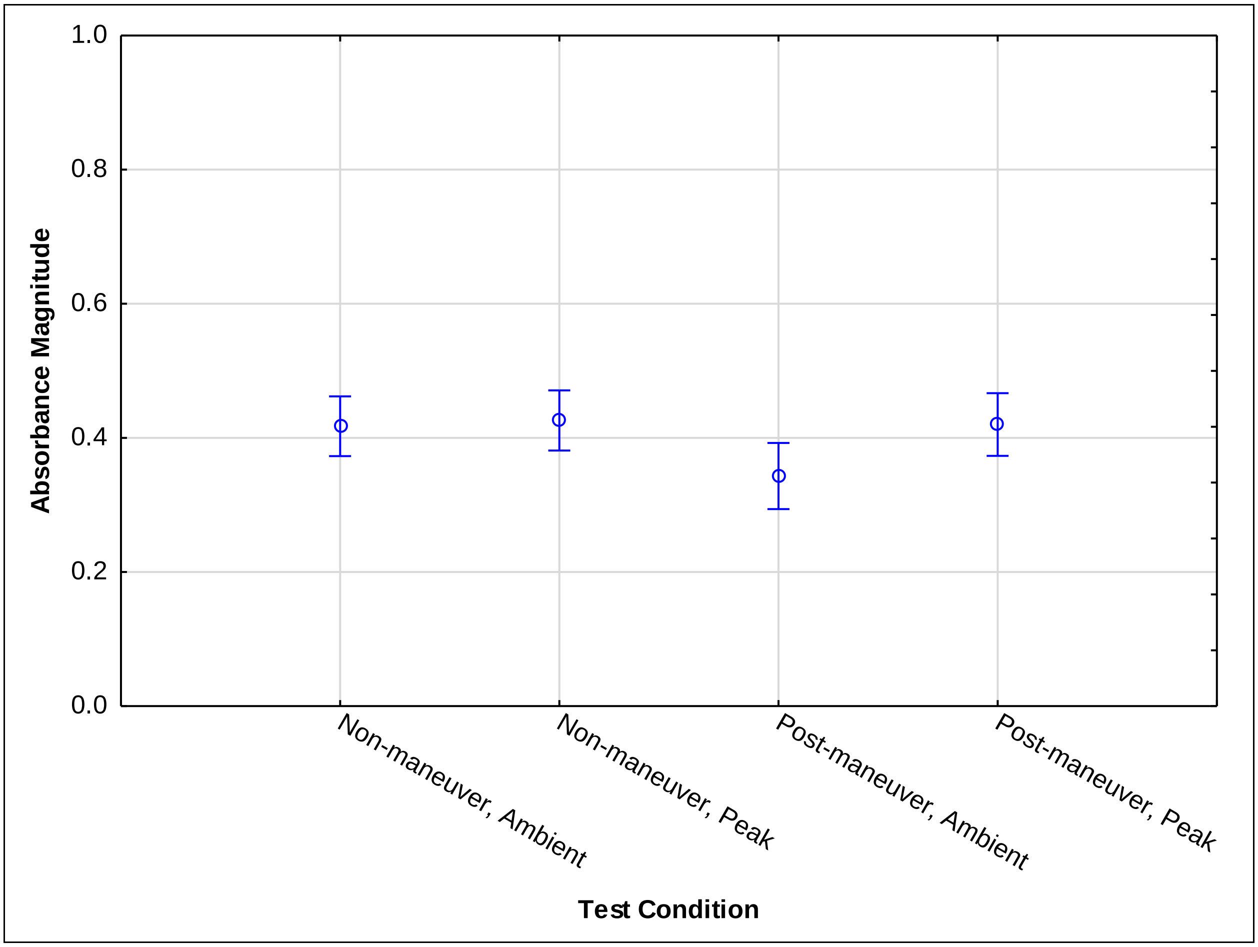


Figure 32: Comparison of power absorbance (PA) magnitude between test conditions (x4). The analysis was collapsed across factors of frequency, gender, ethnicity, and absolute middle ear pressure shift magnitude. A sample size of n=210 PA measures contributed to each of the four test conditions. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 606)=319.57, p=.0000].

Gender

The main effect of gender [F(1, 206)=7.138, p=.008162] was significant. This analysis was collapsed across factors of ethnicity, frequency, test condition (x4), and absolute MEP shift magnitude. Female participants (n=131) had a lower mean PA magnitude than male participants (n=79) (refer to Table 87). This difference between genders was also seen for the analyses comparing only two test conditions.

Gender	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
Female	0.39	0.01	0.38	0.40	131
Male	0.42	0.01	0.40	0.43	79

Table 87: Comparison of mean power absorbance (PA) magnitude between gender groups. The analysis was collapsed across factors of frequency, absolute middle ear pressure magnitude, ethnicity, and test condition (non-maneuver and post-maneuver). Current effect: [F(1, 206)=7.138, p=.008162].

The significant interaction between gender (n=131 female, n=79 male) and frequency [F(15, 3030)=5.614, p=.00000], shows that the variation in PA magnitude across center frequencies did differ for gender groups. A total of n=210 PA measures contributed to each test condition. The graphical display of this interaction was not included as the pattern reflects that already shown in Figure 28. Male participants had greater mean PA magnitude at center frequencies 250 to 2000 Hz and from 6300 to 8000 Hz.

The interaction between test condition (x4), gender, and center frequency [F(45, 9090)=1.7324, p=.00172] was significant. Figure 33 shows the mean PA magnitude across the center frequency range <4000 Hz is lowest for the post-maneuver ambient test condition compared to the other three test conditions. This interaction shows that the variation in PA magnitude across frequencies does differ between gender groups when comparing test conditions (x4) although the pattern for both male and females is similar. For both genders, a trend is seen for mean PA magnitude to be greatest for the post-maneuver peak condition at the higher center frequencies (about 5000 to 8000 Hz).

Figure 33: Comparison of power absorbance magnitude between gender groups and test conditions (x4) as a function of center frequency (250 to 8000 Hz). There were n=131 PA measures contributing to each of the four female test conditions. A sample size of n=79 PA measures contributed to each of the four male test conditions. The analysis was collapsed across

factors of ethnicity and absolute middle ear pressure shift magnitude. Vertical bars denote 95th percent confidence intervals. Current effect: F(45, 9090)=1.7324, p=.00172.

Ethnicity

The main effect of ethnicity [F(2, 202)=1.940, p=.146363] was not significant. The interaction of ethnicity, and frequency [F(30, 3030)=4.0158, p=.0000] was significant, showing that the variation in PA across the center frequency range of 250 to 8000 Hz does differ for Caucasian (n=70), Asian (n=95), and Other (n=45) participants. This analysis was collapsed across factors of gender, absolute MEP shift magnitude, and test conditions (x4). Displayed in Figure 34, absorbance is greatest in the Caucasian groups for low to mid frequencies (~250 to 2500 Hz) and both the Asian and Other ethnic groups had greater mean PA magnitudes for center frequencies 3150 to 8000 Hz.

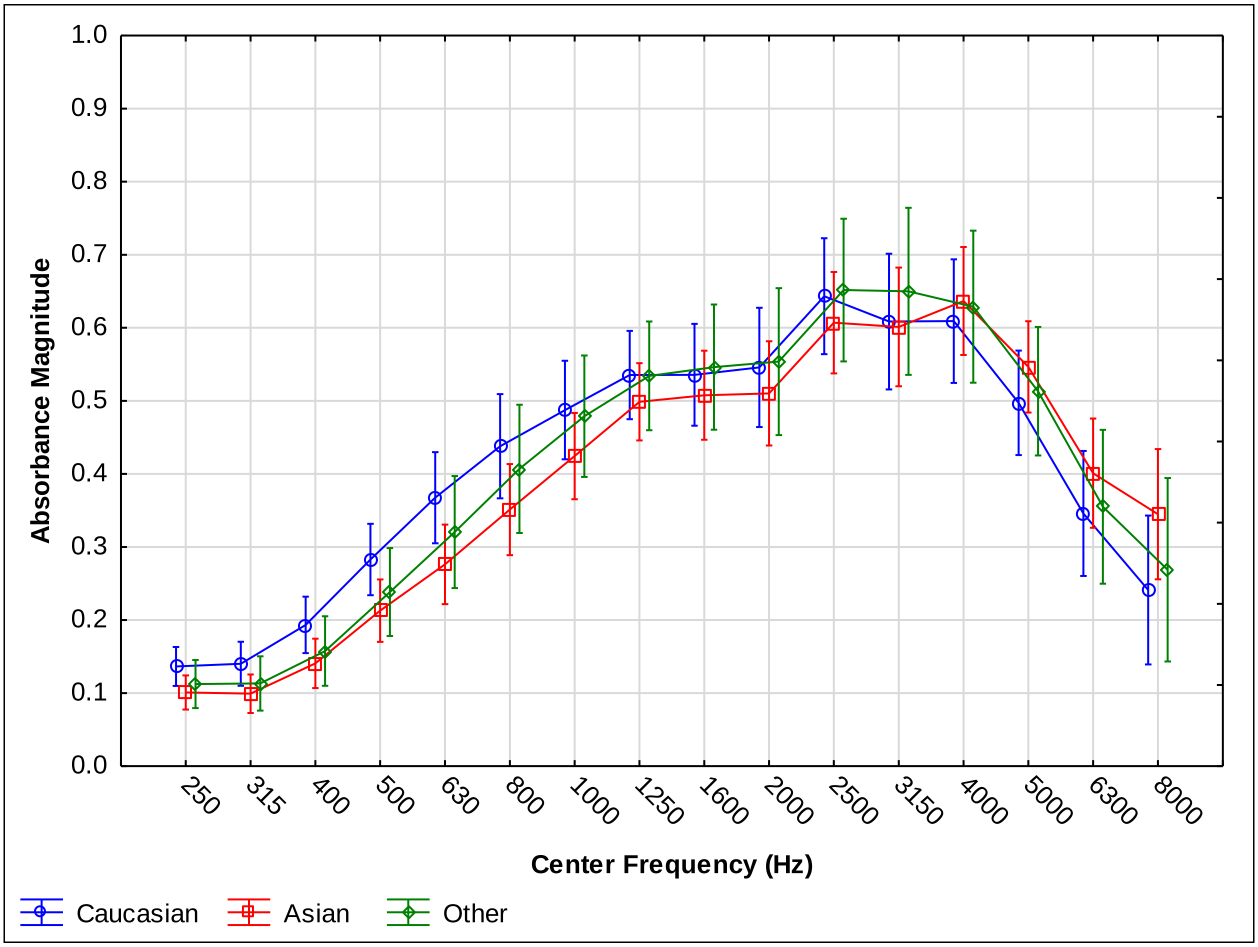


Figure 34: Comparison of power absorbance magnitude between ethnic groups as a function of center frequency (250 to 8000 Hz). Sample sizes for each ethnic group are as follows: Caucasian (n=70), Asian (n=95), and Others (n=45). The analysis was collapsed across factors of gender, absolute middle ear pressure shift magnitude, and test condition (non-maneuver and post-maneuver). Vertical bars denote 95th percent confidence intervals. Current effect: F(30, 3030)=4.0158, p=.00000.

The interaction between ethnicity, frequency, and absolute MEP shift [F(90, 9090)=3.9742, p=.00000] was significant. When comparing the PA magnitude between the four test conditions (non- versus post-maneuver and ambient versus peak) as a function of frequency, the post-maneuver ambient test condition has the lowest PA magnitude <4000 Hz for all three ethnic groups. The trend in absorbance displayed in Figure 35 shows for the post-maneuver ambient condition (uncompensated abnormal MEP), that there is a drop in PA magnitude seen across all ethnicity groups predominately for the mid to low frequencies. The PA measures for the other three test conditions are comparable in magnitude across frequencies. Figure 35 also illustrates the observed increase in PA magnitude for the high frequency region (roughly >5000 Hz) for the post-maneuver ambient test condition for all three ethnic groups.

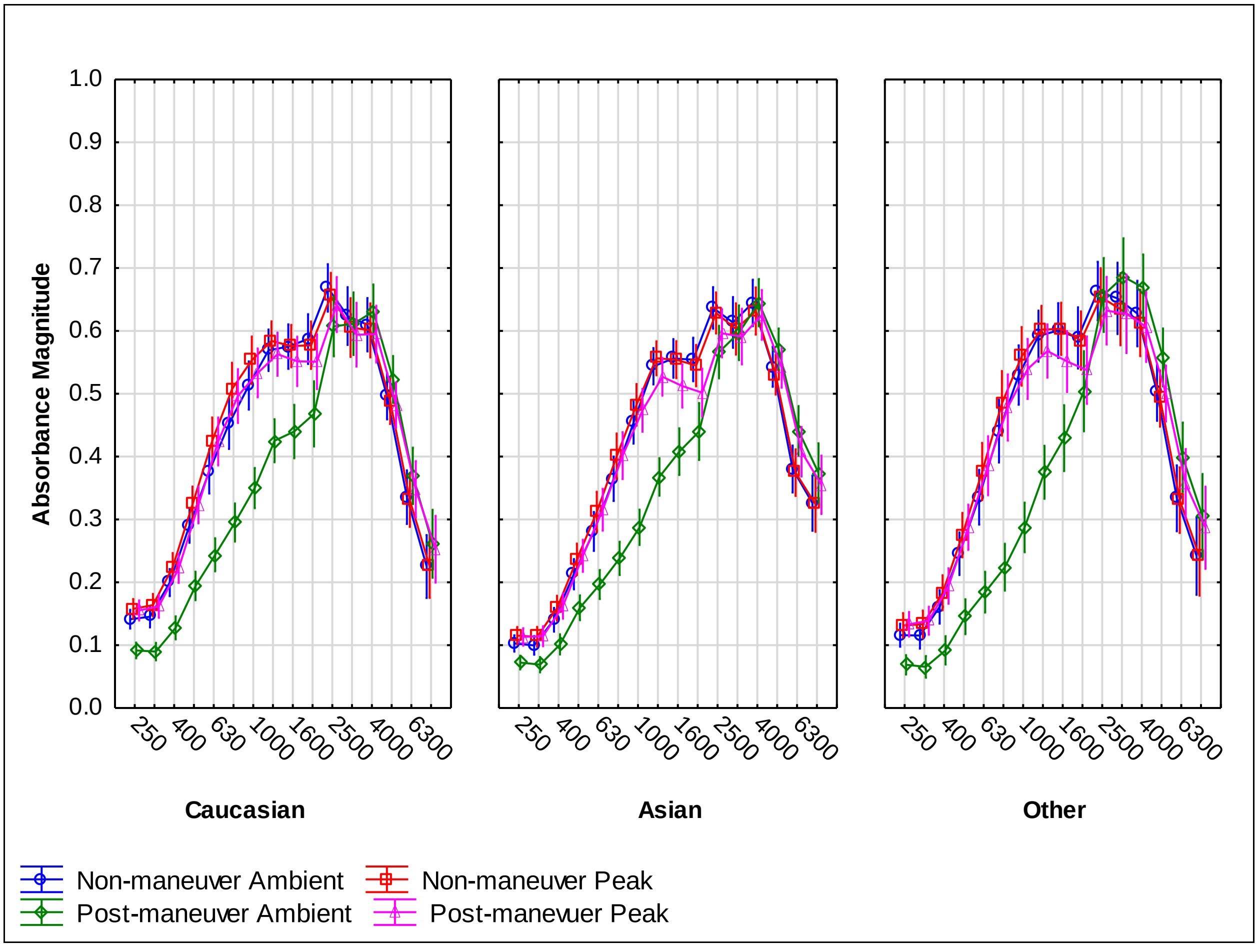


Figure 35: Comparison of power absorbance magnitude between ethnic groups and test conditions (x4) as a function of center frequency (250 to 8000 Hz). The analysis was collapsed across the factors of gender and absolute middle ear pressure shift magnitude. For all four test conditions, there was a sample size of n=70 for the Caucasian group, n=95 for Asians, and n=45 for the Others group. Vertical bars denote 95th percent confidence intervals. Current effect: [F(90, 9090)=3.9742, p=.0000].

Absolute Middle Ear Pressure Magnitude

The interaction between test condition (x4) and absolute MEP shift magnitude [F(12, 606)=44.979, p=0.0000] was significant. The descriptive statistics for this interaction are shown in Table 88. Figure 36 shows as absolute MEP shift magnitude increases (from A to E), the separation in mean PA magnitude between test conditions increases. Post-hoc analysis indicates a significant difference in PA between the post-maneuver ambient test condition and the other three test conditions at categories B to E. The post-maneuver ambient condition had the lowest mean PA magnitude at all five categories (A to E) compared to the other three test conditions. The test conditions non-maneuver ambient, non-maneuver peak, and post-maneuver peak all show equivalent mean PA magnitudes across |MEP| shift categories A to E.

|MEP| Shift (daPa)	Test Condition	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver Ambient	0.42	0.06	0.31	0.53	29
A (0 to 10)	Non-maneuver Peak	0.44	0.06	0.32	0.55	29
A (0 to 10)	Post-maneuver, Ambient	0.41	0.05	0.30	0.51	29

|MEP| Shift (daPa)	Test Condition	Mean PA Magnitude	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Post-maneuver, Peak	0.43	0.06	0.31	0.55	29
B (11 to 25)	Non-maneuver Ambient	0.41	0.06	0.29	0.52	30
B (11 to 25)	Non-maneuver Peak	0.42	0.06	0.30	0.53	30
B (11 to 25)	Post-maneuver, Ambient	0.38	0.05	0.28	0.48	30
B (11 to 25)	Post-maneuver, Peak	0.41	0.06	0.29	0.53	30
C (26 to 50)	Non-maneuver Ambient	0.42	0.05	0.33	0.51	48
C (26 to 50)	Non-maneuver Peak	0.43	0.05	0.33	0.52	48
C (26 to 50)	Post-maneuver, Ambient	0.38	0.04	0.29	0.46	48
C (26 to 50)	Post-maneuver, Peak	0.42	0.05	0.33	0.52	48
D (51 to 99)	Non-maneuver Ambient	0.41	0.04	0.33	0.49	57
D (51 to 99)	Non-maneuver Peak	0.42	0.04	0.34	0.50	57
D (51 to 99)	Post-maneuver, Ambient	0.32	0.04	0.24	0.40	57
D (51 to 99)	Post-maneuver, Peak	0.41	0.04	0.33	0.50	57
E (>99)	Non-maneuver Ambient	0.43	0.05	0.34	0.52	46
E (>99)	Non-maneuver Peak	0.44	0.05	0.34	0.53	46
E (>99)	Post-maneuver, Ambient	0.28	0.04	0.19	0.36	46
E (>99)	Post-maneuver, Peak	0.42	0.05	0.33	0.52	46

Table 88: Comparison of power absorbance (PA) magnitude between test conditions (x4) as a function of absolute middle ear pressure (|MEP|) shift magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(12, 606)=44.979, p=0.0000].

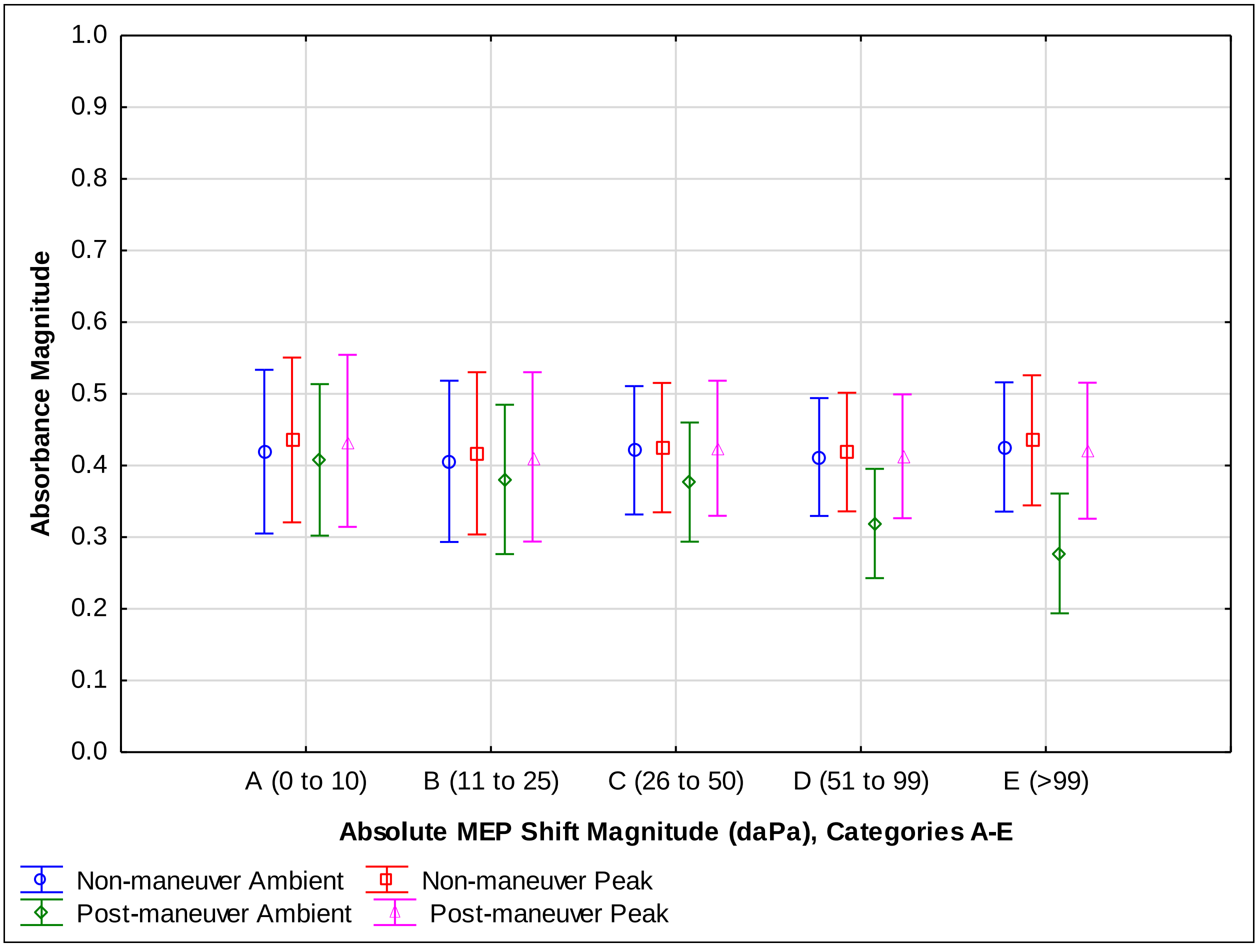


Figure 36: Comparison of power absorbance magnitude between test conditions (x4) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. There was an equivalent sample size for each category for all four test conditions. Sample sizes for each category are as follows: A (n=29), B (n=30), C (n=48), D (n=57), and E (n=46). Vertical bars denote 95th percent confidence intervals. Current effect: [F(12, 606)=44.979, p=0.0000].

The high-order interaction between absolute MEP shift magnitude, test condition (x4), and center frequency [F(180, 9090)=11.510, p=.0000] was significant. Figure 37 shows the same pattern of absorbance across the center frequency range for all five categories (A to E). The difference in mean PA between the post-maneuver ambient condition compared to the other three test conditions is most evident again for frequencies <4000 Hz. This difference in PA magnitude increases with increasing |MEP| shift magnitude (A to E). Figure 37 clearly depicts the increasing drop in PA magnitude for the left tail portion of the response curve with a coinciding shift in the absorbance peak right-ward towards the higher frequencies, as the MEP magnitude increase (categories A to E).

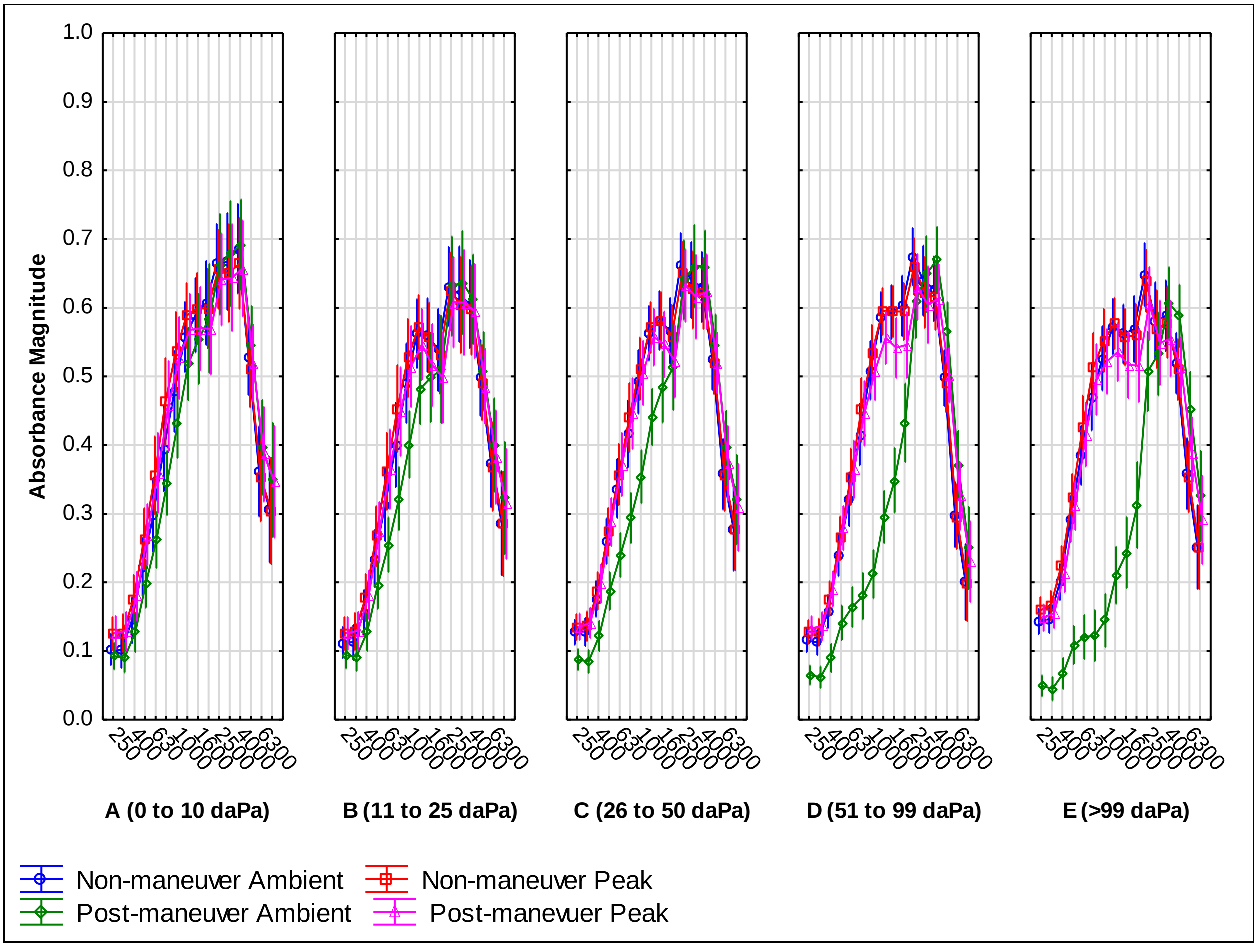


Figure 37: Comparison of power absorbance magnitude between absolute middle ear pressure shift magnitude categories (A to E) and test conditions (x4). The frequency range spans from 250 to 8000 Hz in 1/3 octave bands. The analysis was collapsed across factors of ethnicity and gender. Samples sizes of A (n=29), B (n=30), C (n=48), D (n=57), and E (n=46) contributed to each of the four test conditions. Vertical bars denote 95th percent confidence intervals. Current effect: [F(180, 9090)=11.510, p=0.0000**].**

Chapter 6: Discussion; Evoked Otoacoustic Emissions

Multiple studies have investigated the effect of abnormal pressure, either MEP or external ear canal pressure, on the strength and frequency response pattern of EOAEs. The majority of these studies have focused on altering the pressure within the outer ear canal using relatively small sample sizes. Several studies have also demonstrated the effectiveness of compensating for the presence of abnormal MEP (induced or naturally occurring), but very few have employed a pressure equalizing method and instrument setup with the potential for clinical application. The primary purpose of this study was to demonstrate the impact of abnormal MEP and the effectiveness of compensating for this pressure on the outcome measure of DPOAE and TEOAE absolute amplitude. This study's test procedure involved a test environment, measurement parameters, and a test instrument that have the potential to be implemented into clinical practice. All immittance and EOAE related measurements, both conducted at ambient and a compensating peak pressure, were done using the commercially available Titan Suite platform by Interacoustics. Additional outcome variables of noise level and power absorbance magnitude were also investigated to explore the utility of a compensating pressure method from a clinical perspective. Given the continued replication of findings that show participant characteristics have a significant impact on measures relating to outer, middle, and inner ear structures or properties, factors of gender and ethnicity were considered between-subject factors for all analyses conducted within this study.

Chapter 6 discussion of EOAE results is divided into three subsections: (6.1) Comparison of Absolute EOAE Amplitude between Test Conditions, (6.2) Comparison of Noise Level between

Test Conditions, and (6.3) Participant Characteristics; Examining Gender and Ethnic Differences.

6.1 Comparison of Absolute EOAE Amplitude between Test Conditions

For the current study, it was found that the EOAE absolute amplitude varied significantly between test conditions, but only for certain test condition comparisons and across frequencies. Overall, testing at peak pressure compared to ambient pressure tended to increase absolute EOAE amplitude. It was also found that overall female compared to male participants had greater mean EOAE amplitudes under all test pressure conditions. The significance and response pattern for the interaction between ethnicity, frequency, and test condition varied for different test condition comparisons and between TEOAE and DPOAE measures. Subsection 6.1.1 provides a brief discussion of the general results of EOAE absolute amplitude measures for the main effect of test condition. The results for the various two-test condition comparisons and interaction analyses will be discussed in the following subsections 6.1.2 through 6.1.5: (6.1.2) Non-maneuver Ambient and Post-maneuver Ambient Test Conditions, (6.1.3) Non-maneuver Ambient and Post-maneuver Peak Test Conditions, (6.1.4) Non-maneuver Ambient and Non-maneuver Peak Test Conditions, and (6.1.5) Post-maneuver Ambient and Post-maneuver Peak Test Conditions.

6.1.1 Overview Comparison of Absolute Amplitude between All Test Conditions

Distortion-product Otoacoustic Emissions

The main effect of test condition was significant for the outcome measure of DPOAE absolute amplitude when comparing all four test conditions collapsing across factors of gender, ethnicity, and frequency. The test conditions with the largest to smallest mean DPOAE absolute amplitude was in the order of (1) non-maneuver peak (8.09 dB SPL), (2) non-maneuver ambient (8.01 dB SPL), (3) post-maneuver peak (7.25 dB SPL), and then (4) post-maneuver ambient (6.64 dB SPL).

The following is a summary of the two-test condition comparisons for the main effect analysis of DPOAE test condition. These analyses are for the outcome measure of DPOAE absolute amplitude with all analyses collapsing across factors of gender, ethnicity, and frequency. As was predicted, (1) the difference in absolute DPOAE amplitude between both non-maneuver ambient condition and the post-maneuver ambient test condition was significant. An unpredicted significant difference was found for the comparisons between (2) the non-maneuver ambient test condition compared to the post-maneuver peak condition: For this test condition comparison, the null hypothesis was not supported. A significant difference in DPOAE amplitude between the non-maneuver ambient and post-maneuver peak test conditions was not predicted because it was expected that when the abnormal MEP in the post-maneuver condition is compensated for, DPOAE amplitude would reflect amplitude measures from the baseline (non-maneuver) condition. As predicted for DPOAE measures, (3) the difference between the peak and ambient non-maneuver conditions was not significant. A non-significant difference between the ambient and peak non-maneuver test pressure conditions was expected, as the average MEP for the baseline condition was ±10 daPa from ambient (0 daPa). This average degree of MEP centered on 0 daPa was not expected to be great enough in magnitude to be reflected in a DPOAE amplitude difference between compensated and uncompensated test conditions. As was also predicted, (4) the difference in absolute DPOAE amplitude between the post-maneuver peak and post-maneuver ambient test conditions was significant. These findings for the two-test conditions comparisons were similar for male and female participants as well as for the three ethnic groups. Detailed descriptions of and proposed explanations for the study's DPOAE findings as well as comparisons to published literature will be provided in the remainder of Chapter 6 and in Chapter 7.

Transient Evoked Otoacoustic Emissions

For the outcome measure of TEOAE absolute amplitude, the main effect of test condition was significant when comparing all four test conditions and collapsing the analysis across factors of gender, ethnicity, and frequency. The test conditions with the largest to smallest mean TEOAE absolute amplitude was in the order of (1) non-maneuver peak (3.60 dB SPL), (2) non-maneuver ambient (3.44 dB SPL), (3) post-maneuver peak (3.03 dB SPL), and then (4) post-maneuver ambient (2.38 dB SPL). The trend in mean absolute amplitude across the four test conditions for TEOAE measures is similar to the DPOAE results presented above.

The following is a summary of the two-test condition comparisons for the main effect analysis of TEOAE test condition. These analyses are for the outcome measure of TEOAE absolute amplitude with all analyses collapsing across factors of gender, ethnicity, and frequency. As predicted, (1) the difference in absolute TEOAE amplitude between the non-maneuver ambient and post-maneuver ambient conditions was significant. The average degree of uncompensated abnormal MEP induced in the post-maneuver test condition was expected to be great enough in magnitude to be reflected in a change in TEOAE amplitude when compared to baseline amplitude measures. An unpredicted finding was (2) the significant difference in absolute TEOAE amplitude between the non-maneuver ambient and post-maneuver peak test conditions. A non-significant difference in TEOAE amplitude between these conditions (non-maneuver ambient and post-maneuver peak) was predicted: It was expected that when the abnormal MEP in the post-maneuver condition was compensated for, TEOAE amplitude would reflect the baseline (non-maneuver) amplitude measures. Supporting the null hypothesis, (3) the absolute TEOAE amplitude difference between the non-maneuver ambient and non-maneuver peak test conditions was not significant. A non-significant difference between the ambient and peak non-maneuver test pressure conditions was also expected, as the average MEP for the baseline condition was ±10 daPa from ambient (0 daPa), which is an average degree of MEP not expected to be great enough in magnitude to be reflected in a TEOAE amplitude differences between compensated and uncompensated pressure conditions. The same rationale applies to the DPOAE data. Another predicted finding was (4) the significant difference in absolute TEOAE amplitude for the comparison between the post-maneuver ambient and post-maneuver peak test conditions. Further discussion and explanations regarding this study’s TEOAE findings as well as connections to published literature and clinical applications of these findings will be provided in the remainder of Chapter 6 and in Chapter 7.

There is dissimilarity in findings regarding the significance of measures, for the comparison of absolute TEOAE amplitude between the non-maneuver ambient and the post-maneuver peak test conditions. Presented in Table 45, there is a significant difference in TEOAE amplitude between the non-maneuver ambient (3.44 dB SPL) and post-maneuver peak (3.03 dB SPL) test conditions as presented in the results section 4.2.1. The analysis was collapsed across factors of gender, ethnicity, and frequency. This finding of significance is in contrast to the post-hoc results from the four-test condition comparison shown in Table 64, Table 65, and Figure 18. The four-test condition comparison shows no significant difference in absolute TEOAE amplitude between the non-maneuver ambient and post-maneuver peak test condition. The source of this difference in significance between the two comparison methods was sought after by the study's co-investigator (thesis student, Rae Riddler). However, after review of the original database, review of the approach to statistical analysis, and re-generation of all included figures and tables yielded the same results as the initial analysis. No other discrepancies in outcome analysis were found for the comparison between sections 4.2.1 and the 4.5.1. The source of difference in significance is likely a result of the Statistica software's approach to data analysis. For the four-test condition comparison, the statistics software makes more adjustments for type 1 errors compared to the two-test condition comparison. Less adjustments for inflated type I errors are needed for the two-test condition comparisons because there are fewer levels for comparison. A more conservative approach to analysis is used by the system when the number of levels increased, as in the four-test condition comparison. The reader should note that in the Discussion section of this chapter, Chapter 6, the results from the two-test condition comparison are referenced

6.1.2 Non-maneuver Ambient and Post-maneuver Ambient Test Conditions

The comparison between the non-maneuver ambient and the post-maneuver ambient test conditions was conducted in order to demonstrate the impact of abnormal MEP on the outcome measures of absolute EOAE amplitude. The comparison between these two test conditions represents what is currently done in most clinical settings: Regardless of the degree of MEP that a patient presents with at the time of assessment, EOAEs are measured at a setting of ambient test pressure (i.e. uncompensated). For this study, it was predicted that if abnormal MEP is not compensated for (i.e. post-maneuver ambient condition), the increase or decrease in MEP away from ambient (0 daPa) would result in a reduction of absolute EOAE amplitude relative to the absolute amplitude value observed in the non-maneuver ambient test condition. This change in emission strength between test conditions was expected to occur in a frequency-dependent manner.

Test Condition Comparisons and Frequency Response Patterns

The primary function of the middle ear is altered with a change in MEP status, namely the response of force amplification and the sound transduction to the inner ear are changed. Changes to the middle ear transfer function impact certain frequencies more than others, resulting in a reduction of EOAE amplitude level in particular test frequency regions. The presence of abnormal MEP reduces the vibration velocity of the TM, with the stiffening of the TM most significantly impacting the transmission of low frequencies, primarily ≤ 2 kHz (Perez, 2012). High frequencies are impacted by mass reactance components more so than by stiffness components. As changes in MEP have a greater impact on stiffness components, this leads to a greater change in the low compared to high test frequencies in cases of uncompensated abnormal

MEP. A change in MEP and orientation of the stapes against the oval window of the cochlea will alter the transmission of energy from the middle to inner ear, adding another location along the auditory pathway for the evoking stimulus to be attenuated. Due to these changes along the auditory pathway, it was expected that the degree of EOAE amplitude difference observed between test conditions would differ in a frequency-dependent manner. As the degree of MEP increases, this causes an increase in impedance through the system for the forward and backward traveling signals. For the results of the current study of DPOAE and TEOAE amplitude measures, the observation of increased EOAE level difference between baseline (non-maneuver conditions) and uncompensated abnormal MEP conditions with increasing MEP magnitude fits the model described above. The steady increase in abnormal MEP further alters the natural resonance properties of the auditory pathway, having a greater influence on the middle ear transfer function. In general, EOAEs are considered to be relatively stable measures over time in the absence middle or inner ear pathology therefore, the differences observed between the non-maneuver and post-maneuver test conditions is not due to a time lapse in measurements between conditions. Differences in EOAEs level cannot be attributable to changes at the DP and TE source (inner ear mechanisms) but rather, these level differences are a reflection of the altered transmission pathway due to the abnormal MEP.

A significant difference in mean EOAE amplitude was observed between the non-maneuver ambient and post-maneuver ambient test conditions, with the latter having the lower mean amplitude. For the DPOAE measures averaged over eight test frequencies, 1.5 to 8 kHz, a difference of 1.36 dB SPL was observed. For TEOAE measures averaged over five test frequencies, 1 to 5 kHz, a difference of 1.06 dB SPL was seen between test conditions. These observed amplitude differences between ambient and abnormal MEP test conditions are similar in magnitude to changes observed by other studies investigating the impact of abnormal MEP on EOAE strength. Most of these past studies state a change in amplitude between 1 and 12 dB (Plinkert et al., 1994; Naeve, Margolis, Levine, & Fournier, 1992; Thompson et al., 2015). Some research studies have investigated the impact of abnormal pressure on EOAE level by altering the degree of pressure within the ear canal, while others have looked at the impact of abnormal MEP, either naturally occurring or induced MEP. The amount of EOAE level attenuation differs between studies depending on the included range of test frequencies and on the degree of either abnormal MEP or abnormally induced external ear canal pressure.

The overall interaction between test condition (non-maneuver ambient and post-maneuver ambient) and frequency was significant for DPOAE measures. This difference in DPOAE amplitude between test conditions did differ significantly across frequencies 1.5 to 8 kHz, with the exception of 2000 Hz. The greatest difference in amplitude between test conditions was observed at a frequency of 1.5 kHz and for the mid frequencies between 2.5 kHz to 5 kHz. The mean DPOAE absolute amplitude was consistently greater for the non-maneuver ambient compared to the post-maneuver ambient condition for all test frequencies (1.5 to 8 kHz). The difference in DPOAE level between test conditions was 1.80, 0.70, 1.30, 1.70, 1.40, 2.20, 0.90, 1.00 dB SPL at the corresponding test frequencies 1.5 to 8 kHz. Similar to the current study, Thompson et al. (2013) found NMEP reduced both the component and composite DPOAE levels for frequencies tested 1060 to 3537 Hz. Likewise, Thompson et al. (2015) showed NMEP (ranging from -324 to -65 daPa) reduced DPOAE amplitude across all frequencies 0.5 to 4.0 kHz on average by 4.4 dB but the most significant impact was seen for the lowest test frequencies.

They also demonstrated the participant with NMEP of -324 daPa showed a DPOAE attenuation of 12 dB and the least attenuation of 0.1 dB was observed for a participant with MEP of -129 daPa. Sun and Shaver (2009) indicated a reduction in DPOAE level in the presence of uncompensated NMEP observing the biggest impact on low frequencies 0.6 to 1.5 kHz. For frequencies of 2, 4, 5, and 6 kHz the level reduction was not significant, but was significant at 3 kHz. Sun and Shaver (2009) also observed DPOAE level increasing in the presence of uncompensated NMEP at the highest test frequency of 8 kHz. The current study's findings are consistent with the concluding statements of Sun and Shaver (2009), which states multiple studies have remarked that the change in EOAE level as a function of frequency is highly subject-specific (Avan et al., 2000; Thompson et al., 2015).

Unlike the DPOAE analysis, the interaction between test condition and frequency was not significant for TEOAE measures of absolute amplitude when collapsing the analysis across gender and ethnicity. Although not significant, as expected, the non-maneuver ambient test condition had the greater mean absolute amplitude at each frequency from 1 to 5 kHz. For TEOAE measures, absolute amplitude decreased with increasing frequency for both the non-maneuver ambient and post-maneuver ambient test conditions. The greatest to least difference in TEOAE amplitude between test conditions was seen in the test frequency order of 2, 1, 3, 4 and 5 kHz with differences of 1.44, 1.61, 1.22, 0.64, and 0.40 dB SPL. Naeve et al. (1992) investigated the impact of abnormally induced ear canal pressure on TEOAE level. They found that the presence of abnormal pressure affects the TEOAE spectrum as if acting as a high-pass frequency filter with a cutoff frequency of 2600 Hz. Naeve et al. (1992) used the phrase 'cutoff frequency' to indicate a frequency point at which EOAE level for frequencies below this point were impacted by abnormal MEP but the frequencies above this cutoff frequency were impacted to a much lesser degree. This conclusion by Naeve and colleagues is supported by the current study's TEOAE findings, where the low test frequencies compared to higher frequencies were impacted to a greater degree by the presence of uncompensated abnormal MEP. Contrary to both the Naeve et al. (1992) and the current study, Marshall et al. (1997) found slightly different results for a case study of one participant. They showed for frequencies less than 3.15 kHz that TEOAE amplitude decreased but increased for higher frequencies in the presence of natural NMEP ranging from 0 to -158 daPa (Marshall et al., 1997). This contradicts the present study's findings because, for the current study a reduction in TEOAE amplitude was observed even at frequencies 3, 4, and 5 kHz in cases of uncompensated MEP. A possible explanation for the difference in findings between the Marshall et al. (1997) and the current study could be attributed to the immense difference in sample size and the degree of abnormal MEP under which TEOAE testing occurred. The current study also induced abnormal MEP through the Toynbee and Valsalva maneuvers whereas Marshall and colleagues tested a participant with naturally occurring NMEP and mimicked this abnormal condition by altering the pressure within the external ear canal. Refer to the published Marshall et al. (1997) paper for further details. Further comparison of results from the current study and Marshall et al. (1997) is provided in the following section 6.1.3 for the comparison between non-maneuver ambient and post-maneuver peak test conditions.

Another study investigating the impact of abnormal pressure on EOAE responses found that changes in ear canal pressure significantly effected frequencies lower than 2 kHz but had less impact on frequencies 3 to 6 kHz for measures of both TEOAE level and DPOAE levels

(Plinkert et al., 1994). This finding by Plinkert and colleagues for DPOAE measures is similar to that of the current study. In both studies, the greatest differences in EOAE level between test conditions was observed for lower test frequencies 1.5 kHz. However, the Plinket et al. (1994) study found minimal changes to frequencies > 2 kHz, and only found changes in DPOAE amplitude at frequencies ≥4 kHz for abnormal pressure conditions of ≥±100 daPa. For DPOAE measures, the current study found a minimal amplitude change at 2 kHz, but observed significant differences for frequencies 2.5 to 8 kHz with an average absolute MEP of roughly 65 daPa. The current study's TEOAE results do not match those of the Plinkert et al. (1994) study, who found significant differences in TEOAE level with uncompensated abnormal ear canal pressure at frequencies <2 kHz but minimal changes for frequencies ≥ 2 kHz. The current study found the largest change in TEOAE level between baseline and uncompensated abnormal MEP conditions at the test frequency of 2 kHz. For the current study, TEOAE amplitude differences between test conditions was also observed for frequencies 1, 3, 4, and 5 kHz (in order of greatest to least absolute TEOAE amplitude change). Similar to the DPOAE condition, the average absolute MEP at which TEOAE testing occurred for the current study in the post-maneuver condition was roughly 65 daPa. The Plinkert et al. (1994) study differed from the current study in several ways: (1) they altered the pressure within the external ear canal rather than the MEP, (2) they utilized a wider abnormal pressure range (±100 to 200 daPa), (3) their participant group consisted of a small sample size of 25 young adult participants of unidentified ethnic origin, and (4) they used different EOAE recording instrumentation (ILO 92 Otodynamics London). In addition, it could be speculated that differences in results observed between studies investigating the impact of abnormal pressure on EOAE level may be attributable to differences in the ethnic make-up of the participant population. A detailed discussion regarding the influence of ethnicity on EOAE amplitude level will be provided in Section 6.3 titled: The Effects of Ethnicity and Gender on EOAE Absolute Amplitude.

Absolute Middle Ear Pressure Magnitude

A frequency-dependent change in EOAE level was observed between the non-maneuver ambient and uncompensated (ambient) post-maneuver condition even with a mean absolute MEP of roughly 60 daPa associated with the post-maneuver condition for both DPOAEs and TEOAEs. Following these findings, it was projected that as the magnitude of MEP increases (either in a positive or negative direction), there would be a corresponding decrease in absolute EOAE amplitude. In order to explore this prediction and the source of differences between test conditions, the EOAE data was separated based on a newly introduced between-subject factor of absolute MEP shift magnitude. See Table 4, in the Data Analysis section for a description of the MEP shift magnitude categories A to E. If the EOAE amplitude is not significantly different between the non-maneuver ambient (natural ambient MEP) and the post-maneuver ambient conditions in the presence of induced MEP, then the abnormal MEP may not have been severe enough in magnitude to have caused a change in EOAE strength. Alternatively, if no significant change in emission strength is seen, this may be attributable to an unidentified compensatory mechanism or a procedure limitation impacting the outcome measure of EOAE amplitude.

The findings from the current study for the comparison of absolute EOAE amplitude between the non-maneuver ambient and post-maneuver ambient test conditions as a function of MEP shift magnitude was significant for DPOAE measures but not for TEOAEs. Although the same trend was observed for both EOAEs: As the degree of abnormally induced MEP increased between the non-maneuver to post-maneuver condition, there was a trend for the difference in EOAE level between test conditions to increase. For DPOAE measures, the categories indicating absolute MEP shift magnitudes B (11 to 25 daPa), C (26 to 50 daPa), and D (51 to 99 daPa) showed lower DPOAE levels in the post-maneuver ambient condition though these differences were not statistically significant. As predicted, the lowest mean amplitude compared to all other categories was measured in the post-maneuver condition for category E (MEP= ≥100 daPa). Category E corresponds to the MEP shift of the greatest magnitude and was the only category for DPOAE measures showing a significant difference (3.26 dB SPL difference) between test conditions. For categories A through E, the mean DPOAE amplitude difference between the non-maneuver compared to post-maneuver condition was as follows: -0.04 dB SPL, 0.23 dB SPL, 1.05 dB SPL, 1.27 dB SPL, and 3.26 dB SPL. These analyses were collapsed across factors of gender, ethnicity, and test frequency. For TEOAE level analyses, categories A, B, C, D, and E showed differences of 0.76, 0.4, 0.61, 1.29, 1.82 dB SPL between test conditions, with the post-maneuver ambient condition consistently having the lower mean amplitude.

For a presentation stimulus of 65/55 dB SPL (L_1/L_2) for DPOAEs and 83 dB peSPL for TEOAE stimuli, these differences in EOAE level between test conditions at categories A to E, are fairly consistent with the findings from previous studies. Plinkert et al. (1994) found for both DPOAE (70/65 dB SPL level ratio) and TEOAEs (60 to 90 dB SPL click) a reduction in EOAE was noted with increasing abnormal pressure. For ear canal pressure of ±200 daPa, a TEOAE level decrease of 2.5 to 5.5 dB was noted. For a TEOAE evoking stimulus of 60, 70, 80 and 90 dB SPL, a change of 1.3, 2.1, 2.6 and 2.8 dB was expected for every 100 daPa change in pressure; however, a slightly larger change was found for positive pressure compared to negative conditions.

Similarly, for DPOAE measures, Plinkert and colleagues indicated a 2.5 to 5.3 dB change in level per octave for ear canal pressure -100 to +200 daPa. Again they noted that positive pressure caused a slightly greater attenuation of DPOAE level compared to negative pressure. In addition to differences in mean abnormal pressure conditions, it should be noted that the Plinkert et al. (1994) study was using abnormal pressure created in the external ear canal, compared to the current study which induced abnormal MEP. These differences could account for some of the variation in mean level differences observed between studies. Also consistent with the findings from the current study, Plinkert and colleagues found a greater reduction in amplitude for DPOAEs compared to TEOAE measures for all conditions of various degrees of abnormal pressure. For the current study with an average absolute MEP of roughly 65 daPa averaging across all frequencies, DPOAE amplitude was reduced by 1.36 dB SPL and by 1.06 dB SPL for TEOAEs. The Plinkert et al. (1994) study also noted a change in the cutoff frequency with a change in pressure. As described above, the cutoff frequency is the frequency point at which a change in EOAE level was observed either above or below this level in response to some external change to the system (i.e. pressure change). In the Plinkert et al. (1994) study, a cutoff frequency of 4.6 kHz was noted at -100 daPa, 4.0 kHz at +100 daPa, 5.5 kHz at -200 daPa, and 4.8 kHz at +200 daPa. The cutoff frequency acted as a high-pass frequency filter. The phenomena of a pressure dependent cut-off frequency could partially account for the differences observed between the Plinkert et al. (1994) and the current study regarding exact frequencies at which changes in EOAE level were found to be significant. This occurrence of an increasing frequency cutoff with increasing abnormal MEP pressure will be explored in Chapter 8 with the discussion of frequency-dependent changes in PA magnitude as a function of abnormal MEP.

Consistent with the findings of the current study, Thompson et al. (2013) and work by Sun and Shaver (2009) also demonstrated that participants with the greatest magnitude of NMEP had the largest change in DPOAE level. A study conducted by Avan et al. (2000) with a sample of five normal hearing subjects, showed a significant decrease in DPOAE level even with only +40 daPa of MEP and for some trials, as low as +20 daPa. The current study did not find a significant difference in DPOAE levels between baseline ambient and post-maneuver uncompensated test conditions for the absolute MEP range spanning 11 to 50 daPa. Although not significant in all cases, lower mean amplitude levels were observed for all EOAE measures recorded under conditions of uncompensated abnormal MEP compared to baseline condition measures. For the current study, mean DPOAE amplitude values for both test conditions across absolute MEP categories A to E, are similar in magnitude to the DPOAE level range stated by Avan and colleagues (2000).

6.1.3 Non-maneuver Ambient and Post-maneuver Peak Test Conditions

The primary objective of the current study was to demonstrate the effectiveness of compensating for abnormal MEP by assessing the outcome measure of EOAE absolute amplitude. The comparison of EOAE amplitude from measures obtained in a control baseline condition and a compensated abnormal MEP condition represents a way to assess the effectiveness of pressure compensation. Therefore, it is the following discussion of results from the comparison between the non-maneuver ambient and post-maneuver peak test conditions that represents the study’s main objective. It was predicted that the mean absolute EOAE amplitude would not be significantly different between the two test conditions (non-maneuver ambient and post-maneuver peak). In addition, it would not be unexpected to have the EOAE absolute amplitude in the post-maneuver peak condition be even greater in absolute value if participants' MEP was slightly abnormal (not exactly at 0 daPa) in the non-maneuver ambient condition. This would possibly result if there was pressure deviating from 0 daPa in the non-maneuver baseline condition that was not compensated for, leading to a reduction in EOAE. In the post-maneuver peak condition, if Titan properly compensates for the induced abnormal MEP, it would be expected that any degree of abnormal MEP would be compensated for resulting in an optimal EOAE amplitude response. The results from this test condition comparison are intended to show that an indication of cochlear function and middle ear status can still be derived by means of EOAE assessment, even in the presence of substantial abnormal MEP. By measuring EOAEs at peak pressure, the abnormal MEP is compensated for (i.e. post-maneuver peak test condition) and the true cochlear emission response can be assessed (i.e. comparable to baseline emission strength with ambient MEP).

Test Condition Comparisons and Frequency Response Patterns

A statistically significant difference was found for the current study when comparing the non-maneuver ambient (mean absolute MEP of 10 daPa) and post-maneuver peak (mean absolute MEP of 65 daPa) conditions for the outcome measure of both DPOAE and TEOAE absolute amplitude. For both EOAE analyses, the analysis was collapsed across factors of gender, ethnicity, and frequency. This finding of significance for both EOAE analyses was not predicted. For DPOAE measures, the non-maneuver ambient condition (8.01 dB SPL) is significantly greater in absolute amplitude compared to the post-maneuver peak condition (7.25 dB SPL). While still significant, this difference of 0.76 dB SPL was less than that observed for DPOAE measures from the non-maneuver ambient compared to post-maneuver ambient conditions, which showed a level difference of 1.36 dB SPL. Similarly, for TEOAE measures, the difference between non-maneuver ambient (3.44 dB SPL) and post-maneuver peak (3.03 dB SPL) was a significant TEOAE level difference of 0.41 dB SPL. This is in contrast to the 1.06 dB SPL TEOAE amplitude difference found between non-maneuver ambient and uncompensated post-maneuver test conditions. It was predicted that when the abnormal MEP in the post-maneuver test condition was compensated for, the impact of the MEP would be mitigated so that the mean EOAE amplitude would be equivalent to that observed in the baseline test condition. In this scenario, both test condition measures were expected to reflect a true and equivalent cochlear emission response level.

The interaction between test condition (non-maneuver ambient versus post-maneuver peak) and frequency was not significant for the DPOAE outcome measure of absolute amplitude. This analysis was collapsed across factors of gender and ethnicity. It was predicted that no significant difference in DPOAE amplitude would be observed when comparing measures from the baseline to the compensated abnormal MEP test conditions. Although not significant, overall a greater difference in DPOAE level between conditions was observed for the mid frequency range (~3 to 5 kHz) compared to low and high frequencies. For frequencies 1.5, 2, 2.5, 3, 4, 5, 6, and 8 kHz the difference in DPOAE level between conditions was 0.69, 0.33, 0.58, 0.84, 0.80, 1.47, 0.77, 0.60 dB SPL, with the non-maneuver ambient condition having the greater mean amplitude. Consistent with the current study, Sun and Shaver (2009) testing DPOAE levels 0.6 to 8 kHz, showed DPOAE levels were not significantly different in comparison to baseline measures for all frequencies when compensating for NMEP. The Sun and Shaver (2009) study had 16 young-adult participants induce NMEP between -40 to -420 daPa. Assessment of DPOAEs and pressure compensation was done using a Granson-Stadler Inc. (GSI 60) DPOAE system and a GSI TympStar Middle Ear Analyzer. The peak pressure was manually set by the experimenters, as this is not an automated pressure compensated test instrument like the Titan. There is limited published literature available investigating the effect of MEP compensation for the outcome measure of EOAE amplitude, especially for DPOAEs. The majority of studies that are available focus on the outcome measure of TEOAE level rather than DPOAEs, and many studies alter the ear canal pressure rather than MEP. Additionally, much of this available research uses a pediatric rather than adult test population and does not control for the factor of ethnicity.

The interaction between test condition and frequency was also not significant for TEOAE absolute amplitude, when collapsing across factors of gender and ethnicity. This interaction indicates that the variation in TEOAE amplitude across frequencies of 1 to 5 kHz did not differ significantly between test conditions. The difference in TEOAE level between the non-maneuver ambient and post-maneuver peak test condition was 0.47, 0.46, 0.69, 0.18, and 0.27 at test frequencies of 1, 2, 3, 4 and 5 kHz. The non-maneuver ambient test condition had the larger mean TEOAE amplitude at all test frequencies compared to the post-maneuver condition even with compensation of the post-maneuver induced MEP. Consistent with previous findings by Trine et al. (1993) and the current study, Marshall et al. (1997) demonstrated that the overall TEOAE amplitude spectrum for the compensated pressure condition was comparable to that observed in the ambient MEP (baseline) condition. Unlike the current study, it was observed by Marshall et al. (1997) that the lower test frequencies <1.5 kHz had increased TEOAE amplitude in the compensated compared to baseline test condition. But consistent with the current study, they found that the higher test frequencies (above 1.5 to 2 kHz) were comparable to baseline measures after pressure compensation for NMEP. Differences between the current study and the Marshall et al. (1997) study were regarding instrumentation, sample size, pressure range, and data collection design. Marshall and colleagues had a very small sample size of only a single participant on which they based all test measures over a six month test period. Assessment of TEOAE measures was done at naturally occurring and simulated NMEP of various degrees (-105, -135, and -165 daPa) over this six month test period. Pressure compensation was achieved using a research specific designed modification of a Madsen Z072 immittance meter with MEP being quantified by a separate device, a GSI 1723. These low frequency-specific response findings by Marshall et al. (1997) are not replicated in the current study. The current study demonstrates lower test frequencies having a larger separation in TEOAE level between baseline and compensated MEP conditions with the baseline condition having the greater TEOAE amplitude. In summary, for the current study, compensation for abnormal MEP restored TEOAE amplitude measures to values comparable to those measured in the baseline condition for frequencies of 1 to 5 kHz.

Absolute Middle Ear Pressure

To investigate a potential source of these unexpected differences in mean EOAE level between test conditions (non-maneuver ambient and post-maneuver peak), the impact of MEP magnitude was explored as a between-subject factor. The interaction between test conditions (non-maneuver ambient versus post-maneuver peak) and absolute MEP shift magnitude for the outcome measure of DPOAE absolute amplitude was significant. Determined through post-hoc analysis, the absolute MEP shift categories A, B, C, and D showed no significant difference in mean amplitude between non-maneuver ambient and post-maneuver peak conditions. The only MEP shift category showing a significant difference in level, even with pressure compensation, was category E (≥100 daPa shift). The non-maneuver ambient condition had a greater mean DPOAE amplitude of 1.79 dB SPL compared to the post-maneuver peak condition. The finding of significance for category E but not for categories A to D might imply that Titan is successful at compensating for the presence of abnormal MEP when measuring DPOAEs at peak pressure up to a certain degree of MEP (in this case ≥100 daPa). However, this implication of Titan having a pressure limit on successful pressure compensation is not supported based on the findings from other test condition comparisons. The comparison between the non-maneuver ambient and post-maneuver ambient test conditions also showed a significant difference only for the absolute MEP category E, but not for categories A to D. Even in the presence of MEP of magnitudes corresponding to categories A to D (spanning a range of 0 to 99 daPa), no significant difference was observed between test conditions (uncompensated non-maneuver ambient versus post-maneuver ambient). Therefore, if no significant difference was found when not compensating for the abnormal MEP, then it would be expected that no significant difference would still be observed when compensating for the abnormal MEP. In summary, when assessing DPOAE amplitude in the presence of abnormal MEP of magnitude ≥100 daPa, there is a significant attenuation of DPOAE level regardless of compensation (testing at an ambient or peak pressure setting). However, the DPOAE level did improve by 1.47 dB SPL in the post-maneuver compensated compared to the post-maneuver uncompensated test condition. Further comparisons between DPOAE levels in the post-maneuver ambient versus peak conditions will be explored in section 6.1.4.

The interaction between test conditions (non-maneuver ambient versus post-maneuver peak) and absolute MEP shift magnitude for the outcome measure of TEOAE absolute amplitude was not significant. This finding indicates that for TEOAE measures, there was no significant difference in TEOAE level between the two test conditions across the absolute MEP shift magnitude categories A to E (pressure range of 0 to >100 daPa). This analysis was collapsed across all other factors of gender, ethnicity, and frequency. This finding indicates that regardless of the degree of abnormal MEP, the Titan system was able to compensate for the MEP as reflected in comparable TEOAE level between the test conditions. Although not significant, a greater difference in TEOAE level was observed between conditions with increasing MEP magnitude, a trend that is also consistent with the findings of past studies (Naeve et al., 1992; Perez, 2012).

Impact of Abnormal Pressure on the Stimulus Spectrum and Middle Ear System

In addition to impacting EOAE level, the evoking stimulus spectrum has been shown to change with the presence of abnormal pressure in either the middle ear cavity or outer ear canal. Past studies have noted a decrease in stimulus amplitude at 2.0 to 3.3 kHz and an increase amplitude at frequencies of <1 kHz and >3.3 kHz (Marshall et al. 1997). Similarly, Thompson et al. (2015) observed three findings when examining the sound pressure level (SPL) recorded at the level of the probe microphone for DPOAE primary tones. They found that in the presence of NMEP compared to ambient MEP (1) the SPL was 3 dB SPL lower between 2 and 2.5 kHz, (2) there was an increase in SPL for frequencies >3.5 kHz, and (3) there was a 1.7 dB SPL increase in SPL for frequencies 1 and 1.5 kHz. With a change in pressure within the outer or middle ear the impedance properties of the auditory system, namely the physical compliance of the TM, are altered causing some of the sound energy from the evoking stimuli to not be absorbed as efficiently by the TM and middle ear (Thompson et al., 2013). Resulting from the reduction in sound energy transmission along the auditory pathway is a subsequent reduction in the amount of sound energy reaching the cochlea at certain characteristics frequency locations along the BM. In addition, with reduced energy absorbance there is an increase in the amount of sound energy remaining in the external canal (i.e. increased energy reflectance). The act of pressure compensation is the equalization of pressure on either side of the TM which improves the transmission of the eliciting stimulus, and this may result in improved EOAE amplitude for certain frequencies. Trine et al. (1993) indicated for TEOAE measures taken at equalized pressure levels, a smoother stimulus spectrum and thus an improved stimulus presentation to the cochlea were observed. Based on the frequency-dependent middle ear transfer function, a flat stimulus frequency spectrum is likely not achievable especially under conditions of abnormal MEP changing the system’s acoustic properties. Perez (2012) showed the TEOAE signals altered by about 1 to 5 dB for external ear canal pressure changes of ±50, ±100, and ±200 daPa compared to baseline measures, regardless of the pressure polarity (positive or negative pressure). They showed that the same magnitude pressure changes influenced the meatal response were much more than that observed with TEOAE response levels. In other words, the impact of canal pressurization greatly impacted the acoustic environment and TM stiffness, altering the amount of reflected acoustic energy and thus the presented stimulus spectrum. This change in stimulus energy in a frequency-dependent manner and the frequency selectivity of the middle ear transfer function may account for the differences in EOAE amplitude between compensated and uncompensated test conditions and the impact of abnormal MEP pressure for particular test frequency regions.

As explained in previous sections, the middle ear is responsible for enhancing the amplitude of mid to low frequencies along the transmission pathway from the TM to oval window. The presence of abnormal MEP impacts the vibrational velocity of middle ear components which most significantly impacts frequencies <2 kHz. Thus, when pressure equalization is achieved, the TM and ossicular chain vibrational properties are restored and the normal transmission of acoustic energy is restored. This is likely why the low test frequencies are most significantly impacted by the abnormal MEP when testing in the uncompensated post-maneuver ambient test condition. The basis of compensating for abnormal MEP is introducing an opposing pressure of equal magnitude into the system. In the case of the current study, the pressure between the probe tip end and the TM was altered to be of equal magnitude to the TPP (estimate of MEP). The introduction of this pressure (either positive or negative depending on the TPP reading) alters the orientation of the TM and its contact with the ossicular chain. The aim of pressure compensation is to restore the auditory structures to their natural resting position when external ear canal pressure and MEP are at ambient. By equalizing the pressure on either side of the TM, is it thought that this allows for both improved admittance of the stimulus traveling into the middle ear to the cochlear and for the improved transmission of the returning emission signal from the cochlea to the outer ear canal. Since the middle ear transfer function is frequency dependent, the presence of MEP and thus the compensation of such MEP is expected to occur in a frequency-specific manner. This is observed as differences in EOAE amplitude measures across the test frequency range. This concept of a change in the stimulus energy absorbance and the resulting energy received by the cochlea in the presence of abnormal MEP will be further discussed in Chapter 8 and 9.

Marshall et al. (1997) noted that interpreting findings in which the impact of simulated abnormal MEP conditions on EOAE signals are investigated should be done with caution, as the finer mechanical changes to the middle ear system likely do not perfectly replicate the natural abnormal MEP state. However, this study by Marshall and colleagues (1997) also indicated that simulated NMEP in which the pressure in the external ear canal was manipulated, showed TEOAE amplitude responses approximating the natural NMEP response. This approximation was for the comparison of TEOAE absolute amplitude between compensated and uncompensated test conditions as a function of frequency. Although the induced abnormal MEP state has been shown to somewhat accurately reflect natural states of abnormal MEP, there are differences to note for the comparison of compensated abnormal MEP conditions to baseline normal ambient conditions. Equalizing MEP by means of altering the pressure within the external canal introduces variables not experience in ambient test conditions. The act of introducing compensating pressure can alter the acoustic environment leading to a reduction in EOAE level, by either impacting the evoking stimulus or the returning emission (Zwicker et al., 1983). This could possibly explain why the EOAE level did not exactly return to baseline levels for compensated test conditions. Especially, under conditions such as category E where there is the largest degree of MEP observed in this study. The pressure within the middle ear cavity and the equalizing pressure are still exerting strain on the TM and ossicular chain impacting both structures' natural vibratory motion. When the pressure on either side of the TM is increased, this adds more and more stress to the mechanical structures of the transmission pathway. In addition, compensating for MEP by equalizing the pressure on either side of the TM may improve the acoustic energy transfer across the TM and along the ossicular chain, but differences will still exist at other energy transfer locations. Under conditions of abnormal MEP compared to normal baseline states, the orientation and contact of the stapes against the oval window will be altered. The change in impedance at the level of labyrinthine windows with changes to MEP will also alter EOAE measures to various degrees (Hof et al., 2005b).

6.1.4 Non-maneuver Ambient and Non-maneuver Peak Test Conditions

Based on past research findings, it is expected that for healthy participants with hearing thresholds within a normal range (≤25 dB nHL) and no significant air-bone gaps identified with pure-tone audiometry, EOAEs should be present and robust for baseline measures in the non-maneuver condition when MEP is centered around 0 daPa (Ramos et al., 2013). The mean absolute MEP in the non-maneuver condition referencing the conventional 226 Hz tympanogram estimates was 10.57 daPa (n=110) for the DPOAE condition and 10.55 daPa (n=97) for TEOAE condition. The comparison between non-maneuver ambient and peak test condition outcome measures was included as an analysis to serve as a form of control testing. This comparison between test conditions serves as a way to demonstrate that by collecting EOAE measures with the Titan system set at peak pressure (rather than ambient), that this change to the test settings does not on its own, significantly alter the EOAE amplitude response. It was predicted that the presence of slight abnormal MEP would not cause a significant difference in EOAE amplitude between the two non-maneuver test conditions. If changes are observed in absolute EOAE amplitude between the non-maneuver ambient and peak test conditions it is then the objective to demonstrate that these changes are attributable to (a) the compensation of abnormal MEP, or (b) this change may also be in full or partly attributable to an unknown mechanism. A possible mechanism could be test equipment related changes, such as differences in calibration between test settings (ambient versus peak settings), differences in the system's pump speed, or a difference in the way in which Titan monitors the target pressure throughout EOAE recordings.

Normative data sets are used to facilitate clinical decision making, such as to identify a patient as being normal versus abnormal or in determining an outcome of pass or refer based on a specific measurement response. A normative data set represents what is sometimes referred to as a reference range of data. In a clinical sense, the normative values provide a range of reference between which a comparison group must fall in order to be classified as either normal or abnormal. Normative data can provide a minimum response level, which is often represented by a percentile range such as the 5th percentile curve. This 5th percentile level designates a cut-off level indicating that only 5% of normal individuals are likely to have response measures falling at or below this response level, with 95% of normal participants falling above this level. The 90% range is presented as 5th and 95th percentiles. For measurements from a normal population of participants, 90% of measurements will fall between the 5th to the 95th percentile curve. For a normally distributed set of data, the 95th percentile level corresponds roughly to +2 standard deviations (SD) of the mean and the 5th percentile corresponds to -2 SD from the mean. A comparison of the 90% range between non-maneuver ambient and non-maneuver peak test pressure condition measures is provided in the following sections, for measures of TEOAE and DPOAE absolute amplitude. This comparison was conducted, to determine if collecting EOAE measures with the Titan system set at peak versus ambient pressure resulted in a change in EOAE amplitude. Displayed in Table 89, for DPOAE measures the non-maneuver ambient test condition 5th and 95th percentiles are -5.31 and 19.21 dB SPL (range of 24.52 dB SPL) and the non-maneuver peak test condition has a 90% range of -5.04 and 19.30 dB SPL (range of 24.34

dB SPL). Displayed in Table 90, for TEOAE measures the non-maneuver ambient test condition 5th and 95th percentiles are -13.32 and 16.94 dB SPL (range of 30.26 dB SPL) and the non-maneuver peak test condition has percentile values of -12.24 and 17.18 dB SPL (range of 29.42 dB SPL). Percentiles were calculated collapsing the analysis across factors of gender, ethnicity, and frequency. For both DPOAE and TEOAE measures, the width of the 90% range for the ambient compared to peak test pressure condition are similar. With regards to clinical implications, these findings indicate that testing a patient with ambient MEP in baseline conditions at either a system setting of ambient or peak pressure will not result in system related differences in EOAE amplitude. This is determined based on the comparable width in the 90% response range for peak and ambient measures. In addition, the dispersion around the mean for measures in the ambient and peak test conditions is equivalent, as indicated by calculations of standard deviation. As with all normative data or control samples, the patient population being tested must share similar characteristics to those on which this normative values were based. The current comparison of non-maneuver ambient versus peak pressure condition 90% response ranges was based on a normal hearing young adult population with healthy middle ear status and MEP centered on 0 daPa (±10 daPa).

Test Condition	Mean DPOAE Absolute Amplitude (dB SPL)	SE	SD	5th Prctl	95th Prctl	n
Non-maneuver, Ambient	8.01	1.04	7.30	-5.31	19.21	110
Non-maneuver, Peak	8.09	1.07	7.31	-5.04	19.30	110

Table 89: Descriptive statistics for the comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak). The analysis was collapsed

across factors of gender, ethnicity, and frequency. Values of standard error (SE), standard deviation (SD), 5th and 95th percentiles (Prctl) are provided. Current effect: [F(1, 106)=.48047, p=.48972].

Test Condition	**Mean TEOAE Absolute Amplitude (dB SPL)**	**SE**	**SD**	**5th Prctl**	**95th Prctl**	**n**
Non-maneuver, Ambient	3.44	1.23	9.38	-13.32	16.94	97
Non-maneuver, Peak	3.60	1.20	9.38	-12.24	17.18	97

Table 90: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak). Values of standard error (SE), standard deviation (SD), 5th and 95th percentiles (Prctl) are provided. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 93)=1.7906, p=.18412].

For clinical application of EOAE normative data, it is more useful to represent the 5th and 95th percentile curves as a function of frequency. Figure 38 and Figure 39 represent the 90% range (5th and 95th percentiles) for DPOAE and TEOAE measures, respectively. A mean response curve and percentiles are provided for EAOE measures assessed at both Titan settings of ambient and peak pressure. These data represent a sample of n=110 DPOAE and n=97 TEOAE measures for each of the associated non-maneuver test conditions (ambient and peak). Refer to Appendix A Table 174 for DPOAE and Appendix A Table 175 for TEOAE descriptive statistics. The percentile values for each condition were generated with the analyses collapsed across factors of gender and ethnicity. If the width of the 90% range for measures of EOAE amplitude assessed at ambient versus peak pressure settings are comparable, then this indicates that the same set of normative data could be used for both test pressure settings. From the current study's data presented in Figure 38, the width between the 5th and 95th percentile curves is comparable across the frequency range of 1500 to 8000 Hz when comparing the two pressure conditions. The minimum acceptable DPOAE amplitude response is represented by the 5th percentile curve and it is also highly comparable between peak and ambient test pressure conditions. Similarly for TEOAE measures, the 5th to 95th percentile width is almost identical between the non-maneuver ambient and peak pressure response curves across the frequency range 1000 to 5000 Hz. The minimum acceptable TEOAE amplitude (5th percentile curve) is also comparable between peak and ambient test pressure conditions. Although, a slight difference between pressure conditions is observed at 1000 Hz. In summary, these findings indicate that EOAE measurements assessed at either peak or ambient pressure for normal individuals would provide a comparable pass/refer rate or comparable identification of normal from abnormal responses. Clinically, the same normative data could be used for comparison of Titan EOAE measures assessed at either ambient or peak pressure. A future project using the current study's data would be to create gender-specific and ethnicity-specific normative data for both DPOAE and TEOAE measures.

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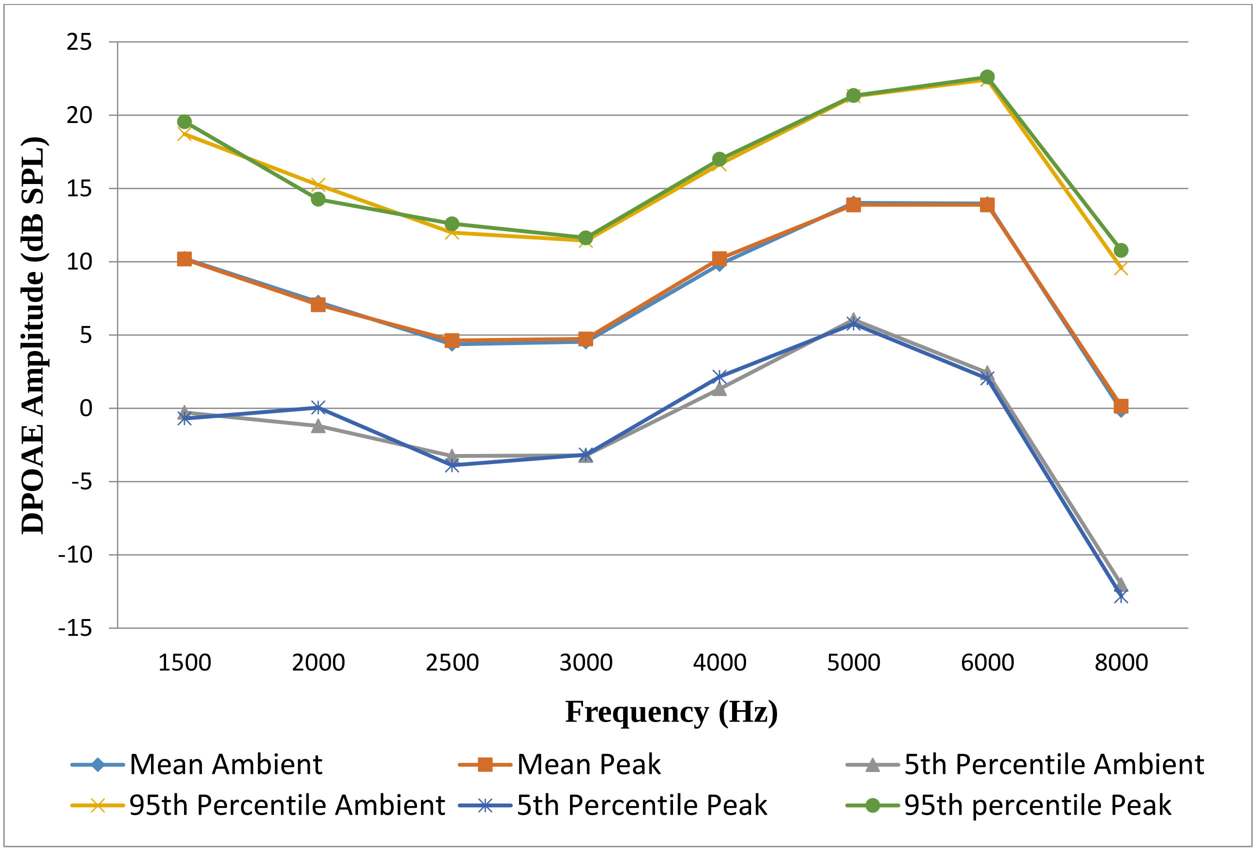


Figure 38: DPOAE absolute amplitude 90% response range for non-maneuver ambient and non-maneuver peak pressure test conditions. Mean values as well as 5th and 95th percentiles for DPOAE amplitude measures are plotted as a function of frequency (1500 to 8000 Hz). DPOAE measures are pooled between gender and ethnic groups. There is a sample size of n=110 DPOAEs measures for all test conditions.

