EFFECT OF DIFFERENT BODY POSITIONS ON WIDEBAND ABSORBANCE AND RESONANT FREQUENCY IN NORMAL HEARING ADULTS.

AKSHA DAYAL

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A Dissertation in Part Fulfilment of the

Degree Of Master of Science

(Audiology)

University of Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE- 570006

CERTIFICATE

This is to certify that this dissertation, entitled **"Effect of Different Body Positions on Wideband Absorbance and Resonant Frequency in Normal Hearing Adults"** is a Bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student registration number **P01124S023003**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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June, 2026

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DECLARATION

This is to certify that this dissertation entitled **"Effect of Different Body Position on Wideband Absorbance and Resonant Frequency in Normal Hearing Adults"** is the result of my own study under the guidance of Dr. Animesh Barman, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for award of any other diploma or degree.

Mysore,

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Dedicated to Almighty YHWH

Every good and perfect gift is from above, coming down from the Father of the heavenly lights, who does not change like shifting shadows.

James 1:17

& to my Precious Teachers……

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"The journey was mine to walk, but I never walked it alone."

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ABSTRACT

Aims and Objectives:

In this research study, the aim was to evaluate the effect of seven different body positions on wideband absorbance and resonant frequency measured at tympanometric peak pressure and ambient pressure conditions.

Method

Sixty ears from adults aged 18 to 45 years with normal hearing and no otological complaints were recruited in this study. Wideband tympanometry was performed using Interacoustic Titan IMP440/WBT440 across 16 frequencies (257.33Hz to 8000 Hz) under ambient pressure and peak pressure conditions in seven different (neck extension, Supine, Neck flexion. Seated, Prone, Right Lateral Recumbent and Left Lateral Recumbent) body positions on the same person. The WBA and resonant frequency measurements were recorded and analysed using non parametric tests.

Results and Discussions:

Absorbance values showed a clear frequency-dependent pattern across all body positions under both ambient pressure (AP) and peak pressure (PP) conditions, with higher absorbance values mainly observed within the mid-frequency region. Significant differences across body positions were predominantly observed at lower frequencies, especially under AP condition. Comparison between AP and PP conditions revealed significant differences mainly from 257.33 Hz to 1000 Hz across all body positions, with neck flexion demonstrating the greatest pressure-related changes in absorbance. Resonant frequency also showed significant variation across body positions, and post hoc analysis demonstrated moderate to large effect sizes for the significant pairwise comparisons.

Conclusion:

The study highlights the need for standardized procedures, particularly when evaluating ears in individuals who require assessment in positions other than the seated posture. The upright position has the maximum absorbance values as compared to the other body positions.; therefore, the assessment is to be typically carried out in this position.

Keywords:

Intracranial pressure, susceptance, supine, neck flexion, neck extension.

Chapter I

INTRODUCTION

The human auditory system is a complex and highly specialized mechanism that enables the perception of sound through the coordinated functioning of the outer, middle, and inner ear. However, the direct transmission of sound from the outer ear to the cochlear fluid presents two major challenges. First, there is a significant mismatch in acoustic impedance between air and cochlear