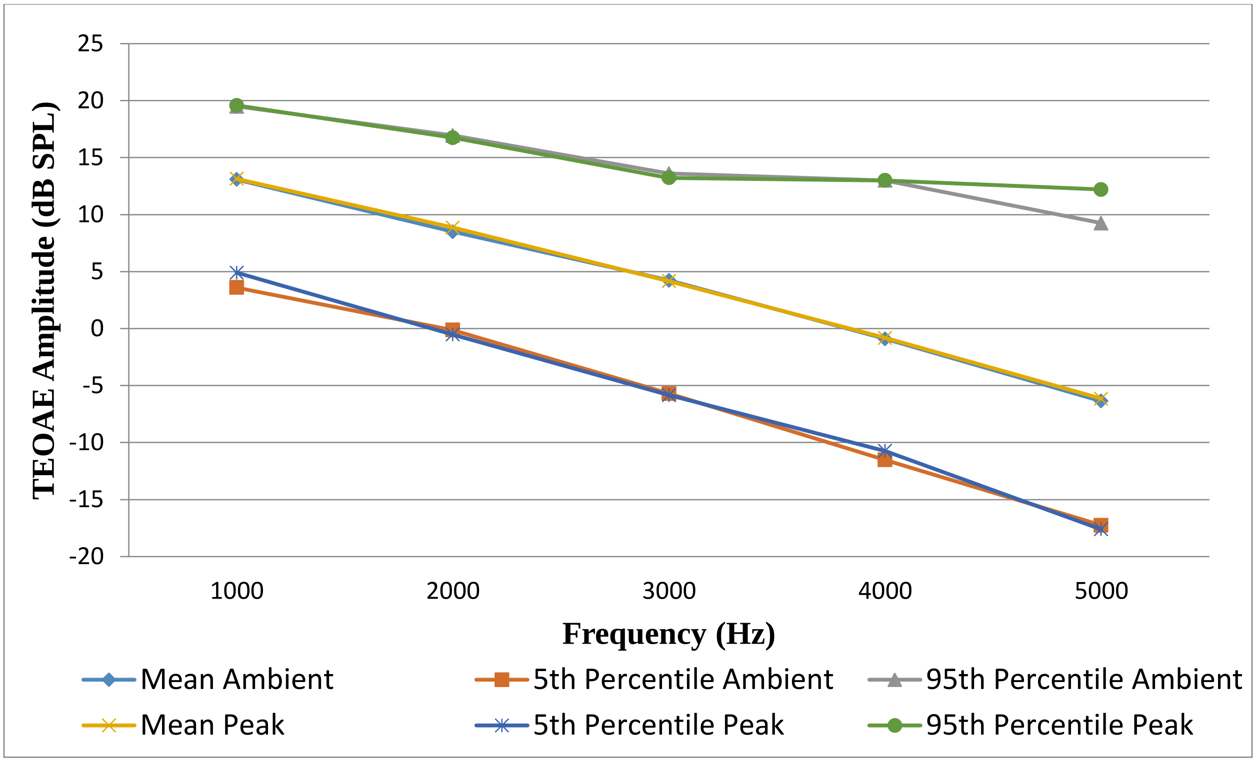


Figure 39: Non-maneuver ambient and non-maneuver peak test pressure condition outcome measures of transient evoked otoacoustic emission (TEOAE) absolute amplitude. Mean values as well as 5th and 95th percentiles for TEOAE absolute amplitude measures are plotted as a function of frequency (1000 to 5000 Hz). TEOAE measures are pooled between gender and ethnic groups. There is a sample size of n=97 TEOAE measures for all test conditions.

Comparison of the Current Study's Findings to Published Literature; Distortion-product Otoacoustic Emissions

The comparison between ambient and peak pressure conditions for the outcome measure of DPOAE absolute amplitude was not significant. This analysis was collapsed across factors of frequency, gender, and ethnicity. A difference of only 0.08 dB SPL was observed between DPOAE test conditions (non-maneuver ambient versus peak). The average DPOAE absolute amplitudes of 8.01 and 8.09 dB SPL for the ambient (n=110) and peak (n=110) test conditions are consistent with a normal emission strength from a healthy and normal hearing young adult population (Ramos et al., 2013; McFadden et al., 2009). For the non-significant interaction of test pressure condition and frequency, no apparent trends in DPOAE level differences were observed across the frequency range of 1.5 to 8 kHz. The response pattern for DPOAE level as a function of test frequency and the mean emission level at each frequency is similar to that observed in past studies (Ramos et al., 2013; Dunckley et al., 2004; Plinkert et al., 1994). Avan et al. (2000) showed for the control DPOAE test condition at ambient MEP, DPOAE levels were 0 to15 dB SPL (mean noise: between -7 to -15 dB SPL) for frequencies <1.5 kHz, and between 10 to -5 dB SPL (mean noise: less than -15 dB SPL) for higher frequencies and 90% of participants had an SNR of at least 12 dB. Dunckley et al. (2004) study investigated gender effects on high frequency DPOAE level. They found similar frequency-specific DPOAE amplitude values for both gender groups compared to the current study. Refer to section 6.3.1 for a comparison of gender and frequency-specific DPOAE normative values between the current study and findings from Dunckley et al. (2004).

Cauwenberge (1996) developed a normative database for DPOAEs based on 101 normal ears from a sample of 101 healthy young adult participants (58 females and 43 males). Testing of DPOAEs was done using the ILO 92 Otodynamics Analyzer. The eleven chosen f_2 frequencies ranged from 696 to 6348 Hz with a 1.22 f_2:f_1 ratio. Evoking stimuli for the DP-grams were presented in 5-dB steps from 70 dB SPL to 80 dB SPL, with a level ratio of L_1=L_2. Given that the current study had a stimulus ratio of 65/55 dB SPL, comparison between the current study and the Cauwenberge (1996) study will be limited to the DP-gram of 70 dB SPL. The

Cauwenberge (1996) f_2 frequency-specific DPOAE amplitude values for a stimulus of 70 dB SPL are presented in Table 91, which represents only a subset of the normative data published in this paper. Despite differences in sample size, instrumentation, stimulus parameters, and participant inclusion criteria existing between the two studies, a similar frequency-DPOAE amplitude response pattern is observed. The Cauwenberge (1996) data shows DPOAE amplitude being low for the low frequency test region with a slight peak around 1.1 kHz (8.7 dB SPL), then increasing in amplitude to a maximum between 4.5 to 5.7 kHz (19.31 to 13.64 dB SPL). The current study (refer to Table 174), found an amplitude peak at the lowest frequency of 1.5 kHz (10.23 dB SPL) sloping to a minimum at 2.5 kHz (4.37 dB SPL), then rising to a maximum between 5 to 6 kHz (14.02 to 13.97 dB SPL). The absolute DPOAE amplitude observed at each test frequency is of similar magnitude between both studies.

	Geometric Mean Frequency: 70 dB SPL (L1=L2)										
Freq. (Hz)	**632**	**753**	**905**	**1142**	**1140**	**1810**	**2278**	**2873**	**3626**	**4561**	**5745**
Mean	1.32	3.59	6.54	8.7	10.35	9.3	7.36	7.64	10.97	19.31	13.64
SD	6.47	5.79	6.49	6.02	5	5.06	4.98	5.22	5.62	4.74	6.1
Max	13	14.9	20.9	19.4	18.9	21.4	19.9	20.7	24.5	29.1	25.8
Min	-11.2	-16.4	-11.7	-10.7	-8	-5.6	-7.2	-5.1	-11.4	7.2	-6

Table 91: Descriptive statistics for the 70 dB SPL Distortion Product-audiogram as published in a paper titled *Distortion Product Otoacoustic Emissions: A Normative Study* (Cauwenberge, 1996). The frequency range represents the f_2 from 696 to 6348 Hz for a sample of n=101 normal ears.

Figure 40 compares DPOAE normative data for a normal hearing young adult population between the current study and published normative data. The displayed normative data represents findings from the current study, both from the non-maneuver ambient and peak pressure conditions, and work by Ramos et al. (2013). Refer to Table 92 for descriptive statistics for the Ramos et al. (2013) study and the non-maneuver ambient test condition data from the current study. As discussed previously, the mean and percentile response curves for ambient and peak pressure data are highly comparable. For both studies, DPOAE measures were obtained using the DPOAE440 module from Titan by Interacoustics with similar test parameters. A frequency ratio of 1.22 and stimulus levels of L_1=65 and L_2=55 dB SPL were set by both studies. Comparing the mean DPOAE amplitude between studies, a similar response is observed for low frequencies roughly <3 kHz. The mean DPOAE amplitude is noticeably lower for frequencies of 3 to 8 kHz in the Ramos et al. (2013) compared to the current study. The 90% range is much wider and the minimal response level (5th percentile curve) is also much lower in amplitude across the entire frequency range of 1.5 to 8 kHz for the Ramos et al. (2013) study compared to the current study's findings. The Ramos et al. (2013) published paper does provide gender-specific normative data tables however; normative data presented in Figure 40 from both studies is collapsed across factors of gender and ethnicity. Differences in the ethnic and gender make-up of the participant pools for each study could account for some of the differences in amplitude level observed across the test frequency range between the two studies. There is a large sample size difference, with the current study normative data being based on n=110 DPOAE measures while the Ramos et al. (2013) study has n=39 DPOAE measures. The presented data for the Ramos et al. (2013) study represents a portion of their published norms, with the original article providing normative data for 13 test frequencies between 500 to 8000 Hz.

Ramos et al. (2013)					**Current Study**				
Frequency f2 (Hz)	**Mean (dB SPL)**	**5th Prctl**	**95th Prctl**	**n**	**Frequency f2 (Hz)**	**Mean (dB SPL)**	**5th Prctl**	**95th Prctl**	**n**
1597	10.2	-9.1	18	39	1500	10.23	-0.28	18.72	110
2000	6.2	-12.5	15.3	39	2000	7.24	-1.2	15.25	110
2519	3.8	-12.8	9.6	39	2500	4.37	-3.26	12	110
3174	3	-7	12.2	39	3000	4.54	-3.22	11.44	110
4000	6.1	-10.9	17.8	39	4000	9.82	1.34	16.66	110
5039	8.3	-9.6	21.7	39	5000	14.02	6.05	21.3	110
6349	3.1	-14.4	21.5	39	6000	13.97	2.43	22.43	110
8000	-6.9	-16.3	6.9	39	8000	-0.14	-12.03	9.56	110

Table 92: DPOAE normative data for a normal hearing young adult population, presented as mean and percentile (5th Prctl and 95th Prctl) values. The current study had participants 18 to 35 years of age, with a sample size of n=110 DPOAE measures. The Ramos et al. (2013) study had participants 18 to 25 years of age with n=39 DPOAE measures. Normative data from both studies are collapsed across factors of gender and ethnicity. Data from the current study represents non-maneuver ambient test condition measures.

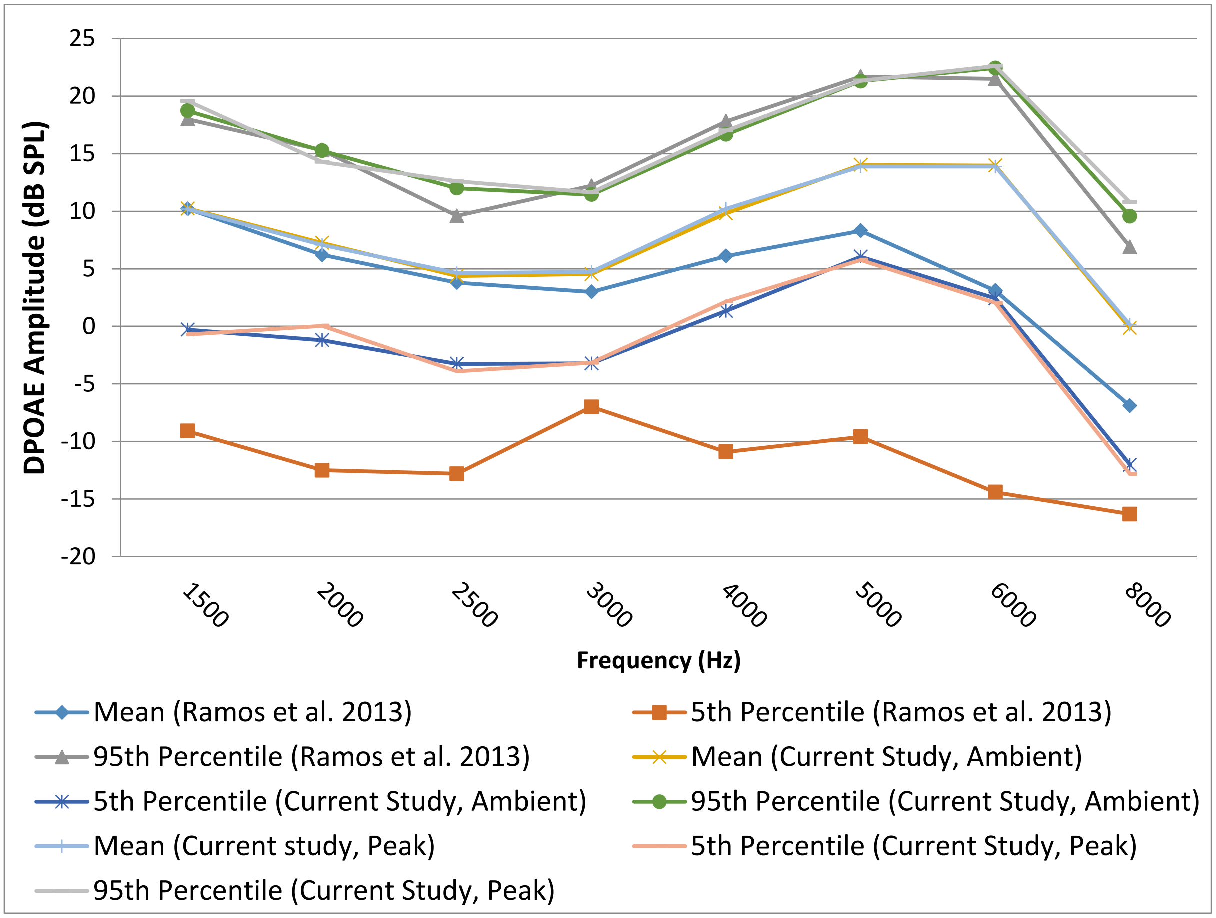


Figure 40: DPOAE normative data for a normal hearing young adult population, presented as mean and percentile (5^{th} and 95^{th}) values. The current study had participants 18 to 35 years of age, with a sample size of n=110 DPOAE measures. The Ramos et al. (2013) study had participants 18 to 25 years of age with n=39 DPOAE measures. The Ramos et al. (2013) data is published as f_2 values spanning a frequency range of 500 to 8000 Hz. The x-axis values reference the current study's frequency range, 1500 to 8000 Hz. Normative data from both studies are collapsed across factors of gender and ethnicity. Data from the current study represents non-maneuver ambient and non-maneuver peak pressure test condition measures.

Table 93 displays the comparison of mean DPOAE absolute amplitude for 5th percentile frequency-specific responses from three studies: (1) Current study, (2) Ramos et al. (2013), and (3) Gorga, Dierking, Johnson, Beauchaine, Garner, and Neely (2005). The data from the Ramos et al. (2013) study and the current study are presented graphically in Figure 40 above, which shows the minimum response 5th percentile DPOAE amplitude curve being substantially lower in magnitude compared to the current study's 5th percentile data. The 5th percentile frequency-specific response for the Gorga et al. (2005) study supports the findings from the Ramos et al. (2013) study. Both these studies show a similar DPOAE amplitude frequency response pattern compared to the current study, but are much lower in magnitude compared to the current study's findings. DPOAE amplitude data from the Gorga et al. (2005) study is based on a sample of normal hearing participants between the ages of 2 to 86 years old. DPOAE measures were obtained using comparable stimulus parameters to the current study using the Bio-logics Scoute 3.45 system. Mean and 95th percentile amplitude measures were not available in the published source for inclusion in this manuscript. Differences observed between the current study and Gorga et al. (2005) data could be accounted for by differences in participant inclusion criteria specifically age or participants, DPOAE instrumentation, and DPOAE stopping criteria. The study by Gorga and colleagues (2005) set a stopping criteria based on an acceptable noise floor level (≤-30 dB SPL) and a test-time of 32 seconds of artifact-free averaging.

DPOAE Absolute Amplitude (dB SPL) 5th Percentiles										
Gorga et al. (2005) n= ~ 115 DPOAE measures										
Frequency (kHz)	**0.75**	**1**	**1.5**	**2**		**3**	**4**		**6**	**7**
5th Percentile	-13.6	-12.35	-9.8	-13.87		-16.25	-9.55		-11.05	-20

DPOAE Absolute Amplitude (dB SPL) 5th Percentiles										
Ramos et al. (2013) n=39 DPOAE measures										
Frequency (kHz)			**1.597**	**2**	**2.519**	**3.174**	**4**	**5.039**	**6.349**	**8**
5th Percentile			-9.1	-12.5	-12.8	-7	-10.9	-9.6	-14.4	-16.3
Current Study n=110 DPOAE measures										
Frequency (kHz)			**1.5**	**2**	**2.5**	**3**	**4**	**5**	**6**	**8**
5th Percentile			-0.28	-1.2	-3.26	-3.22	1.34	6.05	2.43	-12.03

Table 93: Comparison of mean DPOAE absolute amplitude for 5th percentile frequency-specific responses from three studies: Current study, Ramos et al. (2013), and Gorga et al. (2005). Data from the current study is from the non-maneuver ambient test condition. Shaded boxes indicate frequency-specific amplitude data not available for the corresponding study.

Gorga, Neely, Bergman, Beauchaine, Kaminski, Peters and Jesteadt (1993a) in their published paper titled *Otoacoustic emissions from normal-hearing and hearing-impaired subjects: distortion product responses,* present DPOAE amplitude and DPOAE/noise level measurements for a sample of normal hearing and hearing impaired young adult participants. The data associated with the normal hearing population can serve as a reference set of normative data for DPOAE measures. This data was not presented in comparison to the current study's DPOAE measures because raw data values associated with this study were not available in published form. Refer to the published paper by Gorga et al. (1993a) for further test details and graphical representation of their study's findings. Similarly, a paper published by Gorga, Neely, Bergman, Beauchaine, Kaminski, Peters, Schulte and Jesteadt (1993b) titled *A comparison of transient-evoked and distortion product otoacoustic emissions in normal-hearing and hearing-impaired* *subjects* provides TEOAE and DPOAE frequency-specific amplitude and noise level data. Again, this study did not provide the raw data values associated with each test condition for either EOAE amplitude or noise level measure. Due to a lack of access to the raw data, direct comparison to the current study's findings will not be presented in the current manuscript.

Comparison of the Current Study's Findings to Published Literature; Transient Evoked Otoacoustic Emissions

The comparison between the non-maneuver test pressure conditions for the outcome measure of TEOAE absolute amplitude was not significant. A difference of 0.16 dB SPL was observed between the ambient and peak non-maneuver test conditions. The average TEOAE absolute amplitudes of 3.44 dB SPL for the ambient and 3.60 dB SPL for the peak test conditions are consistent with normal emission strength from a healthy normal hearing young adult population (Naeve et al., 1992; Plinkert et al., 1994). The interaction between test condition and frequency was also not significant. Despite not being significant, a trend was observed for the difference in TEOAE level between conditions to increase with increasing frequency from 1 to 5 kHz (differences ranging from 0.05 to 0.43 dB SPL). The response pattern for TEOAE level as a function of test frequency 1 to 5 kHz and the mean emission level at each frequency is similar but not identical to amplitude/frequency patterns observed in past studies. In the non-maneuver ambient test condition of the current study, mean TEOAE amplitude levels of 12.93, 7.92, 3.91, -0.73, and -6.84 dB SPL were associated with frequencies 1 to 5 kHz. A study by McFadden et al. (2009) for an 81 dB peSPL click, showed the emission strength for TEOAEs between 1.5 to 4 kHz decreasing with increasing frequency comparable to the trend observed in the current study. This study used a similar participant inclusion criterion, with participants being between the ages of 18 to 35 with normal hearing. The McFadden et al. (2009) study investigated gender and ear-specific differences in EOAE responses. Sample sizes were as follows: female right ear n=35, female left ear n=35, male left ear n=35 and male right ear n=32. The frequency-specific amplitude means for the McFadden study compared to the current study's findings are consistently lower in amplitude across the frequency range 1.5 to 4 kHz for all gender/ear comparison groups (McFadden et al., 2009). A graphical or table summary for the comparison between the McFadden data and the current study's findings is not provided as the McFadden paper did not provide exact DPOAE or TEOAE amplitude values. Comparison between the two studies was achieved by estimating the EOAE values from the provided summary figures in the McFadden paper.

Shahnaz (2008) assessed TEOAE amplitude with a sample of 81 Caucasian and 81 Chinese normal hearing young adult participants. TEOAEs were assessed using a clinical Otodynamics TEOAE Analyzer. The comparisons between the Shahnaz (2008) and the current study's findings are presented for separate ethnic groups. Comparison of TEOAE amplitude measures is shown across the frequency range 1 to 4 kHz. These comparisons are shown in Table 94 for Caucasian participant data and in Table 95 for Asian participant data. Compared to the current study, Shahnaz (2008) showed a slightly different mean amplitude pattern for TEOAE measures at frequencies of 1 to 4 kHz. For both ethnic groups, the Shahnaz (2008) study showed lower TEOAE amplitudes at the lowest test frequencies 1 and 2 kHz, but larger mean amplitudes at higher test frequencies of 3 and 4 kHz. For both ethnic group comparisons, the overall mean amplitude value collapsing across frequency was larger for the Shahnaz (2008) study compared to the current study. Difference in mean TEOAE amplitude between the two studies could be at least partly attributed to differences in gender distribution in each of the ethnic groups between the studies. For the total n=26 TEOAE measurements in the Caucasian group, n=8 measurements were from male participants and n=18 from female participants. This is in comparison to the Shahnaz (2008) study which had n=37 male and n=44 female associated TEOAE measures. For the total n=48 TEOAE measurements in the Asian group, n=17 measurements were from male participants and n=31 from female participants whereas again, the Shahnaz (2008) study had a more comparable sample size between gender groups. Shahnaz (2008) had n=32 male and n=49 female TEOAE measures contributing to the Asian group measurements. Overall, the Shahnaz (2008) study had a total of n=81 TEOAE measures for each of the ethnic groups (collapsing between genders), which is substantially larger than the sample size of the current study. The difference in TEOAE amplitude between these studies could also be due to the difference in test instrumentation and calibration procedures.

Transient Evoked Otoacoustic Emission Absolute Amplitude								
Current Study – Caucasian Participants					**Shahnaz (2008) – Caucasian Participants**			
Frequency (Hz)	**Mean (dB SPL)**	**SE**	**SD**	**n**	**Frequency (Hz)**	**Mean (dB SPL)**	**SD**	**n**
1000	11.19	0.92	4.05	26	1000	5.7	5.9	81
					1500	8.2	5.0	81
2000	6.40	1.01	5.86	26	2000	5.1	4.5	81
3000	2.06	1.19	5.33	26	3000	4.6	5.1	81
4000	-2.33	1.4	5.66	26	4000	1	5.7	81
Overall	4.72	1.81	7.22	26	Overall	14.1	3.9	81

Table 94: Comparison of ethnic specific TEOAE absolute amplitude normative data between the current study (n=26) and the Shahnaz (2008) study (n=81). All samples are from participants classified as Caucasian. Shaded boxes indicate missing data for the corresponding test frequency.

Data presented for both studies is collapsed across the factor of gender. Data presented from the current study is based on non-maneuver ambient test condition measures.

Transient Evoked Otoacoustic Emissions								
Current Study – Asian Participants					**Shahnaz (2008) – Chinese Participants**			
Frequency (Hz)	**Mean (dB SPL)**	**SE**	**SD**	**n**	**Frequency (Hz)**	**Mean (dB SPL)**	**SD**	**n**
1000	12.97	0.67	13.15	48	1000	7.0	6.1	81
					1500	10.0	5.3	81
2000	8.52	0.74	8.95	48	2000	7.9	4.5	81
3000	3.54	0.88	3.97	48	3000	6.5	5.5	81
4000	-1.84	1.03	-1.69	48	4000	4.5	5.7	81
Overall	6.09	1.33	7.90	48	Overall	16.2	4.1	81

Table 95: Comparison of ethnic specific TEOAE amplitude normative data. The current study represents data from n=48 participants classified as Asian. The Shahnaz (2008) study has n=81 TEOAE measurements from participants classified as Chinese. Shaded boxes indicate missing data for the corresponding test frequency. Data presented for both studies is collapsed across the factor of gender. Data presented from the current study is derived from the non-maneuver ambient test condition.

Summary

For both EOAE outcome measures, the width of the 90% range and amplitude level of the minimal response 5th percentile curve was comparable between the non-maneuver ambient and peak pressure conditions. In summary, no significant difference was observed for EOAE measurements assessed at ambient versus peak pressure in the non-maneuver test condition. These measurements were obtained for both EOAEs when the average MEP was centered on 0 daPa (±10 daPa). The responses from participants in both EOAE test conditions regarding emission strength and frequency response patterns are similar to those observed in previous studies using similar participant populations and test parameters.

6.1.5 Post-maneuver Ambient and Post-maneuver Peak Test Conditions

Measuring EOAEs at tympanic peak pressure as in the peak pressure condition, represents what potentially could be done to compensate for the presence of abnormal MEP during the clinical evaluation of EOAEs. Comparing EOAE measures from these two particular test conditions provides support for the conclusion that it is the factor of pressure compensation that is responsible for the change in EOAE amplitude between test conditions. This comparison also indicates that it is the presence of the abnormal MEP that is responsible for the change in EOAE amplitude and not, for example, changes attributable to other factors. Alternative factors such as test ordering effects or factors arising from having the participants perform the Valsalva or Toynbee maneuver (other than solely the MEP change).

Distortion-product Otoacoustic Emissions

For post-maneuver test condition measures, there was a mean absolute MEP of 64.43 daPa with a range of absolute MEP estimates from 6 to 280 daPa. For the comparison of DPOAE absolute amplitude between the post-maneuver ambient and peak test conditions, a significant difference of 0.61 dB SPL was observed. As predicted, the uncompensated ambient test condition had the lower mean DPOAE amplitude. The interaction between test condition and frequency was not significant. Although the overall interaction between factors was not significant, for all frequencies 1.5 to 8 kHz, the compensated peak test condition had the larger emission strength compared to the uncompensated condition. The difference in DPOAE level between test conditions at each test frequency shows a similar pattern to that already described for the comparison of post-maneuver ambient to the non-maneuver ambient test condition. These findings indicate that in the presence of an average 65 daPa of absolute MEP, if DPOAE testing were to be conducted at a pressure corresponding to the patient's TPP, the resulting emission strength for DPOAE test frequencies of 1, 2, 2.5, 3, 4, 5, 6, and 8 kHz would be on average 1.11, 0.4, 0.66, 0.88, 0.6, 0.71, 0.15, 0.34 dB SPL greater than if the assessment were conducted at ambient pressure. As described in detail in the discussion sections above, these findings of improved DPOAE amplitude with MEP compensation reflect findings of previous work by Sun and Shaver (2009). There is, however, aside from this work by Sun and Shaver (2009) limited scientific literature available that has examined pressure compensation with DPOAEs. The majority of literature that is available regarding pressure compensation and EOAE outcome measures is focused on TEOAEs and pediatric populations, which is also limited in quantity.

Figure 41 illustrates the mean and 90% response range for the DPOAE non-maneuver ambient and post-maneuver test conditions (ambient and peak) for measures of absolute DPOAE amplitude. Refer to Table 96 for the associated descriptive statistics. Also represented on Figure 41 are plots of mean noise level as a function of frequency for each of the three test conditions (non-maneuver ambient, post-maneuver ambient and peak) with corresponding DPOAE amplitude data. The comparison of the 90% range for non-maneuver ambient to the post-maneuver peak test condition measures of absolute amplitude illustrates the potential clinical benefit of assessing DPOAEs at peak pressure compared to ambient in cases of abnormal MEP.

Referencing the minimal response level (5th percentile curve) for the comparison between the post-maneuver ambient and peak test conditions, an improvement in DPOAE amplitude is observed across all frequencies (1.5 to 8 kHz). Although an improvement in DPOAE level is seen with pressure compensation, the post-maneuver compensated test condition 5th percentile and mean amplitude response curves are not exactly equivalent in amplitude to the baseline reference curves (non-maneuver ambient). Based on these findings, if a minimum absolute amplitude response criterion is set to determine a pass/fail or normal/abnormal conclusion, then testing at peak pressure would still result in a fail or abnormal classification. This is true if the 5th percentile curve were to be used as the normative data for minimal acceptable response levels in a clinical setting. The minimal response curve for the peak pressure condition still falls below the 5th percentile curve for the baseline normal condition. If however, the 5th percentile curve from the Ramos et al. (2013) normative data were used as a reference, then the minimal responses from both the post-maneuver ambient and peak test conditions would be considered in normal response range. The 5th percentile curve for both post-maneuver ambient and peak test condition measures falls above the 5th percentile curve for the Ramos et al. (2013) normative data. This data provides an indication of the minimal absolute DPOAE amplitude set for Titan based on a normal hearing population to aid in a clinical decision analysis prior to considering a SNR.

An alternative option to determine if a response if present/absent or abnormal/normal would be to use a minimal level at which the emitted signal must be above the noise floor. This type of criterion is considered a signal-to-noise ratio (SNR) criterion and is different than using solely an absolute EOAE amplitude criterion level (i.e. a cutoff amplitude or threshold level). The SNR represents the level difference (in dB SPL) between the absolute DPOAE amplitude and the mean noise floor level. Usually an SNR of greater than 6 dB is set for DPOAEs (Fay et al., 2008; Ramos et al., 2013). From a clinical perspective, a higher SNR value is sought after, with a greater SNR being associated with higher EOAE measurement reliability (Fay et al., 2008). Consider the current study's results for DPOAE measures of absolute amplitude and mean noise level. If a SNR criterion is chosen rather than solely an absolute DPOAE amplitude criterion referencing the 5th percentile curve, then a clinical benefit to testing at peak pressure is shown. The mean noise level is equivalent across the frequency range between the non-maneuver ambient and both post-maneuver ambient and peak test conditions. If the minimum response curve (5th percentile) is viewed in relation to mean noise level, then a greater SNR is observed for the compensated compared to uncompensated post-maneuver condition across the entire frequency range (1500 to 8000 Hz). This comparison also works when using the mean DPOAE amplitude curve to calculate the SNR. For example, consider the test frequency of 3000 Hz. When comparing the mean DPOAE amplitude to the mean noise floor level, the resulting SNR is 29.63 dB SPL, 29.23 dB SPL, and 27.67dB SPL for the non-maneuver ambient, post-maneuver peak, and post-maneuver ambient test conditions respectively. These values show that the SNR is greatest in the ambient MEP condition but that the abnormal MEP condition has a comparable SNR when testing at peak pressure. For a detailed discussion of the significance of noise level findings and noise level values for the current study, refer to section 6.2 titled: Comparison of Noise Level between Test Conditions. In clinical settings, often both a SNR and absolute EOAE amplitude level are considered when determining EOAE presence or absence. For example, a case could present itself where an acceptable SNR level is achieved but the absolute EOAE amplitude is very low. For example a patient could have an SNR of 6 dB SPL, yet the EOAE absolute amplitude for a given test frequency is only -18 dB SPL. An EOAE amplitude of this level would not be considered a present response in most clinics, falling well below the minimal acceptable amplitude response curve (5th percentile) of the current study. Another potential benefit of testing at a compensated pressure level for clinical EOAE testing is related to the time requirement of testing. For example, if a set SNR is used as a test stop criterion, then a higher SNR is likely to be reached faster (in less time) if testing is conducted at a compensated compared to uncompensated pressure level in cases of abnormal MEP. In general, obtaining a clinical measurement such as an EOAE response or reaching a set SNR in less time has clinical advantages, especially when testing pediatric and uncooperative test populations.

	Current Study – DPOAE Absolute Amplitude (dB SPL)								
	Frequency (Hz)	**1500**	**2000**	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**
Non-maneuver Ambient	Mean	10.20	7.10	4.30	4.48	9.96	13.95	13.88	-0.28
	5th Percentile	-0.28	-1.20	-3.26	-3.22	1.34	6.05	2.43	-12.03
	95th Percentile	18.72	15.25	12.00	11.44	16.66	21.30	22.43	9.56
	SD	5.84	5.52	5.17	4.74	4.62	4.96	5.99	7.62
Post-maneuver Ambient	Mean	8.45	6.40	3.17	2.78	8.48	11.78	12.82	-1.54
	5th Percentile	-2.30	-2.38	-9.70	-7.30	-1.86	3.65	0.22	-17.07
	95th Percentile	17.46	14.41	9.96	10.63	15.8	20.22	21.33	12.49
	SD	5.90	5.08	5.76	5.96	5.38	6.51	6.68	9.28
Post-maneuver Peak	Mean	9.55	6.88	3.90	3.89	9.29	12.85	13.35	-1.03
	5th Percentile	-0.365	-2.11	-5.70	-3.555	-0.01	4.59	1.29	-14.42
	95th Percentile	18.56	14.07	11.74	11.97	16.72	21.06	21.32	12.29
	SD	6.02	5.19	5.48	6.05	5.21	5.75	6.37	8.60

Table 96: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient, post-maneuver ambient and post-maneuver peak) as a function of frequency (1500 to 8000 Hz). Descriptive statistics for 5th and 95th percentiles (Prctl), and standard

deviation are included. Darker shaded data rows distinguish the post-maneuver ambient test condition and the lightly shaded rows distinguish the non-maneuver ambient test condition data.

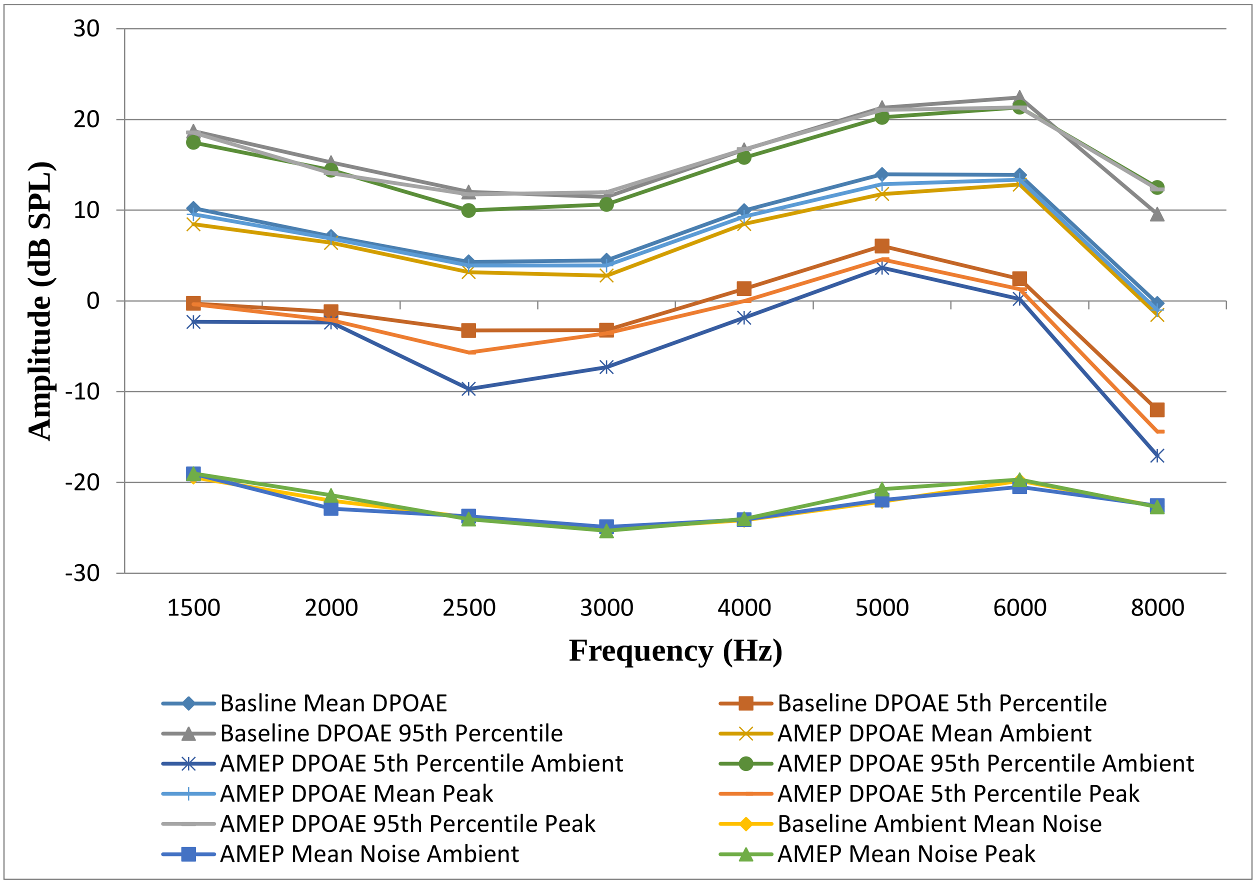


Figure 41: Outcome measures of distortion-product otoacoustic emission (DPOAE) amplitude and mean noise level. Data labeled as baseline represent non-maneuver ambient test pressure condition measures. Post-maneuver measures for ambient and peak pressure test conditions are displayed as abnormal middle ear pressure (AMEP) ambient or peak. Mean and 90% range (5^{th} and 95^{th} percentiles) values for DPOAE amplitude are plotted as a function of frequency (1500 to 8000 Hz). Noise level response curves represent mean noise level for the corresponding three

DPOAE test conditions. DPOAE measures are pooled between gender and ethnic groups. There is a sample size of n=110 DPOAE measures for all test conditions.

A clinical situation in which a true assessment of cochlear integrity and the exact EOAE amplitude is sought after would be in cases of ototoxic monitoring or monitoring of noise-induced hearing loss. In both cases, the EOAE amplitude obtained from one assessment is compared to the outcome measures of another or multiple subsequent assessments. Merely determining EOAE absence/presence or a determination of a pass/fail is not as clinically useful as the exact EOAE amplitude value. It is the actual change in EOAE amplitude between assessment periods that is of interest. As demonstrated by the current study, assessing DPOAEs compensating for abnormal MEP enhances the DPOAE absolute amplitude response across the frequency range 1.5 to 8 kHz. The compensated post-maneuver DPOAE levels reflect the measurements obtained in the baseline test condition. From a clinical perspective, the baseline non-maneuver ambient test condition represents the pre-treatment or pre-noise exposure assessment. Subsequent EOAE evaluations could be represented as the post-maneuver test conditions, with testing conducted at peak pressure if the patient presented with abnormal MEP at the time of testing. Monitoring especially for ototoxicity usually requires the testing of DPOAE across a wider frequency range including higher test frequencies, typically up to 10 kHz. Use of TEOAEs for monitoring of ototoxicity is not as common as DPOAEs due to high frequency TEOAE testing being less reliable.

Transient Evoked Otoacoustic Emissions

When comparing TEOAE measures from the post-maneuver ambient (mean 2.38 dB SPL) to peak (mean 3.03 dB SPL) condition, a significant 0.65 dB SPL amplitude difference was observed. This analysis was collapsed across factors of gender, ethnicity, and frequency. A non-significant interaction was observed between test condition and frequency. TEOAE level differences of 0.97, 1.15, 0.53, 0.46, and 0.13 dB SPL were observed for frequencies 1, 2, 3, 4, and 5 kHz. Although the overall interaction was not significant, TEOAE amplitude was lower for the uncompensated test condition 1 to 5 kHz, with the greatest difference observed at frequencies of 1 and 2 kHz. The frequency-specific changes for TEOAE amplitude and NMEP were consistent with previous studies, with abnormal MEP acting as a high-pass frequency filter with a cut-off between 2 to 3 kHz (Trine et al., 1993; Naeve et al., 1992). The frequency-specific amplitude differences at all test frequencies between test conditions are lower for the current study compared to the average 1.15 to 6.8 dB SPL amplitude changes observed by Trine et al. (1993). Trine and colleagues (1993) compared outcome measures of TEOAE absolute amplitude and reproducibility between compensated and uncompensated test conditions. TEOAE level was recorded for a sample of 14 test ears for a population of participants ranging in age from 2.5 to 58 years old. TEOAEs were obtained using the Otodynamics ILO88 system with use of a modified acoustic immittance system for pressurization. The amplitude discrepancy observed between these two studies is likely due to differences in (1) the degree of abnormal MEP, (2) sample size, (3) population characteristics such as ethnicity, and (4) test instrumentation. The Trine et al. (1993) had MEP ranging from -100 to -310 daPa whereas the current study had absolute abnormal MEP ranging from 5 to 199 daPa with an average of 64.79 daPa across a sample size of n=97 measures.

A study by Hof (2005a) investigating the impact of MEP compensation with a child population, showed mean TEOAE absolute amplitude increased on average by 1.9 dB between compensated and uncompensated conditions. Consistent with the results of the current study, Hof (2005a) found that the greatest impact of pressure compensation was at low frequency bands of 1 and 2 kHz, with no significant differences between pressure conditions at 3 and 4 kHz bands (Hof et al., 2005a). As stated previous, in general published literature concerning TEOAE measures and pressure compensation is limited. Many of the studies that are available focus on a pediatric rather than adult test populations. After a thorough literature search, no published sources could be found for studies investigating the effectiveness of pressure compensation for TEOAE measures using the Titan system.

Figure 42 illustrates the mean and 90% response range for the TEOAE non-maneuver ambient and post-maneuver (ambient and peak) test conditions. The comparison of the normal response range (90% range for non-maneuver test conditions measures) to the post-maneuver peak condition illustrates the potential clinical benefit of assessing TEOAEs at peak pressure. From Figure 42, the most substantial amplitude difference between the non-maneuver and post-maneuver peak test conditions and between the post-maneuver ambient and peak test conditions is seen for frequencies ≤2 kHz, with smaller differences observed at frequencies 3 to 5 kHz. Descriptive statistics for the comparison of mean TEOAE amplitude, standard deviation, and percentiles are shown in Table 97. Referencing the 5th percentile curves in Table 97 for the comparison between the post-maneuver ambient and peak test conditions, an improvement in TEOAE amplitude for the compensated condition is observed across all frequencies (1 to 5 kHz).

The width of the 90% range is comparable between the three test conditions, with no evident trend for the 90% range to be wider or narrow for one particular test condition compared to another. Despite the minimum response curve being larger in amplitude for the compensated versus uncompensated abnormal MEP condition, the peak condition 5th percentile curve approximates but does not exactly match the baseline condition curve. This is similar to the findings for the comparable analysis with DPOAE data. This comparison indicates that if a TEOAE measurement is assessed at peak pressure despite a patient having abnormal MEP, then their response value will approximate or at least fall closer to the range of normal with compensation for abnormal MEP. A more accurate representation of cochlear status as shown by an amplitude increase in TEOAE response, could be achieved more so for low rather than higher test frequencies, primarily for frequencies ≤2 kHz.

If a SNR criterion is used for determining a normal/abnormal TEOAE response, then clinical benefit to assessing TEOAEs at peak rather than ambient pressure in cases of present abnormal MEP can be argued based on the findings of current study. The SNR for TEOAE measures is defined as the difference in level (dB SPL) between the TEOAE absolute amplitude value and the noise floor level at the specific frequency band in question. Ramos et al. (2013) indicate a lower SNR is common for TEOAEs of about 3 to 6 dB SNR compared to an average 5 to 6 dB SNR for DPOAE measures. Considering a SNR response criterion, as depicted in Figure 42, greater clinical benefit testing is seen when testing at peak versus ambient pressure for the mid to low frequency range (frequencies <3 kHz). The mean noise level response is equivalent between the post-maneuver ambient and peak test conditions. Therefore, the small increase in TEOAE amplitude observed in the compensated test condition (post-maneuver peak) will result in a more favorable SNR compared to testing in the uncompensated condition (post-maneuver ambient) for all frequencies 1 to 5 kHz (when referencing the mean TEOAE amplitude response). From Figure 42, the 5th percentile curve of TEOAE amplitude at the test frequency of 4 kHz closely approximates the mean noise level for all three test conditions. Even when calculating the SNR based on the mean TEOAE amplitude curve, there is minimal change in SNR between the three test conditions at frequencies of 4 and 5 kHz. However, as mentioned previously, a minimum SNR of 3 to 6 dB is often used as the criterion for EOAE response presence (Ramos et al., 2013; Sun & Shaver, 2009). For the test frequency of 5 kHz, the 5th percentile absolute TEOAE amplitude curve is actually lower than the mean noise level. In a clinical setting, a negative SNR would result in a determination of an absent EOAE response. At 4 kHz calculating the SNR based on the 5th percentile amplitude curve and mean noise level, results in a SNR of 2.01 dB SPL, 2.35 dB SPL, and 3.2 dB SPL for the non-maneuver ambient, post-maneuver ambient, and post-maneuver peak test conditions. Only the post-maneuver peak test condition response meets the minimum SNR criterion of 3 dB associated with an absolute TEOAE amplitude response of -9.90 dB SPL. This response at 4 kHz may or may not be considered a present/pass TEOAE response. It would dependent on the norms referenced in that clinical setting, and whether only a SNR criterion is used, only a TEOAE amplitude level criterion is used, or both response values are considered in making the clinical decision. Refer to section 6.2 for further discussion regarding noise level differences between test conditions and for mean noise level values.

Test Condition	**Frequency (Hz)**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**SE**	**SD**	**90% Width**	**5th Prctl**	**95th Prctl**	**n**
Post-maneuver, Ambient	1000	11.49	1.01	4.93	15.3	2.10	17.40	97
Post-maneuver, Peak	1000	12.46	0.54	3.57	11	5.40	16.40	97
Non-maneuver, Ambient	1000	12.93	0.51	4.05	15.9	3.60	19.50	97
Post-maneuver, Ambient	2000	6.31	0.60	6.10	17.1	-2.20	14.90	97
Post-maneuver, Peak	2000	7.46	0.60	5.84	17.8	-3.50	14.30	97
Non-maneuver, Ambient	2000	7.92	0.56	5.86	17.08	-0.14	16.94	97
Post-maneuver, Ambient	3000	2.69	0.69	5.30	17.2	-6.20	11.00	97
Post-maneuver, Peak	3000	3.22	0.70	5.25	16.1	-5.70	10.40	97
Non-maneuver, Ambient	3000	3.91	0.67	5.33	19.3	-5.70	13.60	97
Post-maneuver, Ambient	4000	-1.37	0.79	5.56	16.7	-11.30	5.40	97
Post-maneuver, Peak	4000	-0.91	0.80	5.71	18	-9.90	8.10	97
Non-maneuver, Ambient	4000	-0.73	0.78	5.65	24.52	-11.52	13.00	97
Post-maneuver, Ambient	5000	-7.24	0.88	6.06	17.7	-16.80	0.90	97
Post-maneuver, Peak	5000	-7.11	0.88	6.28	18.1	-16.60	1.50	97
Non-maneuver, Ambient	5000	-6.84	0.90	6.78	26.52	-17.26	9.26	97

Table 97: Mean TEOAE absolute amplitude comparison between test conditions (post-maneuver ambient versus peak and non-maneuver ambient) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Standard deviation (SD) and standard error (SE) values are provided. The 5th and 95th percentile (Prtcl) values are provided with the 90% range width (95th minus 5th percentile). Lightly shaded rows distinguish the peak from the ambient post-maneuver test pressure condition. Darker shaded rows distinguish the non-maneuver ambient test condition data.

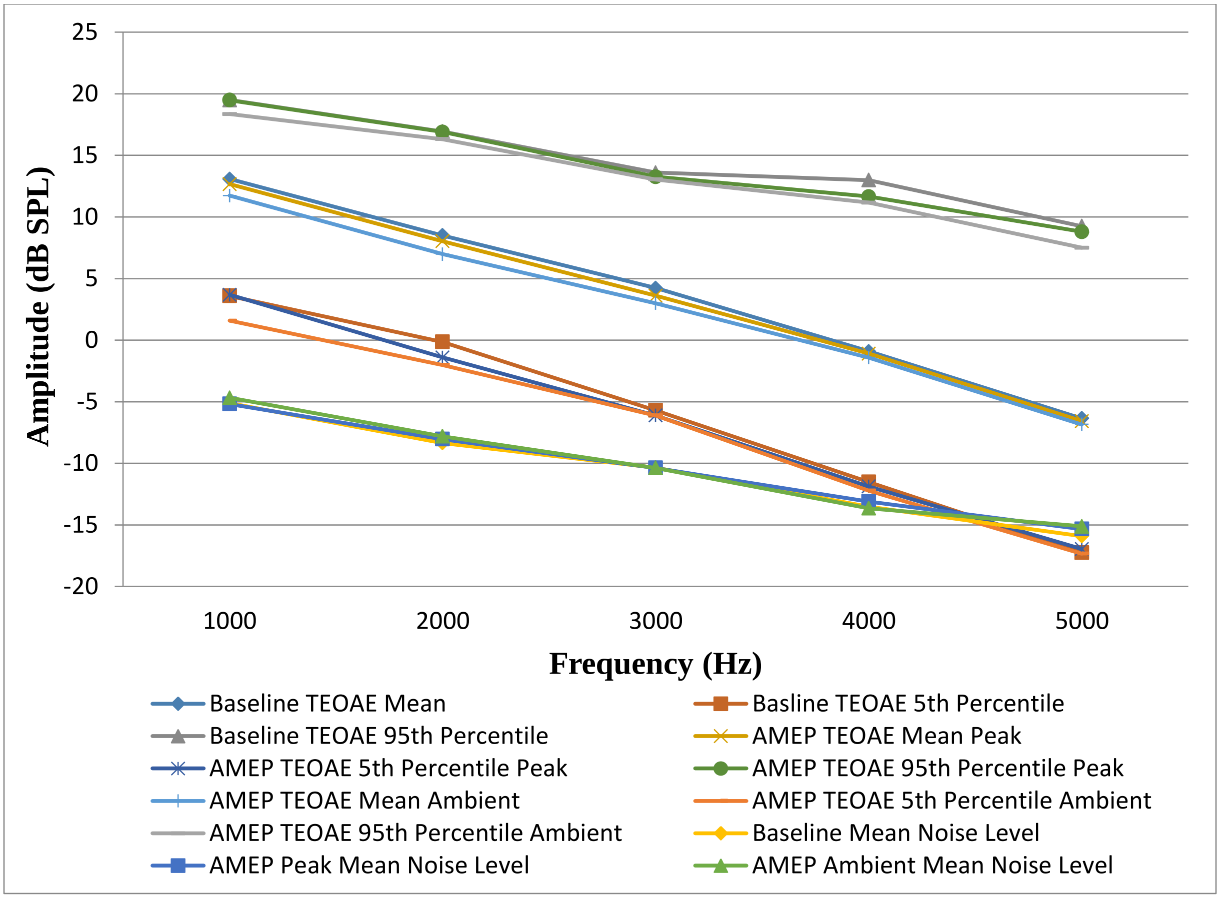


Figure 42: Outcome measures of transient evoked otoacoustic emission (TEOAE) amplitude. Data labeled as baseline TEOAE represent non-maneuver ambient test pressure condition measures of absolute amplitude. Post-maneuver measures of absolute amplitude for ambient and peak pressure test conditions are displayed as abnormal middle ear pressure (AMEP) TEOAE ambient or peak. Mean and 90% range (5^{th} and 95^{th} percentiles) values of TEOAE absolute amplitude measures (n=97) are plotted as a function of frequency (1000 to 5000 Hz). Mean noise level for each three test conditions is also plotted across the frequency range. TEOAE measures of amplitude and noise level are pooled between gender and ethnic groups.

Absolute Middle Ear Pressure

Although a significant difference in TEOAE amplitude was observed comparing the compensated to uncompensated post-maneuver condition, this difference was relatively small in magnitude (0.65 dB SPL). An absolute average MEP of 65 daPa was associated with the post-maneuver test condition measures. An overall greater difference between the post-maneuver ambient and peak test conditions and between the frequency-response curves would likely result if the average MEP was larger in magnitude. A higher stimulus frequency of 83 dB peSPL used to elicit the TEOAEs in the current study may have compensated for the slight conductive barrier introduced with only mild MEP changes. Past researchers have shown an increase in EOAE amplitude level with increasing presentation level of the eliciting stimuli (Naeve et al., 1992; Plinkert et al., 1994; Thompson et al., 2013). The average absolute MEP of 65 daPa induced for the abnormal MEP test condition may have shown a greater impact on TEOAE amplitude levels if a lower stimulus level was used. Although TEOAE testing is conventionally presumed to be a more sensitive measure than DPOAEs, the DPOAE evoking stimulus level was lower in magnitude (65/55 dB SPL) compared to the TEOAE presentation level of 83 dB peSPL. For the current study when comparing DPOAE to TEOAE, there was a difference in stimulus level, a difference in test frequency range used. Moreover, TEOAEs and DPOAEs are composed of different primary cochlear responses. There was also a difference in the number of EOAE responses that contributed to each of the different absolute MEP shift magnitude categories. For example, for TEOAE measures there were n=19 samples in category E (|MEP| ≥100 daPa) and n=25 in the same category for DPOAE measures. These differences between DPOAE and TEOAE measures could in part, potentially account for why the DPOAE amplitude difference between the non-maneuver ambient compared to post-maneuver ambient conditions was greater than was seen for TEOAE measures. Differences in the effective of pressure compensation by Titan for the two measures (DPOAE versus TEOAEs) is not likely a contributing factor here since the comparison is between the two uncompensated test pressure conditions.

The presence of abnormal MEP is reflected in the reduction in overall emission strength (lower mean absolute amplitude) in the uncompensated test condition when the analysis is collapsed across factors of gender, ethnicity, and frequency. The factor of absolute MEP magnitude was explored to investigate if a potential MEP magnitude criterion could be specified. Such criteria could indicate a degree of abnormal MEP that when present at the time of assessment, ought to be compensated for through testing at peak pressure. The interaction between test condition (post-maneuver ambient versus peak) and absolute MEP magnitude was significant for DPOAE outcome measures of absolute amplitude but not for measures of absolute TEOAE amplitude.

Differences in TEOAE level ranged from 0.08 to 0.63 dB SPL between post-maneuver ambient versus peak conditions across absolute MEP magnitude categories of A to E. Although the overall interaction was not significant, there was a trend observed for the TEOAE categories B (n=16), C (n=29), D (n=35) and E (n=22) to have a greater mean absolute amplitude in the post-maneuver peak condition compared to the post-maneuver ambient condition. The largest mean amplitude difference between the ambient and peak conditions was observed at categories D and E, each with a difference of 0.80 dB SPL. Consistent with the current study, Trine et al. (1993) did not find a significant correlation between the degree of NMEP and the change in TEOAE amplitude. As discussed in the previous section, a non-significant interaction was found between factors of absolute MEP shift magnitude and test condition for the comparison of non-maneuver ambient and post-maneuver peak conditions, with no trend noted for TEOAE amplitude across the five MEP magnitude categories. This particular test condition comparison was expected to show no significant amplitude differences. An unexpected non-significant interaction was seen when considering the non-maneuver ambient and post-maneuver ambient conditions. For this comparison however, a trend was observed for the amplitude difference to increase as MEP magnitude increased. Dissimilarities in findings of significance between DPOAE and TEOAE conditions and unpredicted findings could be attributed to the slight differences in absolute MEP magnitude categorization. As explained in Chapter 2, section 2.5.3, two MEP coding systems were used for data analysis. For between maneuver condition comparisons an absolute MEP shift value was used and for within maneuver test condition comparisons an absolute MEP magnitude was used (not a calculation of MEP shift). Slight differences in average of ±5 daPa resulted in small mean amplitude differences for each category A to E and slightly altered sample sizes for each category.

The interaction between test condition (post-maneuver ambient versus peak) and absolute MEP magnitude was significant for DPOAE amplitude measures. Differences in DPOAE amplitude ranged from absolute values of 0.19 to 1.40 dB SPL between post-maneuver ambient and peak conditions across absolute MEP magnitude categories of A to E. As the degree of MEP increased from categories C (26 to 50 daPa), D (51 to 99) to E (≥100 daPa), the DPOAE amplitude difference between pressure conditions increased. The ambient condition showed attenuated emission levels for all categories. Post-hoc analysis showed that the absolute DPOAE amplitude differences between categories were only significant for categories D and E. The largest amplitude differences were observed for category D and E, with respective differences of 1.02

dB SPL and 1.40 dB SPL between the DPOAE compensated and uncompensated conditions. Sun and Shaver (2009) found a similar trend as the current study regarding the degree of abnormal MEP and absolute DPOAE amplitude. They showed a reduction in DPOAE amplitude of 4 to 6 dB SPL for frequencies ≤1000 Hz when the average MEP was ≤-100 daPa. Similar to the current study, as the magnitude of NMEP became larger, a corresponding reduction of DPOAE amplitude was observed. They showed on average reduction of DPOAE amplitude was in the order of 10 to 12 dB for cases where NMEP was >-160 daPa (more negative). Although both studies show equivalent trends, the magnitude of DPOAE amplitude change with abnormal MEP is much larger for the Sun and Shaver (2009) study. This difference between studies is likely attributable to the difference in abnormal MEP range and the number of test samples at each pressure point. Sun and Shaver (2009) for a sample of 70 test ears had NMEP ranging between -70 to -420 daPa whereas the current study had 110 DPOAE measures with an average absolute MEP of 65 daPa (non-absolute pressure range between -140 to +280 daPa).

Summary of Findings

In summary, the comparison between the two post-maneuver sub-conditions serves as an illustration of a clinical situation in which a patient presents with abnormal MEP at the time of EOAE assessment. If EOAE testing were to be conducted following the current clinical protocol of ambient pressure then a false representation of cochlear function would result. This response can be considered ‘false’ because it is reduced emission strength due to abnormal MEP not a due to an actual change in cochlear status. However, if tested at peak pressure in order to compensate for the abnormal MEP, a more accurate representation of the patient’s cochlear function could be realized. This is especially supported by DPOAE outcome measures compared to TEOAEs. The comparison of the normal response range (90% range for non-maneuver test conditions measures) to the post-maneuver peak condition helps illustrate the clinical benefit of assessing EOAEs at peak pressure. Clinical application of compensated EOAE measures is especially seen if a SNR criterion is used rather than solely a criterion based on an absolute EOAE amplitude response. Furthermore, based on the current study's values, using both an SNR and absolute EOAE response criterion would result in more accurate estimates of EOAE strength and likely increase the event of a pass/present rather than fail/absent clinical decision opposed to the use of only one criterion. The intention of exploring the factor of absolute MEP magnitude was to see if a potential MEP magnitude criterion could be specified. This criterion level could indicate the degree of abnormal MEP that would result in more favorable EOAE outcome measures, if testing were conducted at peak rather than ambient pressure. Given the outcome of analyses for test condition comparisons as a function of MEP magnitude, testing DPOAE measures with MEP of ≥26 daPa and for TEOAE MEP of ≥11 daPa, would likely result in more accurate representations of cochlear function. These values were based on the fact that the peak compared to ambient post-maneuver test condition showed the greater mean absolute EOAE amplitude. However, a significant difference between test conditions was only observed for absolute MEP levels ≥51 daPa for DPOAE measures. Post-hoc analysis could not be performed for TEOAE measures to determine the significance of each MEP category comparison between test conditions. For TEOAE measures, MEP magnitude does not seem to impact the resulting emission amplitude between compensated and uncompensated conditions as significantly as DPOAEs. This is likely due to differences in the test frequency range used and likely due to differences in the stimulus presentation level for DPOAE versus TEOAEs as previously discussed. Based on the limited significant findings regarding the factor of absolute MEP magnitude, future research is needed to further explore the concept of a MEP criterion level for pressure compensated EOAE testing. Future work should correct for the limitations of the current study by (1) including a wider range of abnormal MEP, (2) aim for a larger sample size for each MEP category, and (3) explore frequency-specific EOAE amplitude changes as a function of MEP magnitude. Despite these limitations of the current study, based on the overall findings, assessment of EOAEs at a compensated pressure under conditions of abnormal MEP is likely to result in a more accurate but not exact replication of the baseline measures. For the assessment of absolute amplitude for both DPOAE and TEOAE measures, testing at a compensated pressure level is likely to provide a more accurate indication of cochlear status compared to measurements assessed under an uncompensated pressure condition.

Refer to Chapter 9 for a detailed discussion regarding the limitations of current study and suggestions for future research.

6.2 Comparison of Noise Level between Test Conditions

The outcome measure of noise level was of interest to investigate in this study as most clinical settings use a signal-to-noise ratio (SNR) to determine the presence or absence of EOAEs or for making the decision of a pass or refer for further testing. The use of an SNR response criterion can be used independently or in combination with alternative criteria such as a minimum accepted frequency-specific EOAE amplitude response. In addition to its use in determining clinical presence/absence (pass/refer) of EOAEs, noise level can be used as a stopping criterion during testing to increase test efficiency. For example, if the overall noise floor reaches a set criterion level or a set SNR is met, then testing is stopped. A stopping rule based on maximum allowed noise levels or rejection rule can be implemented during EOAE testing to exclude measurement sweeps estimated to contain high levels of noise (artifacts) in order to increase the reliability of the test measure. Based on the current study's results, in order to make a decision regarding the clinical relevance of testing EOAE at a setting of peak or ambient pressure, it was crucial to know how and if noise level changed between test conditions. If noise level was found to significantly differ between test conditions, it would then be of clinical interest to investigate if these changes in noise level are influenced by MEP magnitude. The equivalent comparisons between test conditions and between-subject factors (gender, ethnicity, and absolute MEP magnitude) as were explored with outcome measures of absolute EOAE amplitude were also conducted for EOAE noise level.

6.2.1 Non-maneuver Ambient and Post-maneuver Ambient Noise Level

Explained previously, in a clinical setting regardless of the degree of MEP a patient presents with at the time of assessment, EOAEs are measured at a setting of ambient test pressure (i.e. uncompensated). The comparison between the non-maneuver ambient and the post-maneuver ambient test conditions was conducted in order to demonstrate the impact of abnormal MEP on the outcome measure of EOAE noise level. This analysis was included as a form of control testing. As mentioned above, most clinical settings use a criterion of a minimal SNR and/or a minimum EOAE amplitude response that must be met in order to determine EOAE presence or absence. Therefore, it has direct clinical implications and is of interest to know if the presence of uncompensated abnormal MEP significantly alters EOAE noise level.

Distortion-product Otoacoustic Emissions

The main effect of DPOAE noise level for the comparison between non-maneuver ambient and post-maneuver ambient test conditions was not statistically significant. The only finding of significance for DPOAE noise level was for the main effect of frequency: DPOAE noise level followed a similar pattern as a function of frequency as did DPOAE amplitude measures. The DPOAE noise level response as a function of frequency mimics the results of past studies (Cauwenberge, 1996). This is consistent to findings from a study by Plinkert et al. (1994) that showed no significant change in noise level for DPOAE related measures. The Plinkert et al. (1994) study investigated changes in EOAE amplitude and noise level between ambient and uncompensated abnormal ear canal pressure test conditions with pressure ranging between -200 to +200 daPa. For DPOAE measures of noise level, a non-significant interaction was seen between factors of test condition (non-maneuver versus post-maneuver ambient) and frequency. This indicates that for DPOAEs, the variation in noise level across the test frequency range did not differ between test conditions (ambient and abnormal MEP). These finding for DPOAE measures of noise level are consistent with past research (Sun & Shaver 2009). The outcome measure of noise level was further explored considering the factor of absolute MEP shift magnitude. For DPOAE measures of noise level, a non-significant interaction was seen between factors of test condition and absolute MEP shift magnitude. A significant finding was found for the same interaction (test condition and absolute MEP shift magnitude) but for DPOAE absolute amplitude. This particular comparison was important to include in the final analysis as it signifies that although a significant difference was found for the comparison of absolute amplitude, noise level does not act in the same manner. If a SNR is being used clinically to assess EOAE presence or absence, a change in the SNR value with a change in MEP is likely due to a change in the EOAE amplitude and not from a change in the noise level.

A study by Sun and Shaver (2009) examined the change in noise level for measures of DPOAE under three test conditions: (1) baseline with ambient MEP, (2) NMEP uncompensated, and (3) NMEP compensated. This study used a GSI 60 DPOAE system with research designed tympanometer connecting tubing for pressurization in the compensated MEP test condition. Part of the rejection criterion for a sampling frame set by Sun and Shaver (2009) was a criterion for noise level; a frame was rejected if the recorded noise level exceeded 30 dB SPL. Test acceptance criterion for noise level was set for the average noise level at each test frequency to be ≤-15 dB SPL. This study found that changes in mean noise level for the n=27 test ears were minimal and not statistically significant between the three test conditions. Consistent with the current study, Sun and Shaver (2009) found no significant change in noise level as a function of NMEP magnitude (range between -40 and -420 daPa). After compensation for NMEP, noise level responses did not exactly match baseline measures; however, there was no specific trend observed for the change in noise level across the frequency (f_2) range of 600 to 8000 Hz. This finding is also consistent with the results of the current study. In conclusion, for the Sun and Shaver (2009) results, the response shape of mean noise level was consistent between uncompensated and compensated NMEP pressure conditions a finding also seen with the current study. The only effect of significance for noise level measures with the Sun and Shaver (2009) study was for the main effect of stimulus frequency. A trend was observed across test conditions for the lower frequencies to have a higher noise floor and the greatest impact of NMEP was seen at lower test frequencies of <1000 Hz with an increase in mean noise level at the highest test frequencies of >6000 Hz. These frequency-specific noise level responses are similar to those observed in the current study: A peak in noise level was seen at the lowest test frequency of 1500 Hz, sloping to a minimum at 3000 Hz, rising to a secondary peak in noise level at 6000 Hz. However, unlike the Sun and Shaver (2009) study, the current study noise level followed a downward slope at the highest test frequency of 8000 Hz.

Transient Evoked Otoacoustic Emissions

The main effect of TEOAE noise level for the comparison between non-maneuver ambient and post-maneuver ambient test conditions was significant. The non-maneuver TEOAE condition had a significantly lower mean noise level by 0.33 dB SPL. This is contrary to findings from the Plinkert et al. (1994) study that showed no significant change in noise level for TEOAEs with changes of ear canal pressure (±200 daPa). The current study's finding of a significant difference in mean noise level between test condition is also contrary to the results from a study by Prieve et al. (2008). They found for a study of 3 to 39 months olds that there was no change in noise level for TEOAEs measured between 1 and 4 kHz between conditions of ambient MEP and uncompensated NMEP. From a visual determination of noise level values based on the published figure in Prieve et al. (2008), noise level was highest at frequency of 1.4 kHz. Noise level remained consistent in level from 2 to 4 kHz, with possibly a slight decrease with increasing frequency. Major differences between the Prieve et al. (2008) and the current study include sample size, participant age, test instruments, and the amount of time between TEOAE assessments at ambient MEP versus a NMEP. Refer to the discussion below regarding noise level differences between studies and importance of instrument specific normative values.

Like the analysis for DPOAE measures, the only other finding of significance for TEOAE noise level was for the main effect of frequency: TEOAE noise level consistently decreased as frequency increased. These analyses for the main effect of frequency were collapsed across factors of gender and ethnicity. This observation of noise level being greater in the low frequency range is a well-established finding in past studies.

When collapsing the analysis across the fact of frequency, gender, and ethnicity, the main effect of test condition is significant for measures of TEOAE noise level. In spite of this significant finding, for TEOAE measures of noise level, a non-significant interaction was found between factors of test condition and frequency. This indicated the variation in noise level across the frequency range (1 to 5 kHz) does not differ between test conditions (non-maneuver versus post-maneuver ambient). This finding of non-significance for TEOAE noise level when assessed across a frequency range has greater clinical implications compared to the significant main effect of test condition. In clinical settings, EOAE amplitude, noise, and SNR are most often examined at specific frequencies rather than as a combined overall response combined across frequencies. For TEOAE measures of noise level as well as absolute amplitude, there was a non-significant interaction between factors of test condition (non-maneuver ambient versus post-maneuver ambient) and absolute MEP shift magnitude. However, a trend is seen for TEOAE amplitude to decrease with increasing abnormal MEP in the post-maneuver ambient test condition. In other words, the difference in TEOAE amplitude between the two test conditions increases with an increase in MEP magnitude. This is accompanied by noise level not changing significantly nor changing in a clear trend as MEP magnitude increases for either test condition. For these reasons, from a clinical perspective, if the SNR for TEOAE measures is more favorable for the ambient

MEP condition then the reduction in SNR for the uncompensated abnormal MEP can be attributed to a change in TEOAE amplitude and not to a change in noise level. The lack of significant differences noted for noise level measures with the interaction between test conditions and frequency as well as test conditions and MEP magnitude is favorable from a clinical perspective. On the other hand, the lack of significant differences for these same factor interactions with TEOAE absolute amplitude is unexpected (refer to section 6.1.2 for a detailed discussion of absolute TEOAE amplitude findings).

Addressing Differences in Noise Level Findings

A dissimilarity in significance between DPOAE and TEOAE findings is observed for the current study (as described above) regarding mean noise level for the main effect of test condition (non-maneuver ambient and post-maneuver ambient). This dissimilarity could be attributed to differences in the way noise level is estimated for the two types of EOAEs. There are also slight distinctions noted between the noise level results of the current study compared to published studies. The approach of noise level estimation for DPOAE and TEOAE noise level measures is different for not only the Titan system, but all EOAE test equipment.

Noise level for DPOAE measures is determined by averaging the noise level in the closest frequency bins above and below the frequency point of the distortion-product. Estimation of the noise level in these bordering f_1 and f_2 frequency bands is achieved by use of fast Fourier transforms and it is through statistical analysis that the distortion-product signal is extracted from the surrounding noise (Fay et al., 2008). TEOAE amplitude responses are extracted from the noise floor through a series of repetitive averaging by presenting the click stimulus multiple times. The noise (random artifacts) picked up by the recording system is by nature random. Consequently through averaging over many stimulus repetitions, the random noise is averaged to zero or to a very low level. With this multi-sweep signal-averaging process, the TEOAE amplitude response improves (ideally) over the recording time while the noise floor decreases (Perez, 2012). Increased signal averaging often leads to an improved SNR. For all test systems, TEOAE related noise level is determined within the frequency band corresponding to the associated TEOAE frequency. A frequency bar or band is a frequency bandwidth/range in which both the TEOAE amplitude and noise level are assessed.

Variations in probe insertion depth and in set stop criteria are other possible factors that can contribute to differences in noise level between studies. Muller et al. (2005) state that the standard deviation associated with a change in the position of the sound probe within the ear canal is in the order of 1.6 dB (as cited in Fay et al., 2008). The specific stop criteria such as referencing the SNR or noise floor level and the acceptable noise level criteria are particularly important factors to consider when comparing results between studies. These factors directly influence the number of test sweeps obtained per test frequency or during the allotted EOAE test time. Testing for the current study was conducted with the primary objective of assessing EOAE amplitude changes between compensated and uncompensated MEP conditions. Described in the methods section, no stopping criteria referencing noise level measures were set for either TEOAE or DPOAE measures. A fixed test time of 10 seconds per DPOAE frequency and a total test time of 60 seconds for TEOAE measures were used as a form of stop criteria. The acceptable noise level setting was also de-selected for both EOAEs. This means that for recording of EOAE sweeps in which there was potentially a high level of background noise, these sweeps were not automatically rejected by the system. These high noise sweeps likely lead to the inclusion of noise artifact into the TEOAE amplitude average, which is linked to a reduction in the overall integrity of the test data. When testing in a clinical setting, a stop criterion referencing the noise floor is most often implemented. Based on the differences in test criterion options selected for the current study compared to what would be commonly used clinically, measures of noise level from the current study should be interpreted with caution. Based on these differences, the current study’s noise level values have limited clinical application. Alternative test parameters and suggestions for future studies using the Titan system are presented in the study limitations section of Chapter 9.

Both the surrounding room noise and the patient produced noise will interfere with EOAE recordings making it challenging to extract the low level emission response from the noise floor. Most noticeably, patient movement and breathing introduces low-frequency noise interference. In addition, electrical noise produced by the probe system and test equipment will also contribute to the overall noise level. Instrumentation using a low-noise test microphone, reducing patient movement, and minimizing ambient noise during testing will help in lowering the noise floor level. A lack of calibration standards for EOAE instruments and equipment specific hardware variances can lead to differences in noise level responses between studies. Refer to section 6.2.3 for a further discussion about the importance of instrument specific EOAE (amplitude and noise level) normative data.

6.2.2 Noise Level; Non-maneuver Ambient and Post-maneuver Peak

The comparison of mean noise level between the non-maneuver ambient and post-maneuver peak conditions was not significant for either DPOAE or TEOAE measures. All other main effect analyses (gender and ethnicity) or interactions between factors were found non-significant for both EOAEs, with the exception of the main effect of frequency. For TEOAE measures, noise level deceased with increasing frequency, a trend also observed by other studies (Fay et al., 2008). For DPOAE measures the maximum noise level was detected at the lowest test frequency of 1500 Hz with a minimum noise level observed at 3000 Hz. This is a frequency-specific response pattern similar to that observed by past studies (Gorga et al., 1993b). The pattern of mean noise level plotted as a function of frequency is similar to the pattern observed for mean absolute amplitude plotted as a function of frequency for both EOAEs. There were no findings of significance when analyzing noise level as a function of absolute MEP shift magnitude for either DPOAE or TEOAEs. The presence of compensated abnormal MEP, regardless of the magnitude, did not significantly alter the noise level for either measures of DPOAE or TEOAEs. The clinical relevance of a non-significant change in EOAE noise level between test conditions will be discussed in detail in the following subsections 6.2.3 and 6.2.4.

6.2.3 Noise Level; Non-maneuver Ambient and Non-maneuver Peak

This comparison between the non-maneuver ambient and peak test conditions serves as a way to demonstrate that by collecting EOAE measures with the Titan system set at peak rather than ambient pressure, that this change to the test settings does not on its own significantly alter the resulting noise level.

When collapsing the analysis across factors of gender, ethnicity, and frequency there is no significant difference observed for mean noise level comparisons between the non-maneuver pressure conditions for either DPOAE or TEOAE measures. There are no consistent trends observed for noise level neither between test conditions nor between factors of gender or ethnicity. The overall interaction between test conditions and absolute MEP magnitude is not significant for either EOAE related measure.

Given that EOAE normative data for absolute amplitude is most often represented as mean and percentile response curves as a function of frequency, it would be clinically applicable to also present noise level data in a similar manner. It is ideal in clinical settings to have a low noise floor level during testing of EOAEs. When discussing the 90% response range for noise level measures, the 95th percentile curve represents a maximum allowed response of the noise floor. This is unlike the use of the 5th percentile curve with EOAE amplitude, which represents a minimum accepted response level. For a normally distributed set of data, the 95th percentile approximates a level of 2 SD above the mean noise floor. Accordingly, the 5th percentile response curve approximates 2 SD below the mean noise floor. The percentile values (5th and 95th percentiles) and mean noise levels are based on all n=210 DPOAE measures and n=97 TEOAE measures (pooling across ethnic and gender groups).

The width of the 90$^{\%}$ range for DPOAE noise level assessed at ambient versus peak pressure settings are comparable (refer to Table 98). The largest difference in 90% range between test conditions (non-maneuver ambient and peak) is observed at 6000 Hz, with a 1.3 dB SPL difference. The DPOAE noise level means, 5th percentiles, and 95th percentiles for both non-maneuver test conditions are plotted as a function of frequency in Figure 43. Based on the comparable mean noise floor level and 90% response range for peak and ambient measures, these findings indicate that testing a patient at either a system setting of ambient or peak pressure will not result in system related differences in DPOAE noise level. From the Ramos et al. (2013) study, normative data for mean noise floor levels across the DPOAE frequency range 1597 to 8000 Hz is also included in Figure 43. Data for the 5th and 95th percentile curves was not available from the published study by Ramos and colleagues. Note that the frequency range used for graphical representation of data between the two studies is referencing the frequency range used by the current study. Refer to Table 98 for Ramos et al. (2013) specific frequency points. The mean noise level response from the Ramos et al. (2013) study has a similar frequency response as the current study, but is larger in magnitude compared to the mean response curves for both the non-maneuver test conditions. The Ramos study mean noise floor is lower than both the plotted non-maneuver peak and ambient 95th percentile curves. For example, if in a clinical situation the current study's mean DPOAE frequency-specific amplitude measures were to be used in association with the mean noise level values of the Ramos study to determine DPOAE presence or absence, a clinically acceptable SNR would result (SNR >6 dB SPL). Ramos and colleagues tested each ear for five minutes, allowing 20 seconds of artifact-free averaging to occur at each DPOAE test frequency. The difference in the test time at each frequency (resulting in different total sweeps collected at each frequency) and the test environment noise could be sources of mean noise level differences observed between these studies.

		Current Study DPOAE Noise Level (dB SPL)							
	Freq. (Hz)	**1500**	**2000**	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**
Non-maneuver Ambient	**Mean**	-19.42	-22.01	-23.85	-25.15	-24.18	-22.11	-19.81	-22.63
	5th Prctl	-23.32	-25.53	-26.58	-27.60	-25.80	-23.50	-22.20	-24.60
	95th Prctl	-13.58	-17.40	-18.64	-22.08	-22.00	-19.43	-16.70	-20.61
	SD	3.25	2.69	3.15	2.51	1.37	1.19	4.18	1.18
Non-maneuver Peak	**Mean**	-18.93	-21.69	-23.12	-25.29	-23.53	-21.59	-20.30	-22.53
	5th Prctl	-22.52	-25.53	-26.80	-27.60	-25.80	-23.50	-22.20	-24.60
	95th Prctl	-13.43	-16.89	-19.65	-21.90	-22.00	-19.70	-18.00	-20.20
	SD	3.92	3.75	7.08	3.19	5.00	4.46	2.26	1.40
		Ramos et al. (2013) - Mean Noise Floor Level (dB SPL)							
	f_2 (Hz)	**1597**	**2000**	**2519**	**3174**	**4000**	**5039**	**6349**	**8000**
	Mean	-16.1	-18.3	-21.1	-22.5	-21.9	-20.4	-17.9	-19.7

Table 98: Current Study data is for the comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1500 to 8000 Hz). The 90% range is represented by 5th and 95th percentiles (Prctl). Standard deviation (SD) mean noise level calculated values are provided for each test condition (n=110 DPOAE measures). The analysis was collapsed across factors of gender and ethnicity. Lightly shaded rows distinguish ambient test condition data and darker shaded rows distinguish peak condition data from the current study. Ramos et al. (2013) mean noise floor levels across a frequency range of 1597 to 8000 Hz are provided: DPOAE measures are based on a sample of n=39 test ears.

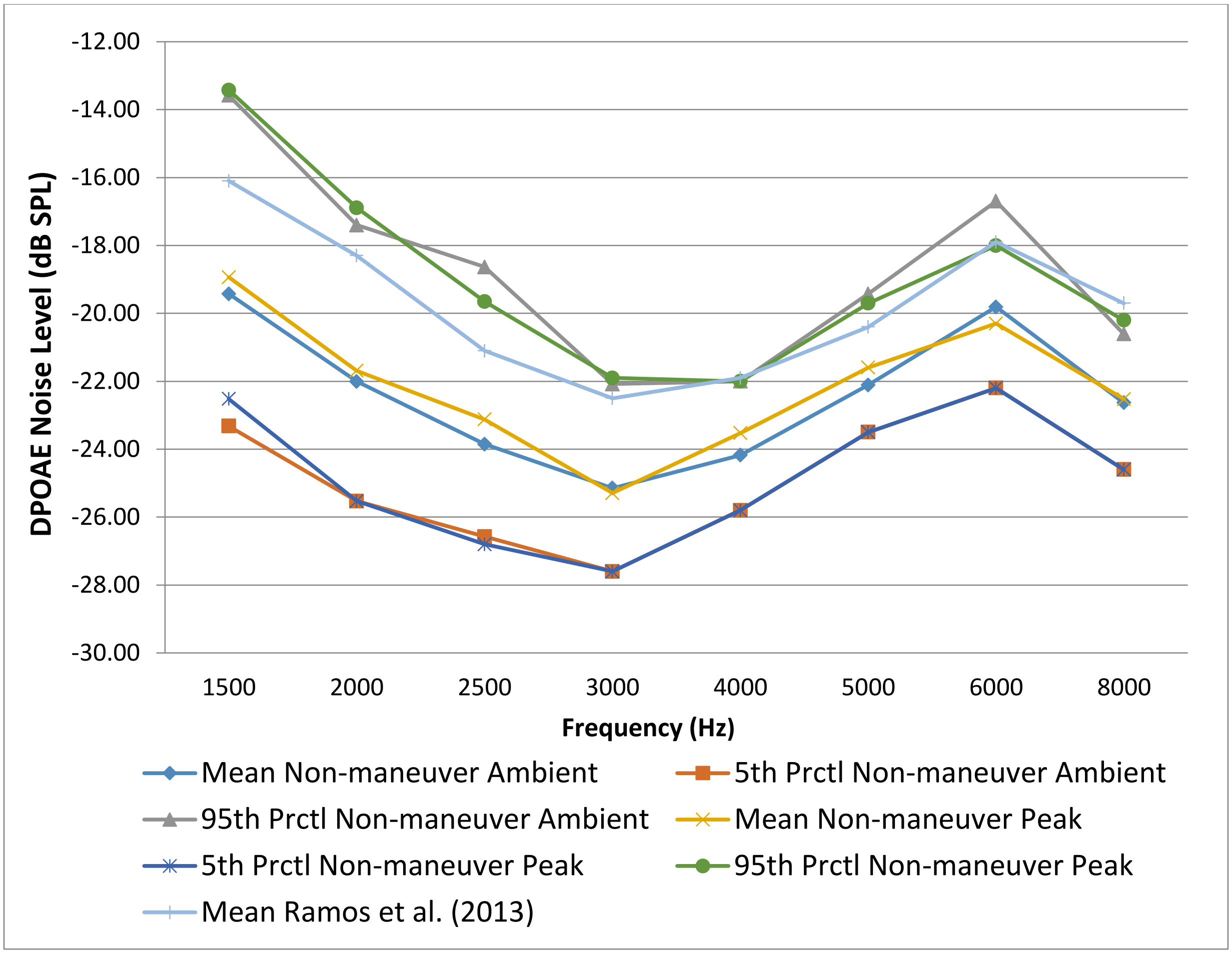


Figure 43: Current study data is for the comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1500 to 8000 Hz). The 5th and 95th percentiles (Prctl) and mean noise level response curves are provided for each test condition (n=110 DPOAE measures). The analysis was collapsed across factors of gender and ethnicity. Original Ramos et al. (2013) mean noise floor levels were presented as a function of frequency over an f_2 range of 1597 to 8000 Hz (sample size of n=39 test ears).

The overall interaction between test condition and frequency for measures of TEOAE noise level was not significant collapsing across factors of gender and ethnicity. Refer to Table 99 for descriptive statistics. The width of the 90$^{\%}$ range for measures of TEOAE noise level assessed at ambient versus peak pressure settings are similar but not equivalent (refer to Figure 44). The 90% range is slightly wider across frequencies 1 to 5 kHz for the peak pressure condition. These findings imply that the calculated mean noise level for the peak pressure condition is not as representative of the data as is the calculated mean noise level for the ambient test condition. In a clinical situation, testing TEOAE at a setting of peak versus ambient pressure could result in a different response outcome, if the mean noise floor is referenced for determining SNRs post-TEOAE recording. Although the difference in noise level between test pressure conditions (ambient versus peak) is small, use of pressure specific norms would be advisable. The difference in noise level between test conditions could be due to numerous factors such as patient movement or breathing at the time of testing, ambient room noise, and/or instrument electrical noise differences between ambient and peak pressure setting. These noise level differences are not likely due to the factor of probe insertion depth since the probe placement was not altered between test conditions (ambient versus peak).

After an extensive literature search, literature declaring raw noise level values for TEOAE measures with an adult population and using similar test parameters and instrumentation as the current study could not be found. Therefore, no graphical comparison of TEOAE noise level between published literature and the current study is provided. There is however, TEOAE noise levels from a study by Shahnaz (2008) presented in the bottom portion of Table 99. The mean noise level measures from the Shahnaz (2008) study is displayed across the frequency range of 1 to 4 kHz for a sample of Caucasian (n=81) and Chinese (n=81) normal-hearing young adults. Comparing the mean noise level between studies, there is an evident difference between the current study's frequency-specific TEOAE noise level and the mean noise level obtained by Shahnaz (2008) for both ethnic groups. There is an evident difference in the frequency response of mean noise level between studies. The current study shows a steep decrease in noise level with increasing frequency while the Shahnaz (2008) displays a more steady mean noise level across frequencies 1 to 4 kHz. In the Shahnaz (2008) study, TEOAEs were assessed using a clinical Otodynamics TEOAE Analyzer. Unlike the current study Shahnaz applied a stop criterion of 260 sweeps and set the instrument's noise rejection level to the system default level (47.3 dB).

Current Study - TEOAE Noise Level (dB SPL)						
Frequency (Hz)		**1000**	**2000**	**3000**	**4000**	**5000**
Non-maneuver Ambient	**Mean**	-5.10	-8.35	-10.35	-13.53	-15.91
	5th Prctl	-8.52	-10.52	-12.90	-15.60	-18.02
	95th Prctl	-1.00	-5.84	-8.30	-11.48	-13.26
	SD	6.83	1.65	1.51	1.86	1.45
	90% width	7.52	4.68	4.60	4.12	4.76
Non-maneuver Peak	**Mean**	-4.83	-7.95	-10.20	-12.82	-16.97
	5th Prctl	-9.30	-11.00	-12.80	-15.74	-17.50
	95th Prctl	-0.90	-5.40	-7.80	-11.28	-11.60
	SD	2.60	3.03	2.46	4.17	15.41
	90% width	8.40	5.60	5.00	4.46	5.90
Ambient minus Peak	**95th Prctl Difference**	-0.10	-0.44	-0.50	-0.20	-1.66

Shahnaz (2008) - TEOAE Noise Level (dB SPL)						
Frequency (Hz)		**1000**	**1500**	**2000**	**3000**	**4000**
Caucasian (n=81)	**Mean**	-7.0	-7.7	-8.6	-7.4	-7.7
	SD	6.1	5.3	5.5	4.7	5.1
Chinese (n=81)	**Mean**	-7.4	-7.9	-8.5	-7.7	-7.4
	SD	6.9	6.3	6.4	5.6	5.6

Table 99: Current Study: Comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1000 to 5000 Hz). The 5th and 95th percentiles (Prctl) and 90% range width are shown. The difference between test condition 95th percentiles is identified by the darkly shaded data row. Standard deviation (SD) mean noise level calculated values are provided for each test condition (n=97 TEOAE measures). The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish data for the peak from the ambient test pressure condition. Shahnaz (2008) study: Mean noise level measures associated with TEOAEs assessed across the frequency range of 1000 to 4000 Hz in a sample of Caucasian (n=81) and Chinese (n=81) normal-hearing young adults. Data was extracted from the Shahnaz (2008) study.

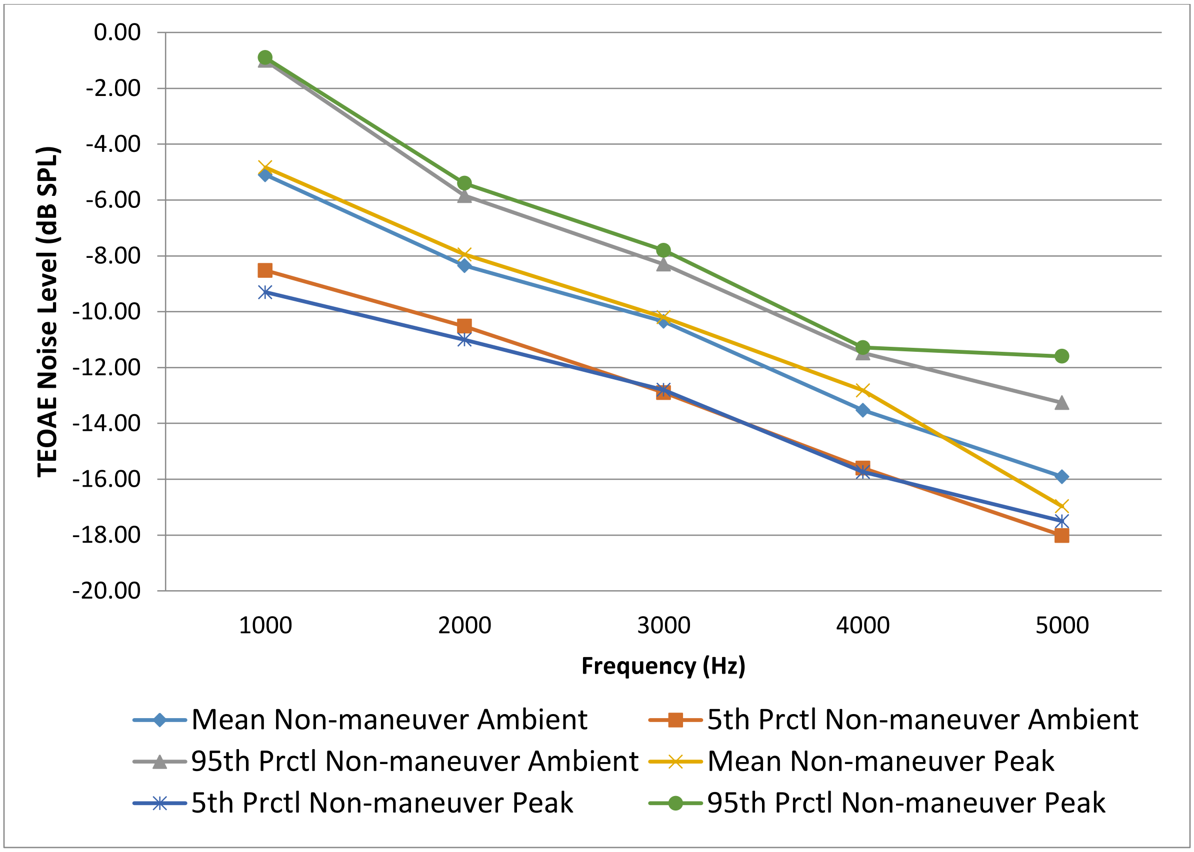


Figure 44: Current study data is for the comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1000 to 5000 Hz). The 5th and 95th percentiles (Prctl) and mean noise level response curves are provided for each test condition (n=97 TEOAE measures). The analysis was collapsed across factors of gender and ethnicity.

Noise Level; Difference between Studies

EOAE noise level is highly variable between test environments and between EOAE test systems. In a review by Christensen (2000), the pass/refer criterion for six different DPOAE systems were investigated. This report states that although DPOAE can be assessed using comparable test parameters, a different criterion is still being used between test systems to determine a pass or refer outcome (Christensen, 2000). Variation in the probe microphone and its specific frequency response was discussed as being the most noteworthy factor contributing to differences in DPOAE amplitude responses observed between test instruments. This report identifies several factors that contribute to differences in noise floor levels between instruments: (1) microphone related electrical noise, (2) test environment, (3) frequency specific averaging time, (4) eartip positions (i.e. isolation), and (5) manufacture set noise floor limitations. In summary, Christenson urges clinicians to understand the instrument-specific criteria when making clinical decisions regarding EOAE presence/absence or when determining a pass/refer outcome. Christenson also recommends that the test protocol and stimulus parameters used to generate the normative data used by the instrument should also be followed precisely when in clinical use. Refer to the Christenson (2000) report for a detailed evaluation of several DPOAE test system pass/refer criteria.

6.2.4 Noise Level; Post-maneuver Ambient and Post-maneuver Peak

Testing at peak pressure rather than ambient pressure represents what potentially could be done clinically to compensate for the presence of abnormal MEP during the evaluation of EOAEs. Comparing EOAE measures between the two post-maneuver test conditions provides an indication if the act of pressure compensation significantly changes measures of noise level. This justification for performing this analysis is also applicable to the above comparison of noise level between the two non-maneuver test conditions. The new variable to consider for the post-maneuver comparison is the presence of abnormal MEP.

Distortion-product Otoacoustic Emissions

The main effect for the comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus peak) was not significant. The mean noise level pattern as a function of frequency 1.5 to 8 kHz was found to be similar to the response curve observed for mean DPOAE absolute amplitude plotted against frequency. The interaction between test condition and frequency was not significant, indicating that mean noise level did not differ between test conditions across the DPOAE frequency range. The interaction between absolute MEP magnitude and test condition was also not significant. The degree of absolute MEP magnitude did not alter the mean noise level between test conditions.

Table 100 displays the mean, 5th percentile, and 95th percentile DPOAE noise level values across frequencies 1.5 to 8 kHz for the current study's post-maneuver peak and ambient test conditions. These mean and 90% response curves for the post-maneuver test conditions are illustrated in Figure 45. Comparing noise level between test conditions (ambient and peak), the largest difference in dispersion around the mean is seen at frequencies 2, 5, and 6 kHz. Overall, the noise level response for the ambient and peak test conditions is highly comparable 1.5 to 8 kHz. Also plotted in Figure 45 is the mean noise level response from the Ramos et al. (2013) study, which represents a normative reference for mean noise floor during DPOAE recordings using the Titan system. Refer to above discussions for details of this study by Ramos et al. (2013). The mean noise floor associated with both post-maneuver test conditions fall well-below the mean level indicated by the Ramos et al. (2013) study. Refer to the discussion in 6.2.3 regarding possible sources of differences in noise level measures between these studies.

		Current Study DPOAE Noise Level (dB SPL)							
Frequency (Hz):		**1500**	**2000**	**2500**	**3000**	**4000**	**5000**	**6000**	**8000**
Post-maneuver Peak	**Mean**	-19.01	-21.42	-24.05	-25.34	-24.00	-20.72	-19.69	-22.70
	5th Prctl	-23.10	-24.98	-26.30	-27.99	-25.80	-23.50	-22.20	-24.60
	95th Prctl	-12.49	-16.04	-20.50	-21.74	-21.78	-17.68	-17.30	-20.61
	SD	3.27	4.33	1.85	1.96	1.38	7.26	5.68	1.16
Post-maneuver Ambient	**Mean**	-19.06	-22.88	-23.72	-24.89	-24.10	-21.94	-20.48	-22.57
	5th Prctl	-23.32	-25.20	-26.80	-27.60	-25.80	-23.50	-22.20	-24.02
	95th Prctl	-12.95	-16.83	-19.43	-21.30	-21.60	-19.20	-17.62	-20.20
	SD	3.40	15.32	4.89	5.28	1.29	1.39	1.52	1.08

Table 100: Current Study data is for the comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus post-maneuver peak) as a function of frequency (1500 to 8000 Hz). The 90% range is represented by 5th and 95th percentiles (Prctl). Standard deviation (SD) mean noise level calculated values are provided for each test condition (n=110 DPOAE measures). The analysis was collapsed across factors of gender and ethnicity. Lightly shaded rows distinguish ambient test condition data from peak condition data.

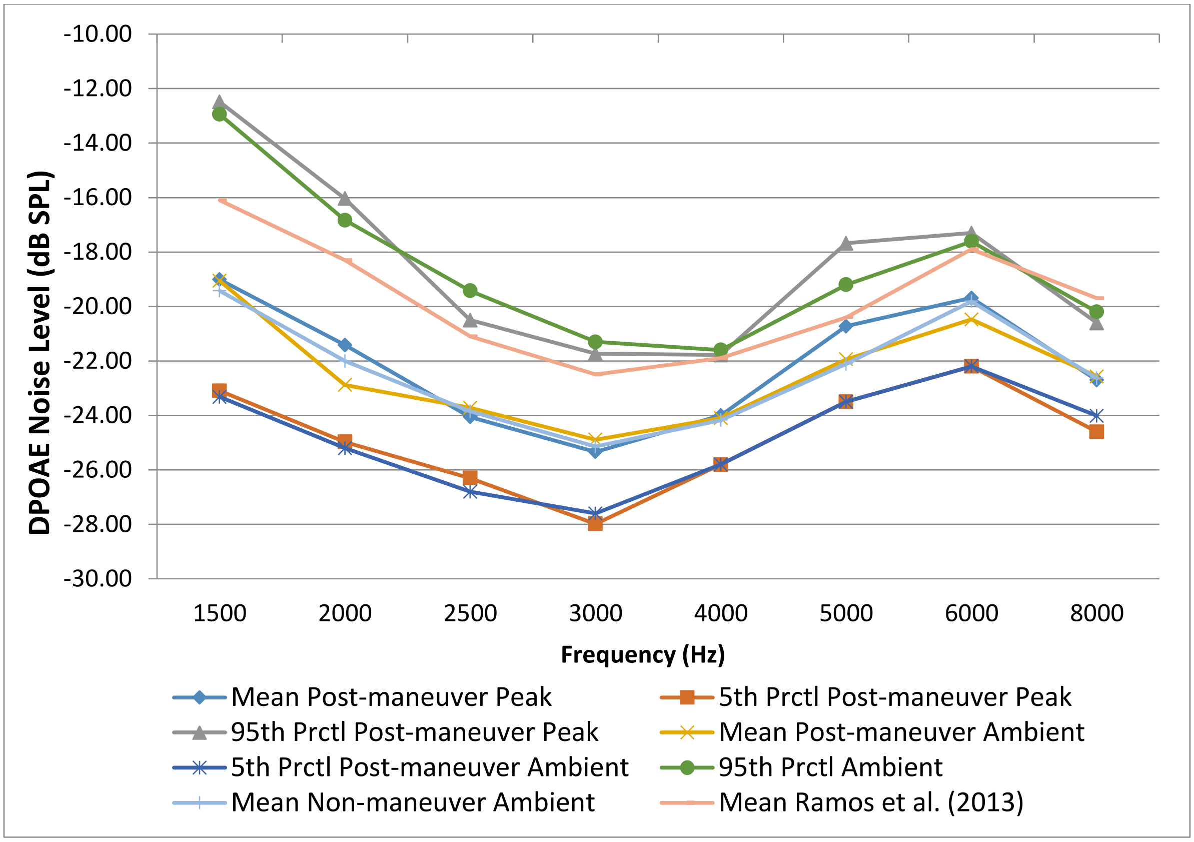


Figure 45: Current study data is for the comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus post-maneuver peak) as a function of frequency (1500 to 8000 Hz). The 5th and 95th percentiles (Prctl) and mean noise level response curves are provided for each test condition (n=110 DPOAE measures). The data was pooled across factors of gender and ethnicity. Ramos et al. (2013) mean noise level (ambient MEP and ambient pressure setting condition) is plotted against the current study's frequency range. Note: The original frequency (f_2) range for the Ramos study was between 500 to 8000 Hz with three frequencies per octave.

Transient Evoked Otoacoustic Emissions

The main effect for the comparison of mean TEOAE noise level between test conditions (post-maneuver ambient versus peak) was not significant. The main effect of frequency was significant. TEOAE noise level decreased as did absolute amplitude, with increasing frequency (1 to 5 kHz). The interaction between absolute MEP magnitude and test condition was not significant for noise level. The magnitude of abnormal MEP did not significantly alter the mean noise level between the compensated and uncompensated test conditions. The interaction between test conditions and frequency was not significant. The mean noise level across frequencies 1 to 4 kHz is shown in Figure 46 for both post-maneuver test conditions (refer to Table 101 for descriptive statistics). Also included in this figure for a baseline reference, is the mean and 90% range noise level measures for the non-maneuver ambient test condition. The mean and width of the 90% response range is comparable between the two post-maneuver test conditions and these are similar to the baseline condition response. Referencing the calculated SD for each condition, the estimated mean noise level for both post-maneuver test conditions is shown to approximate the data equivalently well. Overall, these findings indicate that the act of pressure compensation in the presence of abnormal MEP does not significantly alter the resulting noise level, nor does the presence of abnormal MEP, which are findings further supported with comparison to baseline responses.

A study by Trine et al. (1993) showed for 6 of 12 test ears there was an increase in TEOAE related noise level in the range of 0.3 to 5.15 dB SPL when testing in the compensated versus uncompensated pressure condition. Equalization of middle ear pressure spanned the range of -100 to -310 daPa. Conversely, for the other 6 test ears, there was an increase in noise level on the magnitude of less than a 1 dB noise level change in the ambient compared to peak test pressure condition. This study only discussed 12 of the total 14 test ears regarding noise level. The difference in noise level magnitude change between test conditions observed by Trine and colleagues and the current study is likely due to the difference in TEOAE test frequency range. The Trine et al. (1993) study assessed TEOAE noise level between 500 to 2000 Hz. Including more low frequencies will introduce more noise into the recordings. Differences in sample size, stop criterion, and instrumentation also likely contribute to differences in noise level and response patterns observed between the two studies.

		TEOAE Noise Level (dB SPL)				
Frequency (Hz)		**1000**	**2000**	**3000**	**4000**	**5000**
Post-maneuver Peak	**Mean**	-5.18	-8.04	-10.38	-13.10	-15.33
	5th Prctl	-8.52	-10.54	-12.90	-15.64	-17.86
	95th Prctl	-0.70	-5.80	-8.52	-11.08	-12.76
	SD	2.57	2.21	1.44	3.15	3.61
Post-maneuver Ambient	**Mean**	-4.67	-7.81	-10.38	-13.65	-15.11
	5th Prctl	-8.72	-10.14	-13.18	-15.80	-17.40
	95th Prctl	0.30	-6.14	-8.46	-11.38	-13.30
	SD	7.43	2.67	1.43	1.44	3.55

Table 101: Comparison of mean TEOAE noise level between test conditions (post-maneuver ambient versus post-maneuver peak) as a function of frequency (1000 to 5000 Hz). The 90% range is represented by 5^{th} and 95^{th} percentiles (Prctl). Standard deviation (SD) mean noise level calculated values are provided for each test condition (n=97 TEOAE measures). The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish ambient data for the peak test pressure condition data.

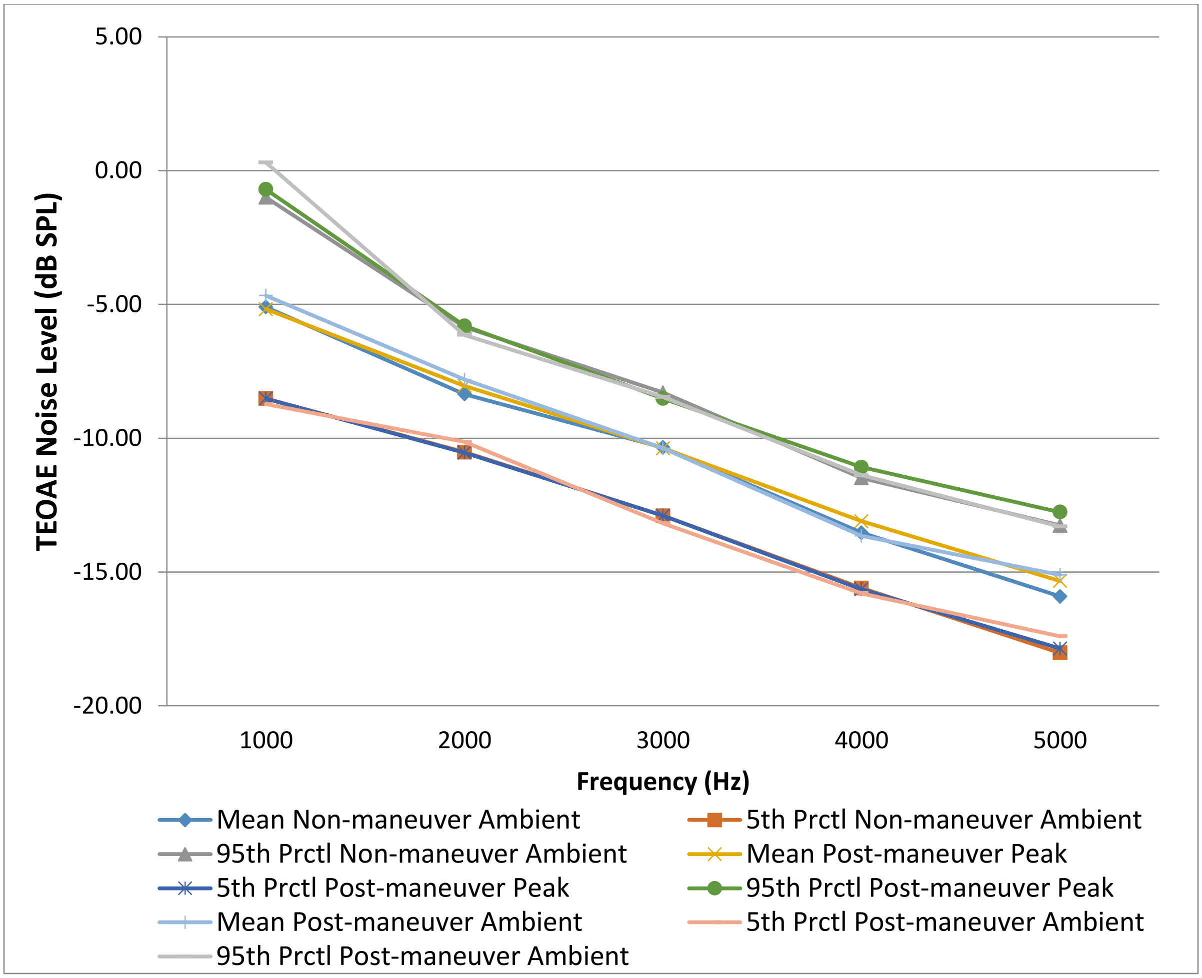


Figure 46: Current study data is for the comparison of mean TEOAE noise level between test conditions (post-maneuver ambient versus peak and non-maneuver ambient) as a function of frequency (1000 to 5000 Hz). The 5th and 95th percentiles (Prctl) and mean noise level response curves are provided for each test condition (n=97 TEOAE measures). The analysis was collapsed across factors of gender and ethnicity.

6.2.5 Summary; Noise Level

Considering the findings from all four test condition comparisons, there were no consistent trends observed for noise level between test conditions, as a function of MEP, or with interactions between gender and ethnicity. Mean noise levels remained relatively constant between test conditions when assessed across the range of test frequencies (1 to 5 kHz for TEOAEs and 1.5 to 8 kHz for DPOAEs). The outcome measure of noise level was investigated to examine the potential clinical implications of testing at a setting of ambient versus peak pressure. As per discussions presented above, improvements in frequency-specific signal-to-noise ratios were observed for both TEOAE and DPOAE measures when testing in the compensated pressure condition.

Refer to Chapter 9 for a detailed discussion regarding the limitations of current study and suggestions for future research.

6.3 The Effects of Ethnicity and Gender on EOAE Absolute Amplitude

There is still much scientific debate over the significance and potential sources of gender and ethnicity based differences in auditory sensitivity, indicated by either behavioral audiometry or through the assessment of EOAEs. The potentially significant impact of between-participants factors such as gender and ethnicity on auditory measures suggests the need for more specified normative data. The development of ethnic and gender specific normative data could lead to better identification of pathology in clinical settings by enhancing test sensitivity and specificity.

In the following manuscript, the gender and ethnic differences observed for DPOAE and TEOAE measures will be presented with a preliminary review of potential sources of these results.

6.3.1 Outcome Measures of Distortion-product Otoacoustic Emissions

Gender Effects

Gender groups showed equivalent responses for the overall comparison of DPOAE amplitude between the four test conditions. Interactions between gender and test condition, as well as gender and frequency were consistently non-significant for all test condition comparisons. Despite not being statistically significant, male participants had consistently lower DPOAE amplitude means compared to female participants for all test condition comparisons, a finding consistent with past research (Dunckley et al., 2004; McFadden et al., 2009). It should be noted that there is an unequal sample size between genders in the current study, with n=46 male associated DPOAE measure compared to females contributing n=64 measures.

Table 102 presents a comparison of DPOAE amplitude as a function of frequency between the current study and findings from a published study, Dunckley et al. (2004). The presented values represent gender-specific normative data. Data for the current study was derived from the non-maneuver ambient test condition. The Dunckley et al. (2004) study used a sample of young-adult participants (ages 18 to 29) with normal hearing. Illustrated in Figure 47, the current study shows larger mean DPOAE amplitude values at all frequencies compared to the Dunckley et al. (2004) normative data for comparisons between both the male and female groups. Despite these amplitude differences, the same trend in amplitude variation across frequencies was observed for both studies. Differences between the two studies include but are not limited to (1) test instrumentation, (2) stimulus parameters, (3) sample size, and (4) control of ethnic make-up of the participant pool. The Dunckley et al. (2004) study used the Otoacoustic Emission Averager (EMAV) software for collection of DPOAE measures with a stimulus level ratio of 65/45 dB SPL and frequency ratio of 1.22.

	Dunckley et al. (2004)		**Current Study**	
	Mean Amplitude dB SPL (Standard Error)		**Mean Amplitude dB SPL (Standard Error)**	
Frequency (Hz)	**Females (n=20)**	**Males (n=17)**	**Females (n=64)**	**Males (n=46)**
1000	8.84 (1.15)	7.16 (1.17)	11.40 (1.03)	8.31 (1.05)
2000	3.27 (0.94)	3.64 (0.72)	7.85 (1.02)	6.02 (1.05)
2500			4.17 (0.97)	4.60 (0.99)
3000	1.73 (0.91)	1.63 (1.07)	3.77 (0.82)	4.26 (0.84)
4000	4.41 (1.07)	3.13 (1.21)	9.28 (0.81)	9.99 (0.82)
5000	4.74 (1.03)	4.62 (1.24)	14.65 (0.89)	14.28 (0.91)
6000	3.06 (1.29)	3.41 (1.56)	14.55 (1.10)	14.49 (1.12)
7000	-0.34 (1.73)	1.23 (1.59)		
8000	-3.05 (1.91)	-0.52 (1.94)	0.10 (1.29)	-1.42 (1.31)

Table 102: Comparison of mean DPOAE amplitude as a function of frequency between the current study and findings from Dunckley et al. (2004). DPOAE measures were collapsed across the factor of ethnicity for both studies. Shaded boxes indicate missing data for the associated test frequency. Data for the current study was derived from the non-maneuver ambient test condition.

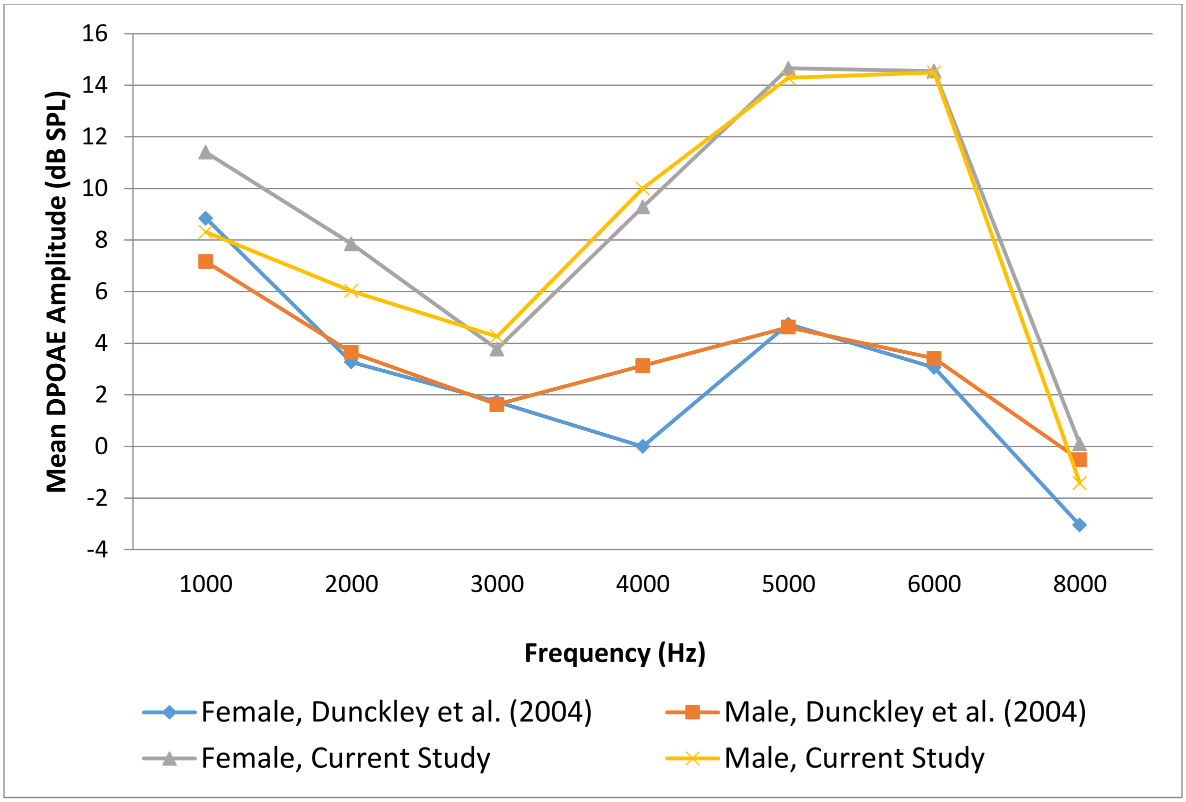


Figure 47: Comparison of mean DPOAE amplitude as a function of frequency between the current study and findings from Dunckley et al. (2004). DPOAE measures were collapsed across the factor of ethnicity for both studies. Data for the current study was derived from the non-maneuver ambient test condition.

Interaction: Test Condition(s) and Ethnicity

A trend was observed for the participant group labeled as Others, to have the largest mean DPOAE amplitude value followed by Asians, and with Caucasians having the lowest mean DPOAE levels. When comparing DPOAE amplitude between test conditions, the response pattern (although separated in amplitude level) between the Caucasian and Asian participants was evidently more comparable relative to the response pattern exhibited by participants in the

Others group. The results for both Caucasians and Asians matched relatively well to the predicted results, with the results for participants in the Others group showing slightly unexpected trends. Interactions between ethnicity and test condition were consistently non-significant for all test condition comparisons with one exception: The interaction between test condition (post-maneuver ambient versus peak) and ethnicity for absolute amplitude was found to be significant. This finding indicates that the difference in DPOAE amplitude between test conditions (post-maneuver ambient versus peak) varied for the three ethnic groups. It was predicted that there would be a significant difference in DPOAE amplitude between this particular test condition comparisons (post-maneuver ambient versus peak) for all ethnic groups. Post-hoc analysis revealed an interesting finding. Despite the main interaction of test condition being significant (post-maneuver ambient versus peak), post hoc analysis revealed that the Asian group was the only ethnic group that had a statistically significant difference in mean DPOAE level between the post-maneuver ambient and peak test conditions. Although not significant, the Caucasian mean amplitude was larger for the peak compared to ambient test condition. Unexpectedly, the mean DPOAE level was greater in the ambient post-maneuver condition compared to the peak pressure condition for the Others group, although this difference was not statistically significant. Possible explanations for these unexpected trends in DPOAE amplitude between test conditions and ethnic groups are as follows. First, there was a difference in the degree of abnormal MEP generated in the post-maneuver test condition between ethnic groups. An uneven distribution of MEP magnitude within each ethnic group could have led to a greater reduction in DPOAE amplitude in the uncompensated test condition for the group with the larger MEP magnitudes. For example, one ethnic group could have had more participants with MEP contributing to the absolute MEP magnitude categories D and E, while another ethnic group could have had more participants contribute to categories B and C. Another possible source of these differences between ethnic groups could be attributed to the maintenance of the induced MEP between test conditions. There was likely a difference, although the significance of which was not determined, between how well the different ethnic groups were able to maintain the induced MEP pre-versus post-EOAE recording in the post-maneuver test condition. If the abnormal MEP is alleviated or reduced between test condition recordings, then in-accurate pressure compensation will occur. A third possible explanation is related to ethnic-specific differences in mechanic-acoustic properties of the middle ear system and the influence of these differences on EOAE amplitude under conditions of abnormal MEP. Refer to section 6.3.3 and Chapter 7 discussions regarding sources of difference between EOAE test conditions and an elaborated discussion of mechanic-acoustic differences between ethnic groups.

Factor Interaction: Frequency and Ethnicity

The interaction between frequency and ethnicity was significant when collapsing across factors of gender and test condition. This interaction was found to be significant for all two-way test condition comparisons: (1) non-maneuver ambient and post-maneuver ambient, (2) non-maneuver and post-maneuver peak, (3) non-maneuver ambient and peak, and (4) post-maneuver ambient and peak. These findings of significance indicate that DPOAE amplitude did vary between ethnic groups across the frequency range 1.5 to 8 kHz. Refer to the Results section of details concerning post-hoc analysis results for frequency-specific differences between ethnic groups.

Collapsing the analysis between all four test conditions also resulted in a significant finding for the interaction of frequency and ethnicity. For ease of reference, the graphical display for this specific interaction is shown below in Figure 48. Tukey's HSD test results indicated a significant difference in absolute DPOAE amplitude between the Caucasian group compared to both the Asian and Other group at only one test frequency, 8 kHz. There was no significant difference found between the Asian and Other group when comparing absolute amplitude means at any of the eight test frequencies. A similar trend in DPOAE amplitude was observed for the three ethnic groups across the range of test frequencies (1.5 to 8 kHz). Caucasian participants tended to have higher DPOAE levels for the mid frequency range 3 to 5 kHz. The Asian and Other participants had higher DPOAE levels for low frequencies 1.5 and 2 kHz as well as at highest test frequencies 6 and 8 kHz. Detailed mean values and associated descriptive statistics can be found in Appendix A Table 140. The results from these interactions of frequency and ethnicity for measures of DPOAE amplitude provide support for the argument that there is a need for ethnic specific normative data. Use of more patient-specific normative data could lead to better identification of pathology in clinical settings by the enhancement of test sensitivity and specificity.

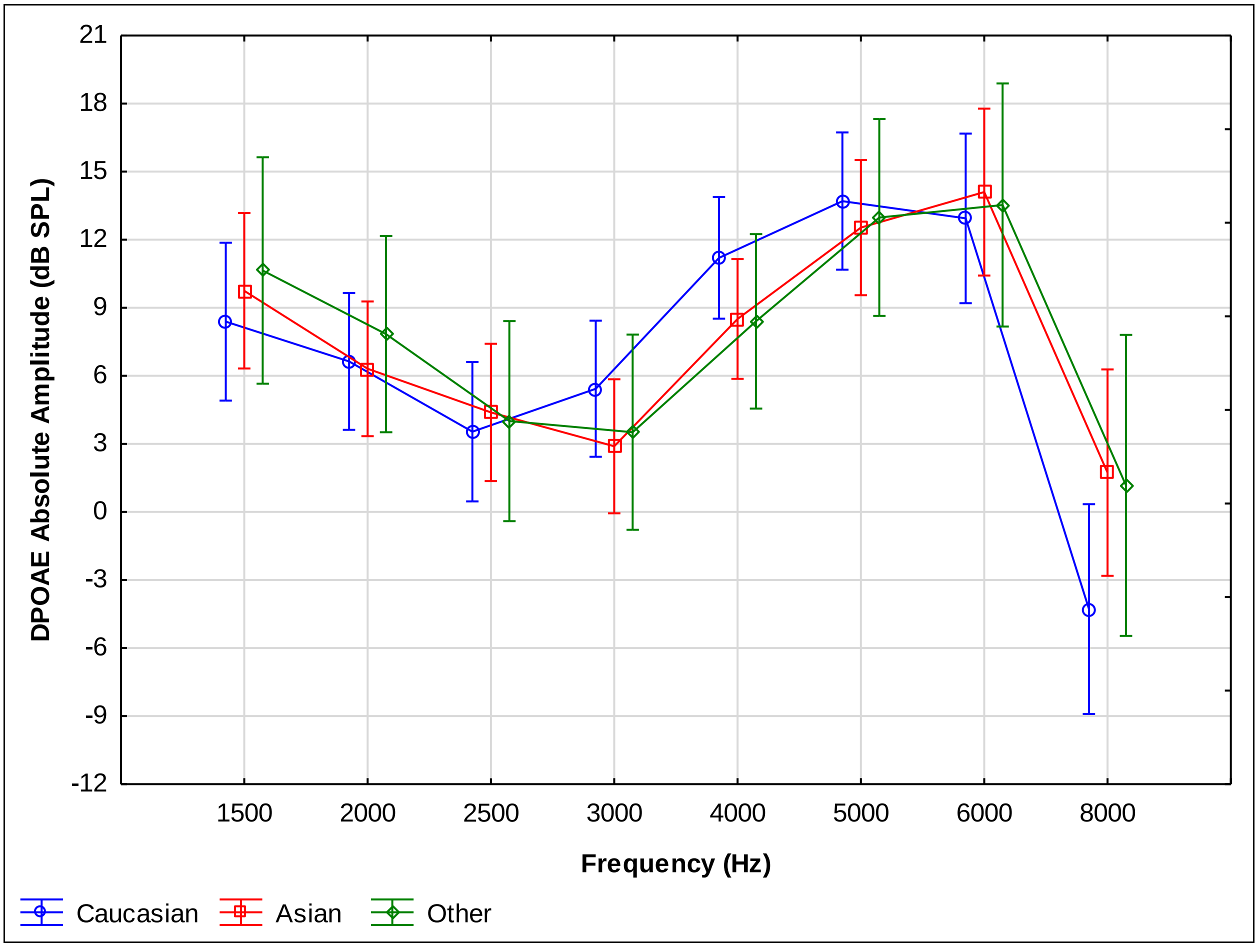


Figure 48: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and test condition (non-maneuver and post-maneuver). Vertical bars denote 95th percent confidence intervals. Sample sizes for the three ethnic groups are as follows: Caucasian (n=43), Asian (n=46) and Other (n=21). Current effect: [F(14, 742)=5.3114, p=.00000].

Comparison of Findings to the Dreisback et al. (2009) Study

The results of the current study for measures of DPOAE absolute amplitude analyzed as a function of ethnicity and gender are consistent with past findings. A study by Dreisback et al.

(2009) investigated the significance of gender and ethnicity on DPOAE measures in a healthy young adult population of 20 Caucasians, 20 African-Americans, and 20 Asians. Frequency was swept from 12 to 2 kHz and after condensing of the obtained data, DPOAE level was assessed over 11 f_2 sample points. Consistent with the current study, Dreisback and colleagues found the main effect of gender and ethnicity to be non-significant. Also consistent with the current study, they found no significant interaction between factors of gender and ethnicity, nor for the interaction between frequency, gender, and ethnicity. Dreisback data was significant for the main effect of DPOAE frequency and for the interaction between frequency and ethnicity, both findings which are consistent with the current study. The Dreisback et al. (2009) study found a significant interaction between frequency and gender which is not replicated in this current study. However, consistent with the current study, Dreisback et al. (2009) showed females having a non-significant but larger mean DPOAE levels compared to males, when collapsing the analysis across frequency. The study by Dreisback and colleagues had equal number of male and female participants in the three ethnic groups, whereas the current study had overall much fewer male participants. This difference in male group sample size may have contributed to the lack of gender effects as a function of frequency seen in the current study. The DPOAE amplitude and noise levels plotted as a function of frequency also showed similar response patterns to those observed in the current study.

6.3.2 Outcome Measures of Transient Evoked Otoacoustic Emissions

Gender Effects

The main effect of gender was significant when collapsing across factors of ethnicity, frequency, and test condition. This interaction was found to be significant for all two-way test condition comparisons: (1) non-maneuver ambient and post-maneuver ambient, (2) non-maneuver and post-maneuver peak, (3) non-maneuver ambient and peak, and (4) post-maneuver ambient and peak. When collapsing the analysis across all four test conditions, the main effect of gender remained significant. For all analyses, male participants had lower TEOAE amplitude means compared to female participants. The interaction between gender and test condition was not significant for any combination of test condition analysis. Similarly, the interaction between gender and frequency was not significant for any combination of test condition analysis. It should be noted that there was an unequal sample size between genders, with n=33 male associated TEOAE measure compared to females contributing n=64 TEOAE measures.

Gender and Ethnicity; Comparison to Past Research Findings

Comparable with the findings of the current study, other studies have also reported stronger TEOAE amplitude for females compared to males, with these sex differences being less substantial for DPOAEs (Dunckley & Dreisbach, 2004; McFadden et al., 2009). It is suggested that dissimilarities between DPOAE and TEOAE sex differences could be due to the different cochlear mechanisms primarily responsible for producing the two EOAEs (McFadden et al., 2009; Shera & Guinan, 1999). Numerous studies have shown SOAEs to be more prevalent and robust in females compared to males. As well, significant differences in SOAE presence and amplitude have also been shown to exist between different ethnic groups. These differences in

SOAE presence and amplitude between genders and ethnicities may account for why females tend to have more robust TEOAE and DPOAE measures. The contribution of SOAE to the overall recorded signal may be artificially enhancing the recorded EOAE response. Whitehead et al. (1993) showed ethnic differences of SOAE prevalence, with African Americans having a higher SOAE prevalence compared to Asians, and higher in Asians compared to Caucasians (as cited in Dreisbach et al., 2007). Additionally, Asian participants tended to have more robust SOAEs and TEOAEs at higher test frequencies compared to Caucasians.

These trends shown by past studies for OAE level differences between ethnic groups are similar to those observed in the current study. Caucasians tended to have the lowest mean TEOAE level, Asians in the middle, and Others ethnic group with the greatest mean TEOAE absolute amplitude collapsing across gender and frequency. The main effect of ethnicity, collapsing across factors of gender, frequency, and test condition was variable in its significance depending on the test condition in question. The main effect of ethnicity was not significant when collapsing between test conditions (1) non-maneuver ambient and post-maneuver ambient, (2) non-maneuver ambient and post-maneuver peak, as well as for (4) post-maneuver ambient and post-maneuver peak test conditions. The main effect of ethnicity was significant when collapsing across test conditions of (3) non-maneuver ambient and non-maneuver peak. A possible explanation for why significance was observed for ethnicity collapsing between these particular test conditions could be because of the amount of abnormal MEP naturally occurring for some participants in the non-maneuver test condition. The magnitude of this abnormal MEP likely varied between the three ethnic groups, but significance of this difference was not explored in this study. As well, there was an uneven sample size for each ethnic group in the current study, which may have impacted the outcome measures. All factor interactions involving ethnicity were non-significant: Interactions between ethnicity and test condition, as well as ethnicity and frequency were consistently non-significant for all test condition comparisons. However, the trend observed in absolute amplitude for the individual ethnic groups was the same: A peak in TEOAE amplitude was observed at 1 kHz sloping to a minimum at 5 kHz. Although the overall interaction between these two factors was not significant, Caucasians (n=26) had on average the lowest TEOAE amplitude, followed by the Asian group (n=48) with a slightly higher mean amplitude, and the Other ethnic group (n=23) had the highest absolute amplitude across all test frequencies. For ease of reference, the graphical display of this interaction between test condition (x4) and ethnicity is shown below in Figure 49. Descriptive statistics for this analysis can be found in the Results section (refer to Table 163).

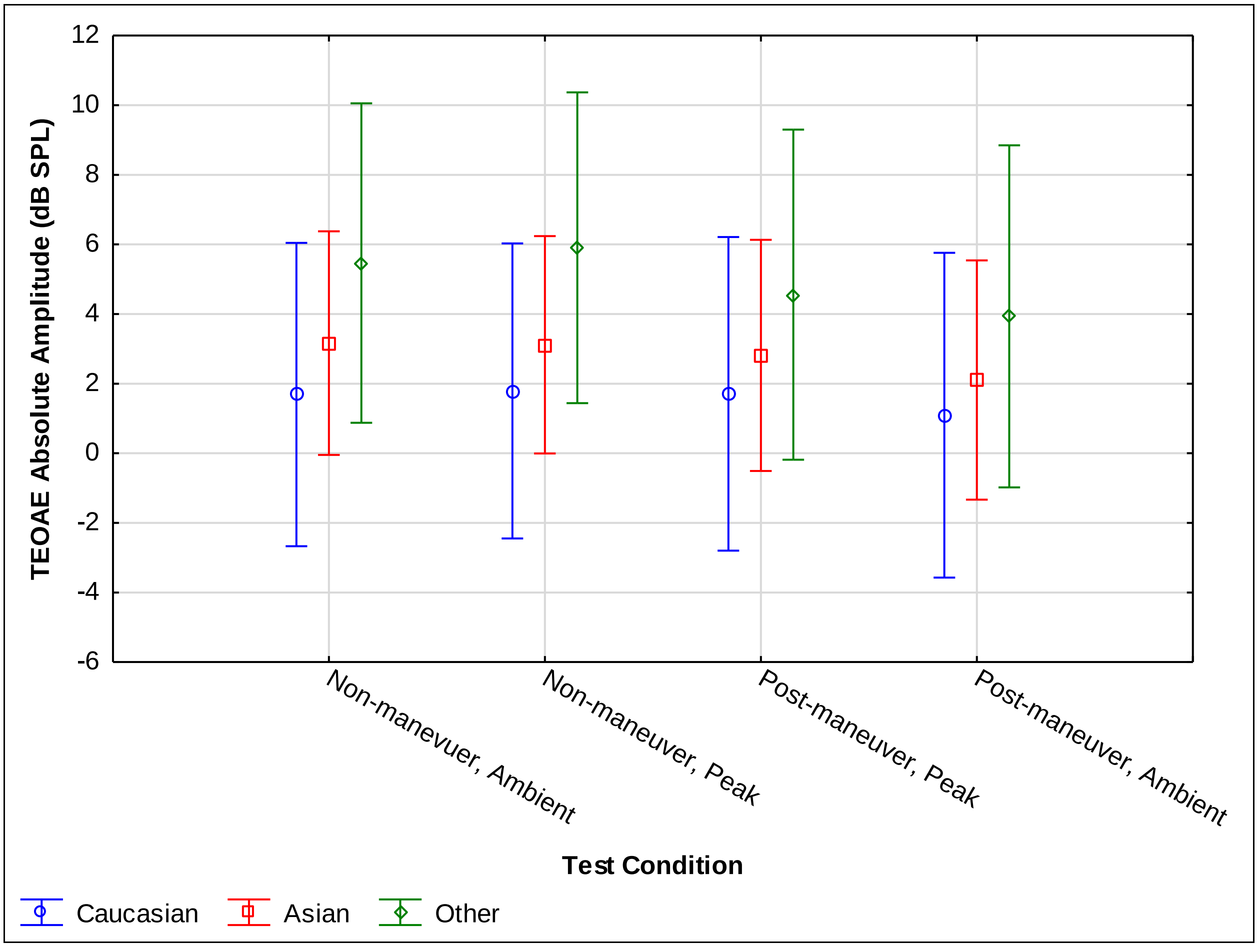


Figure 49: Comparison of mean TEOAE absolute amplitude between ethnic groups (Caucasian n=26, Asian n=48 and Other n=23) as a function of test condition (x4, non-maneuver and post-maneuver). The analysis was collapsed across factors of frequency and gender. Vertical bars denote 95th percent confidence intervals. Current effect: [F(6, 279)=1.7832, p=.10248].

Comparison to Results from Shahnaz (2008)

A study by Shahnaz (2008) investigated the effect of gender and ethnicity on characteristics of TEOAEs for a sample of 81 Chinese and 81 Caucasian normal hearing young adult participants. For the comparison of TEOAE amplitude collapsing across gender, the Chinese group had significantly larger TEOAE amplitude compared to Caucasians (Shahnaz, 2008). The mean TEOAE level was found to be greater for the Chinese groups across frequencies 1 to 4 kHz compared to Caucasians. In both the Caucasian and Chinese groups, females had larger mean TEOAE levels compared to the male participants. This is consistent with the current study because, although not significant, Asian participants had higher mean TEOAE amplitude values in all four test conditions compared to Caucasian participants. Additionally, the current study found a non-significant interaction between ethnicity and frequency (for all test condition comparisons) with Asians having the greater TEOAE amplitude compared to Caucasians across the frequency range 1 to 5 kHz. Results of the Shahnaz (2008) study also show mean noise level being comparable between groups and consistent across frequencies 1 to 4 kHz. Differences in middle ear transmission properties, cochlear originating differences, as well as the factor of body size contributing to variations in ear canal volume and middle ear cavity size were proposed as possible sources for the observed TEOAE amplitude differences between gender and ethnic groups (Shahnaz, 2008). The Shahnaz (2008) study was discussed in the above section 6.2.3 with noise level data presented in Table 99.

6.3.3 Sources of Differences in EOAE Outcome Measures between Test Conditions

The probe placement between EOAE assessments for the same ear (either between test conditions non-maneuver versus post-maneuver or peak versus ambient) was not altered, in order to avoid the confound variable of changing standing wave nulls for between test condition EOAE comparisons. The frequency of the standing wave null changes as the distance between the probe tip and the TM is altered. A decrease in pressure within the ear canal at 4 kHz is characteristic of common standing wave null within the ear canal. Large differences in sound pressure estimates at the level of the TM as large as ±20 dB have been shown with the changing position of the sound source within the external canal (Siegel, 1994). If a different probe placement is used for OAE measurements at two recording times, then there is less certainty that the presented stimulus was of an equivalent presentation level for both recordings. Therefore, a comparable stimulation of the cochlea would have not been achieved and thus, the comparable EOAE related outcome measures such as absolute amplitude would have not been accurate and representative of cochlear function. Differences in the stimulus spectrum with changes in probe placement also account in part for why the higher frequency EOAEs are not as reliable. The concept of probe distance from the TM impacting the frequency spectrum for the eliciting stimulus can also be considered when examining gender and ethnic differences. External ear canal geometry variations as suggested by Perez (2012) can account for variation in EOAE level and phase responses between sexes. The shape of the ear canal becomes more circular moving externally inward to the TM. The canal length typically is 22.5 mm in females and 25.2 mm in males (Perez 2012). Tube models have been employed to study the effect of sound waves within the human ear canal, with fundamentals based on the length of the tube (i.e. ear canal). For a tube model of the human ear canal, frequencies between 2 and 5 kHz are subject to a resonance effect, enhancing hearing sensitivity for this frequency range. Sound waves of various frequencies are altered depending on the absorbance quality of the surrounding tissue and length of the canal. Probe placement in the ear canal can alter the pathway of sound pressure waves as well as the presence of debris such as cerumen, which can alter the propagation of the eliciting stimulus or returning EOAE. Significant interactions for outcome measures considering frequency can be attributed to acoustic transfer functions; (1) the forward propagating pressure wave interaction with the tympanic membrane (TM orientation and properties), (2) the absorbance of the evoking stimulus absorbed by the middle ear, and (3) the ear canal size (length and area), all vary with frequency. Differences observed between gender and ethnic groups could also be due to differences in middle ear cavity structural differences, as the forward and backwards propagating signals travel through the middle ear. Mechano-acoustical properties have been demonstrated to differ between ethnic and gender groups (Shahnaz & Bork, 2006). Accordingly, it is not surprising, that body size indices have been suggested to be correlated to the primary factors contributing to the differences observed between gender and ethnic groups (Shahnaz & Bork, 2006). McFadden et al. (2008) also suggest sex differences could be at least partly attributable to hormonal differences, particularly prenatal exposure to androgens for males and females and underlying genetics. Differences observed between ethnic groups have also been suggested to result from cochlear melanin level differences (Garber et al. 1982, as cited in Dreisback, 2007).

To limit the discussion included in this manuscript to the scope of the study, specific participant characteristics and proposed mechanisms for gender and ethnic EOAE differences will not be further explored. However, refer to Chapter 8 for a continued discussion regarding Power Absorbance differences between ethnic and gender groups. Furthermore, refer to Chapter 8 for further discussion of how changes in Power Absorbance impact EOAE measures and to the Future Directions section of Chapter 9 for a brief outline of suggested participant characteristics that could be controlled for in future studies investigating similar outcome measures as this study.

Chapter 7: Further Investigations; EOAE Test Condition Differences

Potential explanations for the differences or in some cases the lack of a statistically significant difference seen with various test condition comparisons for EOAE outcome measures are explored in Chapter 7. These post EOAE data analysis explorations were focused on factors influencing the outcome of the two-test condition comparisons, with particular focus on potential sources relating to the accuracy of pressure compensation in the peak pressure test conditions. Imprecise pressure compensation could have occurred for numerous reasons, the following are a few proposed possibilities: (i) MEP estimates on which the compensating target pressure was set were not accurate; (ii) Titan could not adequately maintain target pressure throughout recordings and (iii) the induced MEP generated in the post-maneuver test condition changed during EOAE recordings. These potential sources of inaccurate pressure compensation are presented in three sections: (7.1) Comparison between Middle Ear Pressure Estimation Methods, (7.2) Estimation of Titan's Ability to Maintain Target Pressure and (7.3) Participant Maintained Middle Ear Pressure.

7.1 Comparison between Middle Ear Pressure Estimation Methods

Specific protocol settings and the order in which the multiple test measures occurred, was determined prior to the start of data collection (refer to Methods section Chapter 2). With no conscious justification, the 3D-WBT was set to precede the conventional 226 Hz tympogram in regards to test sequence for this study (refer to Procedure section of Methods). Subsequently, the MEP estimate from the 226 Hz tympanogram was selected to determine the TPP for the proceeding compensated EOAE recordings. Therefore, the option was available to have EOAE peak pressure estimates based on the 3D-WBT measure, if the 3D-WBT measure was conducted after the single frequency tympanogram. To investigate if outcome measures (noise level or absolute amplitude) would have been possibly different if the alternative MEP estimation method was selected, the MEP estimates from the two different methods (3D-WBT and conventional 226 Hz tympanogram) were compared. If a significant difference in mean MEP is observed between the methods, this may suggest that selecting one over the other would result in either over- or under-compensation of MEP in peak test conditions. An imprecise estimate of target pressure could contribute to the reduction of absolute EOAE amplitude for measures collected at a setting of peak pressure, since over or under MEP compensation would add to the already unequalized pressure condition on either side of the TM.

7.1.1 Data Analysis

Included in this analysis were the immittance measures conducted in the non-maneuver and post-maneuver conditions pre-EOAE recording. The MEP estimates associated with both DPOAE and TEOAE test conditions were pooled. Furthermore, data was not separated based on whether or not it was generated from a negative or positive post-maneuver condition. In summary, all EOAE test data, from the non-maneuver and post-maneuver conditions, both positive and negative as well as in the DP and TE conditions was all analyzed together. Measures from these various conditions could be analyzed as a single collection of data because a coding system was applied to distinguish the degree of MEP by converting all MEP estimates to absolute values. It was expected that the naturally occurring MEP and the induced MEP was not an influencing factor and therefore, this variable was not considered in this specific analysis.

In order to identify and remove outlier data points from the final analysis, the difference between the average MEP estimates from the two estimation methods was calculated. This difference value was based on all available MEP estimates (n=382 pairs of estimates). The difference between each MEP estimate pair was converted into an absolute value. An upper and lower bound around this mean absolute difference value was determined. These upper and lower bounds are based on a calculation of ±2 standard deviations (SD) from the mean difference. The mean difference (absolute value) between the MEP estimates from the 3D-WBT compared to the conventional tympanogram is 5.72 daPa with 2SD = ±30.19 daPa. Referencing the mean absolute difference value, the +2SD = 35.91 daPa difference was set as the upper limit. Any MEP estimate pair, that had an absolute MEP estimate difference value of ≥30.19 daPa, was removed from further analysis. Considering the lower boundary of a -2SD difference between estimates (-2SD = -24.47 daPa) was not meaningful, as the MEP difference values were converted to absolute values. Three MEP estimate pairs (one estimate from the 3D-WBT and the other from the conventional 226 Hz tympanogram) were identified as outliers, and were subsequently removed from further analysis. These three pairs of data represent only three MEP comparisons of a total of 382 from the initial database. These three outliers had absolute MEP estimate differences of 130 daPa, 219 daPa, and 138 daPa. However, the EOAE measures (absolute amplitude and noise level) associated with these outlying pairs, were still included in the final analysis of EOAE outcome measures. Justification for keeping the EOAE related data in final data analyses is presented in three separate case studies. Refer to figures associated with the outlying MEP estimate case studies. There were n=379 MEP estimate pairs for comparisons included in the final analysis.

The estimated values used to determine the MEP magnitude category, into which each paired comparison would be assigned, was based on the conventional 226 Hz tympanogram. There were eleven possible categories for MEP estimates: A (≥-150 daPa); B (-100 to -149 daPa); C (-51 to -99 daPa); D (-26 to -50 daPa); E (-11 to -25 daPa); F (-10 to +10 daPa); G (+11 to +25 daPa); H (+26 to +50 daPa); I (+51 to +99 daPa); J (+100 to +149 daPa); K (≥+150 daPa). For example, if the conventional 226 Hz estimate indicated a MEP of -155 daPa but the associated 3D-WBT MEP estimate was -148 daPa, then this pair of MEP estimates would receive a category label of A (≥-150 daPa). For this categorization of MEP, the actual negative and positive value of the MEP estimate was considered, not the absolute MEP value.

A t-test for dependent samples was used to compare the mean MEP estimates (in absolute MEP values) from the two estimation methods (3D-WBT versus the conventional 226 Hz tympanogram). From the 3D-WBT, the mean absolute estimated MEP was 39.74 daPa with a SD= 44.94 daPa. The MEP estimates from the conventional 226 Hz tympanogram was 39.80 daPa with SD= 44.89 daPa. Refer to Table 103 for the associated descriptive statistics. In total, there were n=379 comparisons of estimated MEP from the n= 758 individual MEP estimates. The comparison of mean absolute MEP estimates between the two estimation methods is displayed by a Box and Whisker Plot in

Figure 50. In summary, there was no significant difference between the mean absolute MEP estimates from the two estimation methods (conventional 226 Hz tympanogram versus 3D-WBT). The resulting p value was non-significant (p= .86).

	T-test for Dependent Samples; Marked differences are significant at p < .05									
Estimation Method	**|MEP| Mean**	**SD**	**n**	**Diff.**	**SD Diff.**	**t**	**df**	**p**	**CI -95.00%**	**CI +95.00%**
Conventional 226 Hz Tympanogram	39.80	44.89	379	0.06	6.27	0.17	378	0.86	-0.58	0.69
3D-WBT	39.74	44.94								

Table 103: Descriptive statistics for a paired t-test for dependent samples. Comparison was between the conventional 226 Hz tympanogram and 3D-Wideband Tympanogram (3D-WBT) estimates of absolute middle ear pressure (MEP).

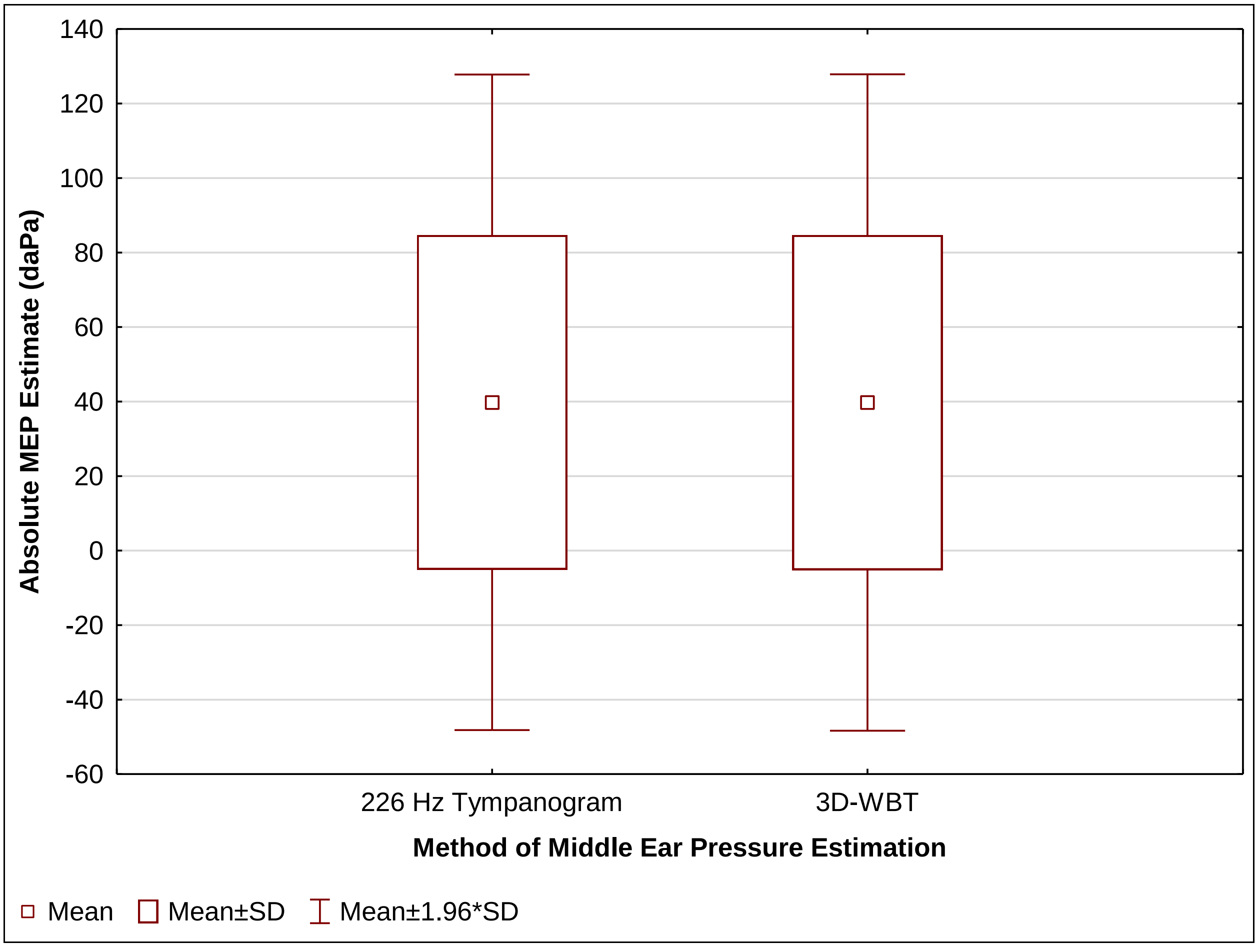


Figure 50: Comparison of absolute middle ear pressure (MEP) estimates from the 3D-wideband tympanogram (3D-WBT) (n=379) versus the conventional 226 Hz tympanogram (n=379). The MEP estimates were pooled from the four test conditions (non-maneuver and post-maneuver). Vertical bars denote 95th percent confidence intervals.

A repeated measure ANOVA approach was selected to compare the MEP estimates from the two estimation methods as a function of MEP magnitude (refer to Table 104). For this analysis non-absolute values were used. The magnitude of MEP was categorized referencing the estimate from the conventional 226 Hz tympanogram. The interaction between the factors of estimation method and MEP magnitude [F(10, 368)=.98520, p=.45575] was not significant (refer to Figure 51). A limitation to this interaction analysis was the unequal number of data points in each MEP category. There was an especially small sample size for comparison within each of the most extreme negative and positive MEP categories (A and K respectively).

Magnitude of MEP	**Estimation Method**	**Mean MEP (daPa)**	**Standard Error**	**-95% CI**	**+95% CI**	**n**
A (≥-150 daPa)	3D-WBT	-172	8.41	-188.55	-155.45	2
A (≥-150 daPa)	226-Tymp	-171	7.35	-184.94	-156.06	2
B (-100 to -149 daPa)	3D-WBT	-123	2.98	-129.16	-117.46	16
B (-100 to -149 daPa)	226-Tymp	-122	2.60	-127.54	-117.33	16
C (-51 to -99 daPa)	3D-WBT	-74	1.91	-77.47	-69.97	39
C (-51 to -99 daPa)	226-Tymp	-74	1.66	-77.27	-70.73	39
D (-26 to -50 daPa)	3D-WBT	-33	2.01	-36.96	-29.04	35
D (-26 to -50 daPa)	226-Tymp	-35	1.76	-38.85	-31.95	35
E (-11 to -25 daPa)	3D-WBT	-16	1.37	-18.66	-13.26	75

Magnitude of MEP	**Estimation Method**	**Mean MEP (daPa)**	**Standard Error**	**-95% CI**	**+95% CI**	**n**
E (-11 to -25 daPa)	226-Tymp	-16	1.20	-18.72	-14.00	75
F (-10 to +10 daPa)	3D-WBT	-3	1.12	-5.31	-0.91	113
F (-10 to +10 daPa)	226-Tymp	-2	0.98	-4.04	-0.19	113
G (+11 to +25 daPa)	3D-WBT	15	2.80	9.87	20.91	18
G (+11 to +25 daPa)	226-Tymp	16	2.45	10.96	20.59	18
H (+26 to +50 daPa)	3D-WBT	37	2.17	32.39	40.94	30
H (+26 to +50 daPa)	226-Tymp	37	1.90	32.77	40.23	30
I (+51 to +99 daPa)	3D-WBT	68	2.33	63.87	73.05	26
I (+51 to +99 daPa)	226-Tymp	69	2.04	65.46	73.47	26
J (+100 to +149 daPa)	3D-WBT	115	3.30	108.51	121.49	13
J (+100 to +149 daPa)	226-Tymp	115	2.88	108.87	120.20	13
K (≥+150 daPa)	3D-WBT	182	3.44	175.58	189.09	12
K (≥+150 daPa)	226-Tymp	184	3.00	178.02	189.81	12

Table 104: Comparison of middle ear pressure (MEP) estimates between the two estimation methods (3D-WBT versus conventional 226 Hz tympanogram) as a function of MEP magnitude (categories A to K). Current effect: [F(10, 368)=.98520, p=.45575].

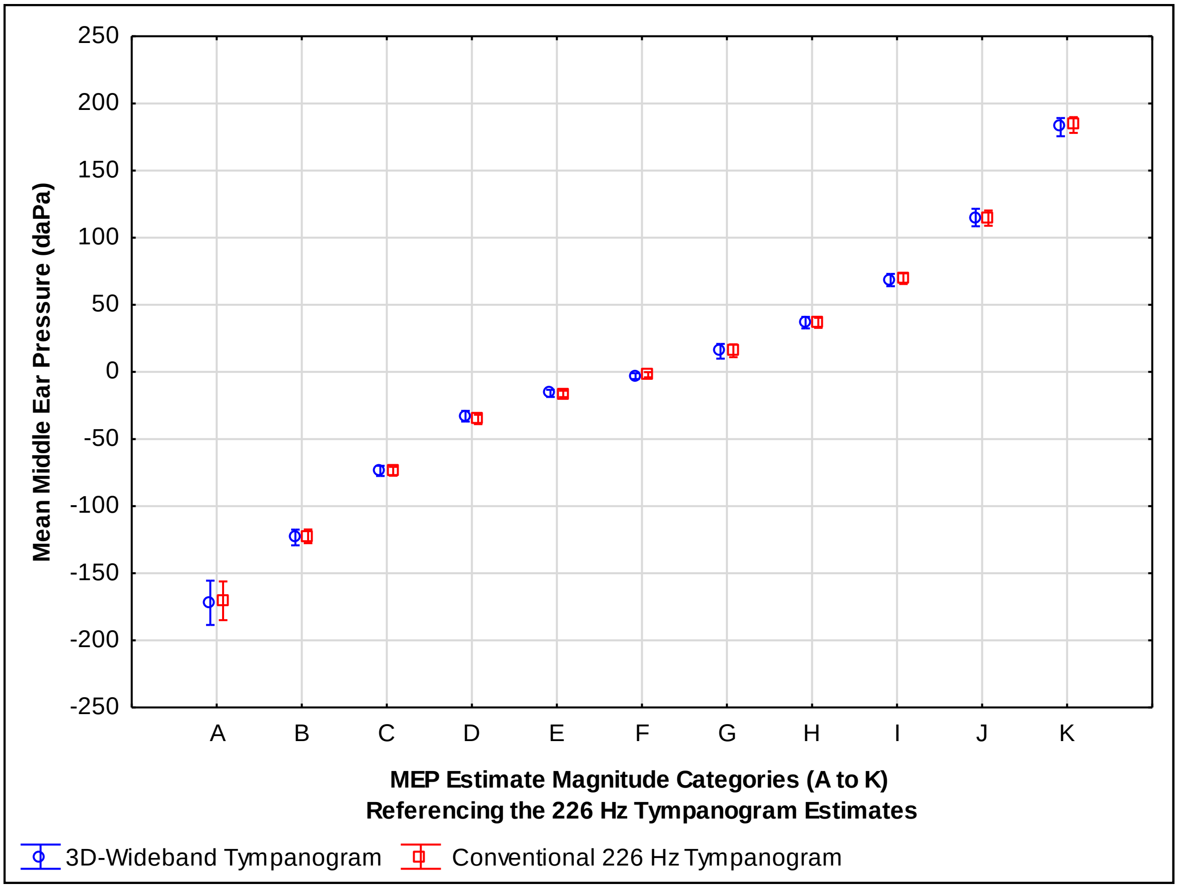


Figure 51: Comparison of mean middle ear pressure (MEP) estimates from the 3D-wideband tympanogram versus the conventional 226 Hz tympanogram, as a function of estimated MEP magnitude categorized A to K. The MEP estimate value used to determine categorization was based on the 226 Hz tympanogram estimate, yielding eleven possible categories: A (≥-150 daPa); B (-100 to -149 daPa); C (-51 to -99 daPa); D (-26 to -50 daPa); E (-11 to -25 daPa); F (-10 to +10 daPa); G (+11 to +25 daPa); H (+26 to +50 daPa); I (+51 to +99 daPa); J (+100 to +149 daPa); K (≥+150 daPa). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(10, 368)=.98520, p=.45575].

7.1.2 Summary of Findings for the Comparison of MEP Estimation Methods

The 226 Hz tympanogram and 3D-WBT differ in the way in which MEP is estimated. The single frequency tympanogram estimates MEP based on the pressure corresponding to maximum admittance peak. The MEP generated by the 3D-WBT is the peak pressure from the wideband averaged tympanogram with averaging limited to a maximum frequency of 2000 Hz and this method of MEP estimation is believed to provide a better prediction of true MEP (J. Huijnen, personal communication, May 3, 2016). The accuracy of MEP estimation using single frequency tympanograms has been questioned, with WAI being suggested as a superior approach for assessing MEP status (Schairer et al., 2011). Stated already in Chapter 1 section (3.1), single frequency tympanograms are thought to provide between a 30 to 70 daPa overestimation of MEP, which is partly dependent on the actual middle ear volume (Eliachar & Norman, 1974; Flisberg et al., 1963; Renvall & Holmquist, 1976 as cited in Shanks & Shohet, 2009). Conventional 226 Hz tympanograms for the estimation of TPP is thought to be a poor indicator of small pressure changes due to the range of inaccuracy but can provide true indications of larger and more extreme deviations in MEP from 0 daPa (Shanks & Shohet, 2009). A study by Sun (2016) compared several outcome measures obtained from a wideband acoustic tympanogram to measurements obtained from a conventional 226 Hz tympanogram. The 0.236 kHz acoustic admittance (0.236 kHz Y_a) measure was extracted from the wideband acoustic tympanogram as it was of a frequency best matching the conventional single frequency tympanogram. This study was based on a sample of 35 test ears. Among the various findings, this study showed that the two measurement methods were (1) comparable in peak admittance, and (2) the 0.236 kHz Ya provided on average a TPP estimate 22 daPa more negative compared to the conventional 226 Hz tympanogram estimate. Overall, Sun (2016) showed a moderate to strong correlation between 0.236 kHz and 226-Hz acoustic immittance measures of TPP, tympanic width, peak admittance, tail value of the tympanogram at ear canal pressures of -300 daPa and +200, and for the variable of the tail to peak ratio for both the negative and positive tails. For the data collected in this study, no significant difference was observed between the MEP estimates (converted to absolute values) generated from the two sequentially run estimation methods (3D-WBT and 226 Hz Tympanogram) for a sample size of n=379 paired comparisons (refer to Figure 50). When the MEP estimate comparisons were categorized based on the degree of either negative or positive MEP, there is still no significant difference found between the two estimates across all eleven MEP categories (refer to Figure 51). However, in the current study, the 3D-WBT MEP estimate was based on the peak of the wideband averaged tympanogram. From these findings, it can be proposed that the variation in mean absolute EOAE amplitude and noise level observed between test conditions (non-maneuver versus post-maneuver as well as peak versus ambient), would not have varied, if the 3D-WBT estimate was selected for determining target peak pressure rather than the conventional 226 Hz tympanogram estimate. In short, the selection of one estimation method over the other would not have altered the target pressure in a significant manner to have contributed to either over or under compensation of MEP during EOAE recordings at a setting of peak pressure.

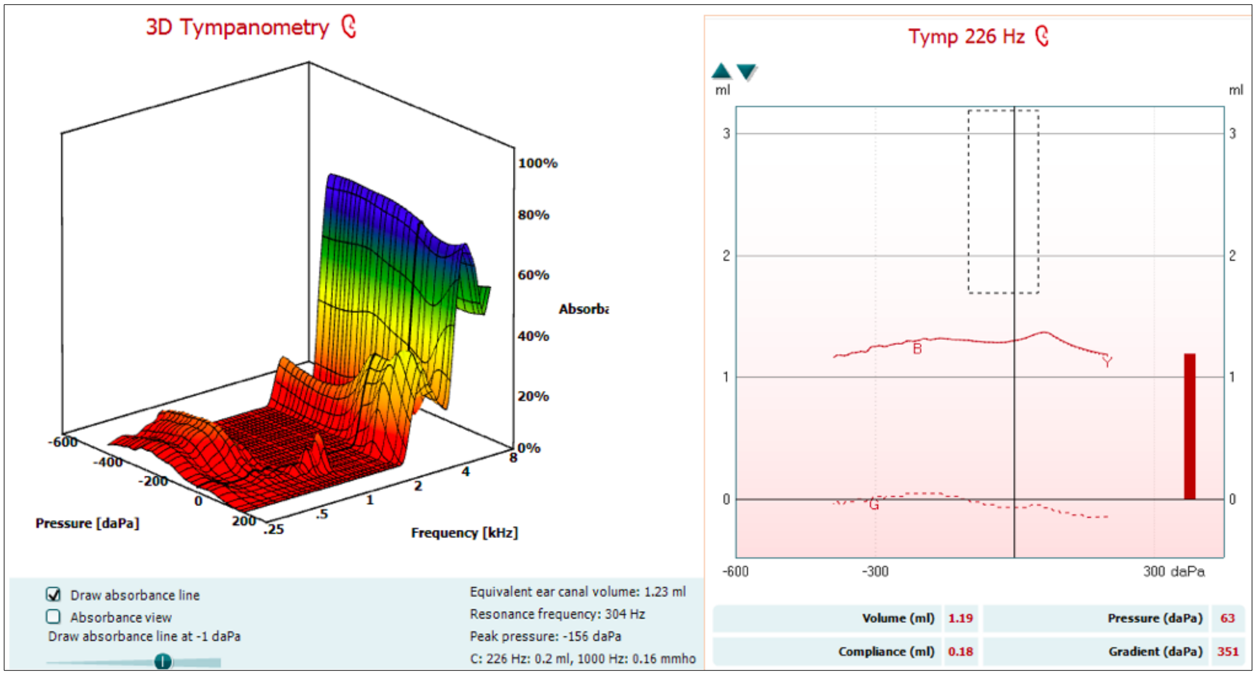
7.1.3 Comparison of Middle Ear Pressure Estimation Methods; Case Studies

The three MEP comparisons that were identified as being outliers from the mean MEP difference (refer to section 7.1.1 Data Analysis) were investigated to determine which estimation method generated the more accurate MEP estimate. Expert opinion by the study’s principle investigator

(Dr. Navid Shahnaz) determined that consistently, the conventional 226 Hz tympogram over the 3D-WBT showed the more likely MEP for the three presented cases. Although these three outlying MEP estimation pairs were excluded from analyses involving the comparison of MEP estimation methods, data associated with these pairs was still included in the final analysis of EOAE outcome measures. In summary, given that the estimate from the 226 Hz tympanogram was used to determine the target pressure for compensated EOAE measures, and it was this estimation method that was deemed most-likely accurate over the 3D-WBT estimate, the EOAE data remained in the final analysis. Further explanation and justification for retaining this data for EOAE analyses is provided in the discussion of the three following case studies.

Case Study (1): Middle Ear Pressure Estimate Comparisons

The 3D-WBT MEP estimate was -156 daPa and the conventional 226 Hz tympanogram estimate was +63 daPa, producing a difference of -219 daPa. These estimate measures are presented in Figure 52. These immittance measures were conducted in the post-maneuver condition immediately following the Valsalva maneuver, a maneuver typically used to induce positive MEP. The conventional 226 Hz tympanogram collected post-EOAE recording indicated a MEP estimate of +62 daPa, providing further support that the 226 Hz tympanogram collected pre-EOAE recording, is a more accurate estimate of MEP than is provided by the 3D-WBT measure. It was the estimate of +63 daPa that was used to determine peak pressure for the subsequently run EOAE measures compensating for the abnormal MEP.



☑ Draw absorbance line
☐ Absorbance view
Draw absorbance line at -1 daPa

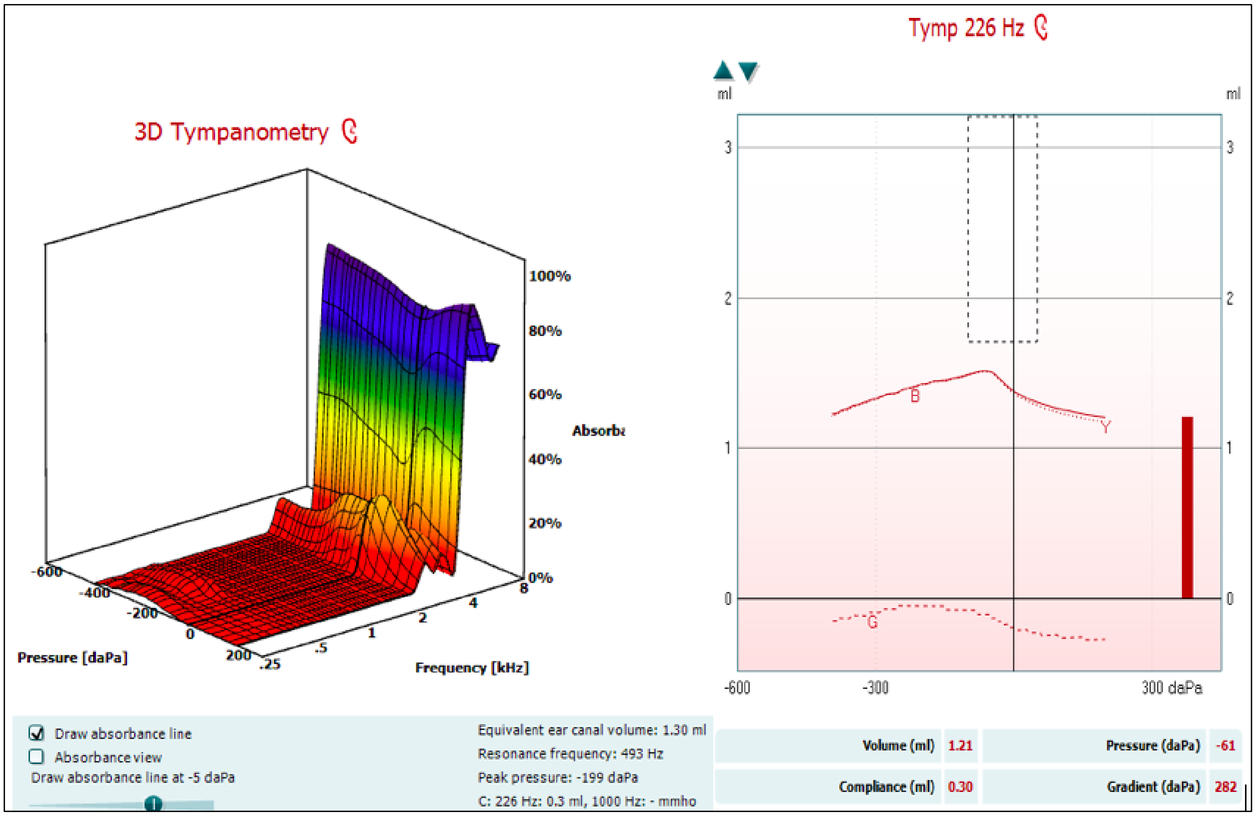
Equivalent ear canal volume: 1.23 ml
Resonance frequency: 304 Hz
Peak pressure: -156 daPa
C: 226 Hz: 0.2 ml, 1000 Hz: 0.16 mmho

Volume (ml)	1.19	**Pressure (daPa)**	63
Compliance (ml)	0.18	**Gradient (daPa)**	351

Figure 52: Case study (1). Comparison of middle ear pressure estimates from the 3D-WBT (-156 daPa) show in the left panel versus the conventional 226 Hz tympanogram (+63 daPa) displayed on the right. Estimates were conducted pre-EOAE recording in the post-maneuver test condition. The 226 Hz tympanogram (uncompensated for ear canal volume) displays the acoustic admittance (Y), susceptance (B) and conductance (G) response curves.

Case Study (2): Middle Ear Pressure Estimate Comparisons

Figure 53 displays in the left panel the 3D-WBT MEP estimate of -199 daPa and the conventional 226 tympanogram estimate of -61 daPa in the right panel. A difference of -138 daPa was observed between the two estimation methods. These immittance measures were conducted in the post-maneuver condition immediately following the Toynbee maneuver, typically used to induce negative MEP. Post-recording of the EOAEs, the conventional 226 Hz tympanogram indicated a MEP estimate of -60 daPa. Based on the consistency of the 226 Hz tympanogram pre- and post-recording of the EOAEs, and the customary morphology of the 226 Hz tympanogram, the MEP estimate from the 226 Hz tympanogram was thought to be a more accurate measure to base the target pressure on for the EOAE recordings.



☑ Draw absorbance line
☐ Absorbance view
Draw absorbance line at -5 daPa

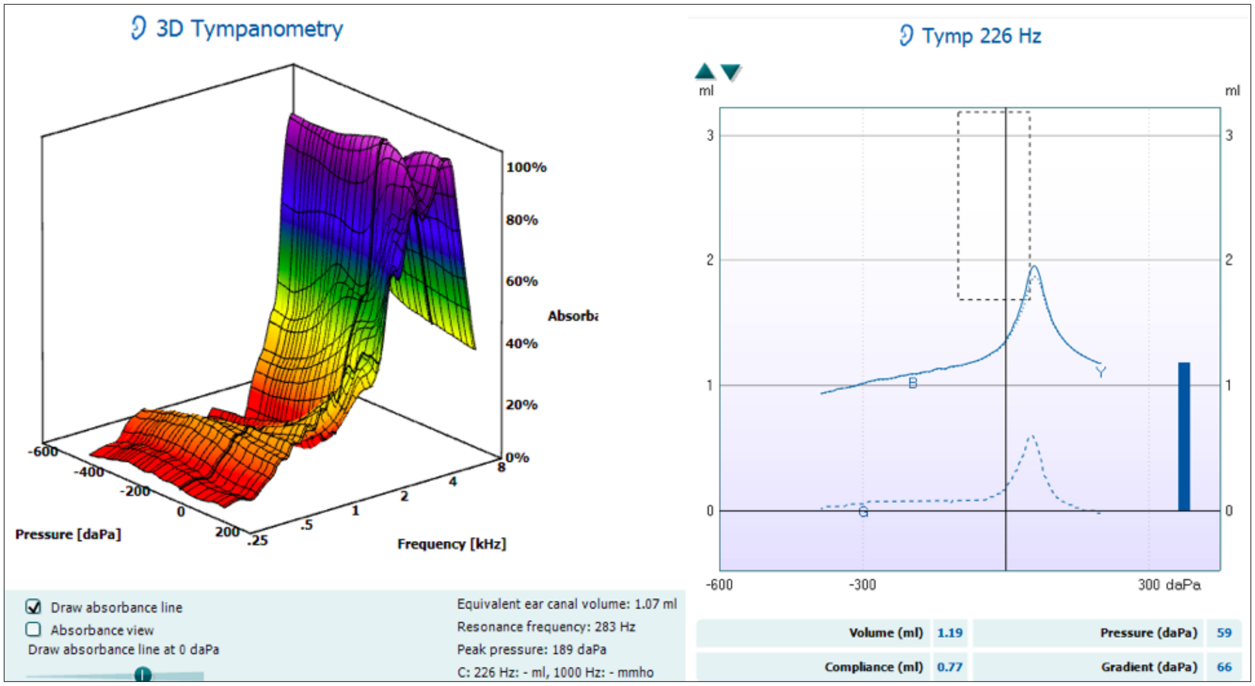
Equivalent ear canal volume: 1.30 ml
Resonance frequency: 493 Hz
Peak pressure: -199 daPa
C: 226 Hz: 0.3 ml, 1000 Hz: - mmho

Volume (ml)	1.21	Pressure (daPa)	-61
Compliance (ml)	0.30	Gradient (daPa)	282

Figure 53: Case study (2). Comparison of middle ear pressure estimates from the left panel 3D-WBT (-199 daPa) versus the right panel conventional 226 Hz tympanogram (-61 daPa). Estimates were conducted pre-EOAE recording in the post-maneuver test condition. The 226 Hz tympanogram (uncompensated for ear canal volume) displays the acoustic admittance (Y), susceptance (B) and conductance (G) response curves.

Case Study (3): Middle Ear Pressure Estimate Comparisons

For case study (3), a MEP estimation difference of +130 daPa was observed. Figure 54 shows the MEP estimate for the 3D-WBT was +189 daPa (left figure panel) and +59 daPa for the conventional 226 tympanogram (right figure panel). Similar to case study (1), the immittance measures for this case (3) were conducted in the post-maneuver condition after the participant had performed the Valsalva maneuver. The positive tail of the 3D-WBT is not displaying normal morphology indicating a possible probe insertion issue or system pressurization error for this measurement. The 226 Hz tympanogram that was collected post-EOAE recording, indicated a MEP estimate of +54 daPa, which further supports the conclusion by the examiner, that in this specific case the pre-EOAE estimate from the 226 Hz tympanogram provides a more accurate estimate of MEP than the 3D-WBT estimation.



☑ Draw absorbance line
☐ Absorbance view
Draw absorbance line at 0 daPa

Equivalent ear canal volume: 1.07 ml
Resonance frequency: 283 Hz
Peak pressure: 189 daPa
C: 226 Hz: - ml, 1000 Hz: - mmho

Volume (ml)	1.19	Pressure (daPa)	59
Compliance (ml)	0.77	Gradient (daPa)	66

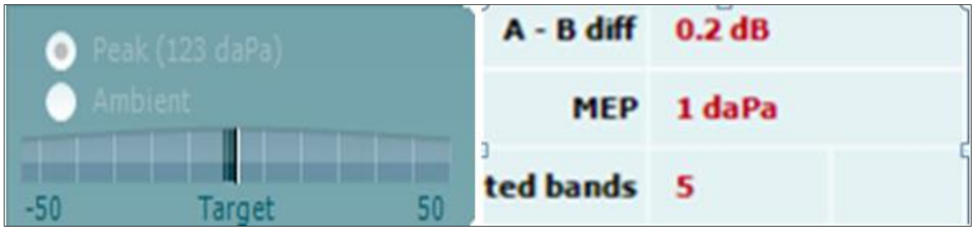
Figure 54: Case (3). Comparison of middle ear pressure estimates from the left panel 3D-WBT (+189 daPa) versus conventional 226 Hz tympanogram (+59 daPa) displayed in the right panel. Estimates were conducted pre-EOAE recording in the post-maneuver test condition. The 226 Hz tympanogram (uncompensated for ear canal volume) displays the acoustic admittance (Y), susceptance (B) and conductance (G) response curves.

7.2 Estimation of Titan's Ability to Maintain Target Pressure

Titan is a unique test system as it is the only commercially available instrument that is capable of measuring EOAEs at a compensated pressure. As already discussed, the target pressure during compensated peak EOAE measures it based on the TPP from the last recorded immittance measure. Titan generates a pressure of equal magnitude relative to the TPP within the outer ear canal (the space between the tympanic membrane and the end of the test probe). Ideally, the compensation pressure during TEOAEs and DPOAEs should be stable and equivalent to TPP. However, during the measurement of DPOAEs and TEOAEs with Titan, a certain degree of drift from target pressure is accepted. In the current study, a significant difference in absolute EOAE amplitude was seen for between test pressure conditions (ambient versus peak) and for certain between test-maneuver condition comparisons. To investigate the possible source of these differences, the stability of the compensation pressure during peak test conditions, was investigated. This area of investigation was specifically important for the post-maneuver condition under which MEP was induced. Findings from these investigations are presented in the following section. The following discussion concerning specific tolerance levels and the Titan

Suite's approach to maintaining target pressure was provided by a clinical training representative with Interacoustics (J. Huijnen, personal communication, November 11, 2016).

The Titan system automatically records and logs the compensation pressure maintained throughout EOAE measurements when testing at both ambient and peak pressure settings. This data provides an indication of how well Titan is able to maintain target pressure and the degree of fluctuation throughout recordings. An estimate of the deviation from target pressure is available for each test frequency only for DPOAEs. For TEOAE measures, Titan only logs the last pressure estimate at the end of the TEOAE recording time. There is also a difference between TE and DP data collection in regards to the ease of monitoring the pressure reached throughout recordings. For TEOAE measures, during recordings a constant pressure value is displayed on the computer screen labelled as a MEP value. This provided an online account of drift from target pressure (refer to the right panel of Figure 55). However, during DPOAE measures, there is no such online indication of an exact pressure value provided (refer to the left panel of Figure 55). For both DPOAE and TEOAE measurements, a recording is not initiated if target pressure is not reached within the manufacturer set tolerance range nor will the recording resume if the system has been paused and the acceptable range of pressure tolerance from target pressure is not being met. It was not explicitly provided by Interacoustics what the pump speed is for both the pressure regulation during EOAE measurements and how the pump slows when the pressure is within close range to target pressure, both factors could potentially impact the degree of over or under shoot of pressure from target.



A - B diff 0.2 dB

MEP 1 daPa

ted bands 5

Figure 55: Computer screen display of the compensation pressure estimate provided by Titan during EOAE recordings. The left panel shows the pressure bar displayed for DPOAE measures and the right panel represents explicit middle ear pressure (MEP) estimated value (representing the degree of pressure created in the external ear canal) presented during TEOAE measures.

7.2.1 Titan Maintaining Target Pressure; Transient Evoked Otoacoustic Emissions

For TEOAE measures, the recording does not begin if the test pressure is not reached within tolerance of ±3 daPa from the target pressure. During the recording of TEOAEs, the compensation pressure is monitored and an in the moment numerical value can be visualized on the computer screen for the tester. This displayed value indicates the compensation pressure achieved by the Titan system. If the compensating pressure is outside the range of ±20 daPa from target pressure, testing is paused automatically by Titan. For TEOAEs specifically, the compensation pressure must be measured outside this tolerance range of ±20 daPa a minimum of two times before recordings are paused. Once the Titan pump returns the pressure to within ±3 daPa of target pressure, the system continues with the EOAE measurement. During the collection of data for this study, if Titan paused the EOAE recordings, this would increase the test time required to complete the EOAE measurements subsequently extending the duration that participants had to maintain the induced MEP for in the post-maneuver test condition.

The final pressure value available for extraction from the saved participant Titan files was pooled for each TEOAE measure. These values were converted to absolute values and the mean pressure values (Titan pressure versus target pressure) were compared using a paired t-test for dependent samples. The mean Titan pressure (58.01 daPa) represents the test pressure maintained by Titan throughout the TEOAE measure collapsed across all frequencies (1 to 5 kHz) for all n=97 TEOAE measures from the post-maneuver peak test condition. The Titan system seems to have been able to maintain the compensation pressure within 6.78 daPa of the mean target pressure (64.97 daPa). The difference between mean pressures (Titan pressure versus Target pressure) was significant; the descriptive statistics are presented in Table 105. The Box and Whisker plot displayed in Figure 56 shows that on average, the system undercompensated by 6.78 daPa throughout TEOAE recordings.

	T-test for Dependent Samples for TEOAE Measures; Post-maneuver Peak Test Condition (n=97)								
	Mean (daPa)	SD	n	Diff.	t	df	p	Confidence -95.00%	Confidence +95.00%
Titan Pressure	58.01	45.08							
Target Pressure	64.79	45.68	97	-6.78	-9.72	96	0.00	-8.17	-5.40

Table 105: Comparison of absolute mean pressure (daPa) between the target pressure and the estimated compensation pressure maintained by Titan for TEOAE measures recorded at peak pressure in the post-maneuver test condition. Absolute mean values were from n=97 samples.

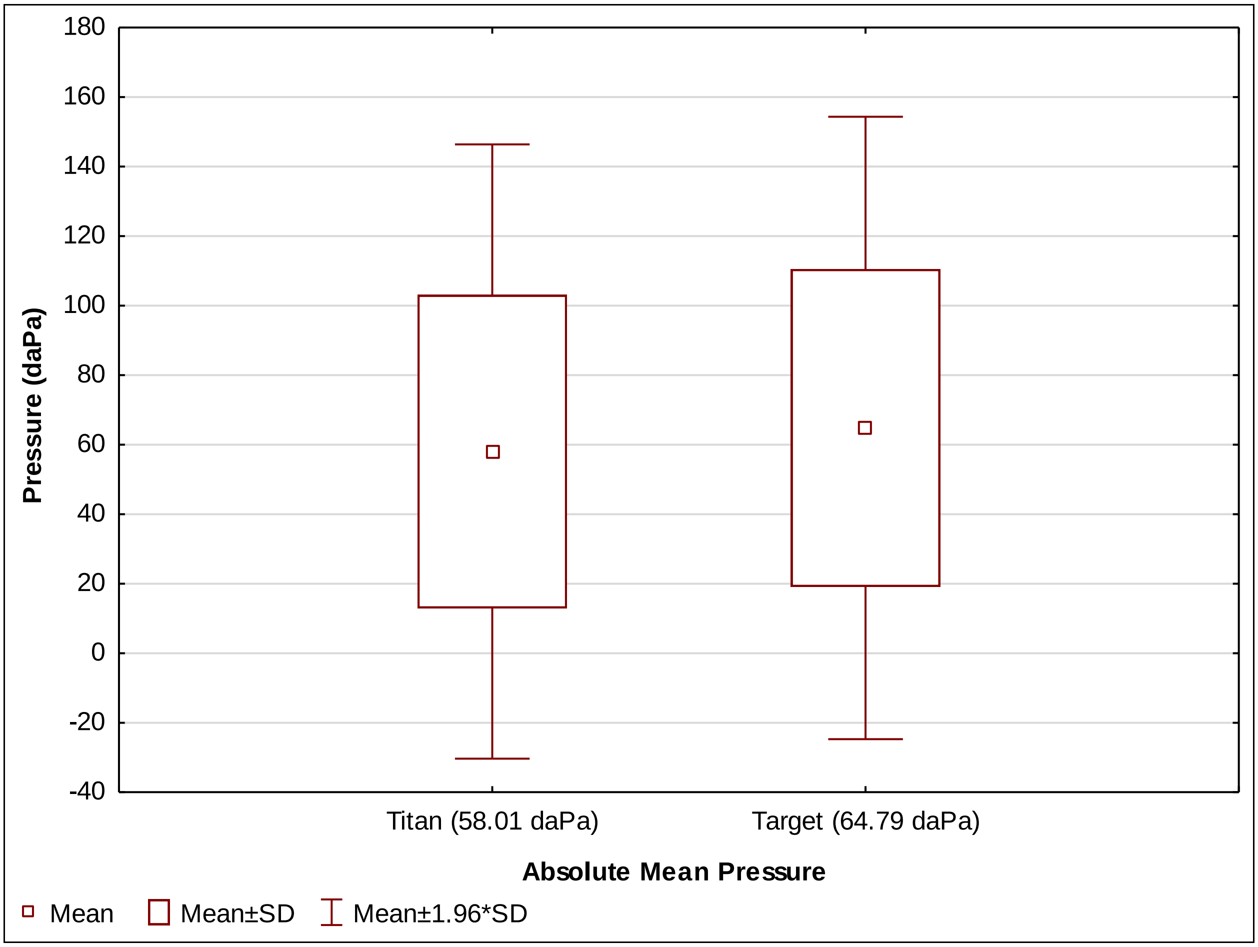


Figure 56: Box and Whisker plot for the comparison of absolute mean pressure between the target pressure (labeled as ‘Target’) and the estimated pressure maintained by Titan (labeled as ‘Titan’) for TEOAE measures recorded in the post-maneuver peak pressure test condition. Target pressure references the tympanic peak pressure estimated from the conventional 226 Hz tympanogram. Absolute mean values were from n=97 samples. The target pressure was determined referencing the middle ear pressure estimate from the last conducted 226 Hz tympanogram. Vertical bars denote 95th percent confidence intervals.

Data is available for the same pressure comparison between titan maintained pressure and target pressure for the non-maneuver test conditions for both TEOAE and DPOAE measures. However, these comparisons were not conducted for this study and are therefore not included in this study.

7.2.2 Titan Maintaining Target Pressure; Distortion-product Otoacoustic Emissions

The pressure monitoring system for DPOAE measures is different from TEOAE measures. The compensating pressure is re-established to target pressure each time Titan starts DPOAE collection at the new test frequency. The pressure that Titan must obtain prior to starting DPOAE measures has a tolerance of ±5 daPa within target pressure. Unlike the TEOAE system, the compensating test pressure is not continually monitored during the collection of DPOAEs at each test frequency. Rather, the compensation pressure is re-assessed prior to the measurement at the next test frequency. It is an option for the system user to manually pause the Titan Suite and have the pump re-establish target pressure if the user suspects target pressure is not being adequately met during recordings at individual frequencies. For this study, this option was not utilized in order to maintain test procedure consistency between all participants.

For DPOAE measures, the final pressure values provided in the stored participant data file for each test frequency were pooled. These pressure estimates were converted to absolute values and the mean pressures (Titan pressure versus target pressure) were compared using a paired t-test for dependent samples. The mean Titan test pressure for each test frequency (x8) and the mean target pressure are presented in Table 106. There was a sample size of n=110 measures for each frequency. The difference between mean pressures for each test frequency (1.5 to 8 kHz) was significant (p<.05). The Box and Whisker plot for one test frequency (1.5 kHz) is displayed in Figure 57 as a sample. A trend was observed for the difference between the Titan maintained compensation pressure and the target pressure to increase as test frequency increased.

	Mean Pressure from T-tests (x8) for Dependent Samples; Post-maneuver Peak Test Condition DPOAE Measures (n=110)							
	1.5 kHz	**2 kHz**	**2.5 kHz**	**3 kHz**	**4 kHz**	**5 kHz**	**6 kHz**	**8 kHz**
(A) Mean Absolute Titan Pressure (daPa)	48.63	47.64	48.85	47.93	47.45	47.04	46.72	46.91
(B) Mean Absolute Target Pressure (daPa)	64.43	64.43	64.43	64.43	64.43	64.43	64.43	64.43
Mean Difference, B-A (daPa)	15.80	16.79	15.58	16.50	16.98	17.39	17.71	17.52

Table 106: Comparison of absolute mean pressure between the target pressure and the estimated pressure maintained by the Titan for DPOAE measures recorded at peak pressure in the post-maneuver test condition. Mean values (in daPa) are shown for the eight test frequencies, 1.5 to 8 kHz. Absolute mean values were from n=110 samples.

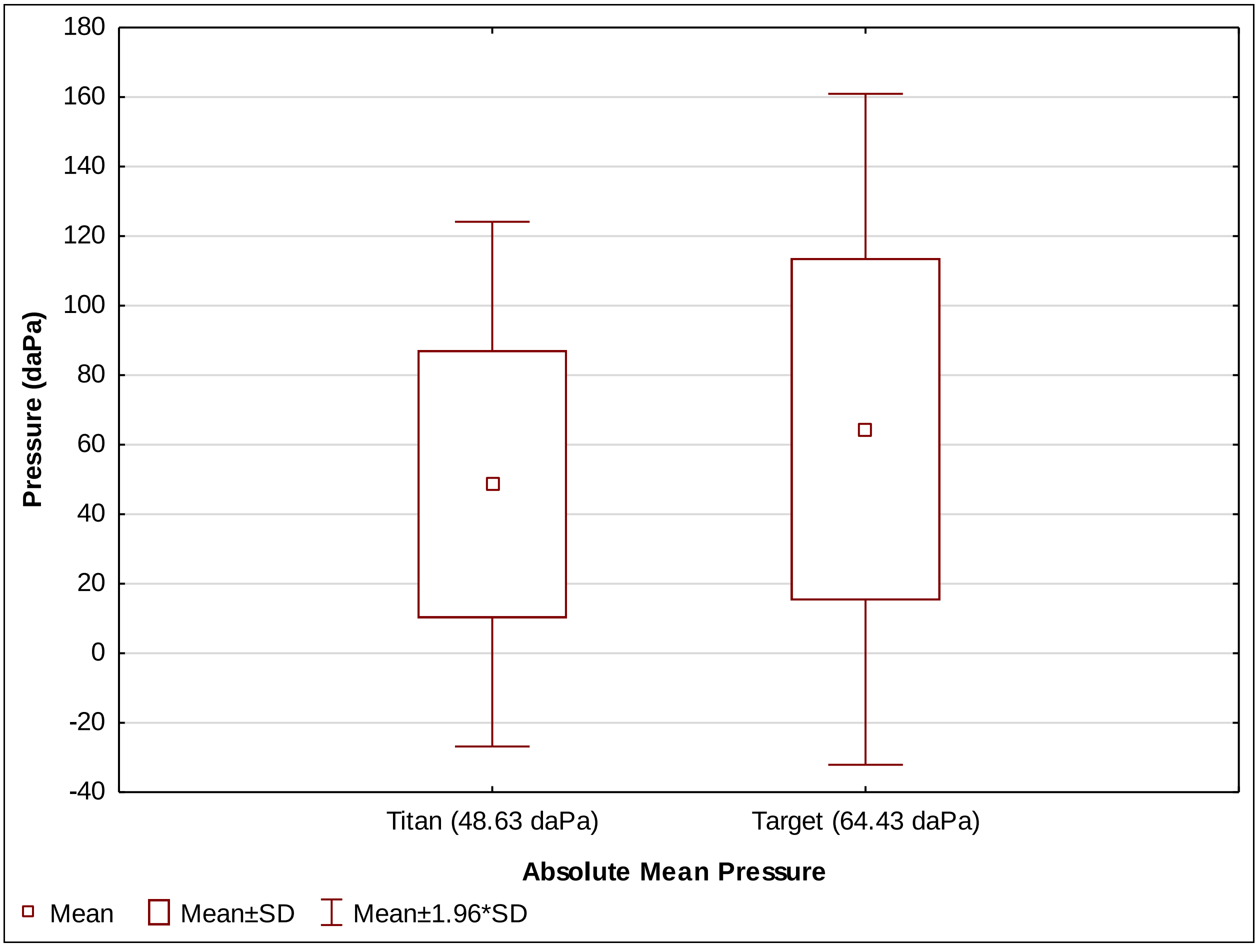


Figure 57: Box and Whisker plot for the comparison of absolute mean pressure between the target pressure (based on the tympanic peak pressure estimate) and the estimated compensation pressure maintained by Titan. Recordings were for DPOAE measures at peak pressure for test frequency 1.5 kHz in the post-maneuver test condition. Absolute mean values were from n=110 samples. Vertical bars denote 95th percent confidence intervals.

7.2.3 Titan Maintaining Target Pressure; Ambient Test Conditions

The initial probe insertion in the ear canal creates a closed air system. For all participants, the probe seal was adequate to allow the pre-EOAE 3D-WBT and single frequency tympanogram to be measured. The EOAE measures could also only start recording if the test system detected an acceptable probe seal and target pressure was met within tolerance. The vast majority of DPOAE and TEOAE measures displayed a pressure value not exactly at 0 daPa for recordings at ambient pressure. The insertion of the probe tip into the participant’s ear canal creates positive pressure within the sealed cavity. The Titan Suite, when testing at either ambient or peak pressure, does not directly compensate for this insertion pressure, but according to a representative of Interacoustics, the Titan system uses the probe pump system to establish a pressure within tolerance of 0 daPa (J. Huijnen, personal communication, November 11, 2016). The pressure point of 0 daPa is set as target pressure for ambient recordings but the exact tolerance levels for establishing ambient pressure were not explicitly provided. Given the positive pressure generated by the probe insertion differed between participants and this exact pressure value is not available nor is the exact manner in which the probe pump re-establishes ambient pressure within the external canal, conclusions regarding Titan’s ability to maintain target pressure at ambient settings cannot be confidently argued by the following calculations and comparisons. The comparison between target pressure (0 daPa) and the pressure maintained by Titan for the ambient test condition measures was provided for reader interest only. The absolute mean pressure maintained by Titan for TEOAE measurements at ambient in the post-maneuver test condition was 4.98 daPa (n=97) and for the non-maneuver ambient condition it was 3.27 daPa (n=97). The absolute mean pressure maintained by Titan for DPOAE measurements (n=110) at ambient in the post-maneuver test condition for each of the eight test frequencies (1.5 to 8 kHz) were as follows: 4.56 daPa, 4.90 daPa, 5.08 daPa, 5.14 daPa, 5.22 daPa, 5.25 daPa, 5.16 daPa, 4.95 daPa. Refer to Methods section for discussion concerning the Titan Suite pump use. For the Titan system, the manufacturer sets tolerance level as well as various pump speeds but the target pressure is not as precise as 1 daPa. Deviations in pressure readings from 0 daPa are likely due to overshoots in the pump pressure moving from a positive pressure starting point (created from the probe insertion) to an end pressure point slightly negative in value (overcompensation for canal pressure) or slightly positive end points (undercompensating for positive canal pressure) (J. Huijnen, personal communication, November 11, 2016).

7.2.4 Summary of Findings

In summary, for TEOAE measures in the post-maneuver peak test condition, the difference between the absolute mean target and compensation pressure was 6.78 daPa. For DPOAE measures in the post-maneuver peak test conditions, the difference between the absolute mean target and the average achieved compensation pressure ranged from a 15.58 to 17.71 daPa. Although an adequate probe seal was obtained for immittance measures prior to EOAEs and the probe placement was not altered, poor probe fit creating small leaks during testing could contribute to the target pressure not being exactly maintained throughout EOAE recordings. As well, the tolerance range of ±20 daPa for online monitoring of TEOAE Titan test pressure may not have been conservative enough for adequate compensation of abnormal MEP during the post-maneuver test condition assessments. These investigations into TEOAE pressure comparisons should be interpreted with restraint. Although the estimate of the pressure maintained during a pressure compensated TEOAE recording is stored in the participant files, it is limited in its post-test application. This saved test data is limited in its use for speculating on the pressure maintained throughout the entire TEOAE testing duration because it only reflects the pressure at the end of the entire recording. In this study, TEOAE measures were set to record for 60 seconds but this was prolonged if Titan paused the recording to re-establish compensation pressure. The test pressure value provided at the recording end point may not be an adequate reflection of the pressure maintained throughout the majority of the TEOAE measure. But based on the comparisons performed, for both EOAE, a consistent under-compensation for peak pressure was observed. In light of these findings it can be speculated that the significant difference observed in mean absolute amplitude between the post-maneuver ambient versus peak test conditions may have been even greater, if Titan had more precisely compensated for the abnormal MEP. Similarly, the difference between the non-maneuver ambient versus peak, and the two non-maneuver conditions versus post-maneuver peak conditions may have resulted in even less of a difference had TPP been better compensated for (i.e. target pressure met more precisely).

Refer to Chapter 9, Study Limitations and Future Directions section for a discussion of study limitations relating to Titan maintaining target pressure, focusing on limitations for TEOAE testing.

7.3 Participant Maintained Middle Ear Pressure

A significant difference in absolute EOAE amplitude was seen for between test pressure conditions (ambient versus peak) and for certain between test-maneuver condition comparisons.

To investigate the possible source of these differences, the stability of the induced MEP for the post-maneuver condition was investigated. This was done by comparing the pre-EOAE recording to the post-EOAE recording MEP estimate for EOAEs from the post-maneuver test condition.

7.3.1 Background and Description of the Analysis

A drawback to testing in the post-maneuver condition was that the participants' MEP was induced and therefore, could be alleviated during testing. During the collection of data for the post-maneuver condition, participants were asked to try and maintain the induced MEP for approximately 170 seconds and 130 seconds for DPOAE and TEOAE conditions, respectively. Participants were instructed to try and not swallow, cough, talk, sneeze, or yawn during recordings as these actions could have potentially released the induced pressure generated by the Toynbee and Valsalva maneuvers. The magnitude of MEP generated by participants in the post-maneuver condition was determined by a conventional 226 Hz tympanogram. Immediately following this immittance measure, EOAEs were assessed at ambient and peak pressure. Countering balancing the test sequence of whether EOAEs were measured at ambient or peak either first or second, was particularly important in the post-maneuver condition as the induced MEP was not expected to be stable throughout EOAE measurements (see Chapter 2 Methods section for further discussion of counterbalancing). If a participant's MEP varied during the collection of EOAEs, either during EOAE recordings within a test condition or transitioning between conditions (ambient versus peak pressure), this would alter the target pressure needed for ideal pressure compensation. Titan would either be over or under compensating for a participants' MEP if this pressure changed from the initial target pressure. In order to assess a participants’ ability to maintain the induced MEP, a post-recording tympanogram was collected. The target pressure set by Titan was based on the 226 Hz tympanogram estimate, therefore this estimation method was also used for post-recording estimates.

The MEP estimates before and after the recording of DPOAEs and TEOAEs were compared by means of a paired t-test for dependent samples. The MEP estimates were analyzed in three parts; (1) all MEP estimates as absolute values, (2) only negative MEP estimates, and (3) only positive MEP estimates. Descriptive statistics for TEOAE associated measures are in Table 107 and DPOAE related measures are shown in Table 109. A mixed ANOVA approach was also used to investigate the interaction between pre/post-recording MEP estimates and the factor of MEP magnitude (absolute, negative, or positive). Factors of gender and ethnicity were not considered for these analyses. This investigation of comparing the pre- and post-EOAE recording MEP estimates could not be conducted for non-maneuver measures, as post-recording tympanograms were not collected.

7.3.2 Pre- versus Post-TEOAE Recording Middle Ear Pressure Estimates

The paired t-test for absolute MEP estimates (n=97 pairs) shows a significant difference between the pre- versus post-TEOAE recording estimates, with a mean difference of 7.04 daPa. Findings are displayed as a Box and Whisker plot in Figure 58. To avoid presenting redundant findings, graphical displays for separated negative and positive MEP estimates are not included in this study but the associated descriptive statistics for these analyses are presented in Table 107.

	T-test For Dependent Samples: TEOAE Associated MEP Estimates								
		Mean MEP (daPa)	**Standard Deviation**	**n**	**Average Difference (daPa)**	**t**	**p**	**CI -95%**	**CI +95%**
Absolute MEP	Pre-recording	57.75	43.52	97	7.04	3.98	.00	-10.55	-3.53
	Post-recording	64.79	45.45	97		-3.98	.00	-10.55	-3.53
Positive MEP	Pre-recording	68.93	50.66	46	13.48	3.50	.00	-21.23	-5.73
	Post-recording	55.46	51.71	46		-3.50	.00	-21.23	-5.73
Negative MEP	Pre-recording	-61.06	-39.80	51	3.47	2.24	.03	0.36	6.58
	Post-recording	-57.59	-37.99	51		-2.24	.03	0.36	6.58

Table 107: Transient evoked otoacoustic emission (TEOAE) data. Comparisons of pre-TEOAE recording versus post-TEOAE recording middle ear pressure (MEP) estimates from the conventional 226 Hz tympanogram from the post-maneuver test condition.

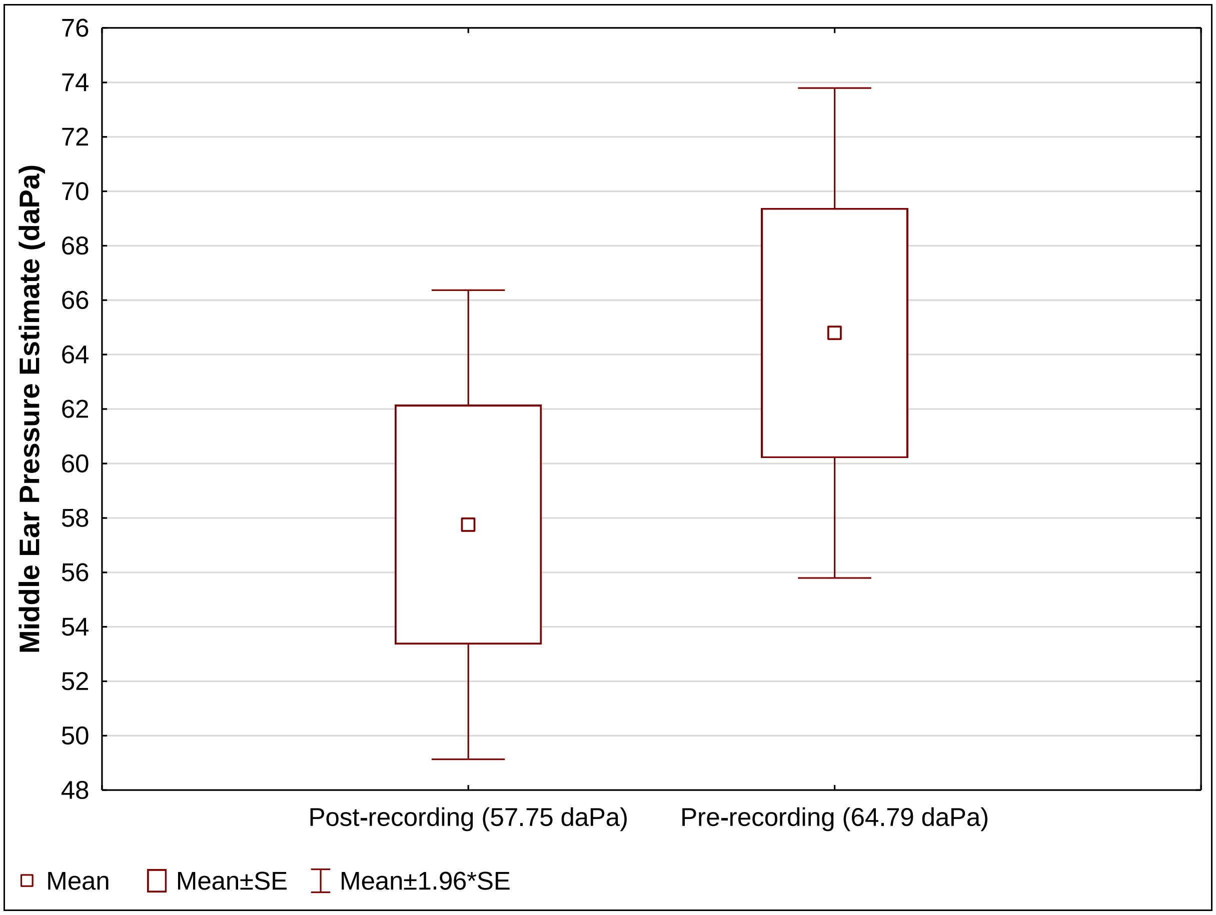


Figure 58: Box & Whisker plot for the comparison of mean absolute middle ear pressure (|MEP|) between the pre-recording (mean= 64.79 daPa) and post-recordings (mean= 57.75 daPa) MEP estimates based on the conventional 226 Hz tympanogram. MEP estimates are associated with post-maneuver transient evoked otoacoustic emission (TEOAE) recordings (n=97). Vertical bars denote 95th percent confidence intervals.

The largest difference in absolute EOAE amplitude observed between test conditions was for comparisons at more extreme MEP magnitudes. For example, both DPOAE and TEOAE analyses showed measures significantly different in absolute amplitude at absolute MEP shift magnitude categories D (MEP= 51 to 99 daPa) and E (MEP= ≥100 daPa) for post-maneuver ambient versus peak test condition comparisons. To investigate if the participants' ability to sustain the abnormal MEP possibly impacted EOAE measurements at these specific pressure levels, the between-subject factor of absolute MEP magnitude was explored for DPOAE and TEOAE data separately.

The interaction between absolute MEP magnitude and pre/post-TEOAE recording estimates [F(4, 92)=3.5576, p=.00959] as shown in Figure 59, is significant. This significant interaction indicates the variation between pre- and post-TEOAE recording estimates differs for the absolute MEP magnitude categories A to E. Table 108 shows the mean MEP estimate values and descriptive statistics. A Tukey's HSD test indicated a significant difference between the pre- and post-recording estimates only at category E (MEP ≥100 daPa). When the MEP estimates are separated based on negative and positive estimates, the same results are shown: A significant difference in MEP between pre- and post-recordings was only seen for MEP shift magnitude category E. The statistical summary for TEOAE measures can be found in section Appendix B Table 219.

|MEP| Magnitude (daPa)	**TEOAE Recording Period**	**Mean |MEP| Estimate (daPa)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Pre-recording	7.67	9.70	-11.59	26.92	3
A (0 to 10)	Post-recording	8.67	13.99	-19.13	36.46	3
B (11 to 25)	Pre-recording	17.81	4.20	9.47	26.15	16
B (11 to 25)	Post-recording	16.50	6.06	4.46	28.54	16
C (26 to 50)	Pre-recording	35.26	3.23	28.84	41.68	27
C (26 to 50)	Post-recording	30.44	4.66	21.18	39.71	27

|MEP| Magnitude (daPa)	TEOAE Recording Period	Mean |MEP| Estimate (daPa)	Standard Error	CI -95.00%	CI +95.00%	n
D (51 to 99)	Pre-recording	73.97	3.02	67.98	79.96	31
D (51 to 99)	Post-recording	69.13	4.35	60.48	77.78	31
E (>99)	Pre-recording	136.60	3.76	129.14	144.06	20
E (>99)	Post-recording	117.35	5.42	106.59	128.11	20

Table 108: Comparison of mean absolute middle ear pressure (|MEP|) between the pre-TEOAE recording and post-TEOAE recording estimates as a function of absolute MEP magnitude in the post-maneuver test condition. All MEP estimates were based on the conventional 226 Hz tympanogram for post-maneuver test condition recordings. Current effect: [F(4, 92)=3.5576, p=.00959].

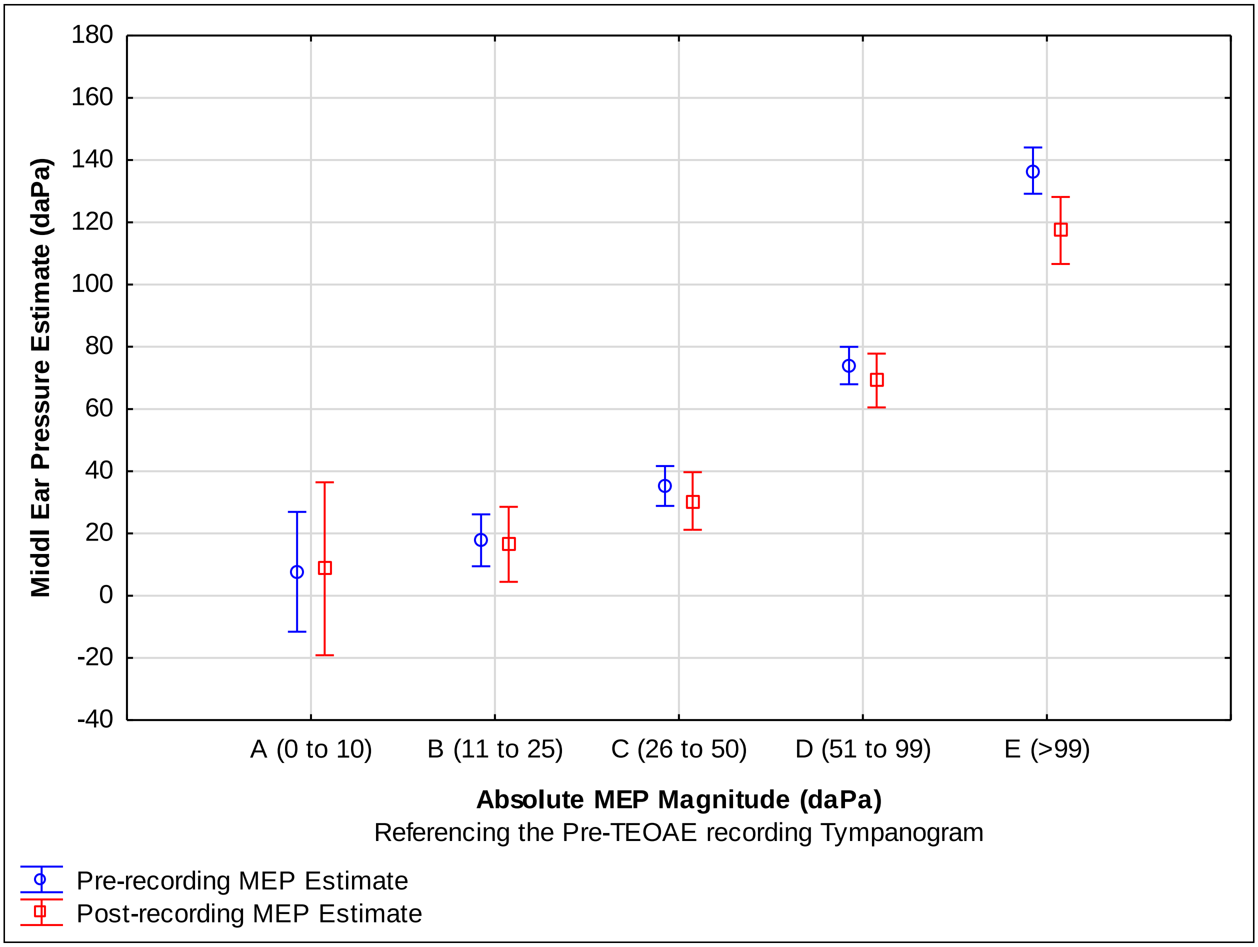


Figure 59: Comparison of mean absolute middle ear pressure (|MEP|) between the pre-TEOAE recording and post-TEOAE recording MEP estimates as a function of absolute MEP magnitude. The MEP estimates were based on the conventional 226 Hz tympanogram in the post-maneuver test condition. Categories A to E represent the absolute MEP magnitude referencing the pre-TEOAE recording tympanogram MEP estimate. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 92)=3.5576, p=.00959].

7.3.3 Pre- versus Post-DPOAE Recording Middle Ear Pressure Estimates

The same approach used for the TEOAE comparisons was applied for comparing estimates associated with DPOAE measures. The paired t-test for absolute MEP estimates shows a significant difference between the two recording periods (pre versus post-OAEs) with a mean difference of 12.15 daPa. Findings are displayed as a Box and Whisker plot in Figure 60. To avoid presenting redundant findings, graphical displays for the negative and positive separated MEP estimates were not included in this manuscript (refer to Table 109 for t-test descriptive statistics).

	T-test For Dependent Samples: DPOAE Associated MEP Estimates								
		Mean MEP (daPa)	**Standard Deviation**	**n**	**Average Difference (daPa)**	**t**	**p**	**CI -95%**	**CI +95%**
Absolute MEP	Pre-recording	64.43	49.25	110	12.15	3.95	.00	-18.25	-6.06
	Post-recording	52.27	42.75	110		3.95	.00	-18.25	-6.06
Positive MEP	Pre-recording	69.79	58.15	52	15.90	2.70	.00	-27.70	-4.11
	Post-recording	53.88	48.72	52		2.70	.00	-27.70	-4.11
Negative MEP	Pre-recording	-59.62	39.53	58	9.41	3.35	.03	3.79	15.04
	Post-recording	-50.21	37.81	58		3.35	.03	3.79	15.04

Table 109: Comparisons of pre-DPOAE recording versus post-DPOAE recording middle ear pressure (MEP) estimates from the conventional 226 Hz tympanogram from the post-maneuver test condition. Three separate data analyses were conducted: (1) absolute MEP (n=110) for all DPOAE measures, (2) only DPOAE measures with associated positive MEP (n=52), and (3) only DPOAE measures with negative MEP (n=58).

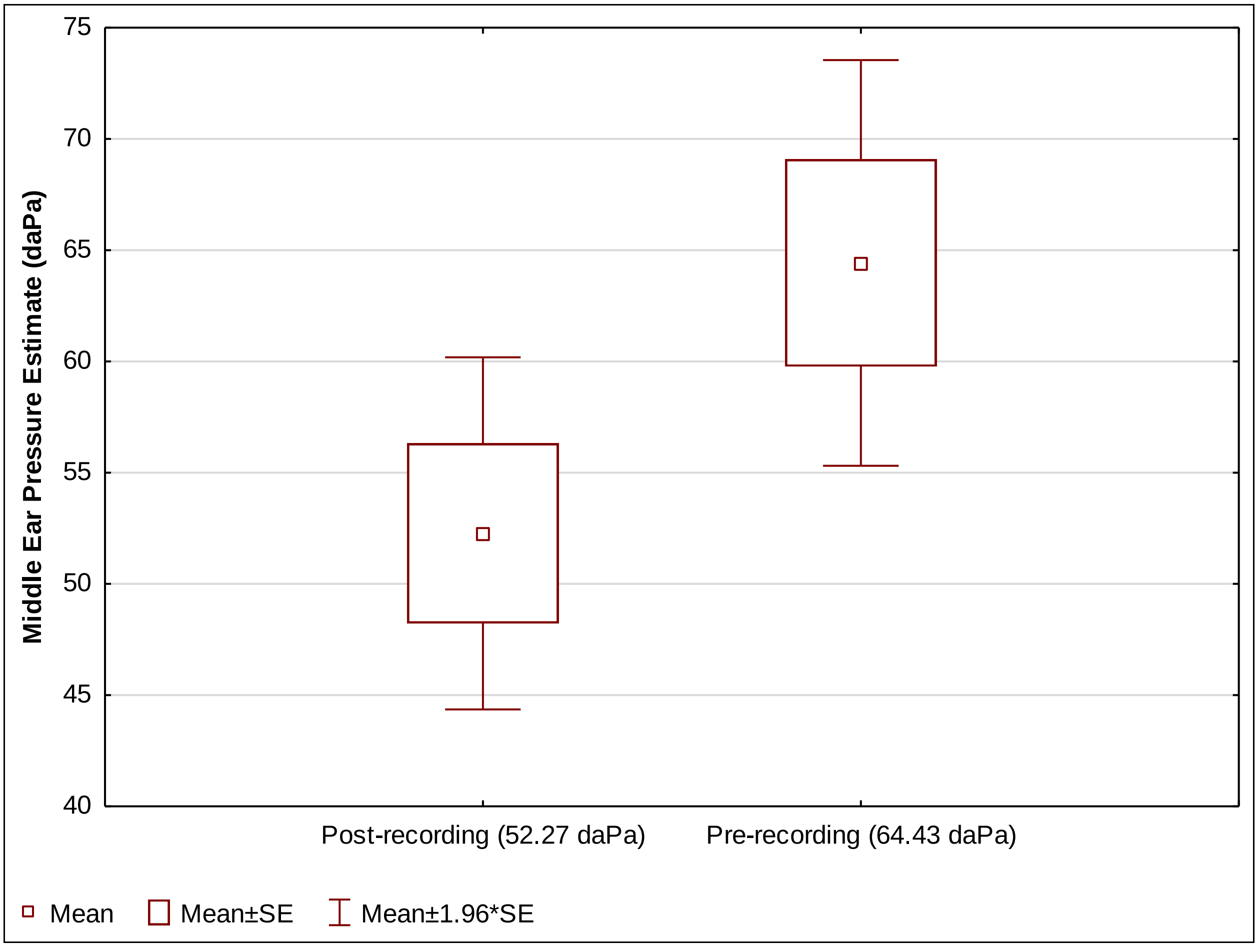


Figure 60: Box & Whisker plot for the comparison of mean absolute middle ear pressure (|MEP|) between the pre-recording (mean |MEP| = 64.43 daPa) and post-recording (mean |MEP| = 52.27 daPa) MEP estimates based on the conventional 226 Hz tympanogram. Estimates are associated

with DPOAE recordings (n=110) from the post-maneuver test condition. Vertical bars denote 95th percent confidence intervals.

The interaction between absolute MEP magnitude and pre/post-DPOAE recording estimates [F(4, 105)=4.3180, p=.00284] was significant, indicating the variation in MEP estimates between pre- and post-recording times did differ between categories A to E (refer to Table 110 for descriptive statistics and graphical illustration in Figure 61). Equivalent to the TEOAE analysis, a Tukey's HSD test shows a significant difference between pre- and post-DPOAE recording estimates only at category E (MEP ≥100 daPa). When the estimates were separated based on negative and positive associated MEP estimates, the same results were shown: A significant difference in MEP between pre and post-DPOAE recordings was only seen for category E. The statistical summary for DPOAE measures can be found in section Appendix B, Table 219.

|MEP| Magnitude (daPa)	**POAE Recording Period**	**Mean |MEP| Estimate (daPa)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Pre-recording	8.17	8.51	-8.70	25.03	6
A (0 to 10)	Post-recording	10.67	11.22	-11.58	32.92	6
B (11 to 25)	Pre-recording	17.17	4.91	7.43	26.91	18
B (11 to 25)	Post-recording	14.72	6.48	1.88	27.57	18
C (26 to 50)	Pre-recording	37.86	3.87	30.19	45.53	29
C (26 to 50)	Post-recording	31.28	5.10	21.16	41.40	29
D (51 to 99)	Pre-recording	70.66	3.52	63.67	77.64	35
D (51 to 99)	Post-recording	61.00	4.65	51.79	70.21	35
E (>99)	Pre-recording	143.55	4.44	134.74	152.35	22

|MEP| Magnitude (daPa)	**POAE Recording Period**	**Mean |MEP| Estimate (daPa)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
E (>99)	Post-recording	108.14	5.86	96.52	119.76	22

Table 110: Comparison of mean absolute middle ear pressure (|MEP|) between the pre-DPOAE recording and post-DPOAE recording MEP estimates as a function of absolute MEP magnitude. All estimates (for both positive and negative associated measures) are based on the conventional 226 Hz tympanogram for the post-maneuver test condition. Absolute MEP magnitude categories A to E reference the pre-recording MEP estimate. Current effect: [F(4, 105)=4.3180, p=.00284].

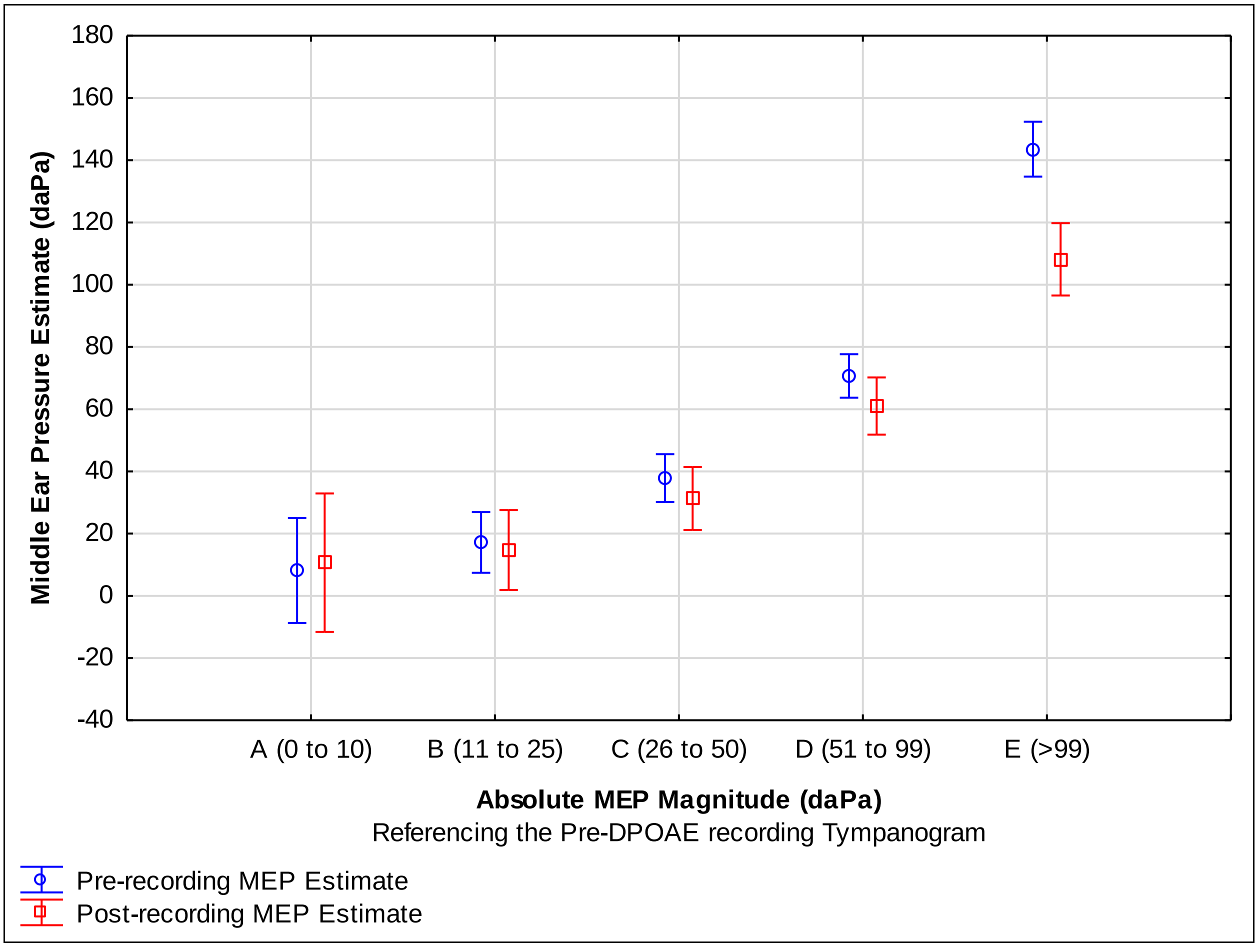


Figure 61: Comparison of mean absolute middle ear pressure (|MEP|) between the pre-DPOAE recording and post-DPOAE recording MEP estimates as a function of absolute MEP magnitude (categories A to E). All MEP Estimates are based on the conventional 226 Hz tympanogram from the post-maneuver test condition. Categories A to E reference the pre-DPOAE recording MEP estimate. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 105)=4.3180, p=.00284].

Table 111 contains the descriptive statistics for the interaction between MEP magnitude and pre/post-DPOAE recording estimates [F(4, 47)=2.6907, p=.04229] for positive MEP measures only. This particular interaction was included in this manuscript because it shows the largest difference observed between pre- and post-recording MEP estimates. For positive MEP recordings, an average difference of 49.73 daPa is seen between the pre- and post-recording estimates in category E (≥100 daPa). It should be noted that when the MEP estimates were separated based on negative and positive measures, the sample size contributing to each magnitude category was considerably smaller, especially for categories A (n=3) and B (n=6).

|MEP| Magnitude (daPa)	**Recording Period**	**Mean (+) MEP Estimate (daPa)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Pre-recording	8.67	15.03	-21.57	38.90	3
A (0 to 10)	Post-recording	14.33	20.61	-27.12	55.79	3
B (11 to 25)	Pre-recording	15.00	10.63	-6.38	36.38	6
B (11 to 25)	Post-recording	15.33	14.57	-13.98	44.65	6
C (26 to 50)	Pre-recording	38.19	6.51	25.10	51.28	16

|MEP| Magnitude (daPa)	**Recording Period**	**Mean (+) MEP Estimate (daPa)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
C (26 to 50)	Post-recording	30.69	8.92	12.74	48.64	16
D (51 to 99)	Pre-recording	69.38	6.51	56.28	82.47	16
D (51 to 99)	Post-recording	58.19	8.92	40.24	76.14	16
E (>99)	Pre-recording	162.91	7.85	147.12	178.70	11
E (>99)	Post-recording	113.18	10.76	91.53	134.83	11

Table 111: Comparison of mean positive middle ear pressure (|MEP|) between the pre-DPOAE recording and post-DPOAE recording MEP estimates as a function of absolute MEP magnitude. All MEP estimates are based on the conventional 226 Hz tympanogram in the post-maneuver test condition. The MEP magnitude references the pre-recording estimate. Current effect: [F(4, 47)=2.6907, p=.04229].

7.3.4 Summary of Findings and Further Categorization of Data

Further investigation regarding how well participants maintained the induced MEP is provided in the following section. This further analysis involved the categorization of the difference between individual MEP estimates for calculations of pre- minus post-recording estimates. A coding system was developed to quantify how well participants were able to sustain the induced abnormal MEP for individual EOAE measures. The MEP estimate difference values were assigned to one of four groups; (i) ≤5 daPa, (ii) 6 to 14 daPa, (iii) 25 to 19 daPa, (iv) ≥20 daPa. These four categories represent the degree of change in MEP between the pre- and post-recording conventional 226 Hz tympanograms. Only measures used in the final EOAE data analyses focused on outcome measures of EOAE amplitude and noise level were categorized using this (i) to (iv) coding system. These codes are tallied for both TEOAE and DPOAE associated estimates and are presented in Table 112. For this analysis, both positive and negative MEP associated conditions were pooled.

	MEP Difference Categories (i –iv); Pre minus Post-recording MEP Estimates			
	≤ 5 daPa	**6 to 14 daPa**	**15 to 19 daPa**	**≥ 20 daPa**
DPOAE	n=69	n=25	n=3	n=13
TEOAE	n=65	n=22	n=3	n=7

Table 112: Tally of DPOAE and TEOAE associated middle ear pressure (MEP) estimates falling into the four categories representing the difference in pressure between pre-OAE recording and post-OAE recording MEP estimates. The four MEP difference categories (i to iv) used are as follows: (i) ≤ 5 daPa, (ii) 6 to 14 daPa, (iii) 15 to 19 daPa, and (iv) ≥20 daPa).

In summary, it can be speculated that some of the variation in absolute amplitude that was observed when comparing between test conditions for both DPOAE and TEOAE analyses, could be due to the fluctuation in MEP during the time span from pre- to post-recording of EOAEs. A significant difference is seen between the pre-recording and post-recording MEP estimates for both DP and TE OAE measures, but only significantly so when the pre-recoding tympanogram estimate indicates a MEP of ≥100 daPa (category E). When the positive and negative MEP estimates were combined, the absolute mean MEP difference between recording periods is greater for the DPOAE measures than TEOAE (although the statistical significance of this difference was not determined). Based on the tallied categorization of differences between pre- and post-recordings for individual participants as shown in Table 112, the majority of participants were able to maintain the induced MEP with ±5 daPa of the pre-recording MEP estimate. For 94/110 DPOAE recordings, the abnormal MEP was maintained within 14 daPa of the pre-recording estimate. A similar incident was seen for TEOAE measures, where 87/97 TEOAE recordings had the MEP within 14 daPa of the initial pre-recording estimate. These findings are helpful for interpreting the differences and lack of statistical differences observed between the post-maneuver ambient and post-maneuver peak test conditions, especially when comparing these test conditions as a function of MEP magnitude. For example, when DPOAE absolute amplitude was compared between the post-maneuver ambient and peak test conditions a significant difference was observed for category E, when absolute MEP was >99 daPa. This difference is at least in part likely due to the over compensation (inaccurate pressure compensation) of MEP because of the loss in induced MEP during the DPOAE recording time (fault of the participant not the Titan system). In addition, the Titan system has also been shown to undercompensate for the presence of abnormal MEP by not exactly maintaining target pressure during peak pressure test conditions.

The impact of the MEP fluctuation may have been at least partially mitigated when comparing ambient versus peak recordings within the post-maneuver condition. The impact of MEP fluctuation may have been limited due to the counter balancing of peak and ambient test conditions (see Methods section Chapter 2, for details of counterbalancing within the study design). Half the participants involved with this study had EOAE measurements conducted in the order of (1) the post-maneuver peak pressure condition, followed by (2) the post-maneuver ambient test pressure condition. For the other 50% of participants, testing was conducted in reverse order (ambient test pressure testing before testing at peak pressure). If the induced MEP is assumed to be lost in a gradual manner as the recording time progresses, this would presumably have had equivalent impact on both test pressure conditions. Overall, 50% of post-maneuver test condition EOAE measures were initiated with the MEP presumably at its peak (initial magnitude). Over the duration of the post-maneuver condition, the induced MEP may have reduced from its originally recorded magnitude. For example, only half the time the change in MEP affected the post-maneuver peak recordings, resulting in imprecise pressure compensation during EOAE measurements.

Inadvertent association of EOAE outcome measures with the different categories of MEP magnitude may have been inaccurate in some cases. The allocation of post-maneuver EOAE measures to the various MEP magnitude categories was based on pre-recording MEP estimates. There were two options for categorizing EOAE measures, one was associating the measurement with the factor of absolute MEP magnitude and the other was the factor of MEP shift magnitude. Both options had category labels A to E and were again, both based on the pre-EOAE recording MEP estimate. If the induced MEP fluctuated in the post-maneuver condition, then for some measures the MEP actually present during EOAE recordings may indicate that data would have been better categorized into a different category (A to E) than what was determined at the pre-recording stage. This slight fluctuation in MEP and resulting miss-categorization of data could provide the supporting argument for why there is not a direct trend in absolute amplitude change as a function of MEP magnitude. For example,

Figure 16 displays the four-test condition comparison of absolute DPOAE amplitude as a function of absolute MEP shift magnitude (categories A to E). This figure shows the |MEP| magnitude category D having a mean absolute amplitude greater than category C for all four-test conditions, despite D (51 to 99 daPa) being associated with the greater MEP compared to category C (26 to 50 daPa). Perhaps the unexpected lower amplitude in category C and not in D could be partially attributed to inaccurate categorization of data into the various categories. An alternative approach to data analysis would be to re-categorize the outcome measures referencing the post-EOAE recording tympanogram MEP estimate (rather than the pre-recording estimate as was done in this study). It would be of interest to see if the response pattern for outcome measures plotted as a function of MEP magnitude (or MEP magnitude shift) changes based on a new categorization method. If this newly proposed approach to pressure categorization is taken, then it should be noted that the MEP estimate on which Titan bases target pressure would not match the presumed actual MEP present during EOAE recordings.

Chapter 8: Discussion; Power Absorbance

Following analysis of EOAE outcome measures, a secondary purpose of this study was to demonstrate the impact of abnormal MEP and the effectiveness of pressure compensation on outcome measures of Power Absorbance (PA) magnitude. The impact of abnormal pressure (MEP or canal pressure) on wideband immittance PA responses has been explored using various instruments (Beers et al., 2010; Robinson et al., 2016; Sun, 2016) but only a few studies have demonstrated the effectiveness of compensating for the presence of abnormal MEP on PA and various other wideband acoustic immittance measures (Jaffer, 2016; Shaver & Sun, 2013; Sun & Shaver, 2009). As in EOAEs, this study's test procedure for PA related measurements involved a test environment, measurement parameters, and test instruments with the intention of implementing the findings into the clinical settings. All PA related measurements, both conducted at ambient and a compensating TPP level, were done using the commercially available Titan Suite platform by Interacoustics.

The objective of investigating PA magnitude in a similar manner as was done for the outcome measure of EOAE absolute amplitude was to see if changes in PA translated into equivalent changes in EOAE amplitude. Theoretically, the compensation mechanism should be similar for both outcome measures and a similar response pattern between the test conditions (non-maneuver versus post-maneuver testing at ambient and peak pressure) was anticipated. Pressure compensation restores both the ossicular chain and the TM to a more normal position, allowing for increased acoustic energy to be absorbed by the middle ear reflected as the increase in PA magnitude and it also recovers the pathway of transmission for the EOAE related forward and backwards propagating signals. If the influence of abnormal MEP or pressure compensation does not yield similar response trends for PA magnitude and EOAE absolute amplitude measures, then this suggests other mechanisms (either physiological or instrument related) are involved and differ between measurement types. If consistent similarities are observed between changes in PA magnitude and EOAE absolute amplitude for peak versus ambient test conditions, then PA measures could possibly be utilized as a predictor of EOAE amplitude changes.

Chapter 8 discussion of PA results is divided into four subsections: (8.1) Predictions and Study Design for Power Absorbance Analyses, (8.2) Comparison of Power Absorbance between Test Conditions, (8.3) Gender Differences in PA and (8.4) PA Differences between Ethnicities. Section 8.2 is further subdivided into sections (8.2.1) through (8.2.2) for discussions concerning specific two-test condition comparisons.

8.1 Predictions and Study Design for Power Absorbance Analyses

Measures in the non-maneuver condition act as a baseline measure, intended to reflect the PA response and transmission properties of a participant’s TM and middle ear system at a clinically normal MEP, or normal healthy state with MEP at ambient, 0 daPa (Fowler & Shanks, 2002). The majority of PA measures in the non-maneuver condition were centered within +/-10 daPa of 0 daPa therefore no significant difference between non-maneuver ambient and peak conditions is expected. When a change in a participant’s MEP is induced, as in the post-maneuver condition, it is predicted that the presence of the abnormal MEP will alter the TM stiffness and orientation thus the transmission properties of the middle ear system. These changes will be reflected in the subsequent change in PA magnitude in a frequency dependent manner. This subsequent effect on

PA magnitude is predicted to occur at least when testing at an ambient test pressure with abnormal MEP. Although, when PA is measured at TPP compensating for the abnormal pressure, PA magnitude is expected to be equivalent to that measured in the absence of abnormal MEP (i.e. the non-maneuver ambient condition). In other words, when PA is assessed at peak pressure it is predicted that the impact of the change in sound energy transmission properties of the middle ear system as a result of the abnormal MEP presence, are mitigated. The resulting measure of PA magnitude for the peak test condition is expected to not show a significant difference from baseline measures (i.e. non-maneuver ambient).

8.2 Power Absorbance Magnitude; Overview Comparison between Test Conditions

For the current study, PA magnitude varied significantly for certain comparisons between test conditions and across frequencies. Overall, as predicted, testing at peak pressure compared to ambient pressure increased mean PA magnitude. This was true for the current study with (a) post-maneuver ambient (PA= 0.35) versus peak (PA= 0.42), (b) non-maneuver ambient (PA= 0.42) versus peak (PA= 0.43), and (c) non-maneuver ambient (PA= 0.42) versus post-maneuver peak (PA= 0.42) test condition comparisons. These presented mean PA values were derived from the main effect analysis of test pressure condition. These analyses were collapsed across factors of ethnicity, gender, and frequency for the comparison of PA incorporating all four-test conditions into the analysis. The significance of the interaction between ethnicity, frequency, and test condition depends on the test conditions under comparison. The trend in PA magnitude across test conditions was as expected: (1) For the post-maneuver ambient condition when the abnormal MEP was not compensated for, there was a drop in PA seen across all ethnicity groups predominately for the mid to low frequencies and (2) for the test conditions when MEP was centered on 0 daPa or abnormal MEP was compensated for, there was a comparable PA magnitude observed across the frequency response curve. The sample size for each test condition when analyzing the WAI was n=210. Findings from the four two-way test condition comparisons will be discussed in sections (8.2.1) through (8.2.4).

8.2.1 Power Absorbance; Non-maneuver Ambient and Post-maneuver Ambient

Mirroring the discussion for EOAEs, this comparison between PA from the non-maneuver ambient and the post-maneuver ambient test conditions was conducted in order to demonstrate the impact of abnormal MEP on the outcome measures of PA. This test condition comparison signifies what is currently done clinically because irrespective of a patient's MEP, PA is assessed at ambient pressure (i.e. uncompensated). When comparing non-maneuver ambient to post-maneuver ambient PA measures, a significant difference in mean PA magnitude was predicted, with mean PA magnitude decreasing as MEP increases for the uncompensated condition.

As previously stated in the EOAE discussions, abnormal MEP reduces the vibrational velocity of the TM, with this stiffening effect of the TM most considerably impacting the transmission of low frequencies into the middle ear, usually ≤ 2 kHz (Lee & Rosowski, 2001 as citied in Perez, 2012). The high frequencies are impacted less from TM stiffness changes because higher frequencies are dominated by mass reactance components. As was seen for EOAEs amplitude outcome measures, with the outcome measure of PA magnitude a larger change in the low frequencies compared to high frequencies is expected with changes in MEP away from ambient (0 daPa).

In this study, a significant difference in mean PA magnitude was observed between the non-maneuver ambient (0.42) and post-maneuver ambient (0.36) test conditions, with the latter having the lower mean PA magnitude value. These values were calculated averaging over the test frequency range of 0.25 to 8 kHz with an absolute MEP average of 10 daPa in the non-maneuver condition and 64 daPa for the post-maneuver condition. The presence of abnormal MEP is reflected in the reduction in overall PA magnitude, when the analysis is collapsed across factors of gender, ethnicity, and frequency. Sound energy is absorbed by the middle ear most effectively at TPP therefore, the non-maneuver ambient test condition with a mean MEP centered at 0 daPa was predicted to have the higher PA magnitude when testing at ambient pressure compared to the post-maneuver ambient test condition which had a mean MEP deviating from ambient.

The MEP estimates were coded in order to investigate if an observed change in PA magnitude was correlated to the magnitude of MEP as was seen with the outcome measure of EOAE absolute amplitude. It was predicted that the more abnormal the MEP became or in other words, the greater deviation from the center range of -10 daPa to +10 daPa, the more change in PA magnitude will be observed in a frequency dependent manner. The comparison of PA between non-maneuver ambient and post-maneuver ambient test pressure conditions as a function of MEP magnitude was significant. The interaction between test condition, center frequency, and absolute MEP shift magnitude was also significant. Overall, with uncompensated abnormal

MEP, there was a noticeable drop in PA magnitude for the low frequencies ≤4 kHz with the largest attenuation in PA magnitude at ≤ 2.5 kHz while the upper tail portion of the response curve 4-8 kHz remained relatively stable in magnitude. Three main finding are consistent with past studies: (1) As the degree of abnormal MEP increases there was a corresponding decrease in PA magnitude, (2) the most evident changes in PA magnitude occurred at frequencies <4 kHz, and (3) for both test conditions (non-maneuver ambient and post-maneuver peak) the peak of the PA curve was observed between frequencies 2.5 to 4 kHz (Beers et al., 2010; Robinson, Thompson, & Allen, 2016; Sun, 2016). This frequency dependent response in PA magnitude as a function of absolute MEP magnitude was found for all ethnic and gender groups.

Changes in PA magnitude in a frequency-specific manner observed for cases of uncompensated abnormal MEP and for baseline responses are in agreement with past findings. Previous studies establishing normative data for ER based on a normal healthy young adult population indicate ER is often high for frequencies <1 kHz, with a reduction in ER between 2 to 4 kHz and an increase in ER >4 kHz (Mazlan et al., 2015; Feeney et al., 2003; Shahnaz & Bork, 2006). Given PA is equivalent to 1-ER, this frequency specific pattern for ER is expected for PA magnitude in the baseline condition. The PA magnitude response as a function of frequency is expected to be a mirror image of the ER response pattern, but in the opposite magnitude direction. For baseline responses, PA is expected to be low <1 kHz, increase between 2 to 4 kHz, and slope down >4 kHz (Mazlan et al., 2015; Sun, 2016).

There is some overlap in PA magnitude for all MEP magnitude categories (A to E) for the higher center frequencies (>4 kHz). Considering all test conditions (non-maneuver and post-maneuver), there was also a trend for the peak PA to shift to a higher center frequency as the MEP magnitude increases for the uncompensated pressure conditions. In addition to the shift in peak PA, the higher frequencies (≥ 4 kHz) showed an increased PA magnitude in the uncompensated conditions compared to the compensated conditions in the presence of abnormal MEP which is in agreement with the results from Robinson et al. (2016), Voss et al. (2012), and Shaver & Sun (2013). The shift in peak PA to a higher frequency in the presence of uncompensated abnormal MEP and difference in peak maxima shapes (described in the following section regarding ethnicity differences in PA response) is described by Robinson et al. (2016) as being a result of changes in local resonance due to changes in middle ear compliance characteristics with changes in MEP.

Shaver (2016) for a sample of 84 healthy adults found frequency-specific differences in energy absorbance between positive and negative ear canal pressure of the same magnitude, however the overall trend between positive and negative pressure conditions was similar to the current study. Shaver (2016) showed as the ear canal pressure deviated from ambient there was a decrease in energy absorbance for the mid to low frequencies and an increase in the high frequency, with this change becoming more prominent as the degree of ear canal pressure increased. It was also demonstrated that for positive pressure, energy absorbance decreased more than the negative pressure condition in the frequency range <2 kHz and was enhanced more for frequencies ≥4 kHz. At the center frequency of 2 kHz, there was no difference observed between the positive and negative pressure conditions. For the high frequencies, the negative pressure condition had a substantial reduction in PA magnitude compared to the positive and ambient test conditions. Similarly, Voss et al. (2012) in a sample of eight human-cadaver ears, observed asymmetries in power reflectance between induced positive and negative MEP test conditions. These asymmetries were most noticeable at higher test frequencies. The positive compared to negative pressure condition power reflectance curve better approximated the ambient pressure condition response curve. The current study did not separate PA measures based on negative or positive MEP, but pooled all PA measures using an absolute MEP coding system. The change in PA magnitude observed between non-maneuver and post-maneuver test conditions for the current study may not be an accurate reflection of the uncompensated abnormal MEP influence on measures of PA. Since the PA measures from both negative and positive MEP conditions were pooled, the response curve differences primarily for the higher center frequency (>4 Hz) may have been cancelled out or partially attenuated. Refer to Chapter 9, Study Limitations and Future Directions for further discussion on limitations using absolute MEP codes.

In order to avoid presenting redundant findings, significant interactions involving factors of gender and ethnicity found across all four test conditions (non-maneuver and post-maneuver ambient or peak) will be discussed in the following sections titled *Ethnicity* and *Gender*.

Ethnicity

For the current study for all four test conditions, the interaction between test condition, ethnicity, and frequency was significant. Mean PA was greatest for the Caucasian group for mid to low frequencies (0.25 to ~2.5 kHz) and greater for the Asian and Other ethnic groups compared to Caucasians for the mid to high frequencies (3.15 to 8 kHz). This is consistent with past studies, showing on average Caucasian adults having lower energy reflectance (higher PA) at the low frequencies compared to Chinese adults (Shahnaz & Bork, 2006; Shaw, 2009). This study's findings are consistent with those by Jaffer (2016) who found Caucasian compared to Chinese participants had mean PA magnitudes greater between 0.5 to 1.25 kHz and lower between 4 to 6.3 kHz. Shahnaz and Bork (2006) found that Chinese adults tend to have significantly lower energy reflectance for higher frequencies than do Caucasian adults. This ER difference between ethnic groups is likely due to body size. In general, middle ear measures for female Caucasians will be more comparable to those of Chinese males than to Caucasian males (Shahnaz & Bork, 2006). Consistent with the current study, Shahnaz and Bork (2006) showed Caucasians had lower ER (higher PA) for frequencies 469 to 1500 Hz, but between 3891 to 6000 Hz Chinese participants showed significantly lower ER (higher PA) measures.

For the non-maneuver test conditions (PA= ambient/peak) when collapsing across frequency and gender, mean PA magnitude was found to be slightly larger on average for Caucasians (PA= 0.39/0.43), followed by Others (PA= 0.39/0.42), then the Asian group (PA=0.37/0.40). These trends in PA magnitude were not significant for between ethnic group comparisons within the same test pressure condition. The finding of Caucasians having higher mean PA at both peak and ambient test pressure conditions compared to Asians is consistent with past studies (Jaffer, 2016; Shaw, 2009).

When collapsing the analysis across all four test conditions, gender, and MEP magnitude the interaction between ethnicity and frequency was significant. Again, the Caucasian group had greater PA response in the mid to low frequency range with Asian and Other groups having higher PA magnitude in the high frequency region. There was a difference in peak PA frequency observed between ethnic groups. Caucasians tended to have a peak PA at 2.5 kHz, Asians at 4 kHz, and Others a rounded peak across frequencies 2.5 to 4 kHz. These differences in PA across the frequency range between ethnic groups were also observed when analyzing each test condition individually. Shahnaz and Bork (2006) suggest that the larger ear canal volume and middle ear cavity volumes typical for Caucasian compared to Chinese participants reduces the stiffness of the middle ear system thus decreasing the system's resonance frequency. Findings by Wan and Wong (2002) also suggest that differences in middle ear cavity size between Chinese and Caucasian could account for the differences observed in energy reflection. They also found a significant difference in equivalent ECV between Chinese males and females. Chinese typically exhibit smaller body sizes than Caucasians which likely correlates to differences in middle ear structures, although as addressed by Wan and Wong (2002) these differences have not been explored in any published literature. Reduced compliance of the TM is associated with smaller middle ear cavity volume (Wan & Wong 2002). Eustachian tube anatomical differences could also account for variation in middle ear measurements between ethnic groups (Robinson et al. 1984 as cited in Wan & Wong 2002).

Gender

The interaction between gender and test condition was never found to be significant for the various two-way test condition comparisons. This lack of significant findings indicates that the pattern observed for PA magnitude to either increase or decrease across test conditions was equivalent for both male and female participants. It should be noted that there was an unequal sample size between genders in the current study. Male (n=79 measures) compared to female (n=131 measures) participants did however have significantly greater mean PA magnitudes in all four test conditions collapsing across factors of frequency, MEP magnitude, and ethnicity. On average, males tended to have a 0.03 greater mean PA magnitude.

The interaction between factors of gender and frequency was significant for all test condition comparisons when collapsing the analysis across factors of absolute MEP magnitude and ethnicity. Post-hoc analysis indicates a significant difference in mean PA magnitude between male and female participants at all center frequencies, with one frequency exception. Only at the center frequency of 2.5 kHz is there no significant difference in PA observed between male and female participants. Across the majority of the center frequency range, male participants (n=79) had on average a greater measure of PA magnitude compared to female participants (n=131), with the exception of frequencies 3150 Hz to 5000 Hz, Consistent with past studies, females consistently show a larger PA magnitude at center frequencies between 3.15 to 5 kHz. For male participants, a peak in PA magnitude was observed at the center frequency of 2.5 kHz. A peak in PA magnitude for the averaged female participant data is seen at a center frequency of 4 kHz. Comparable with the current study's findings, Jaffer (2016) also found female participants had significantly higher mean PA values compared to male participants between frequencies 4 to 6.3 kHz, This frequency-specific gender difference in PA magnitude response is also consistent with past studies by Feeney et al. (2014) (as cited in Jaffer, 2016). Similarly, Rosowski et al. (2012) showed ER at frequencies ≤2 kHz being higher for females compared to males, and ER magnitude at frequencies 3, 4, and 6 kHz being greater for male participants. However, Rosowski et al. (2012) stated that these ER gender differences were only statistically significant at the test frequency 4 kHz. A study by Carpenter et al. (2012) found for frequencies 1.5 to 2.5 kHz females had significantly higher ER magnitude responses compared to males. For frequencies 1 to 1.2 kHz as well as from 3 to 5 kHz, men were found to have the greater ER magnitude response compared to females (as cited in Mazlan et al., 2015). A study by Mazlan et al. (2015) examining the effects of age and gender on wideband energy absorbance also found that males showed significantly higher energy absorbance at lower frequencies while females had higher absorbance magnitude responses at higher frequencies. In contrast to these findings, Shahnaz and Bork (2006) for a sample of 62 Caucasian and 64 Chinese young adult participants found no significant effect of gender nor a significant finding for the interaction between frequency and gender.

As was discussed in Chapter 6 regarding gender and ethnicity differences in EOAE amplitude, differences between gender groups for PA measures could be attributed to variation in mechano-acoustical properties and general size of the middle ear structures such as the TM thickness, middle ear cavity volume, middle ear muscle tone differences, and variation in mass of the ossicular chain as well as differences in external ear canal volume (Shahnaz & Bork, 2006).

Polat, Bas, Hayir, Bulut and Atas (2015) developed a normative data set for wideband tympanometric data for young Turkish adults. They found a significant relationship between absorbance measures and gender for the center frequency range of 3.1 to 6.9 kHz. For the remainder of the test frequency range (226 to 2519 Hz and 8000 Hz) PA magnitude responses between male and female participants were not significantly different, Polat et al. (2015) also demonstrate a significant difference in resonance frequency and ear canal volume between genders as well as a significant relationship between measures of participant height and weight in relation to ear canal volume estimates. These frequency-specific differences between male and female participants observed by Polat and colleagues demonstrate similar trends to past studies for Caucasian and Chinese participants, with males having increased reflectance between 4 to 5 kHz (Shahnaz et al., 2013). Polat and colleagues conclude their study advocating for the development of age, gender, and ethnicity specific wideband acoustic normative data for improved diagnostic use of WAI tests. In section 8.2.3, the PA normative data published by Polat and colleagues will be presented in comparison to the PA measures obtained in the current study.

8.2.2 Power Absorbance; Non-maneuver Ambient and Post-maneuver Peak

As predicted, the results of this comparison indicate no significant difference in mean PA magnitude between the non-maneuver ambient (PA= 0.42) and post-maneuver peak (PA= 0.42). Despite the overall interaction of test condition not being significant, the interaction between test condition and frequency was significant. A difference in PA magnitude between test conditions was largest at 0.63 kHz and 2 kHz with only a 0.05 magnitude difference. Interestingly, for the lowest and highest center frequency ranges, it appears that possibly a state of overcompensation occurred, with the post-maneuver peak test condition having a larger PA magnitude compared to the non-maneuver condition. Another explanation for the enhanced PA in the peak test condition is that a lower PA magnitude resulted in the non-maneuver uncompensated condition because of the n=94 absorbance measures falling into MEP categories B to E. In other words, all PA measures in the non-maneuver ambient test condition did not all have MEPs centered on ambient (0 daPa). Another possible explanation for the difference in PA between non-maneuver ambient and post-maneuver peak conditions as a function of frequency could be due to the act of pressure compensation. Introducing a compensating pressure within the external canal can introduce an additional stress to the TM which may also account for differences in PA magnitude in a frequency-specific manner.

The impact of MEP magnitude was explored as a between-subject factor. The higher-order interaction between test condition (non-maneuver ambient versus post-maneuver peak), absolute MEP shift magnitude, and frequency was not significant. For all absolute MEP shift categories (A to E) there was no significant difference in mean PA magnitude between non-maneuver ambient and post-maneuver peak conditions. For the post-maneuver condition, the response pattern of PA magnitude across frequencies 0.25 to 8 kHz including the center frequency at which the peak magnitude is observed reflects the same response as the baseline assessment. Consistent with the current study, Jaffer (2016) found that compensating for abnormal MEP resulted in a significant enhancement of mean PA displaying increased PA between 0.25 to 2 kHz with a reduction in PA between 3.15 to 5 kHz. These findings of improved PA magnitude when testing at TPP (dynamic pressure) compared to ambient pressure (static pressure) levels are consistent with past studies (Kenny, 2011; Shaw, 2009).

Pressure compensation involved introducing a pressure of equal magnitude to the estimated TPP within the external canal in order to equalize the pressure on either side of the TM. By doing so, the TM orientation and immittance properties were restored to a state approximating a normal condition (i.e. ambient MEP). This restoration of the TM and involved ME structures was enough to allow for comparable absorbance of sound energy to be recorded between the post-maneuver peak (compensated) and ambient non-maneuver conditions. In summary, testing at peak pressure primarily for mid to low frequencies creates a PA response analogous to the non-maneuver condition, regardless of the degree of MEP present. This implies that Titan is successfully able to compensate for changes in MEP pressure for 3D-WBT PA measures.

Consistent with the current study, Shaver and Sun (2013) investigated the impact of NMEP (-40 to -225 daPa) for 35 participants on measures of wideband ER. They found that ER increased primarily in the frequency region 1 to 1.5 kHz by a magnitude of 0.2 to 0.40 with decreasing magnitude >3 kHz on a scale of -0.10 to -0.25 in the frequency range of 4.5 to 5.5 kHz. Also parallel to the findings discussed in the present study, the Shaver and Sun (2013) study also indicated a significant interaction between ER magnitude and the degree of NMEP as well as a frequency shift in ER minimum as NMEP magnitude was altered. Consistent with the current study's findings, Shaver and Sun (2013) also demonstrated ER returning to baseline response levels when the NMEP was compensated for by equalizing the pressure at the level of the ear canal.

8.2.3 Power Absorbance; Non-maneuver Ambient and Non-maneuver Peak

As explained earlier for the equivalent test condition comparison with EOAEs measures, this comparison for PA magnitude serves as a way to demonstrate that for normals in the baseline condition, merely assessing PA at settings of peak rather than ambient pressure with the Titan system does not introduce instrument noise or instrument based changes to the test environment. When comparing a test measure to normative data, if the measure is identified as being outside the acceptable range of normal (ex. below the 95th percentile), then this should reflect only physiological differences between the population on which the norms were based and the participants. A referral or indication of abnormal should not be due to instrument or test settings induced changes to the resulting test measure.

Results from the current study indicate a significant difference in PA magnitude between the non-maneuver ambient (PA= 0.42) versus peak (PA= 0.43) pressure test conditions. The variability of data within each test condition, as determined by the standard deviation and 90% range calculations, is highly similar between the two test conditions (refer to Table 113 for descriptive statistics). This finding of significance indicates that even when testing in the non-maneuver condition when participants had natural MEP with the average absolute MEP estimate being 10 daPa, a significant difference was still observed between ambient and peak pressure conditions. The higher PA magnitude observed in the peak condition could be due to (1) instrument related differences in test parameters between ambient and peak test pressure settings, and/or (2) the greater PA magnitude in the peak test condition could be a reflection of PA enhancement from MEP pressure compensation. The mean PA response for participants with the lower PA magnitude resulting in the non-maneuver ambient (uncompensated) condition could be a consequence of the n=94 non-maneuver PA measures falling into absolute MEP categories B to E. The non-maneuver test conditions had sample sizes for the MEP magnitude categories of A (n=116), B (n=80), C (n=11), D (n=2), and E (n=1). In other words, although there was an average absolute MEP of 10 daPa for the n=210 measures in the non-maneuver condition, not all PA measures in the non-maneuver test condition had MEPs centered on ambient (0 daPa). Even small deviations in MEP from 0 daPa, could be significant enough to create differences in mechano-acoustical properties of the middle ear leading to the difference in PA observed between the test pressure conditions. As was discussed in section (8.2.1) for the comparison of non-maneuver ambient to post-maneuver ambient, a significant difference between test conditions was observed at categories C to E. And for the comparison of all four test conditions, post-hoc analysis indicates a significant difference in PA between the post-maneuver ambient test condition and the other three test conditions at categories B to E. This finding indicates that even for measures falling into category B (representing an absolute MEP range of 11 to 25 daPa), compensation for this small degree of abnormal MEP results in a change in overall PA magnitude. If the difference in PA magnitude observed between conditions is truly a result of MEP equalization in the peak condition, then measures of PA would appear to be more sensitive to abnormal MEP and pressure compensation (at least for the low frequencies) than are EOAE measures of absolute amplitude. The interaction between test conditions for measures of EOAE amplitude showed no significant difference between non-maneuver conditions. A major influencing factor contributing to this difference between PA and EOAE compensation results is likely the difference in the frequency range used for PA versus EOAE testing. Abnormal MEP impacts stiffness components of the middle ear system, which influences the transmission of low frequency sounds more so than high frequencies. The frequency range over which PA measures are assessed includes a large low frequency component and the largest reduction in PA magnitude in cases of uncompensated abnormal MEP is observed in these low frequency regions. Test frequencies for DPOAE or TEOAE measures do not include frequencies as low as PA measures; therefore a difference in the degree of impact that abnormal MEP has on these different outcome measures is not unexplainable. This concept of a difference in test frequency range influencing outcome measures will be discussed in more detail in section 8.4, titled: Linking EOAE Amplitude and Power Absorbance Magnitude Changes.

Test Pressure Condition	**Mean PA Magnitude**	**Standard Error**	**Standard Deviation**	**5th Prctl**	**95th Prctl**	**n**
Ambient	0.42	0.02	0.24	0.04	0.79	210
Peak	0.43	0.02	0.23	0.05	0.79	210

Table 113: Non-maneuver condition measures: Comparison of power absorbance (PA) magnitude between test pressure conditions (ambient versus peak). The analysis was collapsed across factors of ethnicity, gender, and absolute middle ear pressure shift magnitude. Descriptive statistics for the 5th to 95th percentile (Prctl) range are included. Current effect: [F(1, 202)=77.746, p=.00000].

The interaction between test condition and ethnicity was significant, when the analysis was collapsed across factors of gender, frequency, and absolute MEP magnitude. Each of the three ethnic groups show a significantly larger PA magnitude mean associated with the peak compared to the ambient test condition. The overall interaction between test condition and frequency was also significant collapsing across factors of gender, ethnicity, and absolute MEP magnitude. A significant difference in PA magnitude was found at center frequencies 0.25 to 1.25 kHz and 2 to 5 kHz. This study's response curve for PA magnitude as a function of frequency and its similarity to findings from past research findings has already been described in section 8.2.1.

Clinical Relevance; Normative Data for Peak versus Ambient Pressure Settings

In general, instrument characteristics should also be considered when developing normative data. Providing normative data reports on the variability in different groups (i.e. gender, age, or ethnic groups) and the use of normative data can act to improve the test specificity or sensitivity

(Shahnaz et al., 2013). As suggested by Shahnaz et al. (2013), WAI measurements assessed at ambient versus peak pressure may impact normative data which could be used in clinical cases of abnormal MEP for diagnostic purposes. Ideally, PA measures assessed at ambient and peak pressure for patients with normal middle ear status should be comparable, not requiring separate norms for the difference test pressure conditions. Figure 62 represents the 90% range (5th and 95th percentiles) for the wideband acoustic immittance PA measures assessed at both instrument settings of ambient and peak pressure. These data represent a sample of n=210 non-maneuver test condition measures based on a normal hearing young adult population with healthy middle ear status. The 90% ranges presented in Figure 62 were generated collapsing across gender and ethnicity. Comparing the 90% range between PA measures at ambient versus peak pressure settings indicates whether the same set of normative data can be used for both test pressure settings. From the current study's data presented in Table 114, the range between the 5th and 95th percentiles is comparable across most of the frequency range, with the greatest separation occurring <800 Hz. The 90% range in the lowest frequency range is slightly wider for the peak pressure condition, indicating that on average participants had a wider range in PA responses in the peak condition. The minimum acceptable PA magnitude (based on the 5th percentile curve) across frequencies 250 to 8000 Hz is comparable between peak and ambient test pressure conditions with the exception of 2000 Hz. The minimum PA magnitude for the peak test condition is larger by a magnitude of 0.07 compared to the ambient condition. Having the peak and ambient 5th percentile curves being largely equivalent indicates that measurements assessed at either peak or ambient pressure for normal individuals, would provide a comparable pass/refer rate or comparable identification of normal from abnormal ears. These results indicate that the same normative data can be used for comparison of PA measures assessed at either ambient or peak pressure using the Titan system.

The presented data in Table 114 was collapsed across genders and ethnic groups. A project for a future study using this study's collected measures would be to create gender and ethnicity-specific 90% ranges for normative data reference. This ethnicity and gender-specific normative data (i.e. 90% ranges) should be compared to other published norms for similar test populations and for different test instruments. In addition, it would be in the interest of clinical best practice to also check newly developed normative data sets against norms for various other middle ear pathologies. Comparisons between normative databases through the use of receiver operating characteristic curves (commonly called ROC curves), provides insight into how normative data can best be used clinically and the role these norms could potentially play in clinical decision making. ROC curves are commonly used for the evaluation of diagnostic tests, providing an indication of test sensitivity and sensitivity.

Test Condition	**Center Frequency (Hz)**	**Mean PA Magnitude**	**SE**	**SD**	**5th Prctl**	**95th Prctl**	**n**
Non-maneuver Ambient	250	0.12	0.00	0.07	0.02	0.22	210
Non-maneuver Peak	250	0.13	0.00	0.07	0.03	0.26	210
Non-maneuver Ambient	315	0.12	0.01	0.08	0.02	0.25	210
Non-maneuver Peak	315	0.14	0.01	0.08	0.02	0.29	210
Non-maneuver Ambient	400	0.17	0.01	0.10	0.03	0.32	210
Non-maneuver Peak	400	0.19	0.01	0.10	0.04	0.38	210
Non-maneuver Ambient	500	0.25	0.01	0.12	0.07	0.43	210
Non-maneuver Peak	500	0.28	0.01	0.13	0.09	0.52	210
Non-maneuver Ambient	630	0.33	0.01	0.16	0.09	0.60	210
Non-maneuver Peak	630	0.37	0.01	0.17	0.10	0.68	210

Test Condition	Center Frequency (Hz)	Mean PA Magnitude	SE	SD	5^{th} Prctl	95^{th} Prctl	n
Non-maneuver Ambient	800	0.42	0.01	0.18	0.12	0.72	210
Non-maneuver Peak	800	0.46	0.01	0.18	0.13	0.79	210
Non-maneuver Ambient	1000	0.50	0.01	0.17	0.18	0.73	210
Non-maneuver Peak	1000	0.53	0.01	0.16	0.20	0.74	210
Non-maneuver Ambient	1250	0.57	0.01	0.14	0.31	0.74	210
Non-maneuver Peak	1250	0.58	0.01	0.13	0.34	0.75	210
Non-maneuver Ambient	1600	0.58	0.01	0.15	0.32	0.78	210
Non-maneuver Peak	1600	0.58	0.01	0.14	0.34	0.78	210
Non-maneuver Ambient	2000	0.58	0.01	0.16	0.25	0.81	210
Non-maneuver Peak	2000	0.57	0.01	0.16	0.32	0.79	210
Non-maneuver Ambient	2500	0.66	0.01	0.15	0.39	0.88	210
Non-maneuver Peak	2500	0.65	0.01	0.15	0.39	0.88	210
Non-maneuver Ambient	3150	0.63	0.01	0.19	0.30	0.94	210
Non-maneuver Peak	3150	0.61	0.01	0.19	0.31	0.92	210
Non-maneuver Ambient	4000	0.63	0.01	0.18	0.33	0.92	210
Non-maneuver Peak	4000	0.62	0.01	0.18	0.32	0.89	210
Non-maneuver Ambient	5000	0.51	0.01	0.15	0.29	0.76	210
Non-maneuver Peak	5000	0.50	0.01	0.15	0.29	0.76	210
Non-maneuver Ambient	6300	0.35	0.01	0.18	0.05	0.65	210
Non-maneuver Peak	6300	0.35	0.01	0.18	0.05	0.63	210
Non-maneuver Ambient	8000	0.26	0.02	0.21	0.00	0.65	210
Non-maneuver Peak	8000	0.26	0.02	0.21	0.00	0.65	210

Table 114: Non-maneuver condition: Comparison of mean power absorbance (PA) magnitude between test pressure conditions (ambient versus peak) as a function of center frequency (250 to 8000 Hz). The analysis was collapsed across factors of ethnicity, absolute middle ear pressure shift magnitude, and gender. Descriptive statistics for 5^{th} and 95^{th} percentiles (Prctl), standard deviation (SD) and standard error (SE) are included. Shaded data rows distinguish the non-maneuver peak test condition from the ambient condition. Current effect: [F(15, 3030)=62.754, p=.00000].

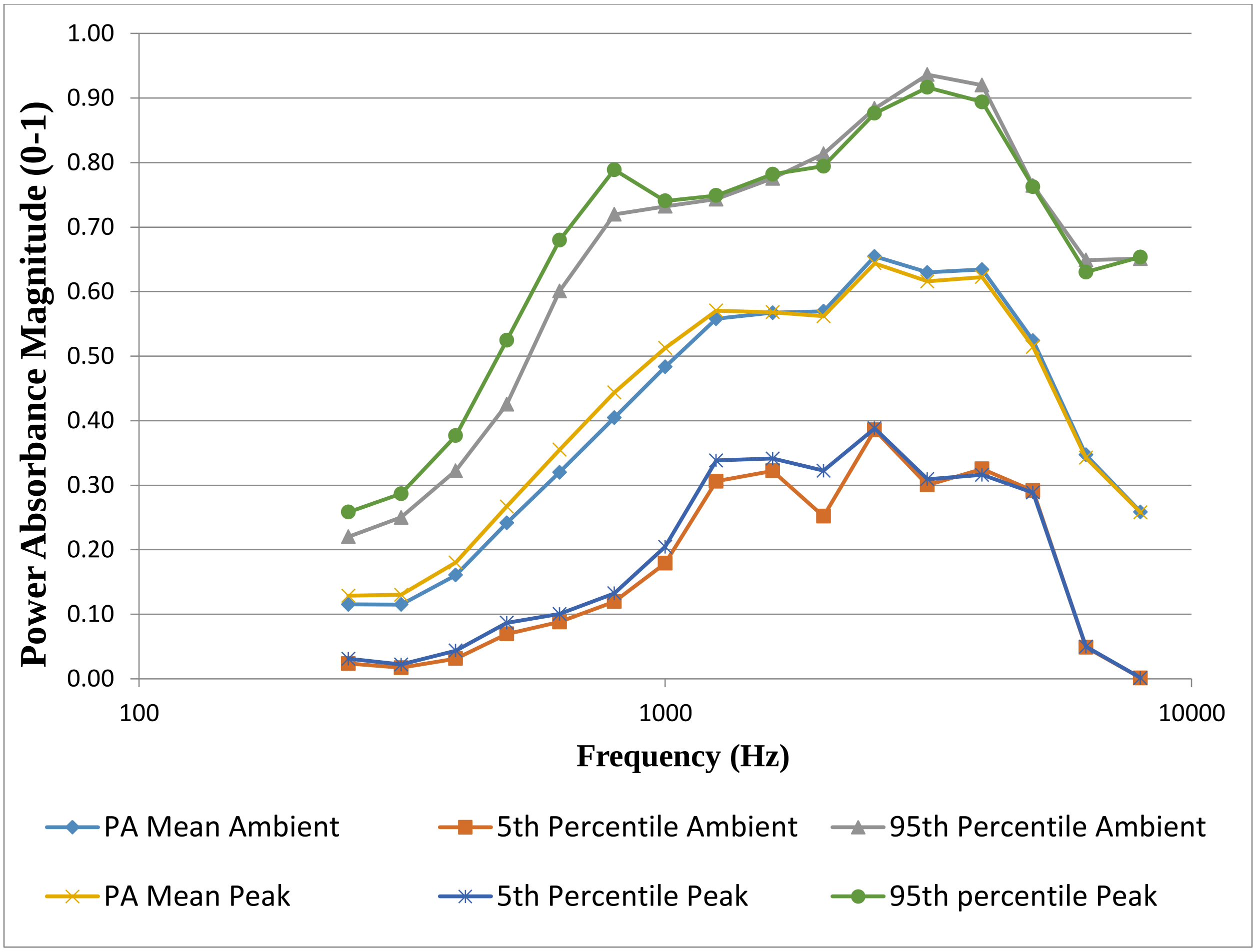


Figure 62: Non-maneuver ambient (n=210) and non-maneuver peak (n=210) test pressure condition outcome measures of power absorbance (PA) magnitude. Mean and the 5th and 95th percentile values of PA magnitude are plotted as a function of frequency. PA data is averaged in 1/3-octaves based on 16 center frequencies from 250 to 8000 Hz. PA measures are pooled between genders and ethnic groups (Caucasian, Asian and Other).

Normative Data Comparison: Polat et al. (2015)

The normative data study by Polat et al. (2015) has already been discussed briefly in previous sections. Polat et al. (2015) developed norms for wideband tympanometric measures based on a population of healthy young-adults of Turkish ethnicity. The comparison between these Turkish PA norms and the current study's measures of PA is of value to include in this manuscript because both studies have similar features, making them appropriate samples for comparison. Analogous to the current study, the test instrument used by Polat et al. (2015) was the Interacoustics Titan Suite, version 3.1 with the IMP440 module. The frequency range over which PA measures were obtained is also similar between studies; refer to Table 115 for exact frequency points.

Figure 63 shows the normative data from Polat et al. (2015) plotted on the same graph as the current study's data. The 10th and 90th percentile values representing an 80% response range are plotted as an indication of each study's dispersion of data (refer to Table 115 for descriptive statistic). For the Polat et al. (2015) norms, a significant interaction was found between PA and gender at center frequencies 3.1 to 6.9 kHz, with females having the greater PA magnitude in this frequency range. It should be noted, that the published Polat et al. (2015) study provides gender-specific normative data; however, for purposes of comparison to the current data, the Polat et al. (2015) PA data combined between gender groups has been displayed. The response pattern of PA magnitude across the frequency range is similar is shape between these two studies, but the magnitude of the responses slightly differ. In comparison to the current study, the Polat et al. (2015) combined gender norms show: (1) Greater PA magnitude across the majority of the frequency range for mean and percentile values, (2) most evident PA magnitude differences at mid frequencies between 800 to 3150 Hz, and (3) a narrower 80% response range in the low frequency region (≤1 kHz). Indicated by calculations of standard deviation, dispersion of the data across frequencies is very similar between studies. The difference in PA magnitude observed between these two studies could be in part attributed to differences in the ethnic and gender composition of the data. The Turkish norms are based on a fairly even distribution of female (n=58) and male (n=51) participants whereas the current study has substantially more PA data from female participants (n=131 PA measures) than male participants (n=79 PA measures). The Polat et al. (2015) norms are also based on just a population of Turkish participants. The PA data presented in Figure 63 and Table 115 for the current study is collapsed between the three ethnic groups (Caucasian, Asian, and Other). Additionally, PA response difference between studies could also be due to difference in each study's inclusion criteria. Polat and colleagues set the following inclusion criteria (not an exhaustive list): Participants had pure-tone hearing thresholds <15 dB with no conductive components, and TEOAE responses between 1 to 4 kHz with a SNR >3 dB. Unlike the current study, future studies with the main objective of developing PA normative data may opt to use more stringent inclusion criteria for PA measures in the development of normative data, such as set criteria for EOAE amplitude/SNR or a MEP inclusion/exclusion criterion. A future project involving the current study's data would again be to generate ethnic- and gender-specific normative data for PA measures.

Differences observed in mean and 80% response range between these two studies supports the concluding remarks by Polat and colleagues in their 2015 publication: They conclude their study by advocating for the development of age, gender, and ethnicity specific wideband acoustic normative data for improved diagnostic use of WAI tests.

Polat et al. (2015) - Normative PA Data (n=218 measures, male & female Turkish participants)																	
Freq. (Hz)		**226**	**324**	**385**	**500**	**629**	**793**	**1000**	**1259**	**1587**	**2000**	**2519**	**3174**	**4000**	**5039**	**6349**	**8000**
	Mean	0.12	0.15	0.19	0.28	0.37	0.52	0.66	0.68	0.67	0.68	0.72	0.71	0.64	0.49	0.44	0.33
	SD	0.05	0.07	0.01	0.11	0.13	0.15	0.14	0.14	0.14	0.15	0.17	0.18	0.18	0.17	0.13	0.24
	10th Prctl	0.06	0.06	0.08	0.15	0.2	0.35	0.48	0.47	0.45	0.47	0.49	0.44	0.36	0.32	0.28	0.08
	90th Prctl	0.19	0.24	0.3	0.41	0.55	0.73	0.84	0.84	0.83	0.88	0.92	0.93	0.86	0.73	0.62	0.72
Current Study (n=210 PA measures)																	
Freq. (Hz)		**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**
Non-maneuver Ambient	**Mean**	0.12	0.12	0.17	0.25	0.33	0.42	0.50	0.57	0.58	0.58	0.66	0.63	0.63	0.51	0.35	0.26
	SD	0.07	0.08	0.10	0.12	0.16	0.18	0.17	0.14	0.15	0.16	0.15	0.19	0.18	0.15	0.18	0.21
	10th Prctl	0.03	0.02	0.04	0.09	0.12	0.16	0.23	0.37	0.40	0.38	0.46	0.35	0.39	0.32	0.14	0.00
	90th Prctl	0.20	0.21	0.28	0.39	0.49	0.63	0.69	0.72	0.73	0.77	0.85	0.89	0.86	0.71	0.55	0.55

Table 115: Current Study: Non-maneuver ambient test condition outcome measures of power absorbance (PA) magnitude (pooled between genders and ethnic groups). Polat et al. (2015) study: A sample of n=218 PA measures from young-adult Turkish participants (female and male). For both studies, mean, the 10th and 90th percentile (Prctl), and standard deviation (SD) values of PA magnitude are shown for each study's respective test frequency (freq.) range.

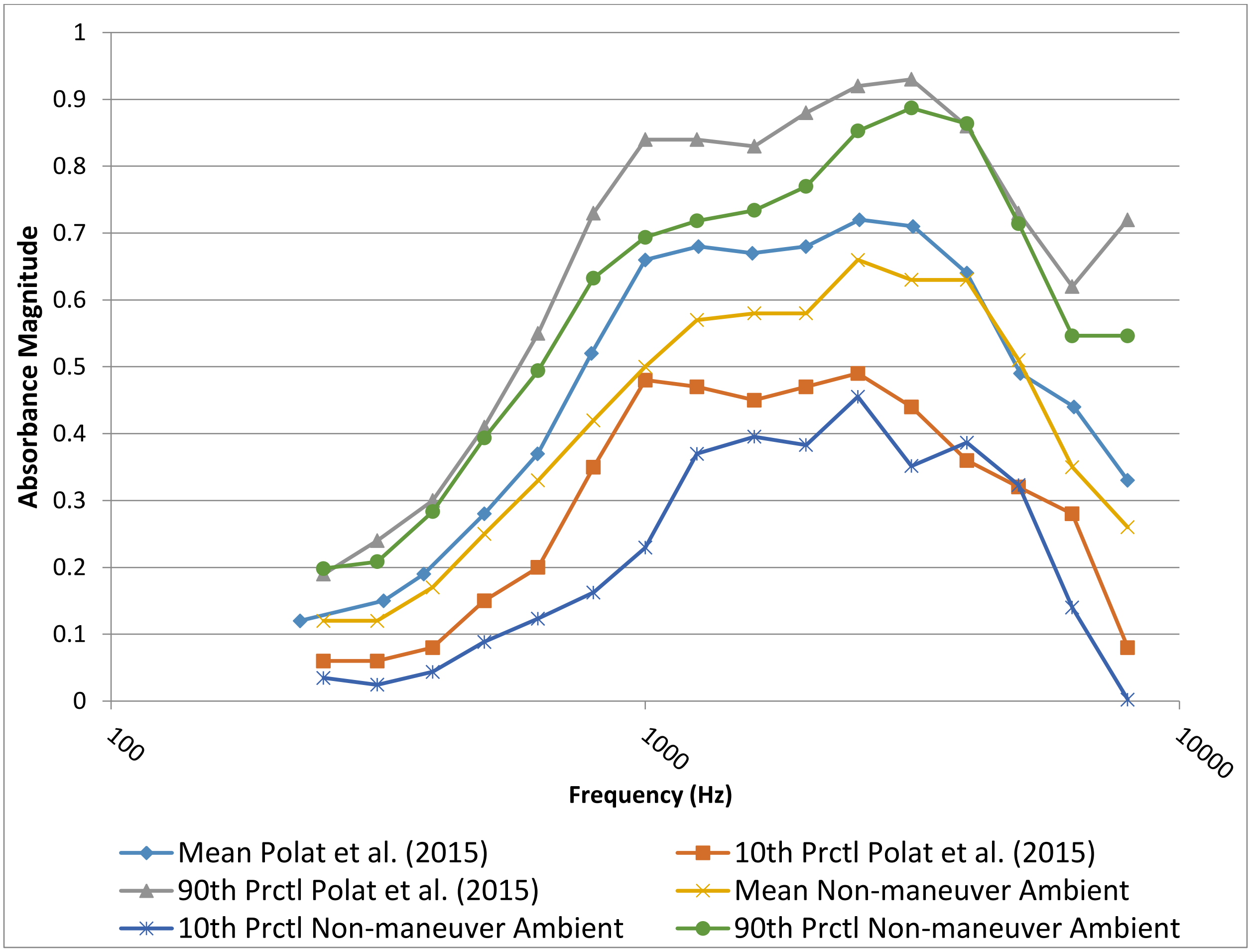


Figure 63: Current Study: Non-maneuver ambient (n=210) and post-maneuver peak (n=210) test pressure condition outcome measures of power absorbance (PA) magnitude. PA measures are pooled between genders and ethnic groups (Caucasian, Asian and Other). Polat et al. (2015) study: A sample of n=218 PA measures from young-adult Turkish participants (female and male). For both studies, mean and the 10^{th} and 90^{th} percentile values of PA magnitude are plotted as a function of frequency. For the current study, PA data is averaged in 1/3-octaves based on 16 center frequencies from 250 to 8000 Hz (note: x-axis center frequencies reference the current study's frequency range).

Normative Data Comparison: Sun (2015)

In the newly published Sun (2015) paper, normative data for measures of wideband acoustics immittance is provided for a large sample (n=84) of healthy and normal hearing young-adults. Similar to the current study, Sun (2015) had a much larger sampling from female participants (n=72) compared to male (n=12) participants. The participant inclusion/exclusion criterion is also similar between studies: Sun (2015) required participants to have (1) normal hearing to pure-tone air-conduction stimuli 250 to 8000 Hz ≤20 dB HL with air-bon gaps ≤15 dB, (2) a single-peaked band pass EA tympanogram, and (3) no EOAE testing was required. Unlike the current study, for inclusion in the Sun (2015) study, participants had to have TPP within the range of +5 to -45 daPa referencing the estimate from the absorbance tympanogram. According to Sun (2015), this pressure range corresponds to approximately ±25 daPa of MEP when referencing a conventional 226 Hz tympanogram. Participant ethnicity was not specified within the Sun (2015) study. Data for Sun (2015) was obtained using an Interacoustics computer run wideband tympanogram (WBT) research system using the Titan probe. This research system was interfaced with WBT software (version 3.2.1), which Sun refers to as a former version of ReflWin software (refer to published study for further details). Normative energy absorbance data published in Sun (2015) is presented in Table 116. Data is shown in half-octave frequencies (0.236 to 8 kHz). Measurements were obtained with MEP centered on 0 daPa (comparative to the current study's non-maneuver ambient test condition). Normative data from the current study and from Sun (2015) were not displayed in graphical format together given the difference in frequency sample points and thus, an incompatible x-axis distribution.

The response pattern of mean PA magnitude between the two studies is similar. Sun (2015) found the lowest mean absorbance at the lowest test frequency (0.236 kHz) with a peak in energy absorbance occurring at 4 kHz. Consistent with the current study, a sloping decrease in absorbance was also noted at higher frequencies. There is a difference between studies for the trend in PA at the highest test frequency of 8 kHz: Sun (2015) show absorbance increasing at 8 kHz relative to mean values at the neighboring test frequency 6 kHz. Contrary to this high-frequency upward trend in absorbance, the current study shows a steady reduction in PA magnitude >4 kHz. The mean PA magnitude as a function of frequency and 80% range responses (95th and 5th percentiles), for these two studies are highly comparable. A comparison of descriptive statistics between Sun (2015) and the current study's is provided in Table 116. Similarities between the Sun (2015) normative data and the current study may be a result of similar participant inclusion criteria, the large sample of female compared to male data, and use of similar test instrumentation.

Current Study - Wideband Acoustic Immittance Adult Normative Data - 16 center frequencies (1/3 octave bands)																		
Non-maneuver Ambient	**kHz**	**0.25**	**0.315**	**0.4**	**0.5**	**0.63**		**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
	mean	0.12	0.11	0.16	0.24	0.32		0.40	0.48	0.56	0.57	0.57	0.65	0.63	0.63	0.52	0.35	0.26
	5th Prctl	0.02	0.02	0.03	0.07	0.09		0.12	0.18	0.31	0.32	0.25	0.39	0.30	0.33	0.29	0.05	0.00
	95th Prctl	0.22	0.25	0.32	0.43	0.60		0.72	0.73	0.74	0.78	0.81	0.88	0.94	0.92	0.76	0.65	0.65
	SD	0.07	0.08	0.10	0.12	0.16		0.18	0.17	0.14	0.15	0.16	0.15	0.19	0.18	0.15	0.18	0.21
Sun (2015) Wideband Acoustic Immittance Adult Normative Data - 11 frequency points (1/2 octave bands)																		
Ambient	**kHz**	**0.236**	**0.354**		**0.5**		**0.71**		**1**		**1.41**	**2**	**2.828**		**4**	**5.66**		**8**
	Mean	0.08	0.11		0.3		0.42		0.56		0.61	0.61	0.73		0.7	0.35		0.38
	5th Prctl	0.03	0.03		0.1		0.24		0.33		0.38	0.37	0.47		0.45	0.06		0.15
	95th Prctl	0.16	0.24		0.4		0.66		0.87		0.83	0.83	0.96		0.95	0.61		0.61
	SD	0.04	0.07		0.1		0.13		0.18		0.14	0.13	0.15		0.15	0.17		0.13

Table 116: Normative energy absorbance data published in Sun (2015): This sample is based on n=84 ears from a normal hearing young-adult population. Power absorbance data is shown in 1/2 octave frequencies (0.236 to 8 kHz). Data from the current study is from the non-maneuver ambient test condition displayed across the frequency range in 1/3 octave bands (0.25 to 8 kHz). Shaded boxes indicate frequency-specific PA data unavailable for the corresponding study. Data from both studies is collapsed across genders.

8.2.4 Power Absorbance; Post-maneuver Ambient and Post-maneuver Peak

Assessing PA at peak pressure represents a potential clinical test protocol to compensate for the presence of abnormal MEP. Comparing PA magnitude from these two particular test conditions provides support for the conclusion that it is the factor of pressure compensation that is responsible for the change in PA magnitude between test conditions. This comparison also identifies the abnormal MEP as being the responsible element for the change in PA magnitude and not, for example, changes attributable to other factors. Other variables being things such as test ordering effects or from alterations other than pressure changes such as having the participants perform the pressure inducing maneuvers. The same rationale for performing this test condition comparison was presented for the equivalent comparison for EOAE measures.

A significant difference in mean PA magnitude of 0.07 was observed between test conditions. As anticipated, the uncompensated ambient (0.35) compared to peak (0.42) test condition had the lower mean PA magnitude. This analysis was collapsed across the factors of frequency, gender, ethnicity, and absolute MEP magnitude. The significant interaction between frequency, test condition, and absolute MEP magnitude clearly shows that when MEP is compensated for (at least in the MEP range of 0 to 276 daPa with a mean of 65 daPa), there is a significant change in PA response compared to the uncompensated condition. In the post-maneuver peak condition, all PA/frequency response curves for the five absolute MEP magnitude categories (A to E) overlap across the entire frequency range and the peak PA magnitude response occurs around the same center frequency (2.5 kHz).

The interaction between test condition (post-maneuver ambient versus peak) and frequency is significant, when collapsing the analysis across factors of gender, ethnicity, and absolute MEP magnitude. The difference in PA magnitude between test conditions across the frequency range 0.25 to 8 kHz displays a similar pattern already described in section (8.2.1), with (1) the most noticeable PA changes occurring <4 kHz, (2) a shift of the response peak to higher center frequencies with uncompensated MEP, and (3) enhanced PA for higher frequencies with uncompensated MEP. As discussed previously, the interaction between test condition and frequency for the non-maneuver ambient and post-maneuver peak conditions is significant. Figure 64 displays the PA magnitude response as a function of frequency for the baseline non-maneuver ambient test pressure condition measures and post-maneuver measures (ambient and peak pressure). The outcome measure of PA magnitude is shown as mean values, as a function of frequency across a log scale. The 90% response range is represented by 5th and 95th percentile curves. These PA measures are pooled between gender and ethnic groups. From Figure 64, it is clearly shown that the compensation of abnormal MEP is reflected in the post-maneuver peak response curve approximating the baseline response curve: PA magnitude for the mean, 5th percentile, and 95th percentile curves are similar in magnitude between the post-maneuver peak and baseline test conditions. However, despite the NMEP being compensated for in the post-maneuver peak condition, there is still a slight difference in PA magnitude observed between these test conditions for the mid frequency region. This difference in PA magnitude between the baseline and compensated test condition is especially evident for the mean and 5th percentile curves. Refer to Appendix A, Table 173 for the descriptive statistics (percentiles and standard deviations) associated with Figure 64. As discussed previously, the response curve for the uncompensated post-maneuver test condition is noticeably different in PA magnitude for the mid to low frequencies (roughly <4 kHz), in comparison to the other two test conditions. As expected, there is an evident decrease in PA magnitude for low frequencies in cases of uncompensated abnormal MEP.

Overall, the results from the current study imply that Titan is able to compensate for abnormal MEP pressure for wideband acoustic immittance PA measures. The result is PA response measures comparable in magnitude and response pattern to test measures assessed at baseline conditions when MEP is centered on 0 daPa (ambient). Refer to the following section 8.2.5 for a discussion concerning the clinical application of pressure compensated PA testing.

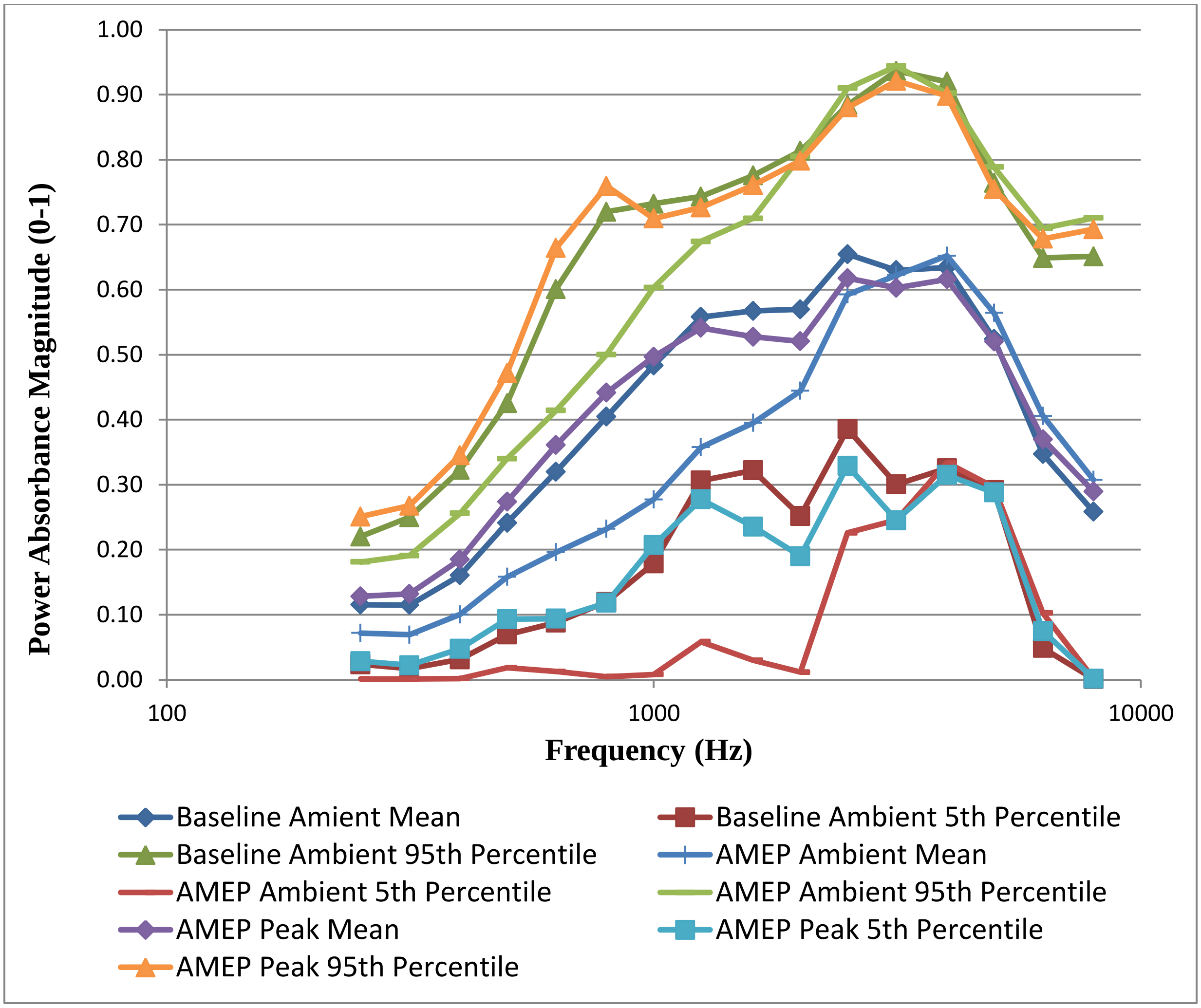


Figure 64: Power absorbance (PA) magnitude. Data labeled as baseline represent non-maneuver ambient test condition measures. Post-maneuver measures for ambient and peak pressure conditions are displayed as abnormal middle ear pressure (AMEP) ambient or peak. Mean and 90% range (5th and 95th percentiles) of PA magnitude as a function of frequency. PA measures are pooled between gender and ethnic groups. There is a sample size of n=210 PA measures for all test conditions. PA measures were analyzed for 1/3-octave bands for 16 center frequencies between 250 to 8000 Hz.

8.2.5 A Clinical Perspective and Scenarios

From a clinical perspective, if a patient presents with abnormal MEP, significant differences in PA magnitude and thus varying indications of middle ear immittance would result if testing is conducted at ambient and not peak pressure. Such a significant difference in outcome measures between ambient and peak settings could be advantageous or unfavorable depending on the clinical question being addressed and purpose of the assessment. If wideband acoustic immittance measures are being conducted to assess general TM and middle ear status in order to identify pathology, then an accurate measure of PA reflecting the pathological status would be required. For example, if a patient presents with a single pathology such as NMEP, testing PA at ambient pressure would be first preferred over a peak setting, so that the abnormal MEP is identified. Testing of PA at ambient pressure in a case of NMEP would result in a response pattern demonstrated in the current study: PA magnitude would be reduced primarily for the mid to low frequencies with a shift in the PA peak to a higher frequency point. Secondary immittance testing for this patient could then be performed at peak pressure. If after pressure compensation the PA magnitude response curve falls within a normal response range compared to normative data, then this supports the conclusions that the sole pathology for this patient is abnormal MEP. The presence of abnormal MEP would also be confirmed by the tympanogram estimate of MEP. If however after pressure compensation PA remained attenuated for the mid to low frequency range, then this would suggest a dual middle ear pathology (refer to the following discussion regarding distinguishing dual pathologies). The sustained reduction in PA magnitude would not be attributed to the compensated NMEP but may indicate middle ear pathology such as otosclerosis. If for the same patient presenting with only NMEP the clinical goal is to assess cochlear function by means of EOAEs, then improved power absorbance would be favorable.

Thus, testing EOAEs at a setting of peak pressure would result in enhanced PA and thus improved cochlear stimulation due additional sound energy being transmitted through the middle ear to the cochlea than would be if testing at ambient pressure. As demonstrated in the current study, assessing EOAE at peak pressure does not require PA to also be assessed at peak pressure. In this clinical example, the benefit of assessing PA at peak pressure and comparing the outcome response to measurements at ambient would be to confirm that NMEP is the only middle ear pathology present. The purpose of examining the impact of peak pressure testing on PA measures in the current study was to demonstrate how a change in middle ear immittance will alter the EOAE strength and to explore the possibility of using PA magnitude changes due to MEP variations as a predictor of EOAE amplitude deviations from baseline measures. The connection between improved energy absorbance and thus an enhancement of the eliciting EOAE stimuli reaching the cochlea leading to a potential change in emission strength will be further discussed in Chapter 8, *Linking EOAE Amplitude & Power Absorbance Magnitude Changes* and in Chapter 9 Conclusions.

A clinical scenario in which it would potentially be advantageous to assess wideband acoustic immittance PA measures at peak pressure would be for a patient with dual pathologies with similar or overlapping features. For example, both otosclerosis and NMEP can increase the stiffness of the middle ear system, produce a type A tympanogram, be unnoticeable with cursory otoscopy, result in absent acoustic reflexes, and contribute to an air-bone gap with behavioral audiometry (Shahnaz et al., 2009). Shahnaz et al. (2009) have demonstrated that energy reflectance has the potential to distinguish otosclerotic from normal ears, with characteristic increase in ER (decrease in absorbance) between 211 to 6000 Hz (statistically significant between 400 and 1000 Hz) for otosclerotic ears. For example, if a patient presents with both otosclerosis and NMEP, teasing part these two conditions by mean of immittance assessment would be difficult at a test setting of ambient pressure. If however, immittance testing was conducted at peak pressure, this would mitigate the influence of the NMEP on the resulting ER or PA response curve, allowing deviations in the reflectance or absorbance response from normative data to be attributable the otosclerotic influence on the TM and middle ear system. Perhaps equalizing for abnormal MEP provides an improved PA magnitude response, but it is not clear yet if this act of pressure equalization impacts the response patterns characteristic of certain pathologies such as otosclerosis. Future studies are required to further investigate the finer mechanic-acoustic changes to the TM and middle ear ossicular chain. There is also a need for the development of or extension of age, gender, ethnic, pressure compensation method, and pathology specific normative data. The current manuscript and study outlines a preliminary database of pressure compensated PA measures for a normal hearing healthy young adult population with specific gender and ethnicity separated data.

Another clinical scenario in which it would potentially be advantageous to assess wideband acoustic immittance PA measures at peak pressure would be in the following case of overlapping middle ear pathologies, in which both pathologies again have similar features. A clinical example of the potential use of pressure compensated PA measures is in cases of otitis media (OM) which can occur with or without effusion. Feeney et al. (2003) demonstrated for cases of OM with effusion, ER was high (close to 1) for the mid to low frequencies <4 kHz with a sharp and narrow notch in ER occurring at the high frequencies (4 to 7 kHz). The ER/PA response curve as a function of frequency is similar for cases of abnormal MEP and OM, especially in cases of extreme abnormal MEP (Feeney et al., 2003). Beers et al. (2010) in a study of school-aged children, indicated a decrease in ER across the entire frequency range of about 315 to 6300 Hz when comparing normal middle ears to ear with mild NMEP, then to ears with severe NMEP, and ears with middle ear effusion displayed the lowest ER magnitude across frequencies. Replicating these findings, Voss (2012) showed for human-cadaver ears changes in energy reflectance were minor when the fraction of the middle ear cavity filled with fluid was small, but ER increases as the amount of fluid increased especially in the low frequency range. These findings are consistent with the current study's findings for the interaction between PA and MEP magnitude, where the greatest reduction in PA magnitude was observed for the mid to low frequency range and this change in PA magnitude was related to the degree of abnormal MEP. When the abnormal MEP was compensated for, the PA/frequency response curve approximated the responses in the non-maneuver test condition. As suggested by Margolis et al. (1999), assessment of ER (or PA) at peak pressure could help in removing the contribution of NMEP to changes in the ER response pattern to better identify other pathologies (such as OM) when comparing to normative data. Additionally, assessing PA (or ER) at TPP could provide an estimate of the amount of middle ear fluid present in cases of OM. For example, if pressure compensation results in restoring PA responses to within a normal range, then likely the abnormal response obtained at ambient test pressure was due to the presence of NMEP. If the PA response is only partially returned to within normal limits after pressure compensation, then this could indicate a small amount of fluid is present in the middle ear space. If however, pressure compensation does not result in returning PA responses to within the 90% range, then this could indicate a middle ear with a substantial amount of fluid as characterized by the ER/PA response pattern when compared to normative data.

8.3 Sources of Differences in Power Absorbance Magnitude

In summary, no significant difference was observed for the comparison of mean PA magnitude between the non-maneuver ambient and post-maneuver peak test conditions collapsing across factors of frequency, gender, ethnicity, and MEP magnitude. For the same two-way test condition comparison with DPOAE and TEOAE measures, a significant difference in mean amplitude was observed. A possibility for why the PA measures compared at peak and ambient pressures were superior to EOAE measures regarding pressure compensation ability could be attributed to the test time required to complete the different measures. Measurements of PA at ambient and peak pressures took on average three seconds to complete. This is in comparison to the average of 170 and 130 seconds participants were requested to maintain the induced MEP during EOAE post-maneuver recordings. A significant change in MEP over the time duration of three seconds is not likely. How well participants maintained MEP pre- versus post-recording of PA measures could be inferred from the 3D-WBT MEP estimate comparison to the proceeding conventional 226 Hz tympanogram estimate. This comparison between MEP estimates from the two estimation methods was shown to be not significant (refer to Chapter 7 discussion). In contrast to EOAE measures, an investigation into how well Titan maintained Target pressure during peak measures could not be conducted. The Titan does not provide an estimate of the compensation pressure it maintained during peak pressure recordings for PA measures.

Refer to Chapter 9 for a review of PA specific study limitations and suggestions for future research.

8.4 Linking EOAE Amplitude and Power Absorbance Magnitude Changes

The main purpose of exploring measures of PA was to compare the change in PA magnitude with the change in EOAE amplitude between test conditions of normal and abnormal MEP. This was expanded by exploring the interaction of PA magnitude and EOAE amplitude as a function of absolute MEP magnitude. It is of interest to examine if similar or different trends are observed with the two outcome measures (EOAE and PA). It was also of interest to see if changes in one measure (either EOAE or PA) could help predict the possible change in the other outcome measure. Overall, when testing EOAEs at compensated pressures, the act of equalizing pressure on either side of the TM allowed for improved stimulus transmission into the middle ear space as demonstrated by the current study.

When there is a change in pressure within the middle ear cavity, there is an increase in energy reflectance for the forward propagating acoustic stimulus in response to the change in transfer function properties (Keefe & Schairer, 2011). The acoustic signals required to elicit DPOAEs and TEOAEs, must first be absorbed into the middle ear cavity to be transmitted to the cochlea and similarly the emitted cochlear response must be sent back to the external ear canal. The abnormal pressure within the middle ear space also impacts the emitted response from the cochlea, impacting the evoked emission amplitude. In summary, when testing PA at a compensating pressure, the increased energy reflectance due to the presence of abnormal MEP is accounted for, and the intended stimulus energy can be transmitted from the external canal into the middle ear. The power loss within the middle ear in cases of normal or abnormal MEP is not known. Although the absorbance enhancement of acoustic energy (eliciting OAE stimuli) into the middle ear space has been shown under conditions of compensated abnormal MEP, there is still an attenuation of this forward moving acoustic energy due to the MEP influence on the ossicular chain and orientation of the labyrinthine windows (Avan et al., 2000). Additionally, there is still the complication of the EOAE to move through the middle ear cavity under abnormal pressure, and then for the emitted response to be measured at the probe within the external canal. The process of pressure compensation requires the modification of pressure in the external canal providing another point along the transmission pathway for the EOAE to be manipulated. In short, the transmission pathway of acoustic PA is less complex compared to the involved forward and backwards travelling pathway of EOAEs. Therefore, persisting differences in PA magnitude response and EOAE amplitude responses even with pressure compensation are expected. Not only is the transmission pathway more complex for EOAEs measures compared to PA measures, the difference in the travelling direction of the involved energy must be considered. For example, the middle ear transfer function increases the transmission of acoustic energy in a frequency-specific manner for forward travelling signals from the external ear canal to the cochlea. This forward transmission pathway is used at least in part, when considering both PA and EOAE measures. However, the evoked OAEs must travel from their cochlear origin to the external ear canal. This pathway is essentially going against the middle ear transfer function (i.e. in the backward direction). Although the structures involved are the same for both forward and backward travelling signals involved in EOAE measures, the finer mechanical-acoustic properties are different. The backward-travelling emission energy will not be enhanced by the middle ear transfer function as is seen for the forward-travelling evoking stimulus. The middle ear transfer function may be different for forward and backward transmission pathways, which could potentially impact different frequencies.

The relatively stable PA magnitude for the mid to high frequencies in the presence of abnormal MEP of various magnitudes is likely to account for why there is less of a change in EOAE amplitude in this frequency region for uncompensated test conditions. As well, the trend for an enhancement in PA for the higher center frequencies with uncompensated MEP could lead to a cancelling effect between improved stimulus level from increased high frequency PA and reduced EOAE strength due to abnormal MEP. For the low frequencies, as observed in the current study, there is a significant reduction in PA magnitude which increases as MEP magnitude increases. The attenuation of EOAE amplitude in the mid to low frequency range is likely caused by a reduction in the sound energy absorbed by the middle ear in this frequency range for conditions of uncompensated abnormal MEP. This is in addition to the attenuation of sound energy from the impact of middle ear transfer function changes influencing the backwards transmitted signals (i.e. emissions). When comparing the response pattern between PA and EOAE measures, it is important to also evaluate the test frequency range used for each measurement type. In the current study, the frequency range tested for DPOAEs was between 1.5 to 8 kHz and for TEOAEs it was between frequencies of 1 to 5 kHz. Testing EOAE at lower frequencies has minimal clinical relevance as the use of TEOAE and DPOAE for detecting hearing loss is limited to about ≥1 kHz. Background noise interferes with the lower test frequencies, often decreasing with intensity as test frequency increases (Gorga et al., 1993b). Gorga and colleagues aimed to evaluate the ability of using TEOAEs and DPOAEs in identifying normal hearing from hearing impaired ears. They concluded that both TEOAE and DPOAE amplitude measures could not be reliably measured below 1 kHz due to the interference of high noise levels (Gorga et al., 1993b). They concluded that both DPOAE and TEOAE measures were able to identify normal from hearing impaired ears most accurately for the mid-to-high frequency between 2 and 4 kHz but not as well for the low frequency range. On the other hand, measures of power absorbance and energy reflectance are not impacted in the same manner by ambient noise therefore; a wider range in test frequencies is used for these measures, often with the lowest frequency point as low as 0.25 kHz. In the current study, the PA frequency range was between 0.25 to 8 kHz. The greatest reduction in PA magnitude with uncompensated MEP was seen in the lowest range of frequencies: PA magnitude decreased in a sloping manner with a decrease in frequency below <4 kHz. Therefore, the greatest attenuation of PA magnitude from uncompensated MEP was observed at frequencies not included in either DPOAE or TEOAE analyses. In a hypothetical situation, in which EOAE could be assessed at low frequencies with minimal impact from ambient noise, then a significantly large reduction in EOAE amplitude would likely result in cases of uncompensated abnormal MEP.

Scheperle, Neely, Kopun and Gorga (2008) showed improved DPOAE measurements between 2 to 8 kHz when the stimulus was calibrated within the ear canal, accounting for the forward pressure level and when accounting for stimulus intensity level. These findings imply that the improved DPOAE response is likely due to the improved and consistent transmission of stimulus energy to the cochlear across the test frequency range. Similarly, Trine et al. (1993) stated that unequalized abnormal MEP created a high pass filter across the TM and through the middle ear cavity. They noted a cut-off frequency of 2 to 3 kHz, above which point acoustic energy characteristic of frequencies ≥2 to 3 kHz would pass relatively unimpeded by the uncompensated

MEP. They also showed NMEP impacting the stimulus spectrum with a peak observed at 4 kHz, which corresponds to the peak PA frequency observed in the current study. Tine et al. (1993) demonstrated that with MEP compensation, the stimulus spectrum was smoothed providing an optimized TEOAE evoking stimulus.

Although not demonstrated in this study, past researchers have indicated an enhancement in EOAE level at high frequencies (primarily ≥8 kHz) in the presence of uncompensated abnormal MEP (Sun & Shaver, 2009). Sun and Shaver (2009) reported an increase in DPOAE level for 8 kHz in the presence of NMEP even following pressure compensation. This could possibly be due to the enhanced absorbance of sound energy in this frequency range in the presence of uncompensated abnormal MEP as demonstrated in the current study. Particularly when absolute MEP was ≥100 daPa (category E), PA magnitude was enhanced for the frequency region between 4 to 6 kHz, accompanied by a shift of the peak PA to a higher center frequency point. The slight variation between studies concerning frequency cutoffs for EOAE amplitude could also be accounted for by a shift in the frequency of PA peaks with abnormal uncompensated MEP. In this context, frequency cutoffs indicate the frequency point at which a significant difference in EOAE amplitude is observed in the presence of abnormal uncompensated MEP, either above or below this frequency point. For example, some studies find a frequency cutoff at lower frequencies of around 2 kHz where as other studies indicate NMEP impacting frequencies at 3.5 kHz and lower. The variation in frequency cutoff points may differ depending on (1) the degree of MEP present during EOAE assessment, (2) the ethnic makeup of the test population, and (3) the gender makeup of the population. Differences between studies regarding ethnicity and gender make-up of the test population may be influencing the outcome of interactions between factors of gender and frequency as well as between ethnicity and frequency. These two between-subject factors interactions were found to be significant for the frequency/magnitude response for PA measures as demonstrated in the current study.

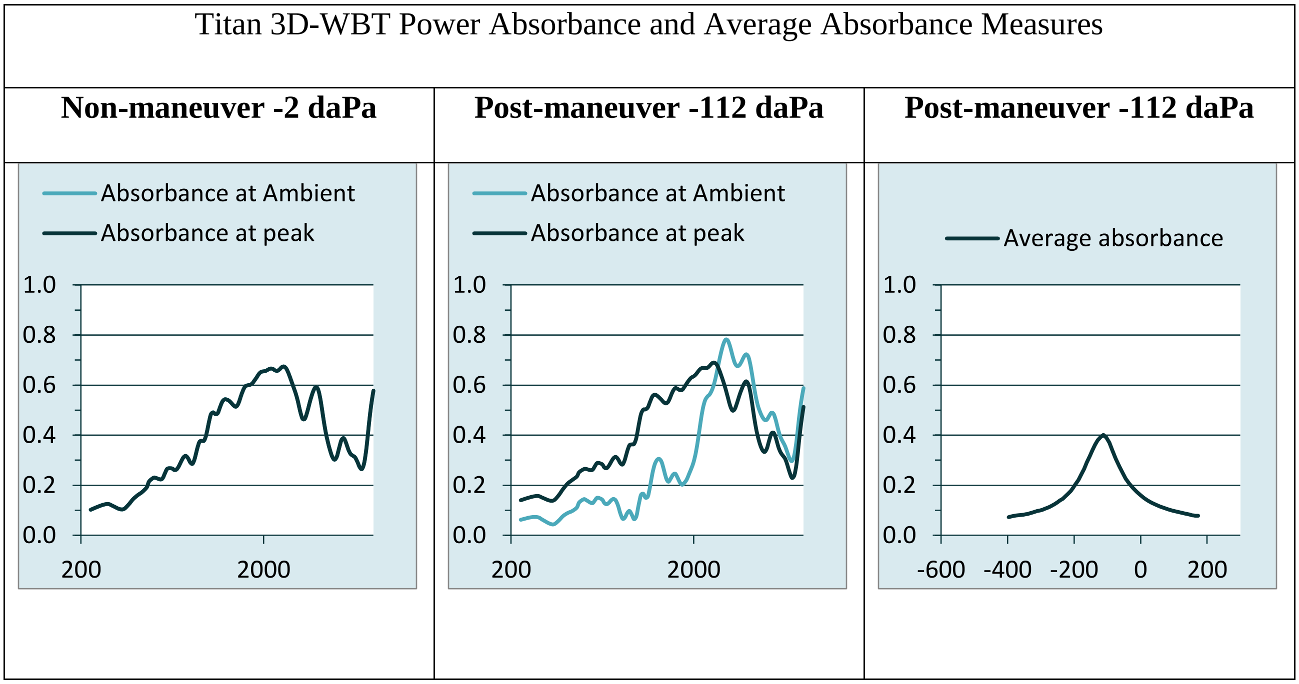
8.5 Case Studies; Power Absorbance and Abnormal Middle Ear Pressure

Case studies 4 and 5 present examples of the frequency dependent change in PA in the presence of both uncompensated and compensated abnormal positive and negative MEP (refer to Figure 65 and Figure 66). These case studies are provided as supplementary evidence for the MEP compensation ability of the Titan Suite.

8.5.1 Case Study (4) Power Absorbance and Negative Middle Ear Pressure

Case study (4) is based on the data from a 24-year-old male participant, identifying as Indian, therefore this data would have been categorized into the ethnic group titled Other. The panel on the left of Figure 65 is the PA measure for the non-maneuver condition corresponding to a MEP of -2 daPa. The absorbance curve representing the measure at ambient is not visible, as it exactly matches the curve response for the peak measure and both curves have been superimposed. The center panel shows the change in response pattern after abnormal MEP has been induced; the MEP estimate for this post-maneuver recording was -112 daPa. There was an absolute MEP shift of 110 daPa between the non-maneuver and post-maneuver test conditions. From the response pattern of the ambient absorbance curve at -112 daPa MEP, it is evident that the PA magnitude decreases most noticeably for the low to mid frequency range. For frequencies roughly >4000

Hz, an increase in PA is seen for the absorbance curve at ambient relative to the peak condition. There is also an evident shift in the peak of the absorbance curve towards to right of the x-axis (towards the higher frequencies) when abnormal MEP is not compensated for. In the post-maneuver test condition, when measured at peak pressure corresponding to TPP, the absorbance curve matches to those curves shown in the non-maneuver condition (left panel). The right panel of Figure 65 is for the 3D-WBT average PA measure corresponding to the post-maneuver condition (MEP -112 daPa), plotted over a pressure range -600 to +200 daPa.



Titan 3D-WBT Power Absorbance and Average Absorbance Measures

Non-maneuver -2 daPa

Post-maneuver -112 daPa

Post-maneuver -112 daPa

Figure 65: Case study (4). Comparison of power absorbance measures taken at ambient (light blue curves) and peak pressure (dark blue curves) for non-maneuver (left panel) and post-maneuver (center panel) conditions plotted as a function of frequency (226 to 8000 Hz). The right panel displays a response of a wideband tympanogram (WBT), displayed as an average absorbance magnitude response plotted against pressure (range of -600 to +200 daPa). This

WBT measure is generated from frequency-averaged absorbance measures over the frequency range of 375 to 2000 Hz. Measurements were from a 24-year-old male participant categorized into the Others ethnic group.

8.5.2 Case Study (5) Power Absorbance and Positive Middle Ear Pressure

Case study (5) is based on data from a 20-year-old Caucasian female participant. The panel on the left of Figure 66 is the PA measure for the non-maneuver condition corresponding to a MEP of -9 daPa. The middle panel shows the change in absorbance response following the Valsalva maneuver at a MEP estimate of +191 daPa. The right panel is a second recording (not included in the final data analysis for this study) from the post-maneuver test condition with a MEP estimate of +284 daPa. From the response pattern of the absorbance curve at ambient in the post-maneuver condition, it is visible again that the PA magnitude decreases most noticeably for the low to mid frequency range in the presence of abnormal MEP (+191 daPa and +284 daPa). An increase in absorbance at ambient pressure compare to the peak pressure condition, is seen for the absorbance curve at frequencies roughly ≥5000 Hz and there is an evident shift in the PA response peak towards the higher frequencies. These same trends were seen in case study (4) for a case of negative MEP.

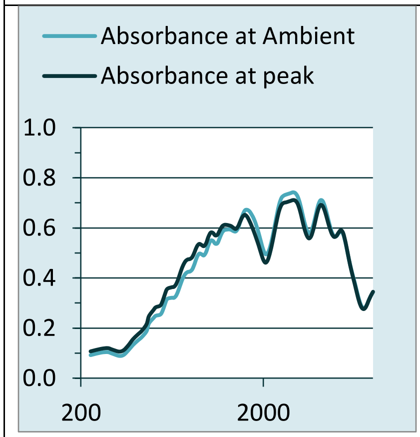
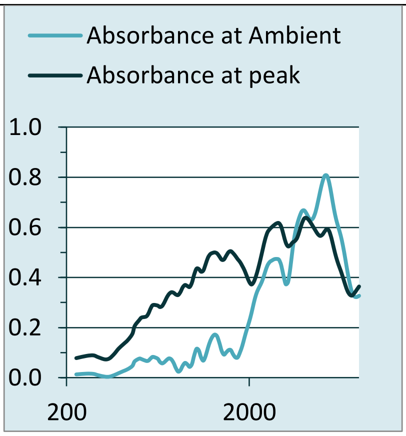
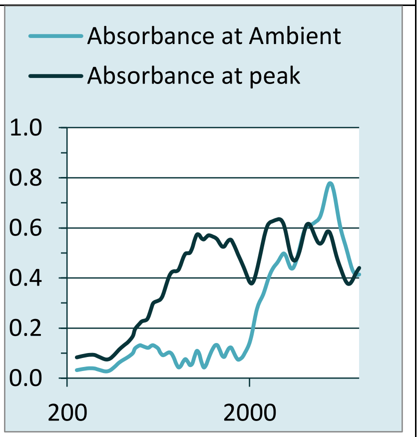
<table>
<tr><th colspan="3">Titan 3D-WBT Power Absorbance Measures</th></tr>
<tr><td>Non-maneuver -9 daPa</td><td>Post-maneuver +191 daPa</td><td>Post-maneuver +284 daPa</td></tr>
<tr><td> </td><td> </td><td> </td></tr>
</table>

Figure 66: Case Study (5).Comparison of power absorbance measures taken at ambient and peak pressure for a non-maneuver (left panel) and two post-maneuver test conditions (center and right panels), plotted as a function of frequency (226 to 8000 Hz). Measurements were from a 20-year-old Caucasian female participant.

Chapter 9: Conclusions

Chapter 9 serves as a conclusion to the current study, with three subsections: (9.1) Study Limitations, (9.2) Future Directions and (9.3) Summary. Section 9.3 provides a brief review of the main findings, theoretical discussions, and avenues of exploration that were discussed in detail within the preceding chapters.

9.1 Study Limitations

A non-exhaustive list of the current study's limitations is provided in the following subsections 9.1.1 through 9.1.6. Titles of the six subsections are as follows: (9.1.1) Sample Size, (9.1.2) Fixed Test Times versus Running in Loops: EOAE Stop Criteria, (9.1.3) Logging Variations from Target Pressure: TEOAE Measures, (9.1.4) Negative versus Positive Middle Ear Pressure, (9.1.5) Power Absorbance Frequency Range, (9.1.6) Categorization of Absolute Middle Ear Pressure and (9.1.7) Middle Ear Pressure Inclusion/Exclusion Criteria. Content within these subsections have been referenced and briefly discussed throughout the discussion portion of this manuscript.

9.1.1 Sample Size

A consistent limitation throughout this study when data is analyzed as a function of MEP magnitude is the small number of data points contributing to the extreme MEP categories. This limitation applies to analyses that referenced either the factor of absolute MEP magnitude or absolute MEP shift magnitude. Correspondingly, when collapsing analyses across the factor of absolute MEP magnitude, the average absolute MEP associated with TEOAE, DPOAE, and PA post-maneuver test condition was roughly 65 daPa. An abnormal MEP of this magnitude can be considered slight relative to the MEP utilized in past studies investigating the impact of abnormal MEP or pressure compensation on either PA or EOAE outcome measures.

A small sample size is also a limitation when comparing EOAE and PA outcome measures as a function of gender and ethnicity. There are fewer male compare to female participants in the current study. An uneven sample size is also seen for the three ethnic groups. There is a comparable sample size for Asian and Caucasian participant groups, but there are only half as many participants contributing to the ethnic category labeled Other.

Numerous individual ANOVAs were conducted to statistically analyze the data obtained in this study. A MANOVA approach to data analysis could have been selected to reduce the number of statistical analyses performed in the current study, however we do not believe it would have changed the overall outcome of the current study.

9.1.2 Fixed Test Times versus Running in Loops: EOAE Stop Criteria

For both DPOAE and TEOAE measures in the current study, no stopping criteria were selected other than a fixed test time. All test parameter options under the stop criteria, DP/TE criteria, and DP/TE reliability tabs within the protocol customization window were de-selected. Rational for this decision is provided in Chapter 2. In this study, test protocol was set to have DPOAE measures record for 10 seconds at each of the eight test frequencies and a total test time of 60 seconds for TEOAE testing. It was suggested by Interacoustics that particularly for DPOAE measures, altering the test protocol may allow for a more ideal test pressure condition. Rather than measuring in fixed time intervals, it was suggested that running in loops would decrease the test time needed for altering the pressure pump between test frequencies by about two seconds and may allow for more accurate pressure compensation (J. Huijnen, personal communication, June 22, 2016). In addition, if a testing in loops approach is selected, it is recommended that a stop criterion referencing the recorded noise floor level or an estimate of SNR be implemented. For example, implementing a stop criteria based on the SNR would allow the system to stop OAE measurements at each DPOAE test frequency once a set noise level has been achieved. With these settings, the noise floor levels could still be used for between participant comparisons. Implementing such a criterion may have provided greater clinical relevance for the current study's normative data, as many clinical settings use a stop criterion referencing the noise floor for EOAE assessments. A fixed time approach to measurements was selected for this study to contribute to test procedure consistency between participants. Additionally, noise level was analyzed as an outcome measure for the comparison between ambient and peak pressure test settings under conditions of ambient MEP.

9.1.3 Logging Variations from Target Pressure: TEOAE Measures

Investigations concerning Titan's ability to maintain target pressure during compensated test pressure TEOAE recordings were limited for the current study. As a review of the discussion from Chapter 7, an estimate of the pressure deviation from target pressure is available for each test frequency only for DPOAEs. For TEOAE measures, Titan only logs the last pressure estimate at the end of the entire TEOAE recording. For future research, it would be beneficial if the Titan software were altered in order for the compensating pressure value to be recorded in a different manner for TEOAE measures. It would be valuable to have post-recording access to an average pressure reached throughout recordings or a pressure value reported after a set time period (ex. every 10 seconds of recording). Minimally, it would be preferred if the Titan system were able to store the pressure reached at least every time the system had to pause and use the pump to re-establish target pressure. It would also be preferred if the target pressure tolerance level (±20 daPa) for TEOAE recordings was reduced. As a reminder to the reader, the tolerance levels for which Titan must maintain target pressure throughout a peak pressure recording differs for DPOEAE and TEOAE modules.

9.1.4 Negative versus Positive Middle Ear Pressure

For a future project or as a suggestion for future research, it is recommended that EOAE and PA measures be separated based in part, on the type of associated MEP, either negative or positive pressure. The manner, in which the data from the current study has been analyzed, does not allow for speculation on the potential impact of positive versus negative MEP on PA and EOAE measures, and if Titan is better able to compensate for one over the other. Plinkert et al. (1994) state PMEP has a greater effect on EOAE (both DPOAE and TEOAE) level reduction compared to NMEP. This pressure polarity dependence on EOAE level is thought to reflect the different displacement of the TM and different impact on ossicular chain geometry. Previous research has also noted PMEP tends to have a greater attenuation on EOAE level compared to NMEP by about 0.6 dB (Perez, 2012). However, there are other published studies that have stated findings to the contrary, indicating positive and negative ear canal pressure impact EOAE strength in an analogous manner (Naeve et al., 1992). It would also be of interest to investigate if there is a significant difference in TM geometry between simulated abnormal pressure conditions, in which the MEP is altered compared to pressurization of the external ear canal. These two methods of pressurization may alter the TM geometry in such a way that impacts EOAE amplitude or noise level differently. These factors should be considered in the design of future studies and when comparing test results between studies using different pressurization methods.

9.1.5 Power Absorbance Frequency Range

Based on the findings from the present study, it can be speculated that if the PA analysis was conducted across a frequency range of 250 Hz to about 4000 Hz, a more salient effect would be observed for the main effect analysis of test condition and for interaction analyses involving the between-subject factors. A greater effect size would likely be noted for the between test condition analyses collapsing across the factor of frequency. This prediction is based on the observations that PA magnitude changes significantly as a function of frequency, with a greater difference between ambient and peak test pressure conditions being observed at the mid to low frequency range (<4 kHz).

9.1.6 Categorization of Absolute Middle Ear Pressure

Some of this variation in PA magnitude between test conditions could also be attributed to how the PA measures were categorized and the possible flaws in this categorization process. When comparing measures across maneuver conditions (i.e. non-maneuver ambient/peak versus post-maneuver peak/ambient), the MEP was referenced based on a categorization method of determining an absolute MEP shift magnitude. Absolute MEP shift magnitude categorization (A to E) only indicates how much change in MEP was measured between non- and post-maneuver conditions, but not where (exact MEP) the absolute MEP starting point was for this shift. For example, considering a single absorbance measure, the starting pressure could have been -30 daPa and shifted to -20 daPa receiving a shift code of A (0 to 10 daPa change). Another absorbance measure could have been starting at 0 daPa in the non-maneuver condition and shifted only to +10 daPa in the post-maneuver, still receiving a category code of A (shift of 0 to 10 daPa). Since this is the coding system used to define the function of MEP Shift, no comments can be made regarding the direction of MEP change (positive or negative direction) or regarding the impact of negative versus positive MEP on PA magnitude or EOAE amplitude. However, the majority of the 210 non-maneuver condition PA measures (116 of 210 measures) had MEP estimates centered on 0 daPa (-10 to +10 daPa) with the next largest group being category B, with MEP between ±11 to 25 daPa. When the interaction of test condition and frequency was analyzed with the MEP based on the post-maneuver 3D-WBT absolute MEP estimate (rather than a shift estimate), a highly similar analysis outcome was found regarding the significance of main effect and interaction analyses.

9.1.7 Middle Ear Pressure Inclusion/Exclusion Criteria

Another limitation of the current study was the lack of inclusion or exclusion criteria concerning participant MEP. If all inclusion/exclusion criteria were met, participants were included in the study regardless of the degree of naturally occurring MEP at the time of testing. This resulted in any degree of MEP being accepted for baseline measures of EOAE and PA data. For future studies, it is suggested that a more conservative approach be taken, in which an inclusion criterion is set for an acceptable MEP magnitude for baseline condition testing. This suggestion is made based on the findings from the current study. For example, when comparing non-maneuver ambient to non-maneuver peak test condition outcome measures, a significant difference was particularly observed for measures of PA magnitude.

9.2 Future Directions

The following subsections 9.2.1 through 9.2.9 provide a non-exhaustive list of potential future research project, ideas to incorporate into future studies, and factors that future researchers may wish to control for. There are three main areas of focus: (1) test populations, (2) participant characteristics, and (3) available data for future analysis.

9.2.1 Test Population: Pathological Population

Future researchers may wish to expand the field's understanding of the benefit and clinical application of compensated EOAE and PA testing by examining an adult population presenting with natural abnormal middle ear pressure or present middle ear pathology. The impact of natural pathology and naturally occurring NMEP may have a significant difference on TM orientation and middle ear properties than normal participants under induced MEP conditions. Compensated EOAE and/or PA measures from pathological ears may result in perhaps similar or different results when comparing outcomes measures or trends seen with normal ears mimicking a state of abnormality. For example, Marshall et al. (1997) investigated the impact of abnormal MEP on the TEOAE response spectrum and the stimulus spectrum. They demonstrated an overall comparable TEOAE response for a single test participant with simulated NMEP and naturally occurring abnormal MEP at pressure levels of -105 and -135 daPa. However, for the MEP condition of -165 daPa, a difference in the TEOAE response spectra was noted between the two MEP conditions (simulated versus natural) but only in the low frequency test region <2 kHz. In this study, MEP was simulated by altering the pressure within the external ear canal. Conventional scientific method requires the comparisons between the simulated population and the actual pathological population in order to substantiate any clinical recommendations based on the findings obtained from both test groups. For the current study, the participant population acted as their own control group and as the test group for simulated MEP pathology (abnormal MEP in the post-maneuver test condition).

9.2.2 Test Population: Pediatric Population

Past studies have demonstrated that maturational changes of the infant ear canal are influencing factors on the reverse transmission of DPOAE responses (Keefe & Schairer, 2011). Eustachian tube function and control also changes with age moving from infancy to adulthood. Due to differences in mobility and altered properties of the tympanic membrane as well as changes in tissue properties of the external ear canal, tympanometry for infants is also widely known to be less accurate and more variable compared to adults. Future research could expand the investigation of compensated PA and compensated EOAE testing to a pediatric population. For a child or difficult to test population, behavioral testing may be possible in only some cases and

EOAEs would be needed as supporting or sole evidence of hearing sensitivity estimates. In pediatric populations, the presence of abnormal MEP and pathological middle ear status commonly causes a conductive loss severe enough to reduce EOAE amplitude. Subsequently, absence of EOAE leads to referrals for a false positive identification of sensorineural loss. With the ability to bypass or mitigate the effects of a compromised middle ear system from abnormal MEP, this could lead to reduced referrals for false positives. Future research could investigate an infant population referencing the peak pressure to a 1000 Hz single frequency tympanogram. Another option to determine target pressure for compensated test conditions would be to reference the 3D-WBT. For a test population <6 months of age when using the Titan Suite, the default calibration parameters record within the range of 800 to 2000 Hz for 3D tympanograms. This is compared to the recording range of 375 to o2000 Hz for children >6 months of age. Research by Prieve et al. (2008) indicated a correlation between reduced TEOAE levels with increasing uncompensated TPP for all frequencies assessed, with no significant change in noise level. For a normal hearing child population, Hof and colleges (2005a) found an average 1.9 dB TEOAE level increase resulting from MEP compensation at 1 and 2 kHz bands but found little impact for frequencies bands centered on 3 and 4 kHz. Future studies working with this age range could investigate the difference or similarities to adults when assessing PA and EOAEs at compensated pressure. Frequency-specific response differences in both EOAE level and PA magnitude would not be unexpected between these two populations, as the density and physical properties of the outer and middle ear system are distinct for both populations: Infants have on average, smaller ear-canal volumes contributing to reduced PA for infants compared to adults (Keefe & Schairer, 2011). Otoacoustic emissions are measured as part of hearing screening programs for infants and newborns. One of the primary reasons for infants failing the hearing screening using EOAEs is adverse middle ear conditions such as NMEP either in the presence or absence of otitis media (Boone, Bower, & Martin, 2005). Compensating for abnormal MEP may potentially reduce the false positives in programs such as newborn hearing screening programs.

9.2.3 Participant Characteristics: Ear Canal Volume and Body Mass Index

Personal characteristics of ear canal volume (ECV) and body mass index (BMI) were recorded for participants involved in the current study. This data is available for future analysis to investigate these between-subject factors as possible covariates contributing to the observed differences across gender and ethnic groups for both outcome measures of PA magnitude and EOAE amplitude. Estimates of ECV are also available from two estimation methods, the 3D-WBT and the conventional 226 Hz tympanogram for between estimation method comparisons. The variables of BMI and ECV can be explored to investigate if one variable over the other of both, prove to be a superior predictor of outcome measure difference between participants groups or between test conditions. Furthermore, although not available from this study, future studies could obtain the head circumference of participants and correlate this measurement to ECV and BMI estimates. Skull size has been linked to differences observed in domestic cats with respect to middle ear cavity volume and estimate of compliance, supporting the finding that body size for cat species partially accounts for variation in auditory related outcome measures (Rosowski et al., 2012). The between-subject factor of head circumference could be explored as another possible predictor of differences between gender and ethnic groups for various outcome measures (PA and EOAEs). Jaffer (2016) showed (1) Caucasians had significantly higher BMI estimates compared to Chinese participants, (2) males participants had a significantly greater

BMI than females, (3) male participants had a larger ECV estimate than females, and (4) Chinese participants had overall, significantly smaller ECV mean values compared to Caucasians.

9.2.4 Participant Characteristics: Blood Type

Recent work by Chow et al. (2016) investigated the impact of participant blood type on otoacoustic emission (SOAEs, TEOAEs, and DPOAEs) strength, finding participants with type O blood had reduced emission strength at certain test frequencies. This study found that for DPOAE frequencies within the range of 1000 to 1500 Hz, participants with type O blood had lower amplitudes compared to those with A, B, or AB blood types. This study showed for measures of TEOAEs within the same frequency range (1000 to 1500 Hz), amplitudes were comparable between blood type groups (Chow et al., 2016). Future studies could explore the potential link between ethnicity, blood type, and OAE strength as a possible source of the difference observed in OAE absolute amplitude between ethnic groups as a function of test frequency. Future studies should consider incorporating blood type as voluntary information during case history in order to analyze outcome measures considering this between-subject factor.

9.2.5 Participant Characteristics: Spontaneous Otoacoustic Emissions

Spontaneous OAEs are more prominent in females and children (Hall, 1999), and can be measured in only 40 to 50% of normal hearing adults (Campbell, 1998 as cited in Perez, 2012). Future studies may wish to control for SOAE presence and strength, when assessing EOAE amplitude as SOAEs can influence the amplitude and response shape of TEOAEs (Kulawiec & Orlando, 1995 as cited in Chow et al., 2016). The current study did not control for SOAEs.

9.2.6 Available Data for Future Analysis: Development of Gender and Ethnic Specific Normative Data Sets

The wideband acoustic immittance PA data separated by gender is available for Caucasian, Asian, and Other ethnic groups. This source of data may be used for the development of ethnic and gender-specific normative PA data for both ambient and peak test pressure settings. Similarly, DPOAE and TEOAE measures at both ambient and peak pressure conditions are available for the development of age, gender, ethnicity, instrument, and test pressure condition specific normative data.

9.2.7 Available Data for Future Analysis: Resonance Frequency

Estimates of resonance frequency (RF) from the 3D-WBT measure for both the non-maneuver and post-maneuver test conditions are available from all participants involved in this study. This RF data was not analyzed for inclusion in this thesis. Past studies have shown a change in RF with changes in MEP, as there is direct relationship between RF and stiffness properties of the middle ear system (Sun & Shaver, 2009). For example, a shift in middle ear RF to a higher frequency has been shown in cases of uncompensated NMEP (Margolis et al., 1999 as cited in Sun & Shaver, 2009). If the RF collected from this study were to be analyzed, it would be essential to analyze this RF data comparing measures between test conditions, non- versus post-maneuver, as a function of non-absolute MEP magnitude change. It would also be important to examine the accuracy of MEP estimate in a similar manner as was done for the current study to identify any outlier if RF is analyzed considering the factor of MEP magnitude. The accuracy of the ECV estimate would also be important to control for, because for 3D-WBT measures, estimates of ECV are used for calculating RF and when generating the MEP estimates. For the current study, the comparison of MEP estimates between the two estimation methods was conducted. A similar analysis could be performed comparing estimates of ECV.

9.2.8 Available Data for Future Analysis: Phase Angle

Phase angle data was collected during the data collection stage of the current study. This data has been extracted from the saved Titan files for all participants and is available for future analysis. This data was extracted from the wideband absorbance measures for each ear involved in this study. Phase angle data is displayed as values corresponding to frequency points ranging from 226 to 8000 Hz. Phase angle data has been grouped into the three categories; non-maneuver ambient, post-maneuver positive MEP, and post-maneuver negative MEP. The analysis of phase angle measure could provide further insight regarding the impact of abnormal MEP on the transmission properties of the middle ear system. Absorbance magnitude as presented in this study represents a magnitude value that is dimensionless. Analysis of phase angle data has the potential to provide more diagnostic information by adding an element of dimension.

9.2.9 Available Data for Future Analysis: Wideband Tympanometry

An averaged wideband tympanogram (WBT) is a measure of average power absorbance across a wide frequency range and pressure range. The Titan IMP440 module provides this average power absorbance reading as a function of frequency across the range of 375 to 2000 Hz and for a pressure range of +300 to -600 daPa. The Titan system displays this measure as a two-dimensional tympanogram, as the PA is frequency averaged being displays across an x-axis of pressure level. The term wideband acoustic immittance is often used to refer to measures of WBT, since WBT reflects an immittance measure of the middle ear. According to the Titan user manual, WBT has the advantage of being less influenced by noise and provides a more accurate indication of middle ear status compared to a conventional single frequency tympanogram. A sample measure of this WBT measure is presented in case study (4) in the right-most panel of Figure 65. This average absorbance measure was collected as an independent sub-measurement within the set immittance protocol for 3D-WBT measures. WBT data (n=210) has been extracted and is separated into sub-categories: (1) non-maneuver condition, natural MEP (2) post-maneuver condition, positive MEP, and (3) post-maneuver condition, negative MEP. This WBT data is available for future analysis. A similar approach to data analysis could be used as was done for the current study's analysis of the independent measures of power absorbance.

9.3 Summary

9.3.1 Objectives

The primary objective of this study was to investigate the impact of testing at ambient compared to peak pressure on outcome measures of evoked otoacoustic emissions. The effect of both induced positive and negative middle ear pressure on absolute amplitude and noise level for distortion-product otoacoustic emissions (1.5 to 8 kHz) and transient evoked otoacoustic emissions (1 to 5 kHz) was assessed. The wideband acoustic immittance measure of power absorbance magnitude over sixteen 1/3 octave bands (frequency range of 0.25 to 8 kHz) was also evaluated under conditions of compensated and uncompensated pressure conditions. The secondary objective of investigating PA magnitude in a similar manner as was done for the outcome measure of EOAE absolute amplitude was to see if changes in PA translated into equivalent changes in EOAE amplitude. Past research does indicate a need to compensate for abnormal middle ear pressure to attain accurate EOAE measures but a constraint on the majority of these past studies was their small sample size and use of clinically unavailable or impractical test equipment. The current study has investigated outcome measures from a fairly large sample of normal-hearing young adult participants between the ages of 18 to 35. The collection of all outcome measures for both EOAE and PA was done using a single test system, Titan Suite by Interacoustics. The use of the Titan system is unique to this study given it is the only commercially available system for measuring EOAEs at a compensated test pressure. The potential change in outcome measures (EOAE absolute amplitude, EOAE noise level, and PA magnitude) dependent on between-subject factors of gender, ethnicity, and absolute MEP magnitude was explored. The variation in outcome measures as a function of test frequency was also examined.

9.3.2 Overall Findings for Evoked Otoacoustic Emission and Power Absorbance Measures

The change in EOAE absolute amplitude, noise level, and PA magnitude between test conditions was explored as multiple two-test condition comparisons. Consistent with past research, findings from the current study show that the presence of uncompensated abnormal MEP results in a reduction of EOAE amplitude and PA magnitude. This change in outcome measures strength is primarily observed for mid to low frequencies.

For both measures of DPOAE and TEOAE absolute amplitude, an equivalent trend was observed across the four test conditions. The test conditions with the largest to smallest mean EOAE absolute amplitude was in the order of (1) non-maneuver peak, (2) non-maneuver ambient, (3) post-maneuver peak, and then (4) post-maneuver ambient. Although the significant difference in EOAE absolute amplitude between the non-maneuver ambient (baseline) and post-maneuver peak (compensated) test conditions was unpredicted, an improvement in EOAE amplitude was still observed with pressure compensation. The comparison of EOAE absolute amplitude between the two post-maneuver conditions (ambient and peak pressure) served as an illustration of a clinical situation in which a patient presents with abnormal MEP at the time of assessment. Outcomes of the current study show that if EOAE testing were to be conducted at ambient pressure following current clinical protocol, resulting would be a false representation of cochlear function. The current study demonstrates that if testing is conducted at peak pressure in order to compensate for the abnormal MEP, a more accurate representation of the patient's cochlear function is realized. Based on the current study's findings, this improvement in EOAE amplitude in the compensated test conditions is more evident with measures of DPOAE compared to TEOAEs. Overall, results of the current study suggest that for the assessment of absolute amplitude for both DPOAE and TEOAE measures, testing at a compensated pressure level is likely to provide a more accurate indication of cochlear status compared to measurements assessed under an uncompensated pressure condition. The outcome measure of noise level was investigated to examine the potential clinical implications of testing at a setting of ambient versus peak pressure when referencing a signal-to-noise ratio as a stop criteria or in clinical decision making regarding EOAE presence/absence or pass/refer. There were no consistent trends observed for changes in noise level between conditions of compensated or uncompensated MEP. Improvements in frequency-specific signal-to-noise ratios were observed for both TEOAE and DPOAE measures when testing in the compensated pressure condition. A noteworthy finding throughout the two-test conditions comparisons was the significance of the interaction between frequency and ethnicity. Differences between the three ethnic groups (Caucasian, Asian, and Other) follow similar trends in comparison to past studies investigating the ethnic-specific differences for EOAE outcome measures.

For PA measures, the test conditions with the greatest to least PA magnitude is in the order of (1) non-maneuver peak, (2, 3) non-maneuver ambient and post-maneuver peak, and (4) post-maneuver ambient. There was no significant mean PA magnitude difference found between the baseline non-maneuver (ambient or peak) compared to post-maneuver peak test conditions. These findings indicate that when the abnormal MEP was compensated for, the admittance of acoustic energy into the middle ear was enhanced. The presence of abnormal MEP shows a change in the transmission properties of the middle ear system as reflected by the significant difference in mean PA magnitude for the comparison between post-maneuver ambient and non-maneuver test conditions. When the abnormal MEP is compensated for, the PA magnitude and frequency-response pattern reflects those seen under conditions of ambient MEP. Frequency-dependent changes in PA magnitude with alteration in MEP and ear canal pressure were linked to frequency-dependent changes in EOAE amplitude. Gender and ethnic specific differences in

PA response as a function of frequency was also examined in the current study. Findings from these analyses are consistent with published normative data.

9.3.3 Theoretical Discussions

The theoretical basis of MEP pressure compensation and reasons for outcome measure differences between test conditions was discussed in detail. Present and robust EOAEs indicate good cochlear integrity, good function of primarily the outer hair cells, and a relatively non-obstructing middle ear pathway. Testing under ambient pressure (uncompensated condition) with abnormal MEP present, EOAEs were reduced in amplitude. This reduction in EOAE strength was attributable to the abnormal MEP acting as an obstruction in the middle ear system based on evidence of present and robust EOAE measurements obtained in baseline measures. In summary, these measures of EOAE amplitude and PA magnitude are compromised due to a reduction in the transmission of sound energy along the involved auditory pathway under conditions of uncompensated MEP. When an OAE evoking stimulus is presented within the ear canal some of this sound energy is reflected back into the ear canal and the response of the cochlea does not represent a true response to the intended stimulus level. Additionally, the backward travelling emitted signals from the cochlea are further attenuated as it must also travel through the impacted ME space to be received by the probe microphone in the external canal. A reduction in sound energy transmission results from a change in TM position and ossicular chain properties under conditions of uncompensated MEP. Pressure compensation within the external ear canal restores both the ossicular chain and the TM to a more normal position, allowing for increased acoustic energy to be absorbed by the middle ear. This increased energy absorbance is reflected in the increase in measured PA magnitude and increase in EOAE amplitude. It is the act of compensating for the elevated MEP that recovers the pathway of transmission for the EOAE related forward and backwards propagating signals.

Addition speculative discussion was provided regarding potential reasons for the difference in pressure compensation effectiveness between PA and EOAE measures. The change in PA between the ambient versus peak test conditions is larger than for the measures of EOAE amplitude. For example, a proposed explanation for this difference was the added complication for EOAEs and not PA, of the back-wards transmitted emission having to propagate through the abnormally pressurized middle ear cavity and through the pressurized external ear canal to be detected by the probe microphone/sensor. In general, in comparison to PA measures, the overall transmission pathway for EOAE signals is much more complex involving cochlea and associated windows. Further discussion was provided exploring the difference in the frequency range used for PA versus EOAE testing. The greater influence of abnormal MEP on the transmission of low frequency sounds more so than high frequencies was discussed. The PA frequency range includes more low frequency component than the EOAE frequency range. The largest reduction in PA magnitude in cases of uncompensated abnormal MEP is observed in these low frequency regions: PA magnitude decreased in a sloping manner with a decrease in frequency below <4 kHz. Therefore, the greatest attenuation of PA magnitude was observed at frequencies not included in either DPOAE or TEOAE analyses

9.3.4 Normative Data

Discussion surrounding the results of the current study was focused on potential clinical implications and the application of these findings as normative data. The obtained outcome measures of TEOAE and DPOAE absolute amplitude and noise level are consistent with published normative data. Power absorbance response patterns and magnitude assessed under different test conditions (pressure compensated versus uncompensated) are also comparable to published normative data referencing studies using similar test populations and study design. As discussed in detail, the development of patient specific normative data could lead to better identification of pathology in clinical settings by enhancing test sensitivity and specificity. In addition to providing age-specific normative data for EOAE and PA measures, findings from this study indicate a need for ethnicity-specific and gender-specific normative data. The current study provides a preliminary database of normative data for TEOAE, DPOAE, and PA measures assessed at instrument settings of ambient and peak pressure. This data was obtained using a commercially available test instrument with test parameters similar to those used in most clinical settings. A large database of TEOAE, DPOAE, and PA outcome measures is available for future analysis such as the development of gender-specific and ethnicity-specific normative data.

9.3.5 Potential Sources Accounting for Differences between EOAE Test Conditions

Potential explanations for the differences seen with various test condition comparisons for EOAE outcome measures were explored. Included in the discussion of the current study, was a presentation of potential sources accounting for the differences in outcome measures for DPOAE and TEOAE observed between test conditions. Avenues of examination included the possible role of imprecise pressure compensation resulting from three proposed sources: (i) inaccuracies of MEP estimates on which the compensating target pressure was based; (ii) Titan’s ability to maintain adequate target pressure (compensation pressure) throughout EOAE recordings, and (iii) the fluctuation in MEP during EOAE recordings in the post-maneuver test condition.

9.3.6 Concluding Remarks

The various potential clinical applications of reducing the influence of abnormal MEP on EOAE and PA measures were discussed in light of the current study's findings. Clinical situations in which it would be advantageous to assess PA measures at peak pressure were presented. These cases involved examples of dual pathology, with similar or overlapping features with one of the pathologies being abnormal MEP. For assessment of EOAEs, testing at a pressure compensating for the presence of abnormal MEP could be beneficial when, for example: (1) testing patients with abnormal middle ear pressure and other middle ear pathologies, potentially providing an alternative means for differential diagnoses; (2) differentiating types of hearing loss, such as sensorineural, conductive, or mixed; (3) conducting ototoxic monitoring by means of EOAEs (Constantinescu et al., 2009); (4) monitoring or testing for threshold shifts in cases of suspected noise induced hearing loss (Kemp, 2002); and (5) reducing false positives with infant screening programs. Supported by past studies measuring EOAEs compensating for abnormal MEP may produce more accurate test results and subsequently, generate a reduced referral rate compared to measures taken at ambient pressure (Hof et al., 2003). This study illustrates the benefit of compensating for abnormal MEP, enhancing the effectiveness of both EOAEs and PA as diagnostic tools. This minor adjustment to EOAE and PA testing procedure of compensating for individual patients' MEP may reduce financial and time burdens associated with continued audiological testing of falsely diagnosed or screened patients.

As it currently stands in the scientific community, research concerning wideband acoustic immittance measures such as power absorbance, middle transmission properties, and the impact of various middle ear pathologies on middle and inner ear related measures is still in its rudimentary stages. The clinical relevance and application of this area of research concerning MEP compensation techniques is in need of continued examination and development. There is also a need for the continued expansion of age, gender, ethnicity, and instrument specific normative data for EOAEs and PA. This study provides preliminary evidence of the benefits of assessing EOAEs and PA at peak compensated pressure. It is hoped that the information obtained from this study will help refine our clinical ability to produce a more accurate statement of cochlear function even when patients present at the time of testing with middle ear pathology such NMEP.

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Appendices

Appendix A Descriptive Statistics

Ethnicity	Frequency (Hz)	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Caucasian	1500	8.13	1.216	5.72	10.54	43
Caucasian	2000	6.58	1.089	4.42	8.74	43
Caucasian	2500	3.35	1.128	1.11	5.59	43
Caucasian	3000	5.19	1.068	3.08	7.31	43
Caucasian	4000	10.74	0.976	8.81	12.68	43
Caucasian	5000	13.58	1.151	11.30	15.87	43
Caucasian	6000	12.72	1.337	10.07	15.37	43
Caucasian	8000	-4.48	1.689	-7.83	-1.13	43
Asian	1500	9.49	1.196	7.12	11.86	46
Asian	2000	6.00	1.071	3.87	8.12	46
Asian	2500	4.02	1.110	1.82	6.22	46
Asian	3000	2.31	1.051	0.23	4.40	46
Asian	4000	8.22	0.960	6.32	10.12	46
Asian	5000	12.10	1.133	9.85	14.35	46
Asian	6000	13.56	1.316	10.95	16.17	46
Asian	8000	1.33	1.662	-1.97	4.62	46
Other	1500	10.36	1.743	6.91	13.82	21
Other	2000	8.03	1.561	4.94	11.13	21
Other	2500	3.88	1.617	0.67	7.09	21
Other	3000	3.53	1.531	0.50	6.57	21
Other	4000	8.40	1.399	5.63	11.18	21
Other	5000	13.10	1.651	9.83	16.38	21
Other	6000	14.24	1.917	10.44	18.04	21
Other	8000	1.34	2.422	-3.47	6.14	21

Table 117: Comparison of mean DPOAE absolute amplitude across ethnic groups as a function frequency. The analysis was collapsed across factors of test condition (non-maneuver ambient and post-maneuver ambient) and gender. Current effect: [F(14, 714)=4.2837, p=.00000].

Cell No.	Tukey HSD test; Within MSE = 5.1448, df = 742.00																	
	Test Condition	FREQ	{1} 10.20	{2} 7.10	{3} 4.30	{4} 4.48	{5} 9.96	{6} 13.95	{7} 13.88	{8} -.28	{9} 8.45	{10} 6.40	{11} 3.17	{12} 2.7818	{13} 8.48	{14} 11.79	{15} 12.82	{16} -1.55
1	Non-maneuver, Ambient	1500		0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Non-maneuver, Ambient	2000	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00
3	Non-maneuver, Ambient	2500	0.00	0.00		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
4	Non-maneuver, Ambient	3000	0.00	0.00	1.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Non-maneuver, Ambient	4000	1.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Non-maneuver, Ambient	5000	0.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
7	Non-maneuver, Ambient	6000	0.00	0.00	0.00	0.00	0.00	1.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
8	Non-maneuver, Ambient	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Post-maneuver, Ambient	1500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	1.00	0.00	0.00	0.00
10	Post-maneuver, Ambient	2000	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
11	Post-maneuver, Ambient	2500	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00		1.00	0.00	0.00	0.00	0.00
12	Post-maneuver, Ambient	3000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00		0.00	0.00	0.00	0.00
13	Post-maneuver, Ambient	4000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00		0.00	0.00	0.00
14	Post-maneuver, Ambient	5000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.06	0.00
15	Post-maneuver, Ambient	6000	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.06		0.00
16	Post-maneuver, Ambient	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table 118: Descriptive statistics for Tukey’s test analysis for the comparison of mean DPOAE absolute amplitude between the non-maneuver ambient and post-maneuver ambient test conditions as a function of frequency. The analysis was collapsed across factors of gender, and ethnicity. Shaded boxes represent comparisons of interest between test conditions.

Cell No.	Tukey HSD test; Pooled MSE = 14.960, df = 123.50											
	MEP Shift (daPa)	Test Condition	{1} 6.68	{2} 6.64	{3} 9.14	{4} 8.85	{5} 7.45	{6} 6.47	{7} 8.80	{8} 7.46	{9} 7.42	{10} 4.13
1	A (0-10)	Non-maneuver, Ambient		1.00	0.82	0.91	1.00	1.00	0.81	1.00	1.00	0.65
2	A (0-10)	Post-maneuver, Ambient	1.00		0.81	0.90	1.00	1.00	0.80	1.00	1.00	0.67
3	B (11-25)	Non-maneuver, Ambient	0.82	0.81		1.00	0.95	0.53	1.00	0.94	0.95	**0.00**
4	B (11-25)	Post-maneuver, Ambient	0.91	0.90	1.00		0.99	0.69	1.00	0.98	0.98	**0.01**
5	C (26-50)	Non-maneuver, Ambient	1.00	1.00	0.95	0.99		0.52	0.95	1.00	1.00	0.06
6	C (26-50)	Post-maneuver, Ambient	1.00	1.00	0.53	0.69	0.52		0.39	0.99	1.00	0.47
7	D (51-99)	Non-maneuver, Ambient	0.81	0.80	1.00	1.00	0.95	0.39		0.07	0.95	**0.00**
8	D (51-99)	Post-maneuver, Ambient	1.00	1.00	0.94	0.98	1.00	0.99	0.07		1.00	**0.05**
9	E (>99)	Non-maneuver, Ambient	1.00	1.00	0.95	0.98	1.00	1.00	0.95	1.00		**0.00**
10	E (>99)	Post-maneuver, Ambient	0.65	0.67	**0.00**	**0.01**	0.06	0.47	**0.00**	**0.05**	**0.00**	

Table 119: Descriptive statistics for Tukey's HSD test results for the comparison of mean DPOAE absolute amplitude between the non-maneuver ambient and post-maneuver ambient test conditions, as a function of absolute MEP shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Bolded values represent significant findings (p<.05). Shaded boxes indicate comparisons of interest between test conditions.

MEP Shift (daPa)	Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	-21.61	3.50	-28.54	-14.67	13
A (0 to 10)	Post-maneuver, Ambient	-21.63	1.80	-25.20	-18.06	13
B (11 to 25)	Non-maneuver, Ambient	-21.91	3.43	-28.71	-15.10	14
B (11 to 25)	Post-maneuver, Ambient	-21.77	1.77	-25.27	-18.26	14
C (26 to 50)	Non-maneuver, Ambient	-22.42	2.42	-27.21	-17.63	27
C (26 to 50)	Post-maneuver, Ambient	-23.38	1.24	-25.85	-20.91	27
D (51 to 99)	Non-maneuver, Ambient	-24.22	2.36	-28.90	-19.54	31
D (51 to 99)	Post-maneuver, Ambient	-22.25	1.21	-24.66	-19.84	31
E (>99)	Non-maneuver, Ambient	-22.56	2.56	-27.63	-17.48	25
E (>99)	Post-maneuver, Ambient	-22.31	1.32	-24.92	-19.70	25

Table 120: Descriptive statistics for comparison of mean DPOAE noise level between the non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute MEP shift magnitude. The analysis collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)= 1.1712 p=.32800].

Ethnicity	Frequency (Hz)	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Caucasian	1500	8.74	1.26	6.25	11.23	43
Caucasian	2000	6.67	1.13	4.44	8.90	43
Caucasian	2500	3.63	1.14	1.38	5.89	43
Caucasian	3000	5.53	1.12	3.31	7.75	43
Caucasian	4000	11.38	0.98	9.43	13.33	43
Caucasian	5000	14.25	1.11	12.06	16.45	43
Caucasian	6000	13.01	1.31	10.42	15.61	43
Caucasian	8000	-4.16	1.65	-7.43	-0.90	43
Asian	1500	10.02	1.24	7.56	12.47	46
Asian	2000	6.42	1.11	4.23	8.62	46
Asian	2500	4.57	1.12	2.35	6.79	46
Asian	3000	3.39	1.10	1.20	5.57	46
Asian	4000	8.76	0.97	6.84	10.68	46
Asian	5000	12.89	1.09	10.73	15.04	46
Asian	6000	14.32	1.29	11.77	16.88	46
Asian	8000	1.94	1.62	-1.27	5.15	46
Other	1500	10.90	1.80	7.33	14.48	21
Other	2000	8.13	1.62	4.92	11.33	21
Other	2500	4.04	1.63	0.80	7.27	21
Other	3000	3.45	1.61	0.26	6.63	21
Other	4000	8.13	1.41	5.33	10.92	21
Other	5000	12.71	1.59	9.57	15.85	21
Other	6000	13.41	1.88	9.69	17.13	21
Other	8000	0.90	2.36	-3.78	5.58	21

Table 121: Comparison of mean DPOAE absolute amplitude across ethnic groups as a function frequency. The analysis was collapsed across factors of test condition (non-maneuver ambient and post-maneuver peak) and gender. Current effect: [F(14, 742)=5.1555, p=.00000].

Test Condition	Test Frequency (Hz)	Mean DPOAE Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	1500	10.23	0.59	9.06	11.40	110
Post-maneuver, Peak	1500	9.54	0.60	8.35	10.74	110
Non-maneuver, Ambient	2000	7.24	0.56	6.12	8.35	110
Post-maneuver, Peak	2000	6.91	0.52	5.87	7.95	110
Non-maneuver, Ambient	2500	4.37	0.53	3.31	5.42	110
Post-maneuver, Peak	2500	3.79	0.56	2.68	4.91	110
Non-maneuver, Ambient	3000	4.54	0.47	3.60	5.48	110
Post-maneuver, Peak	3000	3.70	0.61	2.49	4.92	110
Non-maneuver, Ambient	4000	9.82	0.46	8.92	10.73	110
Post-maneuver, Peak	4000	9.02	0.52	8.00	10.04	110
Non-maneuver, Ambient	5000	14.02	0.50	13.02	15.02	110
Post-maneuver, Peak	5000	12.55	0.59	11.39	13.71	110
Non-maneuver, Ambient	6000	13.97	0.62	12.75	15.19	110
Post-maneuver, Peak	6000	13.20	0.65	11.91	14.49	110
Non-maneuver, Ambient	8000	-0.14	0.74	-1.59	1.32	110
Post-maneuver, Peak	8000	-0.74	0.83	-2.39	0.90	110

Table 122: DPOAE mean absolute amplitude comparison between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of test frequency (1500 to 8000 Hz). The analysis was collapsed across factors of ethnicity and gender. Shaded rows distinguish the post-maneuver peak pressure test condition related data from the non-maneuver ambient test condition. Current effect: [F(7, 742)=1.7185, p=.10144].

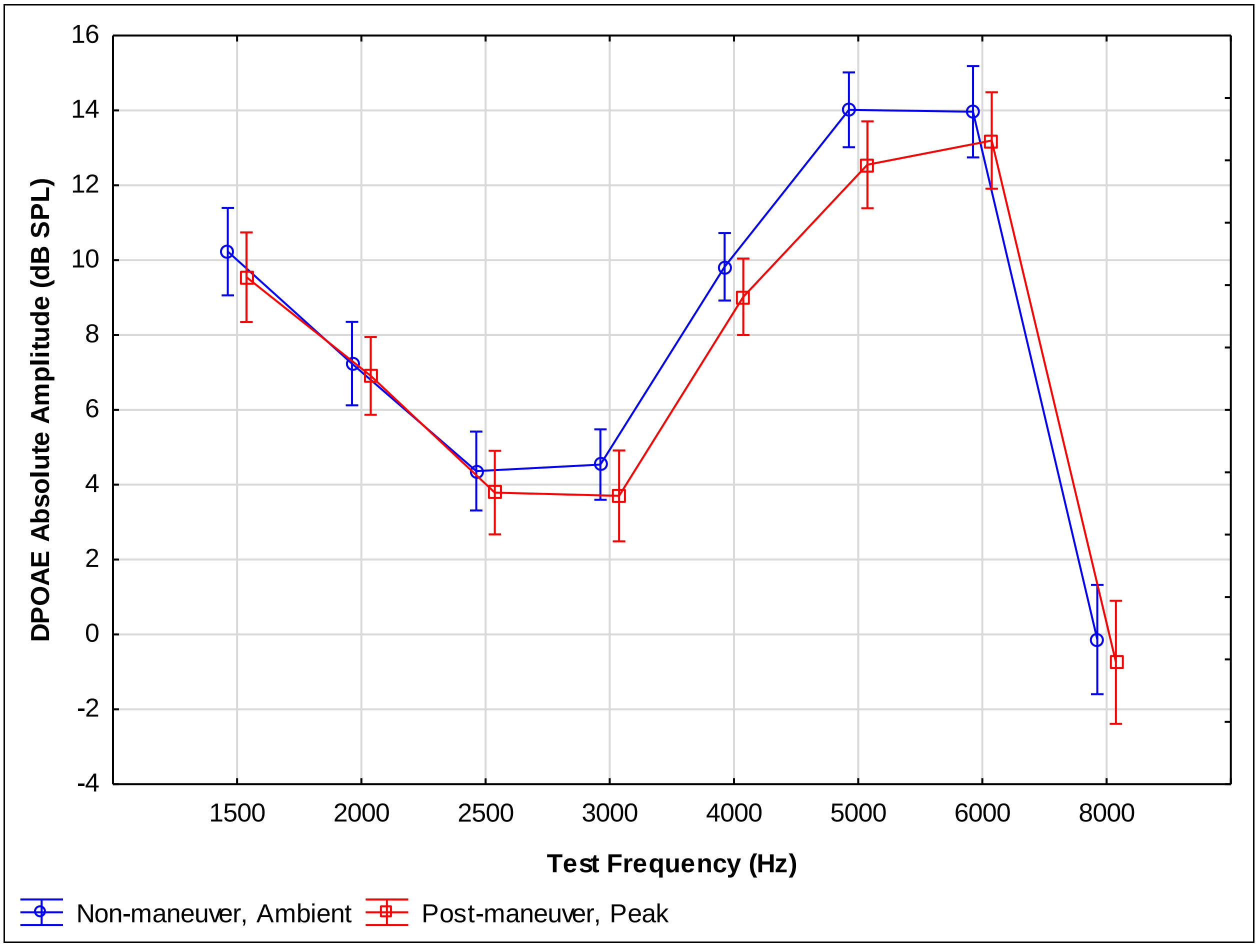

Figure 67: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of ethnicity and gender. Vertical bars denote the 95th percent confidence intervals. Current effect: [F(7, 742)=1.7185, p=.10144].

Cell No.	Tukey HSD test; Pooled MSE = 14.733, df = 113.01											
	|MEP| Shift Magnitude (daPa)	Test Condition	{1} 6.6750	{2} 6.9337	{3} 9.1446	{4} 8.8482	{5} 7.4519	{6} 6.6630	{7} 8.8042	{8} 8.5948	{9} 7.4240	{10} 5.8640
1	A (0 to 10)	Non-maneuver, Ambient		1.00	0.81	0.90	1.00	1.00	0.80	0.88	1.00	1.00
2	A (0 to 10)	Post-maneuver, Peak	1.00		0.89	0.95	1.00	1.00	0.90	0.95	1.00	1.00
3	B (11 to 25)	Non-maneuver, Ambient	0.81	0.89		1.00	0.94	0.63	1.00	1.00	0.94	0.25
4	B (11 to 25)	Post-maneuver, Peak	0.90	0.95	1.00		0.98	0.78	1.00	1.00	0.98	0.38
5	C (26 to 50)	Non-maneuver, Ambient	1.00	1.00	0.94	0.98		0.36	0.94	0.98	1.00	0.89
6	C (26 to 50)	Post-maneuver, Peak	1.00	1.00	0.63	0.78	0.36		0.52	0.66	1.00	1.00
7	D (51 to 99)	Non-maneuver, Ambient	0.80	0.90	1.00	1.00	0.94	0.52		1.00	0.94	0.13
8	D (51 to 99)	Post-maneuver, Peak	0.88	0.95	1.00	1.00	0.98	0.66	1.00		0.98	0.21
9	E (>99)	Non-maneuver, Ambient	1.00	1.00	0.94	0.98	1.00	1.00	0.94	0.98		**0.00**
10	E (>99)	Post-maneuver, Peak	1.00	1.00	0.25	0.38	0.89	1.00	0.13	0.21	**0.00**	

Table 123: Tukey’s HSD test results for the comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute MEP shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Shaded boxes represent comparisons of interest between test conditions for individual MEP shift categories.

|MEP| Shift Magnitude (daPa)	Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	-22.01	1.24	-24.47	-19.55	13
A (0 to 10)	Post-maneuver, Peak	-21.39	1.59	-24.54	-18.25	13
B (11 to 25)	Non-maneuver, Ambient	-21.71	1.22	-24.13	-19.30	14
B (11 to 25)	Post-maneuver, Peak	-22.46	1.56	-25.55	-19.38	14
C (26 to 50)	Non-maneuver, Ambient	-22.50	0.86	-24.20	-20.80	27
C (26 to 50)	Post-maneuver, Peak	-22.69	1.10	-24.86	-20.51	27
D (51 to 99)	Non-maneuver, Ambient	-22.52	0.84	-24.18	-20.87	31
D (51 to 99)	Post-maneuver, Peak	-22.21	1.07	-24.33	-20.08	31
E (>99)	Non-maneuver, Ambient	-22.57	0.91	-24.37	-20.77	25
E (>99)	Post-maneuver, Peak	-22.00	1.16	-24.30	-19.70	25

Table 124: Comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)=1.9389, p=.10964].

Ethnicity	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	1500	9.06	1.28	6.52	11.60	43
Caucasian	2000	6.96	1.15	4.67	9.24	43
Caucasian	2500	3.98	1.09	1.82	6.14	43
Caucasian	3000	5.90	0.99	3.93	7.86	43
Caucasian	4000	11.95	0.93	10.10	13.80	43
Caucasian	5000	14.39	1.02	12.37	16.40	43
Caucasian	6000	13.54	1.33	10.91	16.16	43
Caucasian	8000	-3.50	1.57	-6.60	-0.39	43
Asian	1500	10.28	1.26	7.78	12.78	46
Asian	2000	6.59	1.13	4.35	8.84	46
Asian	2500	4.79	1.07	2.67	6.91	46
Asian	3000	3.46	0.97	1.53	5.39	46
Asian	4000	9.05	0.92	7.23	10.88	46
Asian	5000	13.11	1.00	11.12	15.09	46
Asian	6000	14.61	1.30	12.02	17.20	46
Asian	8000	2.37	1.54	-0.69	5.43	46
Other	1500	11.28	1.84	7.64	14.92	21
Other	2000	7.91	1.65	4.64	11.18	21
Other	2500	4.71	1.56	1.62	7.81	21
Other	3000	4.55	1.42	1.73	7.36	21
Other	4000	9.06	1.34	6.41	11.72	21
Other	5000	14.37	1.46	11.48	17.26	21
Other	6000	13.63	1.90	9.86	17.40	21
Other	8000	1.12	2.25	-3.34	5.58	21

Table 125: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and test condition (non-maneuver ambient versus peak). Current effect: [F(14, 742)=4.9305, p=.00000].

Ethnicity	**Test Condition**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	Non-maneuver, Ambient	7.75	1.57	4.64	10.87	43
Caucasian	Non-maneuver, Peak	7.81	1.62	4.60	11.03	43
Asian	Non-maneuver, Ambient	7.89	1.55	4.82	10.96	46
Asian	Non-maneuver, Peak	8.17	1.60	5.01	11.34	46
Other	Non-maneuver, Ambient	8.37	2.25	3.90	12.84	21
Other	Non-maneuver, Peak	8.28	2.33	3.67	12.89	21

Table 126: Comparison of mean DPOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Other) as a function of test condition (non-maneuver ambient versus non-maneuver peak). The analysis was collapsed across factors of gender and frequency. Current effect: [F(2, 106)=.74709, p=.47622].

Test Condition	Frequency (Hz)	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95%	CI +95%	n
Non-maneuver, Ambient	1500	10.23	0.59	9.06	11.40	110
Non-maneuver, Peak	1500	10.18	0.62	8.96	11.41	110
Non-maneuver, Ambient	2000	7.24	0.56	6.12	8.35	110
Non-maneuver, Peak	2000	7.07	0.55	5.98	8.16	110
Non-maneuver, Ambient	2500	4.37	0.53	3.31	5.42	110
Non-maneuver, Peak	2500	4.62	0.53	3.57	5.68	110
Non-maneuver, Ambient	3000	4.54	0.47	3.60	5.48	110
Non-maneuver, Peak	3000	4.73	0.47	3.79	5.67	110
Non-maneuver, Ambient	4000	9.82	0.46	8.92	10.73	110
Non-maneuver, Peak	4000	10.22	0.44	9.34	11.10	110
Non-maneuver, Ambient	5000	14.02	0.50	13.02	15.02	110
Non-maneuver, Peak	5000	13.89	0.50	12.91	14.87	110
Non-maneuver, Ambient	6000	13.97	0.62	12.75	15.19	110
Non-maneuver, Peak	6000	13.88	0.66	12.57	15.19	110
Non-maneuver, Ambient	8000	-0.14	0.74	-1.59	1.32	110
Non-maneuver, Peak	8000	0.13	0.76	-1.38	1.64	110

Table 127: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (15000 to 8000 Hz). The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish the non-maneuver peak from ambient test pressure condition data. Current effect: [F(7, 742)=.70447, p=.66832].

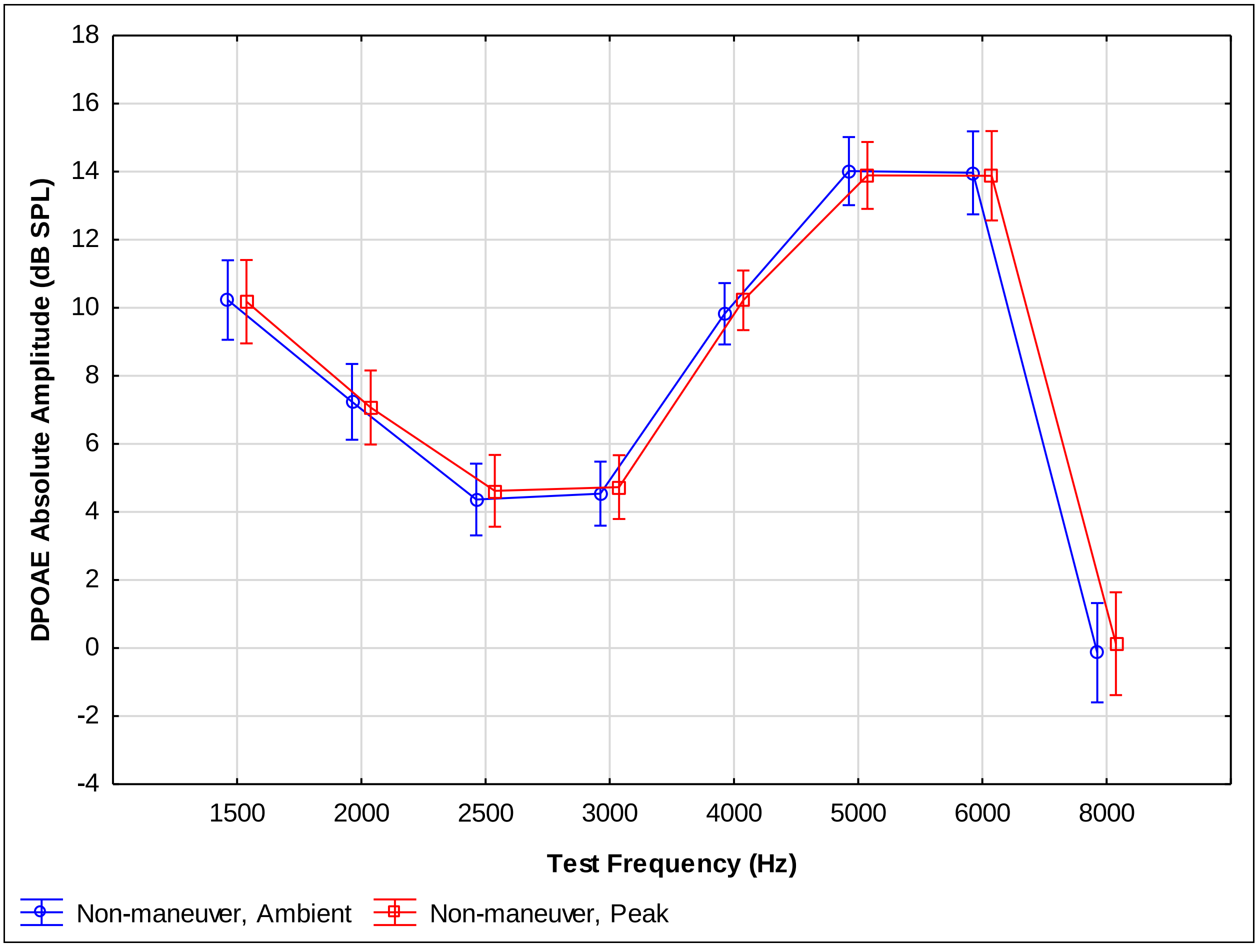

Figure 68: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(7, 742)=.70447, p=.66832].

Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver, Ambient	-22.37	0.45	-23.26	-21.48	110
Non-maneuver, Peak	-22.24	0.80	-23.82	-20.66	110

Table 128: Descriptive statistics for the comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus peak). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(1, 106)=.37809, p=.53994].

Gender	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Female	-21.89	0.28	-22.44	-21.35	64
Male	-22.72	0.30	-23.31	-22.13	46

Table 129: Comparison of mean DPOAE noise level between gender groups. The analysis was collapsed across factors of ethnicity, frequency, and test condition. Current effect: [F(1, 106)=4.2280, p=.4222)].

Gender	Test Condition	Mean DPOAE Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Female	Non-maneuver, Ambient	-22.15	0.60	-23.35	-20.95	64
Female	Non-maneuver, Peak	-21.64	1.08	-23.77	-19.50	64
Male	Non-maneuver, Ambient	-22.59	0.65	-23.88	-21.30	46
Male	Non-maneuver, Peak	-22.85	1.16	-25.14	-20.56	46

Table 130: Comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus peak) and gender groups. The analysis was collapsed across factors of ethnicity and frequency. Current effect: [F(1, 106)=3.7121, p=.05670].

Ethnicity	**Test Condition**	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	Non-maneuver, Ambient	-22.25	0.68	-23.60	-20.91	43
Caucasian	Non-maneuver, Peak	-21.54	1.21	-23.93	-19.15	43
Asian	Non-maneuver, Ambient	-22.74	0.67	-24.06	-21.41	46
Asian	Non-maneuver, Peak	-22.78	1.19	-25.13	-20.42	46
Other	Non-maneuver, Ambient	-22.12	0.97	-24.05	-20.19	21
Other	Non-maneuver, Peak	-22.42	1.73	-25.85	-18.99	21

Table 131: Comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) and ethnic groups. (Caucasian, Asian, and Other). The analysis was collapsed across factors of gender and frequency. Current effect: [F(2, 106)=2.3121, p=.10403].

|MEP| Magnitude (daPa)	**Test Condition**	**Mean Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**|CI| Spread**	**n**
A (0 to 10)	Non-maneuver, Ambient	7.93	1.33	5.29	10.57	5.28	58
A (0 to 10)	Non-maneuver, Peak	7.83	1.37	5.11	10.55	5.44	58
B (11 to 25)	Non-maneuver, Ambient	8.41	1.50	5.44	11.38	5.94	47
B (11 to 25)	Non-maneuver, Peak	8.77	1.54	5.71	11.83	6.12	47
C (26 to 50)	Non-maneuver, Ambient	5.79	5.09	-4.31	15.89	20.20	4
C (26 to 50)	Non-maneuver, Peak	4.95	5.25	-5.46	15.36	20.82	4
D (51 to 99)	Non-maneuver, Ambient	-2.02	10.01	-21.87	17.83	39.70	1
D (51 to 99)	Non-maneuver, Peak	-0.62	10.31	-21.08	19.83	40.92	1

Table 132: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute middle ear pressure (|MEP|) magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 103)=2.4526, p=.06753].

|MEP| Magnitude (daPa)	**Test Condition**	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Non-maneuver, Ambient	-22.26	0.57	-23.40	-21.13	58
A (0 to 10)	Non-maneuver, Peak	-21.96	1.00	-23.95	-19.97	58
B (11 to 25)	Non-maneuver, Ambient	-22.60	0.64	-23.87	-21.32	47
B (11 to 25)	Non-maneuver, Peak	-22.80	1.13	-25.04	-20.57	47
C (26 to 50)	Non-maneuver, Ambient	-22.19	2.19	-26.53	-17.85	4
C (26 to 50)	Non-maneuver, Peak	-21.57	3.83	-29.18	-13.97	4
D (51 to 99)	Non-maneuver, Ambient	-17.63	4.30	-26.16	-9.10	1
D (51 to 99)	Non-maneuver, Peak	-13.18	7.54	-28.13	1.76	1

Table 133: Comparison of mean DPOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 103)= 2.1822, p=.09462].

Ethnicity	**Test Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	1500	7.72	1.24	5.26	10.18	43
Caucasian	2000	6.32	1.07	4.20	8.44	43
Caucasian	2500	3.10	1.19	0.74	5.46	43
Caucasian	3000	4.96	1.23	2.53	7.40	43
Caucasian	4000	10.46	1.07	8.33	12.58	43
Caucasian	5000	13.02	1.28	10.49	15.56	43
Caucasian	6000	12.35	1.40	9.57	15.13	43
Caucasian	8000	-5.06	1.81	-8.65	-1.47	43
Asian	1500	9.23	1.22	6.81	11.65	46
Asian	2000	6.03	1.05	3.95	8.12	46
Asian	2500	3.99	1.17	1.67	6.31	46
Asian	3000	2.33	1.21	-0.06	4.73	46
Asian	4000	7.97	1.06	5.87	10.06	46
Asian	5000	11.97	1.26	9.47	14.46	46
Asian	6000	13.59	1.38	10.85	16.33	46
Asian	8000	1.10	1.78	-2.43	4.64	46
Other	1500	10.01	1.78	6.49	13.54	21
Other	2000	7.77	1.53	4.73	10.81	21
Other	2500	3.30	1.71	-0.09	6.69	21
Other	3000	2.49	1.76	-1.01	5.98	21
Other	4000	7.74	1.54	4.69	10.79	21
Other	5000	11.60	1.83	7.96	15.23	21
Other	6000	13.44	2.01	9.45	17.42	21
Other	8000	1.23	2.60	-3.93	6.38	21

Table 134: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function of frequency. The analysis was collapsed across factors of gender and test condition (post-maneuver ambient versus peak). Current effect: [F(14, 742)=5.1343, p=.00000].

Cell No.	Tukey HSD test; Pooled MSE = 35.991, df = 390.35																									
	Ethnicity	Freq.	{1} 7.99	{2} 6.52	{3} 3.13	{4} 4.89	{5} 10.44	{6} 13.04	{7} 12.36	{8} -5.06	{9} 9.67	{10} 6.38	{11} 4.04	{12} 2.23	{13} 7.95	{14} 11.99	{15} 13.61	{16} 1.10	{17} 9.59	{18} 7.45	{19} 3.26	{20} 2.60	{21} 7.76	{22} 11.57	{23} 13.42	{24} 1.23
1	Caucasian	1500		1.00	0.00	0.23	0.70	0.00	0.00	0.00	1.00	1.00	0.23	0.00	1.00	0.21	0.00	0.00	1.00	1.00	0.32	0.11	1.00	0.85	0.11	0.01
2	Caucasian	2000	1.00		0.10	1.00	0.02	0.00	0.00	0.00	0.69	1.00	0.96	0.11	1.00	0.00	0.00	0.00	0.97	1.00	0.93	0.71	1.00	0.20	0.00	0.13
3	Caucasian	2500	0.00	0.10		0.99	0.00	0.00	0.00	0.00	0.00	0.64	1.00	1.00	0.03	0.00	0.00	1.00	0.01	0.51	1.00	1.00	0.36	0.00	0.00	1.00
4	Caucasian	3000	0.23	1.00	0.99		0.00	0.00	0.00	0.00	0.03	1.00	1.00	0.91	0.75	0.00	0.00	0.31	0.34	1.00	1.00	1.00	0.98	0.01	0.00	0.82
5	Caucasian	4000	0.70	0.02	0.00	0.00		0.59	0.96	0.00	1.00	0.18	0.00	0.00	0.96	1.00	0.69	0.00	1.00	0.97	0.00	0.00	0.99	1.00	0.98	0.00
6	Caucasian	5000	0.00	0.00	0.00	0.00	0.59		1.00	0.00	0.56	0.00	0.00	0.00	0.01	1.00	1.00	0.00	0.89	0.08	0.00	0.00	0.14	1.00	1.00	0.00
7	Caucasian	6000	0.00	0.00	0.00	0.00	0.96	1.00		0.00	0.91	0.00	0.00	0.00	0.09	1.00	1.00	0.00	0.99	0.25	0.00	0.00	0.38	1.00	1.00	0.00
8	Caucasian	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
9	Asian	1500	1.00	0.69	0.00	0.03	1.00	0.56	0.91	0.00		0.10	0.00	0.00	0.98	0.74	0.01	0.00	1.00	1.00	0.01	0.00	1.00	1.00	0.77	0.00
10	Asian	2000	1.00	1.00	0.64	1.00	0.18	0.00	0.00	0.00	0.10		0.73	0.00	1.00	0.00	0.00	0.00	0.94	1.00	0.95	0.75	1.00	0.14	0.00	0.16
11	Asian	2500	0.23	0.96	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.73		0.97	0.01	0.00	0.00	0.26	0.07	0.89	1.00	1.00	0.78	0.00	0.00	0.99
12	Asian	3000	0.00	0.11	1.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.97		0.00	0.00	0.00	1.00	0.00	0.14	1.00	1.00	0.08	0.00	0.00	1.00
13	Asian	4000	1.00	1.00	0.03	0.75	0.96	0.01	0.09	0.00	0.98	1.00	0.01	0.00		0.01	0.00	0.00	1.00	1.00	0.31	0.11	1.00	0.82	0.09	0.00
14	Asian	5000	0.21	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.74	0.00	0.00	0.00	0.01		0.99	0.00	1.00	0.38	0.00	0.00	0.54	1.00	1.00	0.00
15	Asian	6000	0.00	0.00	0.00	0.00	0.69	1.00	1.00	0.00	0.01	0.00	0.00	0.00	0.00	0.99		0.00	0.64	0.02	0.00	0.00	0.04	1.00	1.00	0.00
16	Asian	8000	0.00	0.00	1.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.00	0.00	0.00	0.00		0.00	0.01	1.00	1.00	0.01	0.00	0.00	1.00
17	Other	1500	1.00	0.97	0.01	0.34	1.00	0.89	0.99	0.00	1.00	0.94	0.07	0.00	1.00	1.00	0.64	0.00		1.00	0.00	0.00	1.00	1.00	0.52	0.00
18	Other	2000	1.00	1.00	0.51	1.00	0.97	0.08	0.25	0.00	1.00	1.00	0.89	0.14	1.00	0.38	0.02	0.01	1.00		0.33	0.10	1.00	0.36	0.01	0.00
19	Other	2500	0.32	0.93	1.00	1.00	0.00	0.00	0.00	0.00	0.01	0.95	1.00	1.00	0.31	0.00	0.00	1.00	0.00	0.33		1.00	0.20	0.00	0.00	1.00
20	Other	3000	0.11	0.71	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.75	1.00	1.00	0.11	0.00	0.00	1.00	0.00	0.10	1.00		0.05	0.00	0.00	1.00
21	Other	4000	1.00	1.00	0.36	0.98	0.99	0.14	0.38	0.00	1.00	1.00	0.78	0.08	1.00	0.54	0.04	0.01	1.00	1.00	0.20	0.05		0.53	0.01	0.00
22	Other	5000	0.85	0.20	0.00	0.01	1.00	1.00	1.00	0.00	1.00	0.14	0.00	0.00	0.82	1.00	1.00	0.00	1.00	0.36	0.00	0.00	0.53		1.00	0.00
23	Other	6000	0.11	0.00	0.00	0.00	0.98	1.00	1.00	0.00	0.77	0.00	0.00	0.00	0.09	1.00	1.00	0.00	0.52	0.01	0.00	0.00	0.01	1.00		0.00
24	Other	8000	0.01	0.13	1.00	0.82	0.00	0.00	0.00	0.02	0.00	0.16	0.99	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	

Table 135: Tukey's HSD test results for the comparison of mean absolute amplitude between ethnic groups as a function of frequency. The darker shaded boxes indicate comparisons between the Caucasian group to the Other and Asian ethnic groups. The lightly shaded boxes indicated comparisons between the Asian and Other groups. Analysis was collapsed across factors of gender and test condition.

Test Condition	Test Frequency (Hz)	Mean DPOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Post-maneuver, Ambient	1500	8.43	0.59	7.26	9.59	110
Post-maneuver, Peak	1500	9.54	0.60	8.35	10.74	110
Post-maneuver, Ambient	2000	6.51	0.51	5.49	7.53	110
Post-maneuver, Peak	2000	6.91	0.52	5.87	7.95	110
Post-maneuver, Ambient	2500	3.13	0.59	1.96	4.31	110
Post-maneuver, Peak	2500	3.79	0.56	2.68	4.91	110
Post-maneuver, Ambient	3000	2.82	0.59	1.64	3.99	110
Post-maneuver, Peak	3000	3.70	0.61	2.49	4.92	110
Post-maneuver, Ambient	4000	8.42	0.54	7.34	9.50	110
Post-maneuver, Peak	4000	9.02	0.52	8.00	10.04	110
Post-maneuver, Ambient	5000	11.84	0.67	10.51	13.17	110
Post-maneuver, Peak	5000	12.55	0.59	11.39	13.71	110
Post-maneuver, Ambient	6000	13.05	0.68	11.69	14.41	110
Post-maneuver, Peak	6000	13.20	0.65	11.91	14.49	110
Post-maneuver, Ambient	8000	-1.08	0.90	-2.87	0.71	110
Post-maneuver, Peak	8000	-0.74	0.83	-2.39	0.90	110

Table 136: Comparison of mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) as a function of frequency (1500 to 8000 Hz). The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish the post-maneuver peak pressure data from the post-maneuver ambient test condition data. Current effect: [F(7, 742)=1.2104, p=.29435].

Cell No.	Tukey HSD test; Pooled MSE = 17.090, df = 112.85											
	|MEP| Magnitude (daPa)	Test Condition	{1} 7.2208	{2} 7.0917	{3} 7.3076	{4} 7.4319	{5} 7.9233	{6} 8.2629	{7} 6.7168	{8} 7.8396	{9} 3.6295	{10} 5.3006
1	A (0 to 10)	Post-maneuver, Ambient		1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.68	0.99
2	A (0 to 10)	Post-maneuver, Peak	1.00		1.00	1.00	1.00	1.00	1.00	1.00	0.72	0.99
3	B (11 to 25)	Post-maneuver, Ambient	1.00	1.00		1.00	1.00	1.00	1.00	1.00	0.15	0.88
4	B (11 to 25)	Post-maneuver, Peak	1.00	1.00	1.00		1.00	1.00	1.00	1.00	0.12	0.83
5	C (26 to 50)	Post-maneuver, Ambient	1.00	1.00	1.00	1.00		0.99	0.98	1.00	0.01	0.43
6	C (26 to 50)	Post-maneuver, Peak	1.00	1.00	1.00	1.00	0.99		0.89	1.00	0.00	0.26
7	D (51 to 99)	Post-maneuver, Ambient	1.00	1.00	1.00	1.00	0.98	0.89		0.02	0.17	0.96
8	D (51 to 99)	Post-maneuver, Peak	1.00	1.00	1.00	1.00	1.00	1.00	0.02		0.01	0.42
9	E (>99)	Post-maneuver, Ambient	0.68	0.72	0.15	0.12	0.01	0.00	0.17	0.01		0.00
10	E (>99)	Post-maneuver, Peak	0.99	0.99	0.88	0.83	0.43	0.26	0.96	0.42	0.00	

Table 137: Tukey's HSD test analysis for the comparison of mean DPOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) as a function of absolute MEP magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Shaded boxes represent significant comparisons of interest ($p<.05$).

|MEP| Magnitude (daPa)	**Test Condition**	**Mean DPOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Post-maneuver, Ambient	-21.90	2.74	-27.34	-16.46	6
A (0 to 10)	Post-maneuver, Peak	-19.97	2.60	-25.14	-14.81	6
B (11 to 25)	Post-maneuver, Ambient	-22.84	1.61	-26.03	-19.66	18
B (11 to 25)	Post-maneuver, Peak	-22.61	1.52	-25.63	-19.59	18
C (26 to 50)	Post-maneuver, Ambient	-22.51	1.23	-24.95	-20.07	29
C (26 to 50)	Post-maneuver, Peak	-22.07	1.17	-24.38	-19.75	29
D (51 to 99)	Post-maneuver, Ambient	-22.41	1.20	-24.79	-20.02	35
D (51 to 99)	Post-maneuver, Peak	-22.69	1.14	-24.95	-20.43	35
E (>99)	Post-maneuver, Ambient	-22.24	1.44	-25.10	-19.38	22
E (>99)	Post-maneuver, Peak	-21.75	1.37	-24.46	-19.04	22

Table 138: Comparison of mean DPOAE noise level between test conditions (post-maneuver ambient versus peak) as a function of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 102)=.88142, p=.47791].

Cell No.	Tukey HSD test; Within MSE = 16.631, df = 318.00				
	Test Condition	{1} 7.95	{2} 8.09	{3} 7.34	{4}6.54
1	Non-maneuver Ambient		0.89	**0.01**	**0.00**
2	Non-maneuver Peak	0.89		**0.00**	**0.00**
3	Post-maneuver Peak	**0.01**	**0.00**		**0.00**
4	Post-maneuver Ambient	**0.00**	**0.00**	**0.00**	

Table 139: Tukey's HSD analysis for the comparison of mean DPOAE absolute amplitude between the four test conditions. The analysis was collapsed across factors of gender, ethnicity, and frequency. Bolded values indicate significant (p<.05).

Ethnicity	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	1500	8.39	1.76	4.91	11.87	43
Caucasian	2000	6.64	1.52	3.62	9.65	43
Caucasian	2500	3.54	1.55	0.46	6.62	43
Caucasian	3000	5.43	1.51	2.43	8.43	43
Caucasian	4000	11.20	1.35	8.52	13.89	43
Caucasian	5000	13.71	1.53	10.68	16.73	43
Caucasian	6000	12.94	1.88	9.20	16.68	43
Caucasian	8000	-4.28	2.33	-8.90	0.35	43
Asian	1500	9.75	1.73	6.33	13.18	46
Asian	2000	6.31	1.50	3.34	9.28	46
Asian	2500	4.39	1.53	1.36	7.42	46
Asian	3000	2.90	1.49	-0.05	5.85	46
Asian	4000	8.51	1.33	5.87	11.15	46
Asian	5000	12.54	1.50	9.56	15.51	46
Asian	6000	14.10	1.85	10.42	17.78	46
Asian	8000	1.73	2.30	-2.82	6.29	46
Other	1500	10.65	2.52	5.65	15.64	21
Other	2000	7.84	2.18	3.52	12.17	21
Other	2500	4.01	2.22	-0.40	8.42	21
Other	3000	3.52	2.17	-0.79	7.82	21
Other	4000	8.40	1.94	4.55	12.25	21
Other	5000	12.98	2.19	8.64	17.32	21
Other	6000	13.53	2.70	8.17	18.89	21
Other	8000	1.17	3.35	-5.46	7.81	21

Table 140: Comparison of mean DPOAE absolute amplitude between ethnic groups as a function of frequency. The analysis was collapsed across factors of gender and test condition (x4). Current effect: [F(14, 742)=5.3114, p=.00000].

Test Condition	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
No-maneuver, Ambient	1500	10.23	0.59	9.06	11.40	110
No-maneuver, Ambient	2000	7.24	0.56	6.12	8.35	110
No-maneuver, Ambient	2500	4.37	0.53	3.31	5.42	110
No-maneuver, Ambient	3000	4.54	0.47	3.60	5.48	110
No-maneuver, Ambient	4000	9.82	0.46	8.92	10.73	110
No-maneuver, Ambient	5000	14.02	0.50	13.02	15.02	110
No-maneuver, Ambient	6000	13.97	0.62	12.75	15.19	110
No-maneuver, Ambient	8000	-0.14	0.74	-1.59	1.32	110
Non-maneuver, Peak	1500	10.18	0.62	8.96	11.41	110
Non-maneuver, Peak	2000	7.07	0.55	5.98	8.16	110
Non-maneuver, Peak	2500	4.62	0.53	3.57	5.68	110
Non-maneuver, Peak	3000	4.73	0.47	3.79	5.67	110
Non-maneuver, Peak	4000	10.22	0.44	9.34	11.10	110
Non-maneuver, Peak	5000	13.89	0.50	12.91	14.87	110
Non-maneuver, Peak	6000	13.88	0.66	12.57	15.19	110
Non-maneuver, Peak	8000	0.13	0.76	-1.38	1.64	110
Post-maneuver, Peak	1500	9.54	0.60	8.35	10.74	110
Post-maneuver, Peak	2000	6.91	0.52	5.87	7.95	110
Post-maneuver, Peak	2500	3.79	0.56	2.68	4.91	110
Post-maneuver, Peak	3000	3.70	0.61	2.49	4.92	110
Post-maneuver, Peak	4000	9.02	0.52	8.00	10.04	110
Post-maneuver, Peak	5000	12.55	0.59	11.39	13.71	110
Post-maneuver, Peak	6000	13.20	0.65	11.91	14.49	110
Post-maneuver, Peak	8000	-0.74	0.83	-2.39	0.90	110
Post-maneuver, Ambient	1500	8.43	0.59	7.26	9.59	110
Post-maneuver, Ambient	2000	6.51	0.51	5.49	7.53	110
Post-maneuver, Ambient	2500	3.13	0.59	1.96	4.31	110
Post-maneuver, Ambient	3000	2.82	0.59	1.64	3.99	110
Post-maneuver, Ambient	4000	8.42	0.54	7.34	9.50	110
Post-maneuver, Ambient	5000	11.84	0.67	10.51	13.17	110
Post-maneuver, Ambient	6000	13.05	0.68	11.69	14.41	110
Post-maneuver, Ambient	8000	-1.08	0.90	-2.87	0.71	110

Table 141: Comparison of mean DPOAE absolute amplitude between test conditions (x4, non-maneuver and post-maneuver). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(21, 2226)=1.7589, p=.01780].

Cell No.	Tukey HSD test; Pooled MSE = 15.078, df = 123.42																					
	|MEP| shift Magnitude (daPa)	Condition	{1} 6.68	{2} 7.16	{3} 6.93	{4} 6.64	{5} 9.14	{6} 9.12	{7} 8.85	{8} 8.85	{9} 7.45	{10} 7.59	{11} 6.66	{12} 6.47	{13} 8.80	{14} 9.00	{15} 8.59	{16} 7.46	{17} 7.42	{18} 7.39	{19} 5.86	{20} 4.13
1	A (0 to 10)	Non-maneuver Ambient		1.00	1.00	1.00	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	1.00	1.00	1.00	1.00	1.00	0.93
2	A (0 to 10)	Non-maneuver Peak	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75
3	A (0 to 10)	Post-maneuver Peak	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.85
4	A (0 to 10)	Post-maneuver Ambient	1.00	1.00	1.00		0.98	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.99	1.00	1.00	1.00	1.00	0.94
5	B (11 to 25)	Non-maneuver Ambient	0.98	1.00	1.00	0.98		1.00	1.00	1.00	1.00	1.00	0.93	0.86	1.00	1.00	1.00	1.00	1.00	1.00	0.56	**0.02**
6	B (11 to 25)	Non-maneuver Peak	0.99	1.00	1.00	0.98	1.00		1.00	1.00	1.00	1.00	0.93	0.87	1.00	1.00	1.00	1.00	1.00	1.00	0.58	**0.02**
7	B (11 to 25)	Post-maneuver Peak	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	0.98	0.95	1.00	1.00	1.00	1.00	1.00	1.00	0.73	**0.04**
8	B (11 to 25)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	0.98	0.95	1.00	1.00	1.00	1.00	1.00	1.00	0.73	**0.04**
9	C (26 to 50)	Non-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	0.84	0.47	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.19
10	C (26 to 50)	Non-maneuver Peak	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.57	0.22	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.14
11	C (26 to 50)	Post-maneuver Peak	1.00	1.00	1.00	1.00	0.93	0.93	0.98	0.98	0.84	0.57		1.00	0.86	0.74	0.94	1.00	1.00	1.00	1.00	0.70
12	C (26 to 50)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	0.86	0.87	0.95	0.95	0.47	0.22	1.00		0.75	0.60	0.87	1.00	1.00	1.00	1.00	0.82
13	D (51 to 99)	Non-maneuver Ambient	0.98	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.86	0.75		1.00	1.00	**0.02**	1.00	1.00	0.34	**0.00**
14	D (51 to 99)	Non-maneuver Peak	0.96	1.00	0.99	0.95	1.00	1.00	1.00	1.00	0.99	1.00	0.74	0.60	1.00		1.00	**0.00**	0.99	0.99	0.23	**0.00**
15	D (51 to 99)	Post-maneuver Peak	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.87	1.00	1.00		0.11	1.00	1.00	0.49	**0.00**
16	D (51 to 99)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.02**	**0.00**	0.11		1.00	1.00	0.99	0.15
17	E(>99)	Non-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00		1.00	**0.01**	**0.00**
18	E(>99)	Non-maneuver Peak	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00		**0.01**	**0.00**
19	E(>99)	Post-maneuver Peak	1.00	1.00	1.00	1.00	0.56	0.58	0.73	0.73	1.00	0.99	1.00	1.00	0.34	0.23	0.49	0.99	**0.01**	**0.01**		**0.00**
20	E(>99)	Post-maneuver Ambient	0.93	0.75	0.85	0.94	**0.02**	**0.02**	**0.04**	**0.04**	0.19	0.14	0.70	0.82	**0.00**	**0.00**	**0.00**	0.15	**0.00**	**0.00**	**0.00**	

Table 142: Tukey's HSD test results for the comparison of mean DPOAE absolute amplitude between test conditions (x4) as a function of absolute MEP shift magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Bolded values indicate significant (p<.05).

|MEP| Shift Magnitude (daPa)	Test Condition	Mean Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver Ambient	-21.71	1.22	-24.13	-19.30	14
A (0 to 10)	Non-maneuver Peak	-21.86	2.18	-26.19	-17.53	14
A (0 to 10)	Post-maneuver Peak	-22.46	1.56	-25.55	-19.38	14
A (0 to 10)	Post-maneuver Ambient	-21.77	1.77	-25.27	-18.26	14
B (11 to 25)	Non-maneuver Ambient	-22.50	0.86	-24.20	-20.80	27
B (11 to 25)	Non-maneuver Peak	-22.68	1.54	-25.73	-19.63	27
B (11 to 25)	Post-maneuver Peak	-22.69	1.10	-24.86	-20.51	27
B (11 to 25)	Post-maneuver Ambient	-23.38	1.24	-25.85	-20.91	27
C (26 to 50)	Non-maneuver Ambient	-22.52	0.84	-24.18	-20.87	31
C (26 to 50)	Non-maneuver Peak	-22.10	1.50	-25.08	-19.12	31
C (26 to 50)	Post-maneuver Peak	-22.21	1.07	-24.33	-20.08	31
C (26 to 50)	Post-maneuver Ambient	-22.25	1.21	-24.66	-19.84	31
D (51 to 99)	Non-maneuver Ambient	-22.57	0.91	-24.37	-20.77	25
D (51 to 99)	Non-maneuver Peak	-22.46	1.63	-25.69	-19.23	25
D (51 to 99)	Post-maneuver Peak	-22.00	1.16	-24.30	-19.70	25
D (51 to 99)	Post-maneuver Ambient	-22.31	1.32	-24.92	-19.70	25
E (>99)	Non-maneuver Ambient	-22.01	1.24	-24.47	-19.55	13
E (>99)	Non-maneuver Peak	-21.54	2.23	-25.95	-17.12	13
E (>99)	Post-maneuver Peak	-21.39	1.59	-24.54	-18.25	13
E (>99)	Post-maneuver Ambient	-21.63	1.80	-25.20	-18.06	13

Table 143: Comparison of DPOAE noise level between test conditions (x4) as a function of absolute MEP shift magnitude categories (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(12, 306)=.68374, p=.76704].

Ethnicity	**Frequency (Hz)**	**Mean Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	1000	11.44	1.71	8.0	14.84	26
Caucasian	2000	5.47	1.40	2.7	8.24	26
Caucasian	3000	1.87	1.69	-1.5	5.21	26
Caucasian	4000	-2.77	1.94	-6.6	1.07	26
Caucasian	5000	-9.05	2.22	-13.5	-4.65	26
Asian	1000	11.98	1.26	9.5	14.49	48
Asian	2000	7.70	1.03	5.7	9.74	48
Asian	3000	2.87	1.24	0.4	5.33	48
Asian	4000	-1.82	1.43	-4.7	1.01	48
Asian	5000	-7.55	1.63	-10.8	-4.31	48
Other	1000	13.21	1.80	9.6	16.79	23
Other	2000	8.18	1.47	5.3	11.10	23
Other	3000	5.17	1.78	1.6	8.69	23
Other	4000	1.44	2.04	-2.6	5.49	23
Other	5000	-4.51	2.33	-9.1	0.13	23

Table 144: TEOAE absolute amplitude comparison across ethnic groups as a function of test frequency. The analysis was collapsed across factors of gender and test condition (non-maneuver ambient versus post-maneuver ambient). Current effect: [F(8, 372)=.72124, p=.67279].

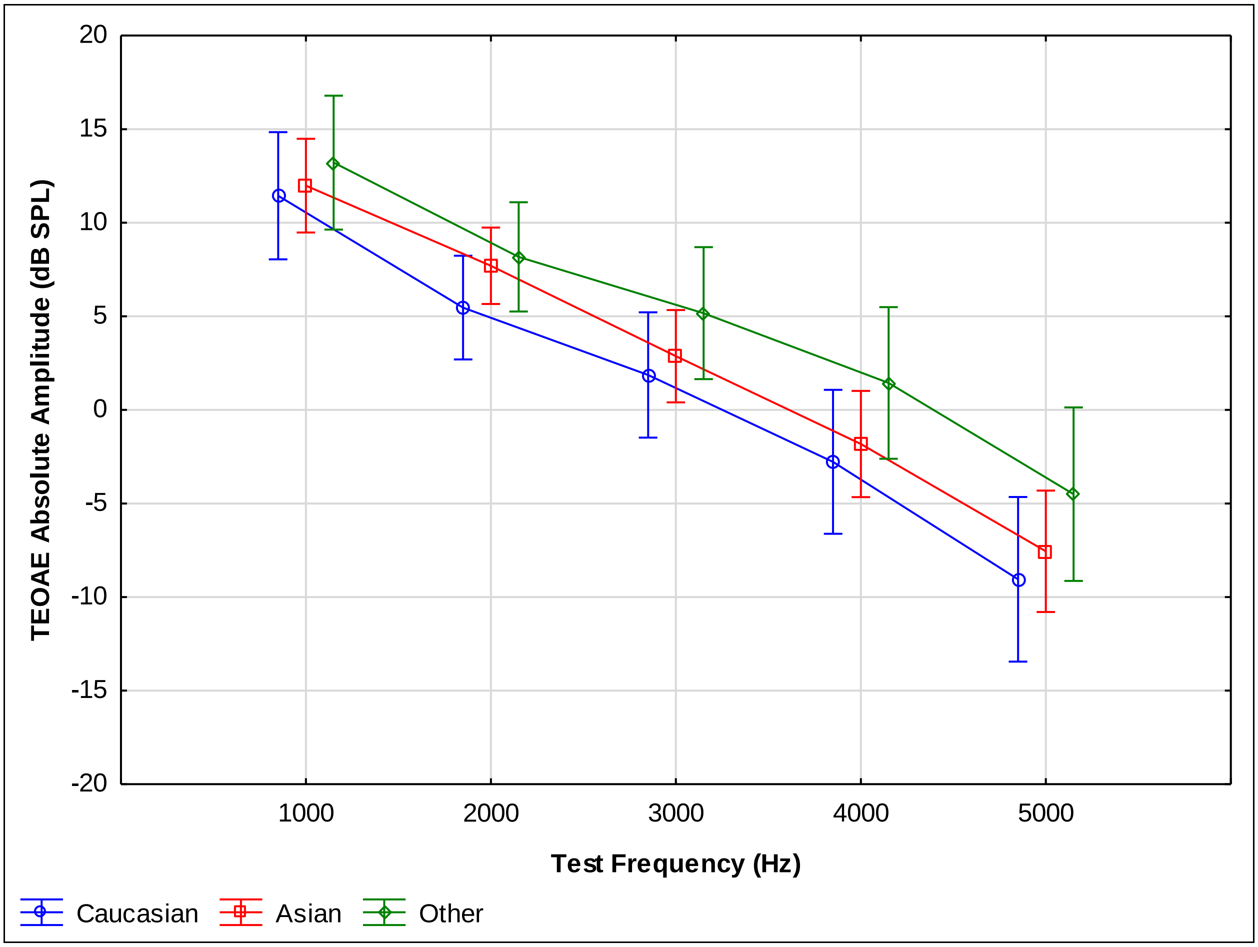

Figure 69: Comparison of mean TEOAE absolute amplitude as a function of test frequency (1000 to 5000 Hz) and ethnicity (Caucasian, Asian, and Other). The analysis was collapsed across factors of gender and test condition (non-maneuver ambient versus post-maneuver ambient). Vertical bars denote 95th percent confidence intervals. Current effect: [F(8, 372)=0.72124, p=0.67279].

Test Condition	**Test Frequency (Hz)**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1000	12.93	0.51	11.92	13.95	97
Post-maneuver, Ambient	1000	11.49	1.01	9.48	13.50	97
Non-maneuver, Ambient	2000	7.92	0.56	6.80	9.04	97
Post-maneuver, Ambient	2000	6.31	0.60	5.12	7.50	97
Non-maneuver, Ambient	3000	3.91	0.67	2.58	5.24	97
Post-maneuver, Ambient	3000	2.69	0.69	1.32	4.07	97
Non-maneuver, Ambient	4000	-0.73	0.78	-2.29	0.82	97
Post-maneuver, Ambient	4000	-1.37	0.79	-2.95	0.21	97
Non-maneuver, Ambient	5000	-6.84	0.90	-8.63	-5.05	97
Post-maneuver, Ambient	5000	-7.24	0.88	-8.98	-5.49	97

Table 145: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of ethnicity and gender. Shaded rows distinguish the post-maneuver peak from the ambient test pressure condition. Current effect: [F(4, 372)=1.3276, p=.25910].

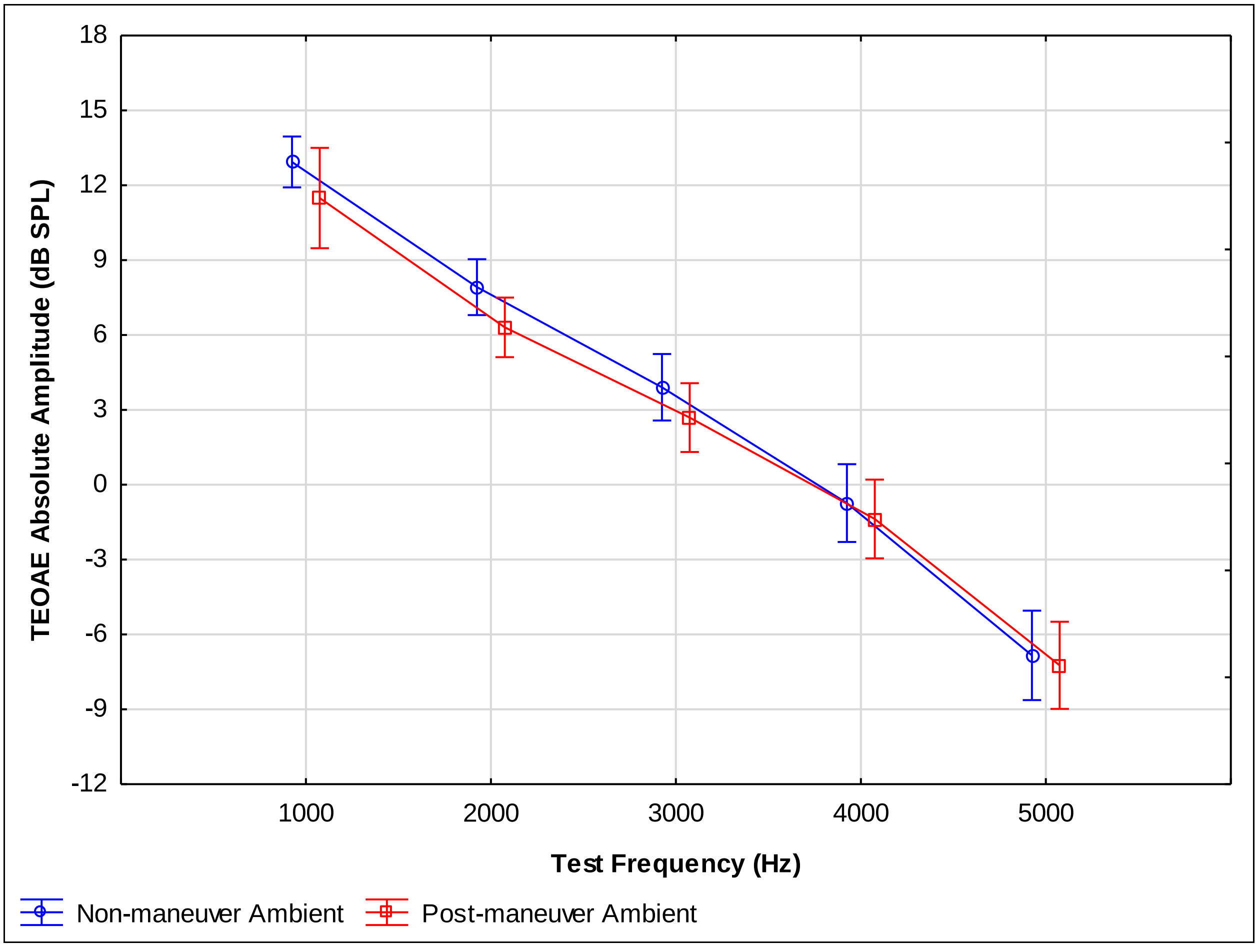

Figure 70: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of test frequency (1000 to 5000 Hz). The analysis was collapsed across factors of ethnicity and gender. Vertical bars denote the 95th percent confidence intervals. Current effect: [F(4, 372)=1.3276, p=.25910].

Test Condition	**Test Frequency (Hz)**	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1000	-5.10	0.77	-6.63	-3.57	97
Post-maneuver, Ambient	1000	-4.67	0.84	-6.32	-3.01	97
Non-maneuver, Ambient	2000	-8.35	0.19	-8.72	-7.98	97
Post-maneuver, Ambient	2000	-7.81	0.30	-8.41	-7.21	97
Non-maneuver, Ambient	3000	-10.35	0.17	-10.68	-10.02	97
Post-maneuver, Ambient	3000	-10.38	0.16	-10.69	-10.06	97
Non-maneuver, Ambient	4000	-13.53	0.21	-13.95	-13.11	97
Post-maneuver, Ambient	4000	-13.65	0.16	-13.97	-13.32	97
Non-maneuver, Ambient	5000	-15.91	0.16	-16.23	-15.59	97
Post-maneuver, Ambient	5000	-15.11	0.40	-15.91	-14.32	97

Table 146: Comparison of mean TEOAE noise levels between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function test frequency (1000 to 5000 Hz). The analysis was collapsed across factors of ethnicity and gender. Shaded rows distinguish the post-maneuver ambient from the non-maneuver ambient test condition data. Current effect: [F(4, 372)=1.8737, p=.11437].

|MEP| Shift Magnitude (daPa)	Test Condition	Mean Noise Level (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	-10.86	1.21	-13.26	-8.46	12
A (0 to 10)	Post-maneuver, Ambient	-10.88	1.27	-13.41	-8.35	12
B (11 to 25)	Non-maneuver, Ambient	-10.41	1.04	-12.48	-8.33	18
B (11 to 25)	Post-maneuver, Ambient	-9.96	1.10	-12.15	-7.78	18
C (26 to 50)	Non-maneuver, Ambient	-10.42	0.99	-12.39	-8.46	18
C (26 to 50)	Post-maneuver, Ambient	-10.38	1.04	-12.45	-8.31	18
D (51 to 99)	Non-maneuver, Ambient	-10.37	0.85	-12.07	-8.68	30
D (51 to 99)	Post-maneuver, Ambient	-9.84	0.89	-11.62	-8.06	30
E (>99)	Non-maneuver, Ambient	-11.21	0.97	-13.14	-9.28	19
E (>99)	Post-maneuver, Ambient	-10.79	1.02	-12.82	-8.76	19

Table 147: Comparison of TEOAE noise level between test conditions (non-maneuver ambient versus post-maneuver ambient) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=.57253, p=.68326].

Test Condition	**Test Frequency (Hz)**	**TEOAE Mean Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1000	12.93	0.51	11.92	13.95	97
Post-maneuver, Peak	1000	12.46	0.54	11.39	13.53	97
Non-maneuver, Ambient	2000	7.92	0.56	6.80	9.04	97
Post-maneuver, Peak	2000	7.46	0.60	6.27	8.64	97
Non-maneuver, Ambient	3000	3.91	0.67	2.58	5.24	97
Post-maneuver, Peak	3000	3.22	0.70	1.83	4.61	97
Non-maneuver, Ambient	4000	-0.73	0.78	-2.29	0.82	97
Post-maneuver, Peak	4000	-0.91	0.80	-2.49	0.68	97
Non-maneuver, Ambient	5000	-6.84	0.90	-8.63	-5.05	97
Post-maneuver, Peak	5000	-7.11	0.88	-8.85	-5.36	97

Table 148: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of test frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Shaded rows identify the post-maneuver peak test condition data, distinguish it from the non-maneuver ambient condition data. Current effect: [F(4, 372)=.83268, p=.50502].

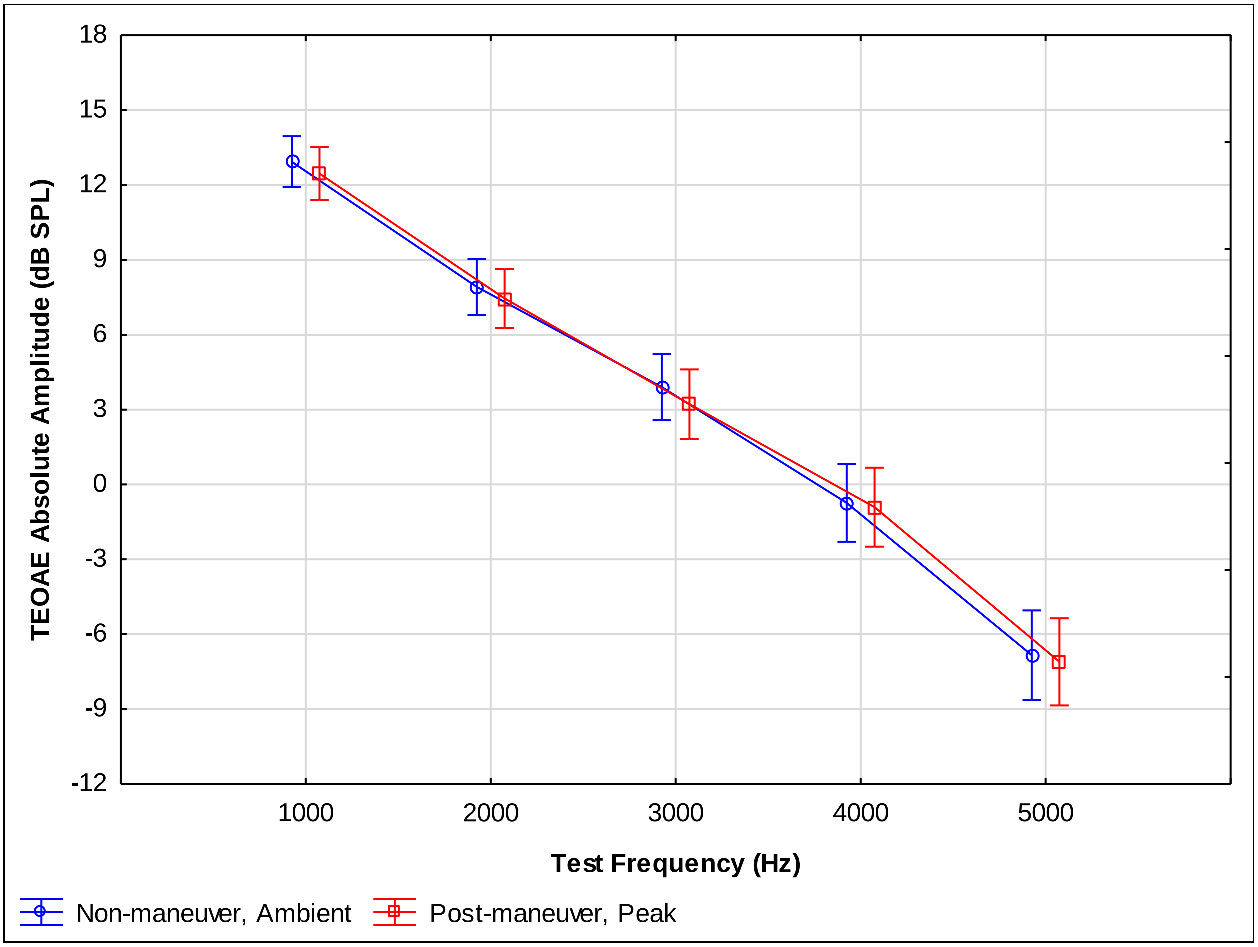

Figure 71: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of test frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. A sample size of n=97 TEOAE measures contributed to each test condition. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 372)=.83268, p=.50502].

Gender	**Test Frequency (Hz)**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	1000	13.29	0.82	11.7	14.92	64
Male	1000	12.11	1.14	9.9	14.37	33
Female	2000	9.20	0.90	7.4	10.99	64
Male	2000	6.18	1.25	3.7	8.66	33
Female	3000	5.09	1.10	2.9	7.27	64
Male	3000	2.04	1.52	-1.0	5.05	33
Female	4000	-0.32	1.26	-2.8	2.19	64
Male	4000	-1.32	1.74	-4.8	2.15	33
Female	5000	-4.87	1.43	-7.7	-2.04	64
Male	5000	-9.07	1.97	-13.0	-5.16	33

Table 149: Comparison of mean TEOAE absolute amplitude between genders as a function of frequency. The analysis was collapsed across factors of ethnicity and test condition (non-maneuver ambient versus post-maneuver peak). Mean TEOAE absolute amplitude data associated with male participants is identified by the shaded rows. Current effect: [F(4, 372)=2.3307, p=.05554].

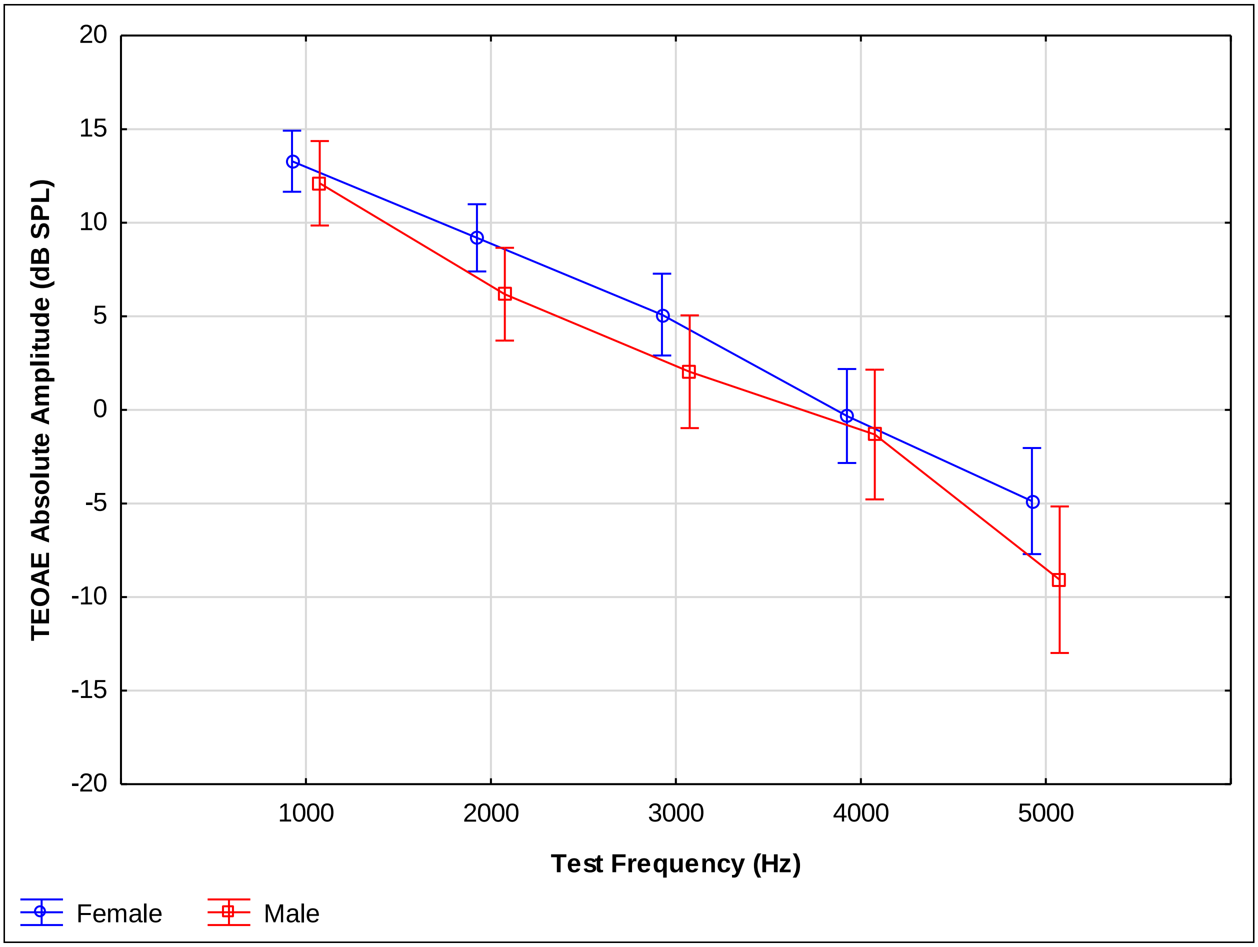

Figure 72: Comparison of mean TEOAE absolute amplitude between genders (n= 33 males and n= 64 females) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of ethnicity and test condition (non-maneuver ambient versus post-maneuver peak). Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 372)=2.3307, p=.05554].

Test Condition	**Frequency (Hz)**	**TEOAE Mean Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1000	-5.10	0.77	-6.63	-3.57	97
Post-maneuver, Peak	1000	-5.18	0.29	-5.76	-4.59	97
Non-maneuver, Ambient	2000	-8.35	0.19	-8.72	-7.98	97
Post-maneuver, Peak	2000	-8.04	0.25	-8.54	-7.54	97
Non-maneuver, Ambient	3000	-10.35	0.17	-10.68	-10.02	97
Post-maneuver, Peak	3000	-10.38	0.16	-10.70	-10.05	97
Non-maneuver, Ambient	4000	-13.53	0.21	-13.95	-13.11	97
Post-maneuver, Peak	4000	-13.10	0.35	-13.80	-12.40	97
Non-maneuver, Ambient	5000	-15.91	0.16	-16.23	-15.59	97
Post-maneuver, Peak	5000	-15.33	0.41	-16.14	-14.52	97

Table 150: Comparison of mean TEOAE noise level as a function of frequency (1000 to 5000 Hz) and test condition (non-maneuver ambient versus post-maneuver peak). The analysis was collapsed across factor of ethnicity. Current effect: [F(4, 372)=.42861, p=.78798].

|MEP| Shift (daPa)	Test Condition	TEOAE Mean Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	3.37	3.27	-3.12	9.87	12
A (0 to 10)	Post-maneuver, Peak	2.57	3.34	-4.06	9.20	12
B (11 to 25)	Non-maneuver, Ambient	4.51	2.82	-1.10	10.13	18
B (11 to 25)	Post-maneuver, Peak	5.04	2.88	-0.68	10.77	18
C (26 to 50)	Non-maneuver, Ambient	3.11	2.67	-2.21	8.42	18
C (26 to 50)	Post-maneuver, Peak	2.75	2.73	-2.67	8.17	18
D (51 to 99)	Non-maneuver, Ambient	3.54	2.30	-1.03	8.11	30
D (51 to 99)	Post-maneuver, Peak	3.05	2.35	-1.61	7.72	30
E (>99)	Non-maneuver, Ambient	2.84	2.63	-2.38	8.05	19
E (>99)	Post-maneuver, Peak	1.99	2.68	-3.33	7.31	19

Table 151: Comparison of TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of ethnicity, frequency, and gender. Current effect: [F(4, 89)=1.9070, p=.11621].

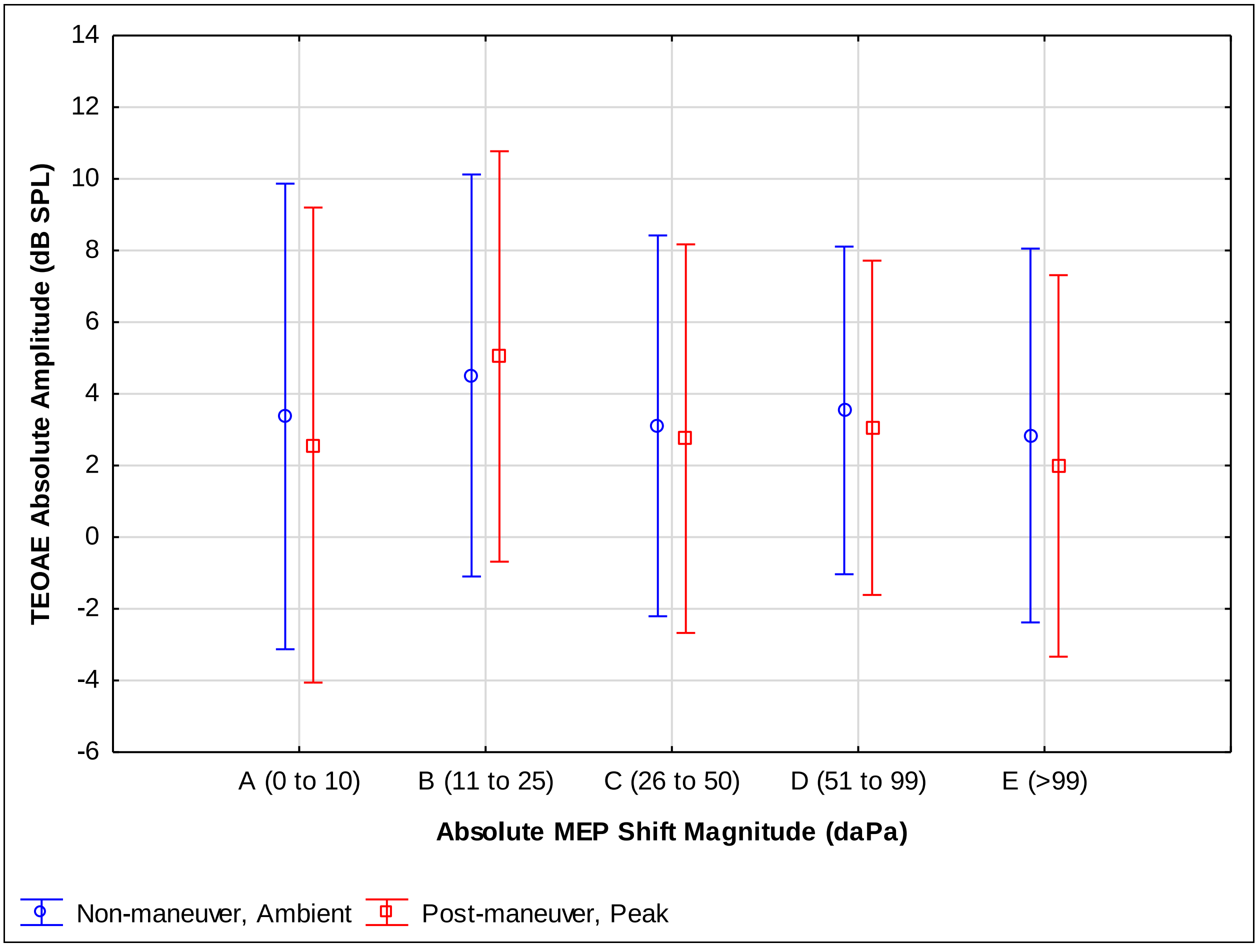

Figure 73: Comparison of TEOAE absolute amplitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude. The analysis was collapsed across factors of ethnicity, frequency, and gender. There is a sample of n=97 TEOAE measures for both test conditions. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 89)=1.9070, p=.11621].

|MEP| Shift (daPa)	**Test Condition**	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Non-maneuver, Ambient	-10.86	1.21	-13.26	-8.46	12
A (0 to 10)	Post-maneuver, Peak	-10.80	0.95	-12.69	-8.91	12
B (11 to 25)	Non-maneuver, Ambient	-10.41	1.04	-12.48	-8.33	18
B (11 to 25)	Post-maneuver, Peak	-9.99	0.82	-11.63	-8.36	18
C (26 to 50)	Non-maneuver, Ambient	-10.42	0.99	-12.39	-8.46	18
C (26 to 50)	Post-maneuver, Peak	-10.85	0.78	-12.39	-9.30	18
D (51 to 99)	Non-maneuver, Ambient	-10.37	0.85	-12.07	-8.68	30
D (51 to 99)	Post-maneuver, Peak	-10.32	0.67	-11.65	-8.99	30
E (>99)	Non-maneuver, Ambient	-11.21	0.97	-13.14	-9.28	19
E (>99)	Post-maneuver, Peak	-10.22	0.76	-11.74	-8.70	19

Table 152: Comparison of mean TEOAE noise level between test conditions (non-maneuver ambient and post-maneuver peak) as a function of absolute middle ear pressure (|MEP|) magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=1.1058, p=.35886].

Ethnicity	**Test Condition**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Caucasian	Non-maneuver, Ambient	1.69	2.20	-2.67	6.05	26
Caucasian	Non-maneuver, Peak	1.79	2.13	-2.45	6.03	26
Asian	Non-maneuver, Ambient	3.16	1.62	-0.05	6.38	48
Asian	Non-maneuver, Peak	3.12	1.57	-0.01	6.24	48
Other	Non-maneuver, Ambient	5.46	2.31	0.87	10.06	23
Other	Non-maneuver, Peak	5.90	2.25	1.44	10.37	23

Table 153: Comparison of mean TEOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Other) as a function of test condition (non-maneuver ambient versus non-maneuver peak). The analysis was collapsed across factors of gender and frequency. Current effect: F(2, 93)=1.5288, p=.22220].

Test Condition	**Test Frequency (Hz)**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95%**	**CI +95%**	**n**
Non-maneuver, Ambient	1000	12.93	0.51	11.92	13.95	97
Non-maneuver, Peak	1000	12.98	0.50	11.99	13.97	97
Non-maneuver, Ambient	2000	7.92	0.56	6.80	9.04	97
Non-maneuver, Peak	2000	8.24	0.54	7.17	9.32	97
Non-maneuver, Ambient	3000	3.91	0.67	2.58	5.24	97
Non-maneuver, Peak	3000	3.84	0.68	2.49	5.18	97
Non-maneuver, Ambient	4000	-0.73	0.78	-2.29	0.82	97
Non-maneuver, Peak	4000	-0.64	0.77	-2.17	0.89	97
Non-maneuver, Ambient	5000	-6.84	0.90	-8.63	-5.05	97
Non-maneuver, Peak	5000	-6.41	0.92	-8.23	-4.58	97

Table 154: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish the non-maneuver peak pressure test condition. Current effect: [F(4, 372)=1.1826, p=.31800].

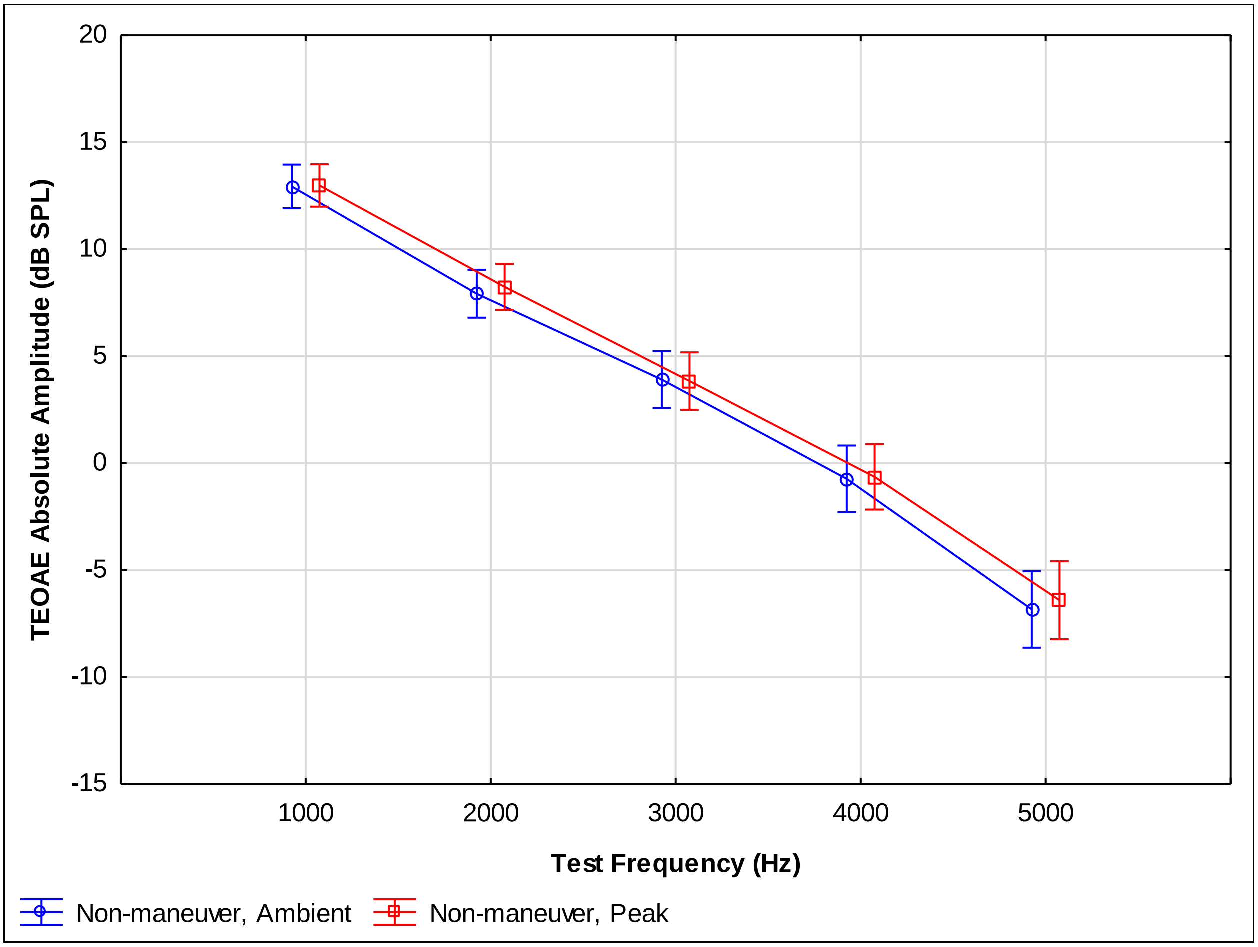

Figure 74: Comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 372)=1.1826, p=.31800].

Test Condition	**Test Frequency (Hz)**	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver, Ambient	1000	-5.10	0.770	-6.63	-3.57	97
Non-maneuver, Peak	1000	-4.83	0.282	-5.39	-4.27	97
Non-maneuver, Ambient	2000	-8.35	0.186	-8.72	-7.98	97
Non-maneuver, Peak	2000	-7.95	0.343	-8.63	-7.27	97
Non-maneuver, Ambient	3000	-10.35	0.167	-10.68	-10.02	97
Non-maneuver, Peak	3000	-10.20	0.276	-10.75	-9.66	97
Non-maneuver, Ambient	4000	-13.53	0.212	-13.95	-13.11	97
Non-maneuver, Peak	4000	-12.82	0.475	-13.76	-11.87	97
Non-maneuver, Ambient	5000	-15.91	0.160	-16.23	-15.59	97
Non-maneuver, Peak	5000	-16.97	1.717	-20.38	-13.56	97

Table 155: Comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender, and ethnicity. Current effect: [F(4, 372)=.56622, p=.68732].

Cell No.	Tukey HSD test; Pooled MSE = 23.934, df = 91.134											
	MEP Magnitude (daPa)	Test Condition	{1} 3.99	{2} 4.12	{3} 2.89	{4} 3.08	{5} 3.589	{6} 3.63	{7} 6.94	{8} 8.42	{9} 4.76	{10} 2.36
1	A (0 to 10)	Non-maneuver, Ambient		1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	A (0 to 10)	Non-maneuver, Peak	1.00		0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	B (11 to 25)	Non-maneuver, Ambient	0.99	0.99		0.99	1.00	1.00	1.00	0.98	1.00	1.00
4	B (11to 25)	Non-maneuver, Peak	1.00	1.00	0.99		1.00	1.00	1.00	0.99	1.00	1.00
5	C (26 to 50)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00
6	C (26 to 50)	Non-maneuver, Peak	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00
7	D (51 to 99)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00	1.00	1.00		0.93	1.00	1.00
8	D (51 to 99)	Non-maneuver, Peak	1.00	1.00	0.98	0.99	1.00	1.00	0.93		1.00	1.00
9	E (>99)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.43
10	E (>99)	Non-maneuver, Peak	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.43	

Table 156: Tukey's HSD test analysis for the comparison of mean TEOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute MEP magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Shaded boxes indicate comparisons of interest between test conditions.

Cell No.	Tukey HSD test; MSE = 5.9187, df = 171.14											
	|MEP| (daPa)	Test Condition	{1} -10.41	{2} -9.97	{3} -11.57	{4} -10.79	{5} -10.64	{6} -15.09	{7} -10.66	{8} -10.88	{9} -11.10	{10} -11.94
1	A (0 to 10)	Non-maneuver, Ambient		0.98	0.57	1.00	1.00	**0.00**	1.00	1.00	1.00	1.00
2	A (0 to 10)	Non-maneuver, Peak	0.98		0.13	0.92	1.00	**0.00**	1.00	1.00	1.00	1.00
3	B (11 to 25)	Non-maneuver, Ambient	0.57	0.13		0.95	1.00	**0.04**	1.00	1.00	1.00	1.00
4	B (11to 25)	Non-maneuver, Peak	1.00	0.92	0.95		1.00	**0.00**	1.00	1.00	1.00	1.00
5	C (26 to 50)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00		**0.02**	1.00	1.00	1.00	1.00
6	C (26 to 50)	Non-maneuver, Peak	**0.00**	**0.00**	**0.04**	**0.00**	**0.02**		0.80	0.85	0.88	0.97
7	D (51 to 99)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00	1.00	0.80		1.00	1.00	1.00
8	D (51 to 99)	Non-maneuver, Peak	1.00	1.00	1.00	1.00	1.00	0.85	1.00		1.00	1.00
9	E (>99)	Non-maneuver, Ambient	1.00	1.00	1.00	1.00	1.00	0.88	1.00	1.00		1.00
10	E (>99)	Non-maneuver, Peak	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	

Table 157: Tukey’s HSD test analysis for the comparison of mean TEOAE noise level between test conditions (non-maneuver ambient versus non-maneuver peak) across categories of absolute MEP magnitude (A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Shaded boxes indicate comparisons of interest between test conditions.

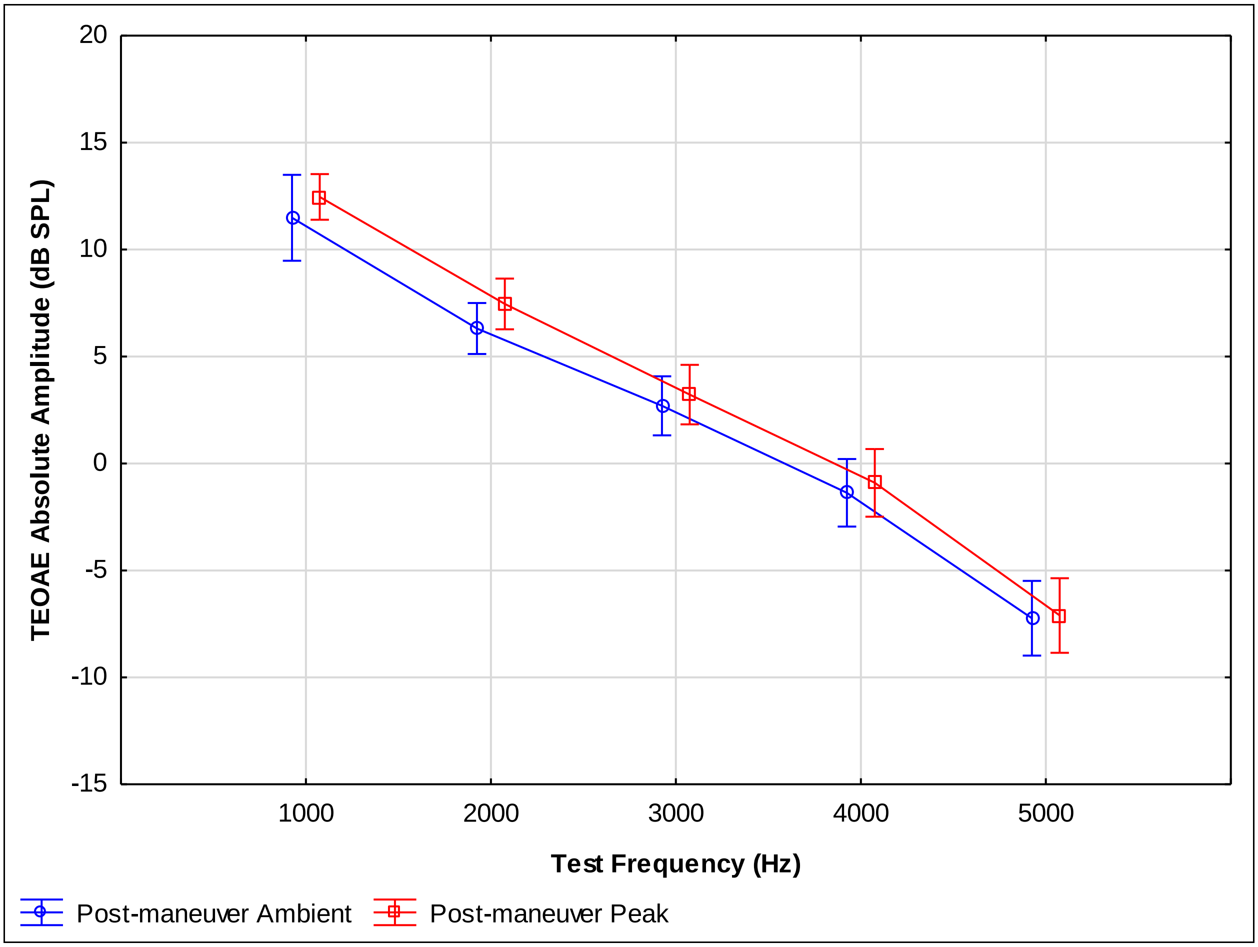

Figure 75: Mean TEOAE absolute amplitude comparison between test conditions (post-maneuver ambient n=97 versus post-maneuver peak n=97) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 372)=.73760, p=.56679].

Test Condition	**Frequency (Hz)**	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Post-maneuver, Ambient	1000	-4.67	0.84	-6.32	-3.01	97
Post-maneuver, Peak	1000	-5.18	0.29	-5.76	-4.59	97
Post-maneuver, Ambient	2000	-7.81	0.30	-8.41	-7.21	97
Post-maneuver, Peak	2000	-8.04	0.25	-8.54	-7.54	97
Post-maneuver, Ambient	3000	-10.38	0.16	-10.69	-10.06	97
Post-maneuver, Peak	3000	-10.38	0.16	-10.70	-10.05	97
Post-maneuver, Ambient	4000	-13.65	0.16	-13.97	-13.32	97
Post-maneuver, Peak	4000	-13.10	0.35	-13.80	-12.40	97
Post-maneuver, Ambient	5000	-15.11	0.40	-15.91	-14.32	97
Post-maneuver, Peak	5000	-15.33	0.41	-16.14	-14.52	97

Table 158: Comparison of TEOAE noise level between test conditions (post-maneuver ambient versus peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Current effect: [F(4, 372)=.58190, p=.67593].

|MEP| Magnitude (daPa)	**Test Condition**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Diff.**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Post-maneuver, Ambient	2.97	0.56	7.04	-11.0	16.95	3
A (0 to 10)	Post-maneuver, Peak	2.41		6.80	-11.1	15.91	3
B (11 to 25)	Post-maneuver, Ambient	2.57	-0.32	3.06	-3.5	8.65	16
B (11 to 25)	Post-maneuver, Peak	2.89		2.96	-3.0	8.77	16
C (26 to 50)	Post-maneuver, Ambient	3.33	-0.63	2.37	-1.4	8.04	27
C (26 to 50)	Post-maneuver, Peak	3.96		2.29	-0.6	8.51	27
D (51 to 99)	Post-maneuver, Ambient	2.53	-0.8	2.44	-2.3	7.39	31
D (51 to 99)	Post-maneuver, Peak	3.33		2.36	-1.4	8.02	31
E (>99)	Post-maneuver, Ambient	0.86	-0.8	2.78	-4.7	6.39	20
E (>99)	Post-maneuver, Peak	1.66		2.68	-3.7	7.00	20

Table 159: Comparison of mean TEOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) as a function of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The absolute amplitude difference between the two test conditions (ambient -peak) is displayed in the column labeled (Diff.). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=.42440, p=.79065].

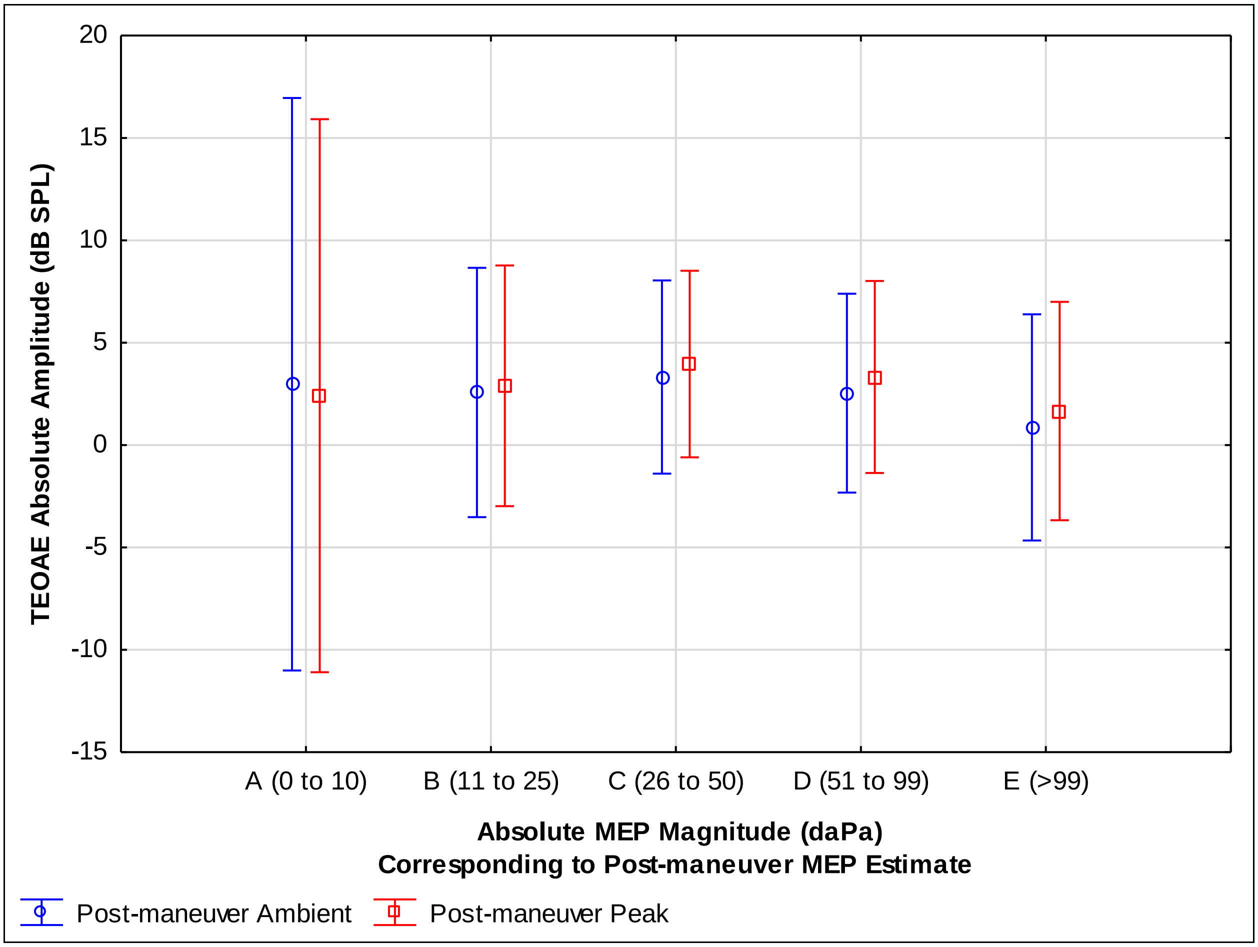

Figure 76: Comparison of mean TEOAE absolute amplitude between test conditions (post-maneuver ambient versus peak) as a function of absolute middle ear pressure (MEP) magnitude (categories A to E). Sample sizes for each category are as follows: A (n=3), B (n=16), C (n=27), D (n=31), and E (n=20). The analysis was collapsed across factors of gender, ethnicity, and frequency. Vertical bars denote 95th percent confidence intervals. Current effect: [F(4, 89)=.42440, p=.79065].

Ethnicity	Test Condition	Freq. (Hz)	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Caucasian	Post-maneuver, Ambient	1000	11.85	2.13	7.6	16.08	26
Caucasian	Post-maneuver, Ambient	2000	3.59	1.20	1.2	5.97	26
Caucasian	Post-maneuver, Ambient	3000	1.32	1.45	-1.6	4.20	26
Caucasian	Post-maneuver, Ambient	4000	-3.65	1.65	-6.9	-0.37	26
Caucasian	Post-maneuver, Ambient	5000	-8.57	1.84	-12.2	-4.92	26
Caucasian	Post-maneuver, Peak	1000	10.58	1.11	8.4	12.79	26
Caucasian	Post-maneuver, Peak	2000	5.66	1.24	3.2	8.13	26
Caucasian	Post-maneuver, Peak	3000	1.36	1.47	-1.6	4.29	26
Caucasian	Post-maneuver, Peak	4000	-2.18	1.65	-5.5	1.11	26
Caucasian	Post-maneuver, Peak	5000	-8.85	1.83	-12.5	-5.22	26
Asian	Post-maneuver, Ambient	1000	11.50	1.73	8.1	14.94	48
Asian	Post-maneuver, Ambient	2000	6.64	0.97	4.7	8.57	48
Asian	Post-maneuver, Ambient	3000	2.27	1.18	-0.1	4.61	48
Asian	Post-maneuver, Ambient	4000	-2.78	1.34	-5.4	-0.12	48
Asian	Post-maneuver, Ambient	5000	-7.72	1.49	-10.7	-4.75	48
Asian	Post-maneuver, Peak	1000	12.40	0.90	10.6	14.19	48
Asian	Post-maneuver, Peak	2000	7.60	1.01	5.6	9.60	48
Asian	Post-maneuver, Peak	3000	2.90	1.20	0.5	5.27	48
Asian	Post-maneuver, Peak	4000	-3.22	1.34	-5.9	-0.55	48
Asian	Post-maneuver, Peak	5000	-7.39	1.48	-10.3	-4.44	48
Other	Post-maneuver, Ambient	1000	12.27	2.33	7.6	16.89	23
Other	Post-maneuver, Ambient	2000	7.96	1.31	5.4	10.56	23
Other	Post-maneuver, Ambient	3000	4.70	1.58	1.6	7.85	23
Other	Post-maneuver, Ambient	4000	0.88	1.80	-2.7	4.46	23
Other	Post-maneuver, Ambient	5000	-3.48	2.01	-7.5	0.51	23
Other	Post-maneuver, Peak	1000	14.44	1.21	12.0	16.85	23
Other	Post-maneuver, Peak	2000	7.21	1.35	4.5	9.90	23
Other	Post-maneuver, Peak	3000	4.93	1.61	1.7	8.13	23
Other	Post-maneuver, Peak	4000	0.85	1.80	-2.7	4.43	23
Other	Post-maneuver, Peak	5000	-3.54	2.00	-7.5	0.42	23

Table 160: Comparison of TEOAE absolute amplitude between test conditions (post-maneuver ambient and peak) and ethnic groups, as a function of frequency. The analysis was collapsed across factor of gender and MEP magnitude. Current effect: [F(8, 356)=2.0201, p=.04329].

|MEP| Magnitude (daPa)	**Test Condition**	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
A (0 to 10)	Post-maneuver, Ambient	-10.0	2.62	-15.2	-4.81	3
A (0 to 10)	Post-maneuver, Peak	-10.6	1.97	-14.5	-6.67	3
B (11 to 25)	Post-maneuver, Ambient	-10.5	1.14	-12.8	-8.25	16
B (11 to 25)	Post-maneuver, Peak	-10.5	0.86	-12.2	-8.78	16
C (26 to 50)	Post-maneuver, Ambient	-10.1	0.88	-11.8	-8.32	27
C (26 to 50)	Post-maneuver, Peak	-10.4	0.66	-11.7	-9.10	27
D (51 to 99)	Post-maneuver, Ambient	-10.3	0.91	-12.1	-8.50	31
D (51 to 99)	Post-maneuver, Peak	-10.5	0.68	-11.9	-9.18	31
E (>99)	Post-maneuver, Ambient	-10.5	1.03	-12.6	-8.49	20
E (>99)	Post-maneuver, Peak	-10.2	0.78	-11.7	-8.64	20

Table 161: Comparison of mean TEOAE noise level between test conditions (post-maneuver ambient versus peak) as a function of absolute middle ear pressure (|MEP|) magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(4, 89)=.38231, p=.82075].

Gender	**Test Condition**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Female	Non-maneuver, Ambient	4.68	1.41	1.88	7.49	64
Male	Non-maneuver, Ambient	2.20	1.95	-1.67	6.07	33
Female	Non-maneuver, Peak	4.90	1.37	2.17	7.63	64
Male	Non-maneuver, Peak	2.31	1.90	-1.46	6.07	33
Female	Post-maneuver, Peak	4.27	1.46	1.37	7.17	64
Male	Post-maneuver, Peak	1.78	2.01	-2.22	5.78	33
Female	Post-maneuver, Ambient	3.71	1.51	0.70	6.71	64
Male	Post-maneuver, Ambient	1.05	2.09	-3.10	5.19	33

Table 162: Comparison of mean TEOAE absolute amplitude between gender groups (n=64 females and n=33 males) as a function of test condition (x4, non-maneuver and post-maneuver). The analysis was collapsed across factors of ethnicity and frequency. Shaded rows distinguish the male participant data from female participant data. Current effect: [F(3, 279)=.09445, p=.96306].

Ethnicity	Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Caucasian	Non-maneuver, Ambient	1.69	2.20	-2.67	6.05	26
Caucasian	Non-maneuver, Peak	1.79	2.13	-2.45	6.03	26
Caucasian	Post-maneuver, Peak	1.71	2.27	-2.80	6.21	26
Caucasian	Post-maneuver, Ambient	1.09	2.35	-3.57	5.76	26
Asian	Non-maneuver, Ambient	3.16	1.62	-0.05	6.38	48
Asian	Non-maneuver, Peak	3.12	1.57	-0.01	6.24	48
Asian	Post-maneuver, Peak	2.81	1.67	-0.51	6.13	48
Asian	Post-maneuver, Ambient	2.10	1.73	-1.33	5.54	48
Other	Non-maneuver, Ambient	5.46	2.31	0.87	10.06	23
Other	Non-maneuver, Peak	5.90	2.25	1.44	10.37	23
Other	Post-maneuver, Peak	4.56	2.39	-0.19	9.30	23
Other	Post-maneuver, Ambient	3.93	2.47	-0.98	8.85	23

Table 163: Comparison of mean TEOAE absolute amplitude between ethnic groups (Caucasian, Asian, and Other) as a function of test condition (x4). The analysis was collapsed across factors of gender and frequency. Shaded rows distinguish data from the Asian participant group from Caucasian and Other groups. Current effect: [F(6, 279)=1.7832, p=.10248].

Test Condition	Frequency (Hz)	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
Non-maneuver Ambient	1000	12.93	0.51	11.92	13.95	97
Non-maneuver Peak	1000	12.98	0.50	11.99	13.97	97
Post-maneuver Ambient	1000	11.49	1.01	9.48	13.50	97
Post-maneuver Peak	1000	12.46	0.54	11.39	13.53	97
Non-maneuver Ambient	2000	7.92	0.56	6.80	9.04	97
Non-maneuver Peak	2000	8.24	0.54	7.17	9.32	97
Post-maneuver Ambient	2000	6.31	0.60	5.12	7.50	97
Post-maneuver Peak	2000	7.46	0.60	6.27	8.64	97
Non-maneuver Ambient	3000	3.91	0.67	2.58	5.24	97
Non-maneuver Peak	3000	3.84	0.68	2.49	5.18	97
Post-maneuver Ambient	3000	2.69	0.69	1.32	4.07	97
Post-maneuver Peak	3000	3.22	0.70	1.83	4.61	97
Non-maneuver Ambient	4000	-0.73	0.78	-2.29	0.82	97
Non-maneuver Peak	4000	-0.64	0.77	-2.17	0.89	97
Post-maneuver Ambient	4000	-1.37	0.79	-2.95	0.21	97
Post-maneuver Peak	4000	-0.91	0.80	-2.49	0.68	97
Non-maneuver Ambient	5000	-6.84	0.90	-8.63	-5.05	97
Non-maneuver Peak	5000	-6.41	0.92	-8.23	-4.58	97
Post-maneuver Ambient	5000	-7.24	0.88	-8.98	-5.49	97
Post-maneuver Peak	5000	-7.11	0.88	-8.85	-5.36	97

Table 164: Comparison of mean TEOAE absolute amplitude between test conditions (x4, non-maneuver and post-maneuver) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. A sample size of n=97 TEOAE measures contributed to each test condition. Current effect: [F(12, 1116)=1.0371, p=.41169].

Test Condition	**Mean TEOAE Noise Level (dB SPL)**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	-10.65	0.46	-11.56	-9.73	97
Non-maneuver Peak	-10.55	0.80	-12.13	-8.98	97
Post-maneuver Peak	-10.40	0.37	-11.13	-9.68	97
Post-maneuver Ambient	-10.32	0.49	-11.29	-9.36	97

Table 165: Comparison of mean TEOAE noise level between test conditions (x4, non-maneuver and post-maneuver, both ambient and peak pressure). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(3, 279)=.46396, p=.70767].

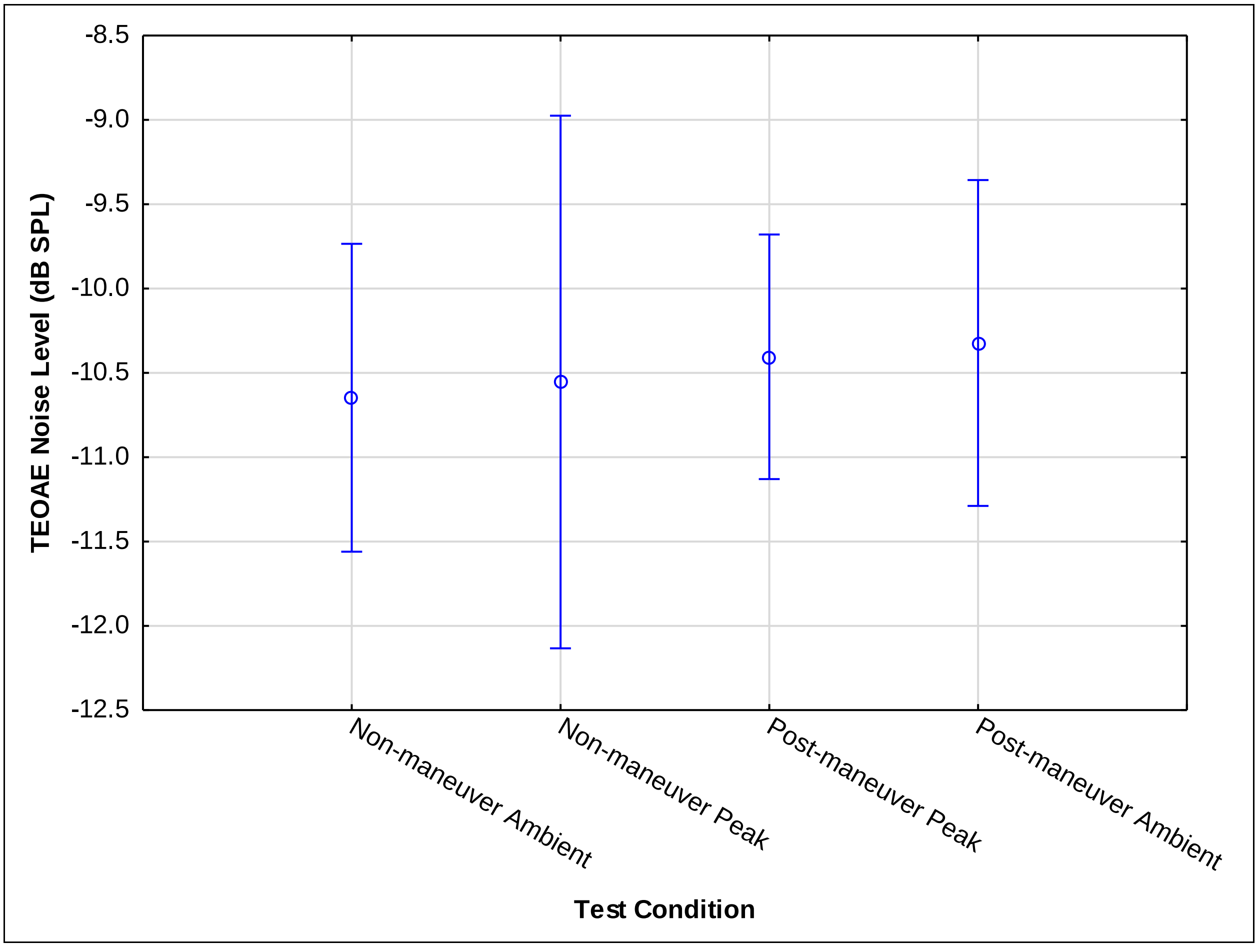

Figure 77: Comparison of mean TEOAE noise level between test conditions (x4, non-maneuver and post-maneuver, bot ambient and peak pressure). The analysis was collapsed across factors of gender, ethnicity, and frequency. A sample size of n=97 TEOAE measures contributes to each of the four test conditions. Vertical bars denote 95th percent confidence intervals. Current effect: [F(3, 279)=.46396, p=.70767].

|MEP| Shift Magnitude (daPa)	Test Condition	Mean TEOAE Absolute Amplitude (dB SPL)	Standard Error	CI -95.00%	CI +95.00%	n
A (0 to 10)	Non-maneuver, Ambient	3.37	3.27	-3.12	9.87	12
A (0 to 10)	Non-maneuver, Peak	3.04	3.16	-3.23	9.31	12
A (0 to 10)	Post-maneuver, Peak	2.57	3.34	-4.06	9.20	12
A (0 to 10)	Post-maneuver, Ambient	2.61	3.46	-4.28	9.49	12
B (11 to 25)	Non-maneuver, Ambient	4.51	2.82	-1.10	10.13	18
B (11 to 25)	Non-maneuver, Peak	5.21	2.73	-0.21	10.63	18
B (11 to 25)	Post-maneuver, Peak	5.04	2.88	-0.68	10.77	18
B (11 to 25)	Post-maneuver, Ambient	4.11	2.99	-1.84	10.05	18
C (26 to 50)	Non-maneuver, Ambient	3.11	2.67	-2.21	8.42	18
C (26 to 50)	Non-maneuver, Peak	3.24	2.58	-1.89	8.37	18
C (26 to 50)	Post-maneuver, Peak	2.75	2.73	-2.67	8.17	18
C (26 to 50)	Post-maneuver, Ambient	2.50	2.83	-3.13	8.13	18
D (51 to 99)	Non-maneuver, Ambient	3.54	2.30	-1.03	8.11	30
D (51 to 99)	Non-maneuver, Peak	3.67	2.22	-0.75	8.08	30
D (51 to 99)	Post-maneuver, Peak	3.05	2.35	-1.61	7.72	30
D (51 to 99)	Post-maneuver, Ambient	2.25	2.44	-2.59	7.09	30
E (>99)	Non-maneuver, Ambient	2.84	2.63	-2.38	8.05	19
E (>99)	Non-maneuver, Peak	2.96	2.54	-2.08	8.00	19
E (>99)	Post-maneuver, Peak	1.99	2.68	-3.33	7.31	19
E (>99)	Post-maneuver, Ambient	1.02	2.78	-4.50	6.55	19

Table 166: Comparison of TEOAE absolute amplitude between test conditions (x4, non-maneuver ambient and peak) as a function of absolute middle ear pressure (|MEP|) shift magnitude (categories A to E). The analysis was collapsed across factors of gender, ethnicity, and frequency. Current effect: [F(12, 267)=1.1628, p=.31017].

Gender	Center Frequency (Hz)	Absorbance Mean	Standard Error	CI -95.00%	CI +95.00%	n
Female	250	0.09	0.01	0.08	0.11	131
Female	315	0.10	0.01	0.08	0.11	131
Female	400	0.14	0.01	0.11	0.16	131
Female	500	0.21	0.01	0.18	0.24	131
Female	630	0.28	0.02	0.25	0.31	131
Female	800	0.34	0.02	0.30	0.37	131
Female	1000	0.39	0.02	0.35	0.42	131
Female	1250	0.45	0.02	0.42	0.49	131
Female	1600	0.46	0.02	0.42	0.51	131
Female	2000	0.48	0.03	0.43	0.54	131
Female	2500	0.61	0.03	0.56	0.66	131
Female	3150	0.64	0.03	0.58	0.69	131
Female	4000	0.66	0.03	0.61	0.70	131
Female	5000	0.55	0.02	0.51	0.60	131
Female	6300	0.38	0.03	0.33	0.43	131
Female	8000	0.28	0.03	0.22	0.34	131
Male	250	0.12	0.01	0.11	0.14	79
Male	315	0.13	0.01	0.11	0.15	79
Male	400	0.17	0.01	0.15	0.20	79
Male	500	0.25	0.02	0.22	0.29	79
Male	630	0.32	0.02	0.28	0.36	79
Male	800	0.40	0.02	0.35	0.44	79
Male	1000	0.46	0.02	0.42	0.51	79
Male	1250	0.51	0.02	0.47	0.55	79
Male	1600	0.52	0.03	0.46	0.57	79
Male	2000	0.52	0.03	0.46	0.59	79
Male	2500	0.62	0.03	0.56	0.68	79
Male	3150	0.59	0.03	0.52	0.66	79
Male	4000	0.60	0.03	0.54	0.66	79
Male	5000	0.50	0.03	0.45	0.55	79
Male	6300	0.39	0.03	0.33	0.46	79
Male	8000	0.34	0.04	0.26	0.41	79

Table 167: Post-maneuver condition: Comparison of mean absorbance magnitude between gender groups as a function of center frequency. The analysis was collapsed across factors of ethnicity, absolute MEP magnitude, and test pressure (ambient versus peak). Current effect: [F(15, 3030)=4.8016, p=.0000].

Ethnicity	Test Pressure	{1} .42112	{2} .43199	{3} .39886	{4} .40496	{5} .42298	{6} .43166
Caucasian	Ambient		**0.00**	0.43	0.76	1.00	0.98
Caucasian	Peak	**0.00**		0.06	0.21	0.99	1.00
Asian	Ambient	0.43	0.06		**0.00**	0.50	0.16
Asian	Peak	0.76	0.21	**0.00**		0.78	0.38
Other	Ambient	1.00	0.99	0.50	0.78		**0.00**
Other	Peak	0.98	1.00	0.16	0.38	**0.00**	

Table 168: Tukey's HSD test analysis for non-maneuver condition measure comparisons of mean absorbance magnitude between ethnic groups and test pressure conditions (ambient versus peak). The analysis was collapsed across factors of frequency, gender, and absolute MEP magnitude. Bolded values indicate significance (p ≤.05).

Cell No.	Tukey HSD test; Within MSE = .01916, df = 618.00				
	Test Condition	{1} .41145	{2} .41969	{3} .34033	{4} .41397
1	Non-maneuver, Ambient		0.00	**0.00**	0.74
2	Non-maneuver, Peak	0.00		**0.00**	0.10
3	Post-maneuver, Ambient	**0.00**	**0.00**		**0.00**
4	Post-maneuver, Peak	0.74	0.10	**0.00**	

Table 169: Tukey's HSD test results for the comparison of absorbance magnitude between test conditions (x4). The analysis was collapsed across factors of frequency, gender, ethnicity, and absolute MEP shift magnitude. Bolded values indicate significant (p <.05).

Tukey HSD test; Post Hoc Tests											
|MEP| Shift (daPa)	Test Condition	{1} .41	{2} .40	{3} .40	{4} .38	{5} .41	{6} .37	{7} .41	{8} .32	{9} .42	{10} .27
A (0 to 10)	Non-maneuver, Ambient		0.99	1.00	0.73	1.00	0.36	1.00	0.00	1.00	0.00
A (0 to 10)	Post-maneuver, Ambient	0.99		1.00	0.94	1.00	0.71	1.00	0.00	0.99	0.00
B (11 to 25)	Non-maneuver, Ambient	1.00	1.00		0.10	1.00	0.78	1.00	0.00	0.98	0.00
B (11 to 25)	Post-maneuver, Ambient	0.73	0.94	0.10		0.54	1.00	0.74	0.01	0.27	0.00
C (26 to 50)	Non-maneuver, Ambient	1.00	1.00	1.00	0.54		0.00	1.00	0.00	1.00	0.00
C (26 to 50)	Post-maneuver, Ambient	0.36	0.71	0.78	1.00	0.00		0.28	0.01	0.04	0.00
D (51 to 99)	Non-maneuver, Ambient	1.00	1.00	1.00	0.74	1.00	0.28		0.00	1.00	0.00
D (51 to 99)	Post-maneuver, Ambient	0.00	0.00	0.00	0.01	0.00	0.01	0.00		0.00	0.10
E (>99)	Non-maneuver, Ambient	1.00	0.99	0.98	0.27	1.00	0.04	1.00	0.00		0.00
E (>99)	Post-maneuver, Ambient	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	

Table 170: Tukey’s HSD analysis for the comparison of absorbance magnitude between non-maneuver ambient and post-maneuver ambient test conditions as a function of absolute MEP shift magnitude (A to E). The analysis was collapsed across frequency, gender, and ethnicity. Bolded values indicate significance (p≤.05).

Test Condition	**Frequency**	**Mean Absorbance Magnitude**	**Standard Error**	**CI -95.00%**	**CI +95.00%**	**n**
Non-maneuver Ambient	250	0.12	0.00	0.11	0.13	210
Non-maneuver Ambient	315	0.12	0.01	0.11	0.13	210
Non-maneuver Ambient	400	0.17	0.01	0.15	0.18	210
Non-maneuver Ambient	500	0.25	0.01	0.23	0.27	210
Non-maneuver Ambient	630	0.33	0.01	0.31	0.35	210
Non-maneuver Ambient	800	0.42	0.01	0.39	0.44	210
Non-maneuver Ambient	1000	0.50	0.01	0.48	0.52	210
Non-maneuver Ambient	1250	0.57	0.01	0.55	0.59	210
Non-maneuver Ambient	1600	0.58	0.01	0.56	0.60	210
Non-maneuver Ambient	2000	0.58	0.01	0.55	0.60	210
Non-maneuver Ambient	2500	0.66	0.01	0.63	0.68	210
Non-maneuver Ambient	3150	0.63	0.01	0.60	0.66	210
Non-maneuver Ambient	4000	0.63	0.01	0.60	0.65	210
Non-maneuver Ambient	5000	0.51	0.01	0.49	0.54	210
Non-maneuver Ambient	6300	0.35	0.01	0.32	0.38	210
Non-maneuver Ambient	8000	0.26	0.02	0.23	0.30	210
Post-maneuver Peak	250	0.13	0.01	0.12	0.14	210
Post-maneuver Peak	315	0.14	0.01	0.13	0.15	210
Post-maneuver Peak	400	0.19	0.01	0.18	0.21	210
Post-maneuver Peak	500	0.28	0.01	0.27	0.30	210
Post-maneuver Peak	630	0.38	0.01	0.35	0.40	210
Post-maneuver Peak	800	0.46	0.01	0.43	0.49	210
Post-maneuver Peak	1000	0.52	0.01	0.49	0.54	210
Post-maneuver Peak	1250	0.55	0.01	0.53	0.57	210
Post-maneuver Peak	1600	0.54	0.01	0.51	0.56	210
Post-maneuver Peak	2000	0.53	0.01	0.50	0.56	210
Post-maneuver Peak	2500	0.62	0.01	0.60	0.65	210
Post-maneuver Peak	3150	0.60	0.02	0.57	0.64	210
Post-maneuver Peak	4000	0.61	0.01	0.58	0.64	210
Post-maneuver Peak	5000	0.51	0.01	0.49	0.53	210
Post-maneuver Peak	6300	0.37	0.01	0.34	0.40	210
Post-maneuver Peak	8000	0.30	0.02	0.27	0.33	210

Table 171: Comparison of absorbance magnitude between test conditions (non-maneuver ambient versus post-maneuver peak) as a function of center frequency. The analysis was collapsed across factors of gender, ethnicity, and absolute MEP shift magnitude. Current effect: [F(15, 3030)=37.202, p=0.0000].

Cell No.	Tukey HSD test; Pooled MSE = .00588, df = 239.26																					
	MEP Shift	Test Condition	{1} .41221	{2} .42800	{3} .40333	{4} .42686	{5} .40109	{6} .41219	{7} .37734	{8} .40732	{9} .41339	{10} .41667	{11} .37131	{12} .41596	{13} .40724	{14} .41365	{15} .31652	{16} .40785	{17} .42092	{18} .42999	{19} .27365	{20} .41569
1	A (0 to 10)	Non-maneuver Ambient		0.69	1.00	0.80	1.00	1.00	0.97	1.00	1.00	1.00	0.76	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
2	A (0 to 10)	Non-maneuver Peak	0.69		0.03	1.00	1.00	1.00	0.55	1.00	1.00	1.00	0.16	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
3	A (0 to 10)	Post-maneuver Peak	1.00	0.03		0.05	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
4	A (0 to 10)	Post-maneuver Ambient	0.80	1.00	0.05		1.00	1.00	0.60	1.00	1.00	1.00	0.19	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
5	B (11 to 25)	Non-maneuver Ambient	1.00	1.00	1.00	1.00		0.98	0.04	1.00	1.00	1.00	0.98	1.00	1.00	1.00	0.00	1.00	1.00	0.99	0.00	1.00
6	B (11 to 25)	Non-maneuver Peak	1.00	1.00	1.00	1.00	0.98		0.00	1.00	1.00	1.00	0.74	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
7	B (11 to 25)	Post-maneuver Peak	0.97	0.55	1.00	0.60	0.04	0.00		0.00	0.89	0.80	1.00	0.82	0.98	0.86	0.05	0.97	0.64	0.27	0.00	0.84
8	B (11 to 25)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.00		1.00	1.00	0.90	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
9	C (26 to 50)	Non-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.89	1.00		1.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
10	C (26 to 50)	Non-maneuver Peak	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00		0.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
11	C (26 to 50)	Post-maneuver Peak	0.76	0.16	0.97	0.19	0.98	0.74	1.00	0.90	0.00	0.00		0.00	0.67	0.34	0.04	0.64	0.17	0.03	0.00	0.35
12	C (26 to 50)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.82	1.00	1.00	1.00	0.00		1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
13	D (51 to 99)	Non-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	0.67	1.00		1.00	0.00	1.00	1.00	1.00	0.00	1.00
14	D (51 to 99)	Non-maneuver Peak	1.00	1.00	1.00	1.00	1.00	1.00	0.86	1.00	1.00	1.00	0.34	1.00	1.00		0.00	1.00	1.00	1.00	0.00	1.00
15	D (51 to 99)	Post-maneuver Peak	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00		0.00	0.00	0.00	0.34	0.00
16	D (51 to 99)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00	1.00	1.00	0.64	1.00	1.00	1.00	0.00		1.00	1.00	0.00	1.00
17	E (>99)	Non-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.64	1.00	1.00	1.00	0.17	1.00	1.00	1.00	0.00	1.00		0.98	0.00	1.00
18	E (>99)	Non-maneuver Peak	1.00	1.00	1.00	1.00	0.99	1.00	0.27	1.00	1.00	1.00	0.03	1.00	1.00	1.00	0.00	1.00	0.98		0.00	0.43
19	E (>99)	Post-maneuver Peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00		0.00
20	E (>99)	Post-maneuver Ambient	1.00	1.00	1.00	1.00	1.00	1.00	0.84	1.00	1.00	1.00	0.35	1.00	1.00	1.00	0.00	1.00	1.00	0.43	0.00	

Table 172: Tukey’s HSD test results for the comparison of power absorbance magnitude between test conditions (x4) as a function of absolute MEP shift magnitude. The analysis was collapsed across factors of gender, ethnicity, and frequency.

Test Condition	**Frequency (Hz)**	**Mean PA Magnitude**	**SE**	**SD**	**5th Prctl**	**95th Prctl**	**n**
Post-maneuver Ambient	250	0.08	0.00	0.06	0.00	0.18	210
Post-maneuver Ambient	315	0.08	0.00	0.06	0.00	0.19	210
Post-maneuver Ambient	400	0.12	0.01	0.08	0.00	0.26	210
Post-maneuver Ambient	500	0.18	0.01	0.10	0.02	0.34	210
Post-maneuver Ambient	630	0.22	0.01	0.12	0.01	0.41	210
Post-maneuver Ambient	800	0.27	0.01	0.15	0.00	0.50	210
Post-maneuver Ambient	1000	0.33	0.01	0.17	0.01	0.61	210
Post-maneuver Ambient	1250	0.40	0.01	0.18	0.06	0.68	210
Post-maneuver Ambient	1600	0.44	0.01	0.21	0.03	0.71	210
Post-maneuver Ambient	2000	0.47	0.02	0.23	0.01	0.82	210
Post-maneuver Ambient	2500	0.61	0.02	0.20	0.22	0.92	210
Post-maneuver Ambient	3150	0.63	0.02	0.21	0.24	0.95	210
Post-maneuver Ambient	4000	0.65	0.01	0.18	0.33	0.90	210
Post-maneuver Ambient	5000	0.54	0.01	0.16	0.29	0.79	210
Post-maneuver Ambient	6300	0.40	0.02	0.19	0.10	0.70	210
Post-maneuver Ambient	8000	0.31	0.02	0.23	0.00	0.71	210
Post-maneuver Peak	250	0.14	0.01	0.07	0.03	0.25	210
Post-maneuver Peak	315	0.14	0.01	0.08	0.02	0.27	210
Post-maneuver Peak	400	0.19	0.01	0.10	0.05	0.35	210
Post-maneuver Peak	500	0.29	0.01	0.13	0.09	0.47	210
Post-maneuver Peak	630	0.38	0.01	0.17	0.09	0.68	210
Post-maneuver Peak	800	0.46	0.01	0.18	0.11	0.76	210
Post-maneuver Peak	1000	0.52	0.01	0.17	0.20	0.71	210
Post-maneuver Peak	1250	0.56	0.01	0.14	0.26	0.73	210
Post-maneuver Peak	1600	0.54	0.01	0.16	0.23	0.77	210
Post-maneuver Peak	2000	0.53	0.02	0.18	0.18	0.81	210
Post-maneuver Peak	2500	0.62	0.02	0.18	0.33	0.89	210
Post-maneuver Peak	3150	0.60	0.02	0.21	0.24	0.92	210

Test Condition	Frequency (Hz)	Mean PA Magnitude	SE	SD	5th Prctl	95th Prctl	n
Post-maneuver Peak	4000	0.61	0.02	0.19	0.31	0.91	210
Post-maneuver Peak	5000	0.51	0.01	0.15	0.29	0.76	210
Post-maneuver Peak	6300	0.37	0.02	0.19	0.07	0.69	210
Post-maneuver Peak	8000	0.30	0.02	0.23	0.00	0.69	210

Table 173: Comparison of mean power absorbance (PA) magnitude between post-maneuver ambient and peak test conditions as a function of center frequency (250 to 8000 Hz). The analysis was collapsed across factors of ethnicity, absolute middle ear pressure shift magnitude, and gender. Descriptive statistics for 5th and 95th percentiles (Prctl), standard deviation (SD) and standard error (SE) are included. Shaded data rows distinguish the non-maneuver peak test condition from the ambient condition. Current effect: [F(15, 3030)=122.01, p=.00000].

Test Condition	**Frequency (Hz)**	**Mean DPOAE Absolute Amplitude (dB SPL)**	**SE**	**SD**	**5th Prctl**	**95th Prctl**	**n**
Non-maneuver, Ambient	1500	10.23	0.59	5.84	-0.28	18.72	110
Non-maneuver, Peak	1500	10.18	0.62	6.13	-0.70	19.57	110
Non-maneuver, Ambient	2000	7.24	0.56	5.52	-1.20	15.25	110
Non-maneuver, Peak	2000	7.07	0.55	5.36	0.05	14.27	110
Non-maneuver, Ambient	2500	4.37	0.53	5.17	-3.26	12.00	110
Non-maneuver, Peak	2500	4.62	0.53	5.18	-3.90	12.60	110
Non-maneuver, Ambient	3000	4.54	0.47	4.74	-3.22	11.44	110
Non-maneuver, Peak	3000	4.73	0.47	4.72	-3.16	11.64	110
Non-maneuver, Ambient	4000	9.82	0.46	4.62	1.34	16.66	110
Non-maneuver, Peak	4000	10.22	0.44	4.54	2.16	17.00	110
Non-maneuver, Ambient	5000	14.02	0.50	4.96	6.05	21.30	110
Non-maneuver, Peak	5000	13.89	0.50	4.83	5.77	21.34	110
Non-maneuver, Ambient	6000	13.97	0.62	5.99	2.43	22.43	110
Non-maneuver, Peak	6000	13.88	0.66	6.47	2.04	22.61	110
Non-maneuver, Ambient	8000	-0.14	0.74	7.62	-12.03	9.56	110
Non-maneuver, Peak	8000	0.13	0.76	7.91	-12.83	10.77	110

Table 174: Comparison of mean DPOAE absolute amplitude between test conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (15000 to 8000 Hz). The 90% range is represented by 5th and 95th percentiles (Prctl). Standard deviation (SD) and standard error (SE) values are provided for each test condition. The analysis was collapsed across factors of gender and ethnicity. Shaded rows distinguish data for the peak from the ambient test pressure condition. Current effect: [F(7, 742)=.70447, p=.66832].

Test Condition	**Test Frequency (Hz)**	**Mean TEOAE Absolute Amplitude (dB SPL)**	**SE**	**SD**	**5th Prctl**	**95th Prctl**	**n**
Non-maneuver, Ambient	1000	12.93	0.51	4.05	3.60	19.50	97
Non-maneuver, Peak	1000	12.98	0.50	3.89	4.90	19.58	97
Non-maneuver, Ambient	2000	7.92	0.56	5.86	-0.14	16.94	97
Non-maneuver, Peak	2000	8.24	0.54	5.87	-0.52	16.74	97
Non-maneuver, Ambient	3000	3.91	0.67	5.33	-5.70	13.60	97
Non-maneuver, Peak	3000	3.84	0.68	5.59	-5.84	13.22	97
Non-maneuver, Ambient	4000	-0.73	0.78	5.65	-11.52	13.00	97
Non-maneuver, Peak	4000	-0.64	0.77	5.68	-10.74	13.00	97
Non-maneuver, Ambient	5000	-6.84	0.90	6.78	-17.26	9.26	97
Non-maneuver, Peak	5000	-6.41	0.92	6.40	-17.62	12.20	97

Table 175: Comparison of mean TEOAE absolute amplitude between test pressure conditions (non-maneuver ambient versus non-maneuver peak) as a function of frequency (1000 to 5000 Hz). The analysis was collapsed across factors of gender and ethnicity. Descriptive statistics are shown for 5th and 95th percentiles (Prctl), standard deviation (SD) and standard error (SE). Shaded rows distinguish the peak from the ambient test pressure condition. Current effect: [F(4, 372)=1.1826, p=.31800].

Appendix B Statistical Analysis

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.1287				
	SS	Degree of Freedom	MS	F	p
Intercept	**82926.00**	**1**	**82926.00**	**362.3178**	**0.000000**
Gender	78.78	1	78.78	0.3442	0.558655
Ethnicity	174.93	2	87.47	0.3822	0.683323
Error	24260.90	106	228.88		
NON_POST	**721.25**	**1**	**721.25**	**26.3879**	**0.000001**
NON_POST *Gender	13.46	1	13.46	0.4924	0.484384
NON_POST *Ethnicity	16.91	2	8.45	0.3093	0.734619
Error	2897.26	106	27.33		
FREQ	**32106.43**	**7**	**4586.63**	**115.8156**	**0.000000**
FREQ*Gender	380.32	7	54.33	1.3719	0.214037
FREQ*Ethnicity	**2740.78**	**14**	**195.77**	**4.9433**	**0.000000**
Error	29385.33	742	39.60		
NON_POST *FREQ	**86.01**	**7**	**12.29**	**2.3882**	**0.020261**
NON_POST *FREQ*Gender	9.26	7	1.32	0.2571	0.969897
NON_POST *FREQ*Ethnicity	72.58	14	5.18	1.0077	0.443156
Error	3817.47	742	5.14		

Table 176: Statistical analysis summary of mixed ANOVA for the comparison between DPOAE non-maneuver ambient versus post-maneuver ambient absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 10.7682				
	SS	Degree of Freedom	MS	F	p
Intercept	**776324.9**	**1**	**776324.9**	**19315.63**	**0.000000**
Gender	12.5	1	12.5	0.31	0.577729
Ethnicity	45.6	2	22.8	0.57	0.568775
Error	4260.3	106	40.2		
NON_POST	1.9	1	1.9	0.09	0.765148
NON_POST*Gender	26.8	1	26.8	1.24	0.267708
NON_POST*Ethnicity	17.9	2	8.9	0.41	0.661473
Error	2284.6	106	21.6		
FREQ	**4954.3**	**7**	**707.8**	**31.18**	**0.000000**
FREQ*Gender	82.5	7	11.8	0.52	0.820451
FREQ*Ethnicity	193.8	14	13.8	0.61	0.858174
Error	16840.7	742	22.7		
NON_POST*FREQ	65.7	7	9.4	0.45	0.868873
NON_POST *FREQ*Gender	28.1	7	4.0	0.19	0.986823
NON_POST *FREQ*Ethnicity	205.3	14	14.7	0.71	0.768827
Error	15398.8	742	20.8		

Table 177: Statistical analysis summary of the mixed ANOVA for DPOAE non-maneuver ambient versus post-maneuver ambient noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 14.7071				
	SS	Degree of Freedom	MS	F	p
Intercept	**74955.53**	**1**	**74955.53**	**346.5347**	**0.000000**
Gender	142.56	1	142.56	0.6591	0.418776
Ethnicity	299.75	2	149.87	0.6929	0.502465
|MEP| Shift	**2198.28**	**4**	**549.57**	**2.5408**	**0.044267**
Error	22062.62	102	216.30		
NONVSPOS	**452.46**	**1**	**452.46**	**19.6260**	**0.000024**
NONVSPOS*Gender	19.86	1	19.86	0.8614	0.355540
NONVSPOS*Ethnicity	14.79	2	7.40	0.3208	0.726262
NONVSPOS*|MEP| Shift	**545.76**	**4**	**136.44**	**5.9182**	**0.000253**
Error	2351.51	102	23.05		
FREQ	**28644.61**	**7**	**4092.09**	**106.7777**	**0.000000**
FREQ*Gender	407.15	7	58.16	1.5177	0.157886
FREQ*Ethnicity	**2298.34**	**14**	**164.17**	**4.2837**	**0.000000**
FREQ*|MEP| Shift	**2022.40**	**28**	**72.23**	**1.8847**	**0.004012**
Error	27362.93	714	38.32		
NONVSPO*FREQ	61.19	7	8.74	1.7180	0.101623
NONVSPOS *FREQ*Gender	9.00	7	1.29	0.2528	0.971303
NONVSPOS *FREQ*Ethnicity	70.28	14	5.02	0.9867	0.464995
NONVSPO*FREQ *|MEP| Shift	184.73	28	6.60	1.2967	0.141192
Error	3632.73	714	5.09		

Table 178: Statistical analysis summary of the mixed ANOVA for DPOAE non-maneuver ambient versus post-maneuver ambient noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 10.7250				
	SS	Degree of Freedom	MS	F	p
Intercept	**675983.7**	**1**	**675983.7**	**17325.18**	**0.000000**
Gender	32.1	1	32.1	0.82	0.366802
Ethnicity	83.0	2	41.5	1.06	0.348964
|MEP| Shift	280.5	4	70.1	1.80	0.135092
Error	3979.8	102	39.0		
NON_POST	0.0	1	0.0	0.00	0.992730
NON_POST*Gender	17.6	1	17.6	0.82	0.366826
NON_POS*Ethnicity	14.9	2	7.5	0.35	0.706237
NON_POS *|MEP| Shift	100.3	4	25.1	1.17	0.328004
Error	2184.2	102	21.4		
FREQ	**4158.6**	**7**	**594.1**	**26.24**	**0.000000**
FREQ*Gender	62.0	7	8.9	0.39	0.907816
FREQ*Ethnicity	239.8	14	17.1	0.76	0.717243
FREQ*|MEP| Shift	673.5	28	24.1	1.06	0.379279
Error	16167.2	714	22.6		
NON_POST*FREQ	66.4	7	9.5	0.47	0.859450
NON_POST*FREQ *Gender	16.3	7	2.3	0.11	0.997424
NON_POST*FREQ *Ethnicity	238.9	14	17.1	0.84	0.628386
NON_POST*FREQ *|MEP| Shift	850.8	28	30.4	1.49	0.050226
Error	14547.9	714	20.4		

Table 179: Statistical analysis summary of the mixed ANOVA for DPOAE non-maneuver ambient and post-maneuver ambient noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.2328				
	SS	Degree of Freedom	MS	F	p
Intercept	**89948.66**	**1**	**89948.66**	**387.6458**	**0.000000**
Gender	48.75	1	48.75	0.2101	0.647628
Ethnicity	62.30	2	31.15	0.1342	0.874527
Error	24596.06	106	232.04		
AMB_PEAK	**222.32**	**1**	**222.32**	**16.7227**	**0.000084**
AMB_PEAK *Gender	3.15	1	3.15	0.2370	0.627407
AMB_PEAK *Ethnicity	72.39	2	36.19	2.7224	0.070311
Error	1409.23	106	13.29		
FREQ	**32097.07**	**7**	**4585.30**	**116.7839**	**0.000000**
FREQ*Gender	410.38	7	58.63	1.4931	0.166302
FREQ* Ethnicity	**2833.88**	**14**	**202.42**	**5.1555**	**0.000000**
Error	29133.20	742	39.26		
AMB_PEAK *FREQ	36.71	7	5.24	1.7185	0.101435
AMB_PEAK *FREQ *Gender	20.32	7	2.90	0.9512	0.466131
AMB_PEAK *FREQ *Ethnicity	56.90	14	4.06	1.3321	0.182134
Error	2264.01	742	3.05		

Table 180: Results of statistical analysis of DPOAE absolute amplitude non-maneuver ambient versus post-maneuver peak test conditions, considering factors of gender, frequency, and ethnicity. Bolded values indicate significance (p<.05).

Effect	Adjusted Univariate Tests for Repeated Measure: Sigma-restricted parameterization														
	Degree of Freedom	F	p	G-G Epsilon	G-G Adj. df1	G-G Adj. df2	G-G Adj. p	H-F Epsilon	H-F Adj. df1	H-F Adj. df2	H-F Adj. p	Lowr. Bnd Epsilon	Lowr. Bnd Adj. df1	Lowr. Bnd Adj. df2	Lowr. Bnd Adj. p
AMB_PEAK	**1**	**0.00**	**1.00**	**1.00**	**106.00**	**0.00**	**1.00**	**1.00**	**106.**	**0.00**	**1.00**	**1.00**	**106.00**	**0.00**	**0.00**
AMB_PEAK *Gender	1	0.63	1.00	1.00	106.00	0.63	1.00	1.00	106.	0.63	1.00	1.00	106.00	0.63	0.63
AMB_PEAK *Ethnicity	2	0.07	1.00	2.00	106.00	0.07	1.00	2.00	106.	0.07	1.00	2.00	106.00	0.07	0.07
Error	106														
FREQ	**7**	**0.00**	**0.57**	**4.01**	**425.11**	**0.00**	**0.62**	**4.31**	**456.**	**0.00**	**0.14**	**1.00**	**106.00**	**0.00**	**0.00**
FREQ*Gender	7	0.17	0.57	4.01	425.11	0.20	0.62	4.31	456.	0.20	0.14	1.00	106.00	0.22	0.17
FREQ*Ethnicity	**14**	**0.00**	**0.57**	**8.02**	**425.11**	**0.00**	**0.62**	**8.61**	**456.**	**0.00**	**0.14**	**2.00**	**106.00**	**0.01**	**0.00**
Error	742														
AMB_PEAK *FREQ	7	0.10	0.75	5.27	559.11	0.12	0.82	5.74	608.	0.12	0.14	1.00	106.00	0.19	0.10
AMB_PEAK *FREQ*Gender	7	0.47	0.75	5.27	559.11	0.45	0.82	5.74	608.	0.46	0.14	1.00	106.00	0.33	0.47
AMB_PEAK *FREQ*Ethnicity	14	0.18	0.75	10.55	559.11	0.21	0.82	11.48	608.4	0.20	0.14	2.00	106.00	0.27	0.18
Error	742														

Table 181: Greenhouse-Geisser test results for the outcome measures of DPOAE absolute amplitude for test conditions non-maneuver ambient and post-maneuver peak. Descriptive statistics represent the analysis incorporating factors of gender, ethnicity, frequency, and test condition. Bolded values represent significant (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.2816				
	SS	Degree of Freedom	MS	F	p
Intercept	**769072.5**	**1**	**769072.5**	**19446.75**	**0.000000**
Gender	100.8	1	100.8	2.55	0.113402
Ethnicity	62.0	2	31.0	0.78	0.459018
Error	4192.0	106	39.5		
AMB_PEAK	7.5	1	7.5	0.64	0.426209
AMB_PEAK *Gender	1.8	1	1.8	0.15	0.699412
AMB_PEAK *Ethnicity	50.1	2	25.0	2.14	0.123140
Error	1242.6	106	11.7		
FREQ	**5799.2**	**7**	**828.5**	**80.18**	**0.000000**
FREQ*Gender	74.5	7	10.6	1.03	0.408040
FREQ*Ethnicity	143.4	14	10.2	0.99	0.460018
Error	7666.7	742	10.3		
AMB_PEAK *FREQ	85.8	7	12.3	1.52	0.157623
AMB_PEAK *FREQ *Gender	45.9	7	6.6	0.81	0.576783
AMB_PEAK *FREQ*Ethnicity	138.4	14	9.9	1.23	0.251328
Error	5989.9	742	8.1		

Table 182: Results of statistical analysis of DPOAE noise level non-maneuver ambient versus post-maneuver peak test conditions considering factors of gender, frequency, and ethnicity. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 14.9539				
	SS	Degree of Freedom	MS	F	p
Intercept	**79836.46**	**1**	**79836.46**	**357.0183**	**0.000000**
Gender	94.83	1	94.83	0.4241	0.516375
Ethnicity	161.73	2	80.87	0.3616	0.697434
|MEP| Shift	1786.81	4	446.70	1.9976	0.100479
Error	22809.25	102	223.62		
NONVSPOS	**156.19**	**1**	**156.19**	**12.9077**	**0.000506**
NONVSPOS *Gender	5.08	1	5.08	0.4201	0.518346
NONVSPOS *Ethnicity	**83.90**	**2**	**41.95**	**3.4667**	**0.034944**
NONVSPOS *|MEP| Shift	**174.95**	**4**	**43.74**	**3.6144**	**0.008496**
Error	1234.28	102	12.10		
FREQ	**28514.34**	**7**	**4073.48**	**108.8010**	**0.000000**
FREQ*Gender	444.34	7	63.48	1.6954	0.106927
FREQ*Ethnicity	**2468.30**	**14**	**176.31**	**4.7091**	**0.000000**
FREQ*|MEP| Shift	**2401.24**	**28**	**85.76**	**2.2906**	**0.000192**
Error	26731.96	714	37.44		
NONVSPOS*FREQ	35.85	7	5.12	1.6823	0.110121
NONVSPOS *FREQ*Gender	20.37	7	2.91	0.9560	0.462458
NONVSPOS *FREQ*Ethnicity	54.24	14	3.87	1.2726	0.218609
NONVSPOS *FREQ* |MEP| Shift	90.35	28	3.23	1.0599	0.382433
Error	2173.66	714	3.04		

Table 183: Results of statistical analysis mixed ANOVA, for outcome measures of DPOAE absolute amplitude for non-maneuver ambient and post-maneuver peak test conditions. The analysis was done considering factors of gender, frequency, ethnicity, test condition, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.2390				
	SS	Degree of Freedom	MS	F	p
Intercept	**672453.7**	**1**	**672453.7**	**16847.03**	**0.000000**
Gender	122.7	1	122.7	3.07	0.082618
Ethnicity	62.3	2	31.2	0.78	0.460817
|MEP| Shift	120.7	4	30.2	0.76	0.556368
Error	4071.4	102	39.9		
AMBTPP	4.4	1	4.4	0.39	0.532534
AMBTPP*Gender	1.5	1	1.5	0.13	0.718186
AMBTPP *Ethnicity	43.3	2	21.6	1.91	0.153089
AMBTPP*|MEP| Shift	87.8	4	22.0	1.94	0.109642
Error	1154.8	102	11.3		
FREQ	**5169.9**	**7**	**738.6**	**71.17**	**0.000000**
FREQ*Gender	74.1	7	10.6	1.02	0.415585
FREQ*Ethnicity	121.6	14	8.7	0.84	0.629007
FREQ*|MEP| Shift	257.6	28	9.2	0.89	0.636050
Error	7409.0	714	10.4		
AMBTPP*FREQ	72.7	7	10.4	1.31	0.240308
AMBTPP*FREQ *Gender	49.8	7	7.1	0.90	0.505863
AMBTPP*FREQ *Ethnicity	**197.9**	**14**	**14.1**	**1.79**	**0.036485**
AMBTPP*FREQ *|MEP| Shift	**346.6**	**28**	**12.4**	**1.57**	**0.032331**
Error	5643.3	714	7.9		

Table 184: Results of statistical analysis mixed ANOVA, for outcome measures of DPOAE noise level for non-maneuver ambient and post-maneuver peak test conditions. The analysis was done considering factors of gender, frequency, ethnicity, test condition, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 14.4713				
	SS	Degree of Freedom	MS	F	p
Intercept	**100171.4**	**1**	**100171.4**	**478.3310**	**0.000000**
Gender	45.9	1	45.9	0.2194	0.640467
Ethnicity	67.2	2	33.6	0.1603	0.852068
Error	22198.4	106	209.4		
AMB-PEAK	2.8	1	2.8	0.4805	0.489725
AMB-PEAK *Gender	2.5	1	2.5	0.4232	0.516740
AMB-PEAK* Ethnicity	8.7	2	4.4	0.7471	0.476219
Error	618.1	106	5.8		
FREQ	**32448.1**	**7**	**4635.4**	**122.2514**	**0.000000**
FREQ*Gender	366.0	7	52.3	1.3791	0.210930
FREQ*Ethnicity	**2617.3**	**14**	**187.0**	**4.9305**	**0.000000**
Error	28134.6	742	37.9		
AMB-PEAK *FREQ	15.7	7	2.2	0.7045	0.668318
AMB-PEAK *FREQ*Gender	7.0	7	1.0	0.3166	0.946658
AMB-PEAK *FREQ*Ethnicity	46.8	14	3.3	1.0526	0.398303
Error	2355.0	742	3.2		

Table 185: Statistical analysis summary of mixed ANOVA for DPOAE non-maneuver ambient versus non-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 12.1507				
	SS	Degree of Freedom	MS	F	p
Intercept	**769505.4**	**1**	**769505.4**	**11937.20**	**0.000000**
Gender	**272.5**	**1**	**272.5**	**4.23**	**0.042218**
Ethnicity	264.5	2	132.2	2.05	0.133616
Error	6833.1	106	64.5		
AMB_PEAK	6.2	1	6.2	0.38	0.539944
AMB_PEAK *Gender	60.8	1	60.8	3.71	0.056696
AMB_PEAK *Ethnicity	75.7	2	37.9	2.31	0.104034
Error	1735.6	106	16.4		
FREQ	**5192.5**	**7**	**741.8**	**84.21**	**0.000000**
FREQ*Gender	92.6	7	13.2	1.50	0.163066
FREQ*Ethnicity	175.9	14	12.6	1.43	0.134646
Error	6536.3	742	8.8		
AMB_PEAK *FREQ	57.4	7	8.2	1.13	0.342803
AMB_PEAK *FREQ*Gender	43.5	7	6.2	0.86	0.541257
AMB_PEAK *FREQ*Ethnicity	105.4	14	7.5	1.04	0.414803
Error	5391.9	742	7.3		

Table 186: Statistical analysis summary of mixed ANOVA for DPOAE non-maneuver ambient versus non-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 13.9898				
	SS	Degree of Freedom	MS	F	p
Intercept	**4902.81**	**1**	**4902.812**	**25.05079**	**0.000002**
Gender	201.24	1	201.236	1.02821	0.312955
Ethnicity	40.74	2	20.370	0.10408	0.901246
|MEP|	**2039.75**	**3**	**679.916**	**3.47401**	**0.018776**
Error	20158.63	103	195.715		
AMB-PEAK	1.95	1	1.945	0.34726	0.556960
AMB-PEAK *Gender	5.51	1	5.510	0.98366	0.323621
AMB-PEAK*Ethnicity	11.27	2	5.637	1.00643	0.369087
AMB-PEAK*|MEP|	41.21	3	13.738	2.45264	0.067532
Error	576.92	103	5.601		
FREQ	**4925.24**	**7**	**703.605**	**18.64554**	**0.000000**
FREQ*Gender	386.32	7	55.188	1.46249	0.177489
FREQ*Ethnicity	**2736.37**	**14**	**195.455**	**5.17957**	**0.000000**
FREQ*|MEP|	927.07	21	44.146	1.16988	0.270628
Error	27207.54	721	37.736		
AMB-PEAK*FREQ	**56.35**	**7**	**8.050**	**2.59487**	**0.011965**
AMB-PEAK *FREQ*Gender	9.61	7	1.373	0.44262	0.875368
AMB-PEAK *FREQ*Ethnicity	54.32	14	3.880	1.25062	0.233342
AMB-PEAK *FREQ*|MEP|	**118.22**	**21**	**5.630**	**1.81463**	**0.014274**
Error	2236.77	721	3.102		

Table 187: Statistical analysis summary of mixed ANOVA for DPOAE non-maneuver ambient versus non-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.4361				
	SS	Degree of Freedom	MS	F	p
Intercept	**78473.64**	**1**	**78473.64**	**1363.578**	**0.000000**
Gender	149.11	1	149.11	2.591	0.110536
Ethnicity	186.82	2	93.41	1.623	0.202289
|MEP|	**905.43**	**3**	**301.81**	**5.244**	**0.002081**
Error	5927.63	103	57.55		
AMB_PEAK	**77.42**	**1**	**77.42**	**4.886**	**0.029281**
AMB_PEAK *Gender	37.51	1	37.51	2.367	0.126964
AMB_PEAK *Ethnicity	67.07	2	33.53	2.117	0.125640
AMB_PEAK *|MEP|	103.72	3	34.57	2.182	0.094620
Error	1631.84	103	15.84		
FREQ	**873.48**	**7**	**124.78**	**16.428**	**0.000000**
FREQ*Gender	81.67	7	11.67	1.536	0.151779
FREQ*Ethnicity	158.55	14	11.32	1.491	0.108282
FREQ*|MEP|	**1059.89**	**21**	**50.47**	**6.645**	**0.000000**
Error	5476.41	721	7.60		
AMB_PEAK *FREQ	**739.50**	**7**	**105.64**	**18.082**	**0.000000**
AMB_PEAK*FREQ*Gender	56.88	7	8.13	1.391	0.205999
AMB_PEAK *FREQ*Ethnicity	98.94	14	7.07	1.210	0.262756
AMB_PEAK*FREQ*|MEP|	**1179.47**	**21**	**56.17**	**9.613**	**0.000000**
Error	4212.39	721	5.84		

Table 188: Statistical analysis summary of mixed ANOVA for DPOAE non-maneuver ambient versus non-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.6792				
	SS	Degree of Freedom	MS	F	p
Intercept	**74560.84**	**1**	**74560.84**	**268.0152**	**0.000000**
Gender	113.44	1	113.44	0.4078	0.524478
Ethnicity	98.86	2	49.43	0.1777	0.837454
Error	29488.80	106	278.20		
AMB_PEAK	**142.70**	**1**	**142.70**	**9.6368**	**0.002446**
AMB_PEAK *Gender	3.59	1	3.59	0.2422	0.623647
AMB_PEAK *Ethnicity	**143.21**	**2**	**71.61**	**4.8358**	**0.009777**
Error	1569.62	106	14.81		
FREQ	**31032.18**	**7**	**4433.17**	**104.2530**	**0.000000**
FREQ*Gender	438.45	7	62.64	1.4730	0.173557
FREQ *Ethnicity	**3056.55**	**14**	**218.33**	**5.1343**	**0.000000**
Error	31552.20	742	42.52		
AMB_PEAK *FREQ	32.76	7	4.68	1.2104	0.294349
AMB_PEAK *FREQ*Gender	17.33	7	2.48	0.6401	0.722873
AMB_PEAK *FREQ *Ethnicity	75.96	14	5.43	1.4032	0.145142
Error	2869.11	742	3.87		

Table 189: Statistical analysis summary of mixed ANOVA for DPOAE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Adjusted Univariate Tests for Repeated Measure: Sigma-restricted parameterization Effective hypothesis decomposition														
	Degree of Freedom	F	p	G-G Epsilon	G-G Adj. df1	G-G Adj. df2	G-G Adj. p	H-F Epsilon	H-F Adj. df1	H-F Adj. df2	H-F Adj. p	Lowr. Bnd Epsilon	Lowr. Bnd Adj. df1	Lowr. Bnd Adj. df2	Lowr. Bnd Adj. p
AMB_PEAK	**1**	**9.64**	**0.00**	**1.00**	**1.00**	**106.00**	**0.00**	**1.00**	**1.00**	**106.00**	**0.00**	**1.00**	**1.00**	**106.00**	**0.00**
AMB_PEAK *Gender	1	0.24	0.62	1.00	1.00	106.00	0.62	1.00	1.00	106.00	0.62	1.00	1.00	106.00	0.62
AMB_PEAK *Ethnicity	**2**	**4.84**	**0.01**	**1.00**	**2.00**	**106.00**	**0.01**	**1.00**	**2.00**	**106.00**	**0.01**	**1.00**	**2.00**	**106.00**	**0.01**
Error	106														
FREQ	**7**	**104.25**	**0.00**	**0.57**	**3.99**	**422.91**	**0.00**	**0.61**	**4.28**	**453.96**	**0.00**	**0.14**	**1.00**	**106.00**	**0.00**
FREQ *Gender	7	1.47	0.17	0.57	3.99	422.91	0.21	0.61	4.28	453.96	0.21	0.14	1.00	106.00	0.23
FREQ *Ethnicity	**14**	**5.13**	**0.00**	**0.57**	**7.98**	**422.91**	**0.00**	**0.61**	**8.57**	**453.96**	**0.00**	**0.14**	**2.00**	**106.00**	**0.01**
Error	742														
AMB_PEAK *FREQ	7	1.21	0.29	0.71	5.00	530.12	0.30	0.78	5.43	575.26	0.30	0.14	1.00	106.00	0.27
AMB_PEAK *FREQ*Gender	7	0.64	0.72	0.71	5.00	530.12	0.67	0.78	5.43	575.26	0.68	0.14	1.00	106.00	0.43
AMB_PEAK *FREQ *Ethnicity	14	1.40	0.15	0.71	10.00	530.12	0.18	0.78	10.85	575.26	0.17	0.14	2.00	106.00	0.25
Error	742														

Table 190: Statistical summary for G-G test of DPOAE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis incorporated factors of gender, ethnicity, frequency, and test condition. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 7.3067				
	SS	Degree of Freedom	MS	F	p
Intercept	**1541018**	**1**	**1541018**	**17669.90**	**0.000000**
Gender	228	1	228	2.62	0.108535
Ethnicity	220	2	110	1.26	0.287918
Error	9244	106	87		
AMB_PEAK	24	3	8	0.35	0.787771
AMB_PEAK *Gender	171	3	57	2.52	0.058070
AMB_PEAK *Ethnicity	176	6	29	1.30	0.256405
Error	7187	318	23		
FREQ	**10795**	**7**	**1542**	**77.63**	**0.000000**
FREQ*Gender	125	7	18	0.90	0.504565
FREQ*Ethnicity	306	14	22	1.10	0.352680
Error	14740	742	20		
AMB_PEAK *FREQ	231	21	11	0.69	0.844453
AMB_PEAK *FREQ*Gender	175	21	8	0.52	0.962743
AMB_PEAK *FREQ *Ethnicity	452	42	11	0.68	0.944779
Error	35408	2226	16		

Table 191: Statistical analysis summary of mixed ANOVA for DPOAE post-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.1119				
	SS	Degree of Freedom	MS	F	p
Intercept	**51352.40**	**1**	**51352.40**	**197.8197**	**0.000000**
Gender	83.79	1	83.79	0.3228	0.571184
Ethnicity	216.91	2	108.45	0.4178	0.659623
|MEP|	**3010.42**	**4**	**752.61**	**2.8992**	**0.025574**
Error	26478.38	102	259.59		
AMB_PEAK	**53.32**	**1**	**53.32**	**3.8509**	**0.052443**
AMB_PEAK *Gender	9.62	1	9.62	0.6951	0.406370
AMB_PEAK *Ethnicity	**142.32**	**2**	**71.16**	**5.1393**	**0.007472**
AMB_PEAK*|MEP|	**157.34**	**4**	**39.34**	**2.8410**	**0.027965**
Error	1412.28	102	13.85		
FREQ	**22136.32**	**7**	**3162.33**	**78.3070**	**0.000000**
FREQ*Gender	485.08	7	69.30	1.7160	0.102102
FREQ*Ethnicity	**2138.82**	**14**	**152.77**	**3.7830**	**0.000003**
FREQ*|MEP|	**2718.20**	**28**	**97.08**	**2.4039**	**0.000078**
Error	28834.00	714	40.38		
AMB_PEAK*FREQ	17.68	7	2.53	0.6548	0.710473
AMB_PEAK*FREQ *Gender	13.71	7	1.96	0.5076	0.829173
AMB_PEAK*FREQ *Ethnicity	85.75	14	6.13	1.5877	0.077160
AMB_PEAK*FREQ *|MEP|	114.50	28	4.09	1.0599	0.382412
Error	2754.61	714	3.86		

Table 192: Statistical analysis summary of mixed ANOVA for DPOAE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 7.2643				
	SS	Degree of Freedom	MS	F	p
Intercept	**1344294**	**1**	**1344294**	**15578.76**	**0.000000**
Gender	305	1	305	3.54	0.062831
Ethnicity	207	2	104	1.20	0.305170
|MEP|	443	4	111	1.28	0.281647
Error	8802	102	86		
AMB_PEAK	11	3	4	0.16	0.922070
AMB_PEAK *Gender	153	3	51	2.23	0.085068
AMB_PEAK *Ethnicity	158	6	26	1.15	0.331439
AMB_PEAK*|MEP|	188	12	16	0.68	0.767045
Error	6999	306	23		
FREQ	**9098**	**7**	**1300**	**65.70**	**0.000000**
FREQ*Gender	111	7	16	0.80	0.583711
FREQ*Ethnicity	327	14	23	1.18	0.285761
FREQ*|MEP|	616	28	22	1.11	0.314995
Error	14124	714	20		
AMB_PEAK*FREQ	258	21	12	0.78	0.747107
AMB_PEAK*FREQ *Gender	173	21	8	0.52	0.963291
AMB_PEAK*FREQ *Ethnicity	555	42	13	0.84	0.758838
AMB_PEAK*FREQ *|MEP|	1673	84	20	1.26	0.055476
Error	33735	2142	16		

Table 193: Statistical analysis summary of mixed ANOVA for DPOAE post-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 21.4094				
	SS	Degree of Freedom	MS	F	p
Intercept	**173788.8**	**1**	**173788.8**	**379.1516**	**0.000000**
Gender	151.9	1	151.9	0.3314	0.566074
Ethnicity	160.7	2	80.4	0.1753	0.839444
Error	48586.4	106	458.4		
ALL	**1089.0**	**3**	**363.0**	**21.8279**	**0.000000**
ALL*Gender	13.6	3	4.5	0.2716	0.845833
ALL*Ethnicity	157.2	6	26.2	1.5758	0.153553
Error	5288.5	318	16.6		
FREQ	**63371.6**	**7**	**9053.1**	**121.1566**	**0.000000**
FREQ*Gender	767.6	7	109.7	1.4675	0.175586
FREQ*Ethnicity	**5556.3**	**14**	**396.9**	**5.3114**	**0.000000**
Error	55443.8	742	74.7		
ALL*FREQ	**157.1**	**21**	**7.5**	**1.7589**	**0.017796**
ALL*FREQ *Gender	61.3	21	2.9	0.6861	0.850719
ALL*FREQ *Ethnicity	240.3	42	5.7	1.3454	0.069088
Error	9467.1	2226	4.3		

Table 194: Summary of statistical analysis (mixed ANOVA) for the comparison of DPOAE absolute amplitude measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, and frequency. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 12.0396				
	SS	Degree of Freedom	MS	F	p
Intercept	**1552355**	**1**	**1552355**	**10709.43**	**0.000000**
Gender	100	1	100	0.69	0.407965
Ethnicity	53	2	27	0.18	0.833069
Error	15365	106	145		
ALL	178	3	59	1.14	0.331208
ALL*Gender	350	3	117	2.25	0.082512
ALL*Ethnicity	556	6	93	1.79	0.101101
Error	16494	318	52		
FREQ	**12109**	**7**	**1730**	**32.61**	**0.000000**
FREQ*Gender	324	7	46	0.87	0.528092
FREQ*Ethnicity	620	14	44	0.84	0.630538
Error	39355	742	53		
ALL*FREQ	1099	21	52	1.14	0.300074
ALL*FREQ *Gender	1197	21	57	1.24	0.207015
ALL*FREQ *Ethnicity	**2711**	**42**	**65**	**1.40**	**0.045066**
Error	102399	2226	46		

Table 195: Summary of statistical analysis (mixed ANOVA) for the comparison of DPOAE noise level measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 20.9256				
	SS	Degree of Freedom	MS	F	p
Intercept	**155716.8**	**1**	**155716.8**	**355.6148**	**0.000000**
Gender	268.7	1	268.7	0.6136	0.435263
Ethnicity	396.8	2	198.4	0.4531	0.636941
|MEP|	3922.6	4	980.6	2.2395	0.069912
Error	44663.8	102	437.9		
ALL	**710.0**	**3**	**236.7**	**15.9116**	**0.000000**
ALL*Gender	20.7	3	6.9	0.4632	0.708186
ALL*Ethnicity	155.0	6	25.8	1.7365	0.112096
ALL*|MEP|	**737.1**	**12**	**61.4**	**4.1300**	**0.000005**
Error	4551.4	306	14.9		
FREQ	**56611.7**	**7**	**8087.4**	**112.9584**	**0.000000**
FREQ*Gender	824.0	7	117.7	1.6442	0.119865
FREQ*Ethnicity	**4716.7**	**14**	**336.9**	**4.7057**	**0.000000**
FREQ*|MEP|	**4324.1**	**28**	**154.4**	**2.1570**	**0.000542**
Error	51119.7	714	71.6		
ALL*FREQ	130.6	21	6.2	1.4742	0.075819
ALL*FREQ*Gender	55.9	21	2.7	0.6309	0.899011
ALL*FREQ*Ethnicity	240.8	42	5.7	1.3588	0.062826
ALL*FREQ*|MEP|	428.8	84	5.1	1.2099	0.097635
Error	9038.3	2142	4.2		

Table 196: Summary of statistical analysis (mixed ANOVA) for the comparison of DPOAE absolute amplitude measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 12.0396				
	SS	Degree of Freedom	MS	F	p
Intercept	**1552355**	**1**	**1552355**	**10709.43**	**0.000000**
Gender	100	1	100	0.69	0.407965
Ethnicity	53	2	27	0.18	0.833069
Error	15365	106	145		
ALL	178	3	59	1.14	0.331208
ALL*Gender	350	3	117	2.25	0.082512
ALL*Ethnicity	556	6	93	1.79	0.101101
Error	16494	318	52		
FREQ	**12109**	**7**	**1730**	**32.61**	**0.000000**
FREQ*Gender	324	7	46	0.87	0.528092
FREQ*Ethnicity	620	14	44	0.84	0.630538
Error	39355	742	53		
ALL*FREQ	1099	21	52	1.14	0.300074
ALL*FREQ*Gender	1197	21	57	1.24	0.207015
ALL*FREQ*Ethnicity	**2711**	**42**	**65**	**1.40**	**0.045066**
Error	102399	2226	46		

Table 197: Summary of statistical analysis (mixed ANOVA) for the comparison of DPOAE noise level measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.6534				
	SS	Degree of Freedom	MS	F	p
Intercept	**6684.22**	**1**	**6684.221**	**27.2794**	**0.000001**
Gender	**1437.31**	**1**	**1437.312**	**5.8659**	**0.017376**
Ethnicity	1358.18	2	679.090	2.7715	0.067744
Error	22787.62	93	245.028		
AMB_AMB	**222.78**	**1**	**222.784**	**18.0160**	**0.000052**
AMB_AMB *Gender	1.69	1	1.689	0.1366	0.712568
AMB_AMB*Ethnicity	26.86	2	13.432	1.0862	0.341740
Error	1150.03	93	12.366		
FREQ	**34628.28**	**4**	**8657.071**	**212.5858**	**0.000000**
FREQ*Gender	260.25	4	65.063	1.5977	0.174254
FREQ*Ethnicity	234.97	8	29.371	0.7212	0.672790
Error	15148.85	372	40.723		
AMB_AMB*FREQ	43.22	4	10.806	1.3276	0.259102
AMB_AMB *FREQ*Gender	21.00	4	5.250	0.6450	0.630708
AMB_AMB *FREQ*Ethnicity	81.45	8	10.181	1.2508	0.268299
Error	3027.96	372	8.140		

Table 198: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver ambient absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 5.5385				
	SS	Degree of Freedom	MS	F	p
Intercept	**86918.86**	**1**	**86918.86**	**2833.515**	**0.000000**
Gender	95.09	1	95.09	3.100	0.081581
Ethnicity	35.20	2	17.60	0.574	0.565429
Error	2852.80	93	30.68		
AMB_AMB	**20.80**	**1**	**20.80**	**4.384**	**0.039006**
AMB_AMB*Gender	0.07	1	0.07	0.015	0.902417
AMB_AMB*Ethnicity	25.38	2	12.69	2.675	0.074211
Error	441.26	93	4.74		
FREQ	**11401.88**	**4**	**2850.47**	**128.964**	**0.000000**
FREQ*Gender	107.86	4	26.96	1.220	0.301859
FREQ*Ethnicity	101.70	8	12.71	0.575	0.798367
Error	8222.28	372	22.10		
AMB_AMB*FREQ	23.77	4	5.94	1.874	0.114375
AMB_AMB*FREQ *Gender	2.72	4	0.68	0.215	0.930164
AMB_AMB* FREQ*Ethnicity	21.56	8	2.69	0.850	0.559427
Error	1179.86	372	3.17		

Table 199: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.8291				
	SS	Degree of Freedom	MS	F	p
Intercept	**6674.77**	**1**	**6674.769**	**26.6393**	**0.000001**
Gender	**1287.40**	**1**	**1287.399**	**5.1381**	**0.025830**
Ethnicity	**1675.48**	**2**	**837.739**	**3.3434**	**0.039803**
MEP Shift	487.67	4	121.918	0.4866	0.745542
Error	22299.95	89	250.561		
AMB_AMB	**178.59**	**1**	**178.594**	**14.5556**	**0.000251**
AMB_AMB*Gender	0.55	1	0.549	0.0448	0.832928
AMB_AMB *Ethnicity	10.99	2	5.493	0.4477	0.640555
AMB_AMB *MEP Shift	58.02	4	14.504	1.1821	0.324191
Error	1092.01	89	12.270		
FREQ	**33756.73**	**4**	**8439.182**	**207.2910**	**0.000000**
FREQ*Gender	234.18	4	58.544	1.4380	0.220887
FREQ*Ethnicity	235.76	8	29.470	0.7239	0.670444
FREQ*MEP Shift	655.47	16	40.967	1.0063	0.449204
Error	14493.39	356	40.712		
AMB_AMB*FREQ	38.44	4	9.611	1.1669	0.325080
AMB_AMB *FREQ*Gender	19.39	4	4.847	0.5886	0.671119
AMB_AMB *FREQ*Ethnicity	80.83	8	10.104	1.2269	0.282040
AMB_AMB*FREQ* MEP Shift	96.07	16	6.005	0.7291	0.764170
Error	2931.89	356	8.236		

Table 200: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 5.5546				
	SS	Degree of Freedom	MS	F	p
Intercept	**82773.15**	**1**	**82773.15**	**2682.762**	**0.000000**
Gender	85.14	1	85.14	2.760	0.100190
Ethnicity	67.02	2	33.51	1.086	0.341983
MEP Shift	106.82	4	26.71	0.866	0.487931
Error	2745.98	89	30.85		
AMB_AMB	14.99	1	14.99	3.102	0.081645
AMB_AMB *Gender	0.03	1	0.03	0.005	0.942763
AMB_AMB *Ethnicity	26.07	2	13.03	2.697	0.072937
AMB_AMB *MEP Shift	11.07	4	2.77	0.573	0.683257
Error	430.19	89	4.83		
FREQ	**10738.03**	**4**	**2684.51**	**121.934**	**0.000000**
FREQ*Gender	87.07	4	21.77	0.989	0.413602
FREQ*Ethnicity	227.99	8	28.50	1.294	0.245033
FREQ*MEP Shift	384.54	16	24.03	1.092	0.361182
Error	7837.74	356	22.02		
AMB_AMB*FREQ	19.61	4	4.90	1.556	0.185666
AMB_AMB*FREQ *Gender	3.53	4	0.88	0.280	0.891082
AMB_AMB*FREQ *Ethnicity	19.54	8	2.44	0.775	0.625126
AMB_AMB *FREQ*MEP Shift	57.92	16	3.62	1.149	0.308354
Error	1121.94	356	3.15		

Table 201: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.5426				
	SS	Degree of Freedom	MS	F	p
Intercept	**8257.59**	**1**	**8257.591**	**34.1828**	**0.000000**
Gender	**1344.76**	**1**	**1344.756**	**5.5667**	**0.020397**
Ethnicity	1356.01	2	678.006	2.8066	0.065533
Error	22466.18	93	241.572		
AMB_PEAK	**33.78**	**1**	**33.776**	**5.1724**	**0.025248**
AMB_PEAK*Gender	0.00	1	0.003	0.0005	0.981785
AMB_PEAK*Ethnicity	26.51	2	13.256	2.0299	0.137125
Error	607.30	93	6.530		
FREQ	**36382.41**	**4**	**9095.602**	**260.6080**	**0.000000**
FREQ*Gender	325.38	4	81.345	2.3307	0.055541
FREQ*Ethnicity	258.18	8	32.272	0.9247	0.495870
Error	12983.35	372	34.901		
AMB_PEAK*FREQ	6.31	4	1.578	0.8327	0.505016
AMB_PEAK*FREQ *Gender	1.03	4	0.258	0.1361	0.968928
AMB_PEAK*FREQ *Ethnicity	13.64	8	1.704	0.8995	0.516867
Error	704.91	372	1.895		

Table 202: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and test frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 4.0308				
	SS	Degree of Freedom	MS	F	p
Intercept	**87600.32**	**1**	**87600.32**	**5391.796**	**0.000000**
Gender	25.85	1	25.85	1.591	0.210296
Ethnicity	18.21	2	9.11	0.560	0.572849
Error	1510.97	93	16.25		
AMB_PEAK	11.61	1	11.61	1.055	0.306909
AMB_PEAK*Gender	19.35	1	19.35	1.760	0.187932
AMB_PEAK *Ethnicity	2.35	2	1.17	0.107	0.898976
Error	1022.84	93	11.00		
FREQ	**10789.63**	**4**	**2697.41**	**295.169**	**0.000000**
FREQ*Gender	31.86	4	7.96	0.872	0.481033
FREQ*Ethnicity	46.48	8	5.81	0.636	0.747661
Error	3399.53	372	9.14		
AMB_PEAK*FREQ	13.04	4	3.26	0.429	0.787976
AMB_PEAK*FREQ *Gender	23.35	4	5.84	0.768	0.546765
AMB_PEAK*FREQ *Ethnicity	66.16	8	8.27	1.088	0.370908
Error	2828.66	372	7.60		

Table 203: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.7013				
	SS	Degree of Freedom	MS	F	p
Intercept	**8045.76**	**1**	**8045.758**	**32.6357**	**0.000000**
MEP Shift	524.82	4	131.205	0.5322	0.712376
Ethnicity	**1716.17**	**2**	**858.085**	**3.4806**	**0.035042**
Gender	**1196.52**	**1**	**1196.523**	**4.8534**	**0.030174**
Error	21941.36	89	246.532		
AMB_PEAK	**28.78**	**1**	**28.783**	**4.5797**	**0.035088**
AMB_PEAK *MEP Shift	47.94	4	11.985	1.9070	0.116210
AMB_PEAK *Ethnicity	7.26	2	3.629	0.5774	0.563466
AMB_PEAK*Gender	0.30	1	0.301	0.0479	0.827328
Error	559.36	89	6.285		
FREQ	**35198.74**	**4**	**8799.685**	**249.7526**	**0.000000**
FREQ*MEP Shift	440.18	16	27.511	0.7808	0.707562
FREQ*Ethnicity	235.49	8	29.436	0.8355	0.571810
FREQ*Gender	299.91	4	74.978	2.1280	0.076868
Error	12543.16	356	35.234		
AMB_PEAK*FREQ	6.48	4	1.621	0.8903	0.469788
AMB_PEAK *FREQ*MEP Shift	**56.74**	**16**	**3.546**	**1.9478**	**0.015776**
AMB_PEAK *FREQ*Ethnicity	21.76	8	2.720	1.4940	0.157841
AMB_PEAK *FREQ*Gender	1.20	4	0.300	0.1649	0.956052
Error	648.17	356	1.821		

Table 204: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 4.0621				
	SS	Degree of Freedom	MS	F	p
Intercept	**83283.10**	**1**	**83283.10**	**5047.305**	**0.000000**
Gender	25.70	1	25.70	1.558	0.215286
Ethnicity	6.25	2	3.13	0.189	0.827776
MEP Shift	42.42	4	10.61	0.643	0.633430
Error	1468.55	89	16.50		
AMB_PEAK	8.92	1	8.92	0.815	0.369088
AMB_PEAK*Gender	16.00	1	16.00	1.461	0.229979
AMB_PEAK *Ethnicity	7.39	2	3.69	0.337	0.714510
AMB_PEAK *MEP Shift	48.43	4	12.11	1.106	0.358861
Error	974.41	89	10.95		
FREQ	**10369.02**	**4**	**2592.26**	**281.618**	**0.000000**
FREQ*Gender	37.14	4	9.28	1.009	0.402904
FREQ*Ethnicity	67.34	8	8.42	0.914	0.504386
FREQ*MEP Shift	122.60	16	7.66	0.832	0.648410
Error	3276.93	356	9.20		
AMB_PEAK*FREQ	12.08	4	3.02	0.410	0.801533
AMB_PEAK*FREQ *Gender	15.88	4	3.97	0.539	0.707448
AMB_PEAK*FREQ *Ethnicity	112.01	8	14.00	1.900	0.058953
AMB_PEAK*FREQ *MEP Shift	**205.32**	**16**	**12.83**	**1.741**	**0.037773**
Error	2623.34	356	7.37		

Table 205: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and MEP shift magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.1797				
	SS	Degree of Freedom	MS	F	p
Intercept	**9801.23**	**1**	**9801.228**	**42.5356**	**0.000000**
Gender	**1397.80**	**1**	**1397.804**	**6.0662**	**0.015619**
Ethnicity	**1947.88**	**2**	**973.938**	**4.2267**	**0.017501**
Error	21429.44	93	230.424		
AMB_PEAK	5.37	1	5.374	1.7906	0.184118
AMB_PEAK*Gender	0.60	1	0.600	0.2000	0.655736
AMB_PEAK*Ethnicity	9.18	2	4.588	1.5288	0.222201
Error	279.10	93	3.001		
FREQ	**36461.55**	**4**	**9115.388**	**246.6767**	**0.000000**
FREQ*Gender	295.79	4	73.948	2.0011	0.093768
FREQ*Ethnicity	252.85	8	31.606	0.8553	0.554562
Error	13746.43	372	36.953		
AMB_PEAK*FREQ	6.66	4	1.664	1.1826	0.318001
AMB_PEAK*FREQ*Gender	9.79	4	2.447	1.7386	0.140802
AMB_PEAK*FREQ*Ethnicity	8.29	8	1.036	0.7362	0.659534
Error	523.51	372	1.407		

Table 206: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus non-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 6.3213				
	SS	Degree of Freedom	MS	F	p
Intercept	**88849.66**	**1**	**88849.66**	**2223.527**	**0.000000**
Gender	141.13	1	141.13	3.532	0.063330
Ethnicity	130.25	2	65.13	1.630	0.201513
Error	3716.18	93	39.96		
NONMAN	1.70	1	1.70	0.064	0.801427
NONMAN*Gender	5.74	1	5.74	0.215	0.644133
NONMAN*Ethnicity	86.77	2	43.39	1.623	0.202855
Error	2486.11	93	26.73		
FREQ	**12431.80**	**4**	**3107.95**	**92.219**	**0.000000**
FREQ*Gender	81.03	4	20.26	0.601	0.662098
FREQ*Ethnicity	528.08	8	66.01	1.959	0.050605
Error	12537.10	372	33.70		
NONMAN*FREQ	72.71	4	18.18	0.566	0.687316
NONMAN*FREQ*Gender	24.00	4	6.00	0.187	0.945148
NONMAN*FREQ*Ethnicity	382.00	8	47.75	1.487	0.160006
Error	11941.80	372	32.10		

Table 207: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus non-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.3788				
	SS	Degree of Freedom	MS	F	p
Intercept	**1827.60**	**1**	**1827.600**	**7.72742**	**0.006636**
Gender	**1318.08**	**1**	**1318.076**	**5.57306**	**0.020423**
Ethnicity	**1968.06**	**2**	**984.030**	**4.16065**	**0.018733**
MEP	380.17	4	95.044	0.40186	0.806836
Error	21049.27	89	236.509		
NONMAN	0.21	1	0.205	0.07246	0.788409
NONMAN*Gender	0.01	1	0.012	0.00437	0.947467
NONMAN*Ethnicity	15.52	2	7.758	2.73595	0.070289
NONMAN* MEP	26.72	4	6.681	2.35598	0.059694
Error	252.38	89	2.836		
FREQ	**5796.01**	**4**	**1449.003**	**38.45442**	**0.000000**
FREQ*Gender	334.77	4	83.692	2.22106	0.066304
FREQ*Ethnicity	270.61	8	33.826	0.89769	0.518439
FREQ* MEP	331.98	16	20.748	0.55063	0.918553
Error	13414.46	356	37.681		
NONMAN*FREQ	3.21	4	0.804	0.58753	0.671872
NONMAN*FREQ*Gender	8.37	4	2.093	1.53005	0.192876
NONMAN*FREQ*Ethnicity	9.87	8	1.233	0.90154	0.515196
NONMAN*FREQ* MEP	36.50	16	2.281	1.66757	0.050885
Error	487.01	356	1.368		

Table 208: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus non-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 5.9599				
	SS	Degree of Freedom	MS	F	p
Intercept	**13939.25**	**1**	**13939.25**	**392.4301**	**0.000000**
Gender	**187.34**	**1**	**187.34**	**5.2741**	**0.023993**
Ethnicity	131.59	2	65.79	1.8523	0.162876
MEP	**554.87**	**4**	**138.72**	**3.9053**	**0.005730**
Error	3161.31	89	35.52		
NOMAN	19.05	1	19.05	0.8050	0.372034
NOMAN*Gender	17.59	1	17.59	0.7431	0.390975
NOMAN*Ethnicity	93.74	2	46.87	1.9804	0.144043
NOMAN* MEP	**379.78**	**4**	**94.95**	**4.0118**	**0.004878**
Error	2106.33	89	23.67		
FREQ	**2135.44**	**4**	**533.86**	**17.5630**	**0.000000**
FREQ*Gender	125.21	4	31.30	1.0298	0.391703
FREQ*Ethnicity	**607.62**	**8**	**75.95**	**2.4987**	**0.011911**
FREQ* MEP	**1715.81**	**16**	**107.24**	**3.5279**	**0.000006**
Error	10821.29	356	30.40		
NOMAN*FREQ	67.25	4	16.81	0.5864	0.672718
NOMAN*FREQ *Gender	56.30	4	14.08	0.4909	0.742418
NOMAN*FREQ *Ethnicity	**491.07**	**8**	**61.38**	**2.1409**	**0.031516**
NOMAN*FREQ*MEP	**1734.45**	**16**	**108.40**	**3.7807**	**0.000002**
Error	10207.35	356	28.67		

Table 209: Statistical analysis summary of mixed ANOVA for TEOAE non-maneuver ambient versus non-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15.9910				
	SS	Degree of Freedom	MS	F	p
Intercept	**5767.70**	**1**	**5767.697**	**22.5554**	**0.000007**
Gender	**1441.75**	**1**	**1441.751**	**5.6382**	**0.019628**
Ethnicity	1005.41	2	502.703	1.9659	0.145807
Error	23781.23	93	255.712		
POSTMAN	**83.07**	**1**	**83.069**	**8.4336**	**0.004601**
POSTMAN*Gender	1.54	1	1.540	0.1564	0.693443
POSTMAN*Ethnicity	0.48	2	0.238	0.0242	0.976088
Error	916.03	93	9.850		
FREQ	**34114.06**	**4**	**8528.515**	**215.8367**	**0.000000**
FREQ*Gender	271.34	4	67.835	1.7167	0.145567
FREQ*Ethnicity	213.34	8	26.668	0.6749	0.713713
Error	14699.11	372	39.514		
POSTMAN*FREQ	26.48	4	6.620	0.7376	0.566793
POSTMAN*FREQ *Gender	20.90	4	5.225	0.5821	0.675793
POSTMAN*FREQ *Ethnicity	132.57	8	16.571	1.8462	0.067397
Error	3338.83	372	8.975		

Table 210: Statistical analysis summary of mixed ANOVA for TEOAE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance (p<.05)

Effect	Adjusted Univariate Tests for Repeated Measure:Sigma-restricted parameterization Effective hypothesis decomposition													
	Degree of Freedom	F	p	G-G Epsilon	G-G Adj. df1	G-G Adj. df2	G-G Adj. p	H-F Epsilon	H-F Adj. df1	H-F Adj. df2	H-F Adj. p	Lowr. Bnd Epsilon	Lowr. Bnd Adj. df1	Lowr .Bnd Adj. df2	Lowr. Bnd Adj. p
POSTMAN	**1.0**	**8.43**	**0.00**	**1.00**	**1.00**	**93.00**	**0.00**	**1.00**	**1.00**	**93.00**	**0.00**	**1.00**	**1.00**	**93.0**	**0.00**
POSTMAN *Gender	1.0	0.16	0.69	1.00	1.00	93.00	0.69	1.00	1.00	93.00	0.69	1.00	1.00	93.0	0.69
POSTMAN *Ethnicity	2.0	0.02	0.98	1.00	2.00	93.00	0.98	1.00	2.00	93.00	0.98	1.00	2.00	93.0	0.98
Error	93.0														
FREQ	**4.0**	**215.84**	**0.00**	**0.70**	**2.80**	**260.73**	**0.00**	**0.75**	**2.99**	**278.33**	**0.00**	**0.25**	**1.00**	**93.0**	**0.00**
FREQ*Gender	4.0	1.72	0.15	0.70	2.80	260.73	0.17	0.75	2.99	278.33	0.16	0.25	1.00	93.0	0.19
FREQ*Ethnicity	8.0	0.67	0.71	0.70	5.61	260.73	0.66	0.75	5.99	278.33	0.67	0.25	2.00	93.0	0.51
Error	372.0														
POSTMAN *FREQ	4.0	0.74	0.57	0.52	2.09	194.27	0.49	0.55	2.21	205.24	0.49	0.25	1.00	93.0	0.39
POSTMAN *FREQ*Gender	4.0	0.58	0.68	0.52	2.09	194.27	0.57	0.55	2.21	205.24	0.58	0.25	1.00	93.0	0.45
POSTMAN *FREQ*Ethnicity	8.0	1.85	0.07	0.52	4.18	194.27	0.12	0.55	4.41	205.24	0.11	0.25	2.00	93.0	0.16
Error	372.0														

Table 211: Statistical summary for G-G test of TEAOE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis incorporated factors of gender, ethnicity, frequency, and test condition. Bolded values indicate significance (p<.05).

	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 4.3709				
	SS	Degree of Freedom	MS	F	p
Intercept	**84921.47**	**1**	**84921.47**	**4445.128**	**0.000000**
Gender	28.65	1	28.65	1.500	0.223828
Ethnicity	35.68	2	17.84	0.934	0.396696
Error	1776.71	93	19.10		
POSTMAN	1.33	1	1.33	0.131	0.718220
POSTMAN*Gender	21.78	1	21.78	2.144	0.146461
POSTMAN*Ethnicity	36.74	2	18.37	1.808	0.169619
Error	944.55	93	10.16		
FREQ	**10788.19**	**4**	**2697.05**	**243.902**	**0.000000**
FREQ*Gender	31.96	4	7.99	0.723	0.576933
FREQ*Ethnicity	35.44	8	4.43	0.401	0.920012
Error	4113.54	372	11.06		
POSTMAN*FREQ	24.76	4	6.19	0.582	0.675933
POSTMAN*FREQ *Gender	28.75	4	7.19	0.676	0.609283
POSTMAN*FREQ *Ethnicity	87.14	8	10.89	1.024	0.417416
Error	3957.91	372	10.64		

Table 212: Statistical analysis summary of mixed ANOVA for TEOAE post-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, and frequency. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.1406				
	SS	Degree of Freedom	MS	F	p
Intercept	**2840.54**	**1**	**2840.539**	**10.9034**	**0.001383**
MEP	595.13	4	148.782	0.5711	0.684280
Gender	**1490.56**	**1**	**1490.562**	**5.7215**	**0.018862**
Ethnicity	1404.42	2	702.212	2.6954	0.073024
Error	23186.10	89	260.518		
POSTMAN	15.99	1	15.992	1.5834	0.211557
POSTMAN*MEP	17.15	4	4.286	0.4244	0.790650
POSTMAN*Gender	0.49	1	0.488	0.0483	0.826595
POSTMAN*Ethnicity	0.86	2	0.428	0.0423	0.958557
Error	898.88	89	10.100		
FREQ	**16917.41**	**4**	**4229.352**	**106.5278**	**0.000000**
FREQ*MEP	565.25	16	35.328	0.8898	0.581401
FREQ*Gender	227.41	4	56.852	1.4320	0.222851
FREQ*Ethnicity	304.72	8	38.089	0.9594	0.467644
Error	14133.86	356	39.702		
POSTMAN*FREQ	7.16	4	1.789	0.1996	0.938475
POSTMAN*FREQ *MEP	148.41	16	9.276	1.0350	0.418463
POSTMAN*FREQ *Gender	15.40	4	3.849	0.4295	0.787298
POSTMAN*FREQ *Ethnicity	**144.83**	**8**	**18.104**	**2.0201**	**0.043286**
Error	3190.42	356	8.962		

Table 213: Statistical analysis summary of mixed ANOVA for TEOAE post-maneuver ambient versus post-maneuver peak absolute amplitude measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 4.4591				
	SS	Degree of Freedom	MS	F	p
Intercept	**43420.48**	**1**	**43420.48**	**2183.721**	**0.000000**
Gender	28.78	1	28.78	1.447	0.232163
Ethnicity	23.68	2	11.84	0.595	0.553475
MEP	7.06	4	1.76	0.089	0.985751
Error	1769.65	89	19.88		
POSTMAN	2.18	1	2.18	0.209	0.648673
POSTMAN*Gender	20.49	1	20.49	1.964	0.164532
POSTMAN*Ethnicity	41.59	2	20.80	1.993	0.142312
POSTMAN*MEP	15.96	4	3.99	0.382	0.820751
Error	928.59	89	10.43		
FREQ	**5886.31**	**4**	**1471.58**	**130.866**	**0.000000**
FREQ*Gender	30.52	4	7.63	0.679	0.607173
FREQ*Ethnicity	61.79	8	7.72	0.687	0.703199
FREQ*MEP	110.33	16	6.90	0.613	0.873428
Error	4003.20	356	11.24		
POSTMAN*FREQ	8.54	4	2.13	0.200	0.938023
POSTMAN*FREQ *Gender	15.06	4	3.77	0.354	0.841420
POSTMAN*FREQ *Ethnicity	123.21	8	15.40	1.447	0.175736
POSTMAN*FREQ *MEP	167.71	16	10.48	0.985	0.473042
Error	3790.20	356	10.65		

Table 214: Statistical analysis summary of mixed ANOVA for TEOAE post-maneuver ambient versus post-maneuver peak noise level measures. The analysis included factors of test condition, gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 21.7836				
	SS	Degree of Freedom	MS	F	p
Intercept	**15303.14**	**1**	**15303.14**	**32.2493**	**0.000000**
Gender	**2839.38**	**1**	**2839.38**	**5.9836**	**0.016320**
Ethnicity	2875.70	2	1437.85	3.0301	0.053107
Error	44130.96	93	474.53		
Condition	**354.23**	**3**	**118.08**	**14.4815**	**0.000000**
Condition*Gender	2.31	3	0.77	0.0945	0.963060
Condition*Ethnicity	87.23	6	14.54	1.7832	0.102477
Error	2274.84	279	8.15		
FREQ	**70544.81**	**4**	**17636.20**	**246.8823**	**0.000000**
FREQ*Gender	562.18	4	140.55	1.9674	0.098849
FREQ*Ethnicity	443.65	8	55.46	0.7763	0.623865
Error	26574.07	372	71.44		
Condition*FREQ	63.94	12	5.33	1.0371	0.411692
Condition *FREQ*Gender	35.63	12	2.97	0.5780	0.861235
Condition *FREQ*Ethnicity	163.39	24	6.81	1.3251	0.135528
Error	5733.82	1116	5.14		

Table 215: Summary of statistical analysis (mixed ANOVA) for the comparison of TEOAE absolute amplitude measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, and frequency. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 6.4470				
	SS	Degree of Freedom	MS	F	p
Intercept	**173748.9**	**1**	**173748.9**	**4180.235**	**0.000000**
Ethnicity	91.8	2	45.9	1.105	0.335671
Gender	148.5	1	148.5	3.572	0.061869
Error	3865.5	93	41.6		
TESTS	25.2	3	8.4	0.464	0.707671
TESTS*Ethnicity	197.6	6	32.9	1.817	0.095776
TESTS*Gender	48.8	3	16.3	0.898	0.442779
Error	5058.1	279	18.1		
FREQ	**23116.2**	**4**	**5779.0**	**205.842**	**0.000000**
FREQ*Ethnicity	341.1	8	42.6	1.519	0.148870
FREQ*Gender	96.1	4	24.0	0.856	0.490568
Error	10444.0	372	28.1		
TESTS*FREQ	201.3	12	16.8	0.847	0.601849
TESTS*FREQ *Ethnicity	691.5	24	28.8	1.455	0.072779
TESTS*FREQ *Gender	69.6	12	5.8	0.293	0.990569
Error	22106.4	1116	19.8		

Table 216: Summary of statistical analysis (mixed ANOVA) for the comparison of TEOAE noise level measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, and frequency. Bolded values indicate significance ($p<.05$).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 21.9780				
	SS	Degree of Freedom	MS	F	p
Intercept	**15042.71**	**1**	**15042.71**	**31.1422**	**0.000000**
Gender	**2512.70**	**1**	**2512.70**	**5.2019**	**0.024950**
Ethnicity	**3665.92**	**2**	**1832.96**	**3.7947**	**0.026212**
MEP Shift	1141.06	4	285.27	0.5906	0.670325
Error	42989.90	89	483.03		
TEST	**284.17**	**3**	**94.72**	**11.6987**	**0.000000**
TEST*Gender	1.86	3	0.62	0.0767	0.972515
TEST*Ethnicity	55.51	6	9.25	1.1426	0.337854
TEST*MEP Shift	112.98	12	9.41	1.1628	0.310166
Error	2161.86	267	8.10		
FREQ	**68557.49**	**4**	**17139.37**	**238.1614**	**0.000000**
FREQ*Gender	502.05	4	125.51	1.7441	0.139737
FREQ*Ethnicity	415.30	8	51.91	0.7214	0.672678
FREQ*MEP Shift	954.39	16	59.65	0.8289	0.652557
Error	25619.68	356	71.97		
TEST*FREQ	54.65	12	4.55	0.8859	0.561096
TEST*FREQ *Gender	35.76	12	2.98	0.5797	0.859837
TEST*FREQ *Ethnicity	168.43	24	7.02	1.3651	0.112789
TEST*FREQ *MEP Shift	243.17	48	5.07	0.9854	0.502631
Error	5490.65	1068	5.14		

Table 217: Summary of statistical analysis (mixed ANOVA) for the comparison of TEOAE absolute amplitude measures considering factors of test conditions (x4, non-maneuver and post-maneuver), gender, ethnicity, frequency, and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 27.0104				
	SS	Degree of Freedom	MS	F	p
Intercept	**255835.0**	**1**	**255835.0**	**350.6694**	**0.000000**
MEP	**302038.3**	**4**	**75509.6**	**103.4999**	**0.000000**
Error	67119.7	92	729.6		
PRE_POST	**828.5**	**1**	**828.5**	**5.9180**	**0.016921**
PRE_POST*MEP	**1992.2**	**4**	**498.0**	**3.5576**	**0.009591**
Error	12879.7	92	140.0		

Table 218: Comparison of mean absolute middle ear pressure (MEP) between the pre-TEOAE recording and post-TEOAE recording MEP estimates as a function of absolute MEP magnitude. Estimates were based on the conventional 226 Hz tympanogram. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 26.9556				
	SS	Degree of Freedom	MS	F	p
Intercept	**382802.6**	**1**	**382802.6**	**526.8384**	**0.000000**
|MEP|	**330607.2**	**4**	**82651.8**	**113.7509**	**0.000000**
Error	76293.4	105	726.6		
PRE_POST	**4024.8**	**1**	**4024.8**	**8.6894**	**0.003945**
PRE_POST*|MEP|	**8000.1**	**4**	**2000.0**	**4.3180**	**0.002837**
Error	48634.1	105	463.2		

Table 219: Comparison of mean absolute middle ear pressure (MEP) between the pre-DPOAE recording and post-DPOAE recording MEP estimates as a function of absolute MEP magnitude. Estimates were based on the conventional 226 Hz tympanogram. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.4182				
	SS	Degree of Freedom	MS	F	p
Intercept	**697.7582**	**1**	**697.7582**	**3990.243**	**0.000000**
Gender	**0.9894**	**1**	**0.9894**	**5.658**	**0.018307**
Ethnicity	0.5878	2	0.2939	1.681	0.188849
MEP	**4.0483**	**4**	**1.0121**	**5.788**	**0.000198**
Error	35.3230	202	0.1749		
postman	**4.7028**	**1**	**4.7028**	**405.517**	**0.000000**
postman *Gender	0.0154	1	0.0154	1.332	0.249782
postman *Ethnicity	0.0609	2	0.0305	2.628	0.074713
postman *MEP	**3.1750**	**4**	**0.7938**	**68.445**	**0.000000**
Error	2.3426	202	0.0116		
FREQ	**131.3704**	**15**	**8.7580**	**240.721**	**0.000000**
FREQ*Gender	**2.6204**	**15**	**0.1747**	**4.802**	**0.000000**
FREQ*Ethnicity	**4.0491**	**30**	**0.1350**	**3.710**	**0.000000**
FREQ*MEP	**4.9653**	**60**	**0.0828**	**2.275**	**0.000000**
Error	110.2389	3030	0.0364		
postman ***FREQ**	**7.0857**	**15**	**0.4724**	**122.007**	**0.000000**
postman *FREQ *Gender	0.0820	15	0.0055	1.412	0.131998
postman *FREQ *Ethnicity	**0.5077**	**30**	**0.0169**	**4.371**	**0.000000**
postman *FREQ *MEP	**3.7791**	**60**	**0.0630**	**16.268**	**0.000000**
Error	11.7313	3030	0.0039		

Table 220: Statistical analysis summary for post-maneuver condition absorbance measures (positive and negative MEP associated measures). The analysis considered factors of gender, ethnicity, frequency, and test pressure (ambient versus peak), and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.4293				
	SS	Degree of Freedom	MS	F	p
Intercept	**78.8479**	**1**	**78.84795**	**427.8239**	**0.000000**
Gender	**1.3002**	**1**	**1.30016**	**7.0546**	**0.008537**
Ethnicity	0.9141	2	0.45707	2.4800	0.086289
MEP	1.2529	4	0.31323	1.6996	0.151484
Error	37.2286	202	0.18430		
Non-man	**0.1518**	**1**	**0.15180**	**170.4860**	**0.000000**
Non-man *Gender	0.0001	1	0.00014	0.1591	0.690372
Non-man *Ethnicity	**0.0055**	**2**	**0.00273**	**3.0715**	**0.048521**
Non-man *MEP	**0.1683**	**4**	**0.04207**	**47.2529**	**0.000000**
Error	0.1799	202	0.00089		
FREQ	**15.0637**	**15**	**1.00425**	**28.6737**	**0.000000**
FREQ*Gender	**3.3133**	**15**	**0.22088**	**6.3068**	**0.000000**
FREQ*Ethnicity	**4.5372**	**30**	**0.15124**	**4.3183**	**0.000000**
FREQ*MEP	1.7554	60	0.02926	0.8354	0.812809
Error	106.1203	3030	0.03502		
Non-man *FREQ	**0.3780**	**15**	**0.02520**	**69.3124**	**0.000000**
Non-man *FREQ *Gender	0.0046	15	0.00031	0.8495	0.622155
Non-man *FREQ *Ethnicity	**0.0164**	**30**	**0.00055**	**1.5022**	**0.039097**
Non-man *FREQ *MEP	**0.5824**	**60**	**0.00971**	**26.7032**	**0.000000**
Error	1.1015	3030	0.00036		

Table 221: Statistical analysis summary for non-maneuver condition absorbance measures (positive and negative MEP associated measures). The analysis considered factors of gender, ethnicity, frequency, and test pressure (ambient versus peak), and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.4001				
	SS	Degree of Freedom	MS	F	p
Intercept	**811.2168**	**1**	**811.2168**	**5068.692**	**0.000000**
Ethnicity	0.4073	2	0.2037	1.273	0.282348
Gender	**1.1390**	**1**	**1.1390**	**7.117**	**0.008256**
MEP	**3.3325**	**4**	**0.8331**	**5.206**	**0.000519**
Error	32.3290	202	0.1600		
AMB_AMB	**5.6993**	**1**	**5.6993**	**360.349**	**0.000000**
AMB_AMB*Ethnicity	0.0445	2	0.0222	1.407	0.247343
AMB_AMB*Gender	0.0100	1	0.0100	0.629	0.428511
AMB_AMB*MEP	**4.0019**	**4**	**1.0005**	**63.256**	**0.000000**
Error	3.1949	202	0.0158		
FREQ	**182.3009**	**15**	**12.1534**	**366.736**	**0.000000**
FREQ*Ethnicity	**3.7115**	**30**	**0.1237**	**3.733**	**0.000000**
FREQ*Gender	**2.6776**	**15**	**0.1785**	**5.387**	**0.000000**
FREQ*MEP	**4.1151**	**60**	**0.0686**	**2.070**	**0.000003**
Error	100.4122	3030	0.0331		
AMB_AMB*FREQ	**8.7904**	**15**	**0.5860**	**127.493**	**0.000000**
AMB_AMB*FREQ *Ethnicity	**0.6414**	**30**	**0.0214**	**4.651**	**0.000000**
AMB_AMB*FREQ *Gender	0.1118	15	0.0075	1.621	0.060677
AMB_AMB*FREQ *MEP	**4.3184**	**60**	**0.0720**	**15.658**	**0.000000**
Error	13.9275	3030	0.0046		

Table 222: Statistical analysis summary for non-maneuver ambient versus post-maneuver ambient test condition absorbance measures (positive and negative MEP associated measures). The analysis considered factors of gender, ethnicity, frequency, and test pressure (ambient versus peak), and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.4361				
	SS	Degree of Freedom	MS	F	p
Intercept	**962.0369**	**1**	**962.0369**	**5057.365**	**0.000000**
Gender	**1.3031**	**1**	**1.3031**	**6.850**	**0.009534**
Ethnicity	0.8379	2	0.4189	2.202	0.113196
MEP	0.2765	4	0.0691	0.363	0.834456
Error	38.4254	202	0.1902		
AMB_PEAK	0.0218	1	0.0218	2.453	0.118881
AMB_PEAK *Gender	0.0007	1	0.0007	0.073	0.786854
AMB_PEAK *Ethnicity	0.0052	2	0.0026	0.291	0.747815
AMB_PEAK *MEP	0.0627	4	0.0157	1.766	0.137061
Error	1.7923	202	0.0089		
FREQ	**163.7587**	**15**	**10.9172**	**303.787**	**0.000000**
FREQ*Gender	**2.9161**	**15**	**0.1944**	**5.410**	**0.000000**
FREQ*Ethnicity	**4.4338**	**30**	**0.1478**	**4.113**	**0.000000**
FREQ*MEP	2.7056	60	0.0451	1.255	0.090911
Error	108.8898	3030	0.0359		
AMB_PEAK *FREQ	**1.1578**	**15**	**0.0772**	**37.202**	**0.000000**
AMB_PEAK *FREQ*Gender	0.0077	15	0.0005	0.247	0.998525
AMB_PEAK *FREQ *Ethnicity	0.0499	30	0.0017	0.802	0.769055
AMB_PEAK*FREQ*MEP	0.1053	60	0.0018	0.846	0.795249
Error	6.2864	3030	0.0021		

Table 223: Statistical analysis summary for non-maneuver ambient versus post-maneuver peak test condition absorbance measures (positive and negative MEP associated measures). The analysis considered factors of gender, ethnicity, frequency, and test pressure (ambient versus peak), and absolute MEP magnitude. Bolded values indicate significance (p<.05).

Effect	Repeated Measures Analysis of Variance. Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.5876				
	SS	Degree of Freedom	MS	F	p
Intercept	**1791.040**	**1**	**1791.040**	**5187.288**	**0.000000**
Gender	**2.465**	**1**	**2.465**	**7.138**	**0.008162**
Ethnicity	1.340	2	0.670	1.940	0.146363
MEP Shift	2.132	4	0.533	1.544	0.190850
Error	69.746	202	0.345		
ALL	**9.908**	**3**	**3.303**	**319.570**	**0.000000**
ALL*Gender	0.015	3	0.005	0.483	0.693930
ALL*Ethnicity	0.111	6	0.019	1.791	0.098600
ALL*MEP Shift	**5.578**	**12**	**0.465**	**44.979**	**0.000000**
Error	6.263	606	0.010		
FREQ	**330.841**	**15**	**22.056**	**329.820**	**0.000000**
FREQ*Gender	**5.631**	**15**	**0.375**	**5.614**	**0.000000**
FREQ*Ethnicity	**8.056**	**30**	**0.269**	**4.016**	**0.000000**
FREQ*MEP Shift	5.067	60	0.084	1.263	0.084962
Error	202.625	3030	0.067		
ALL*FREQ	**16.447**	**45**	**0.365**	**125.208**	**0.000000**
ALL*FREQ*Gender	**0.228**	**45**	**0.005**	**1.732**	**0.001724**
ALL*FREQ*Ethnicity	**1.044**	**90**	**0.012**	**3.974**	**0.000000**
ALL*FREQ*MEP Shift	**6.048**	**180**	**0.034**	**11.510**	**0.000000**
Error	26.535	9090	0.003		

Table 224: Statistical analysis summary for the comparison of absorbance magnitude for all four test conditions (positive and negative MEP associated measures). The analysis considered factors of gender, ethnicity, frequency, and absolute MEP shift magnitude. Bolded values indicate significance (p<.05).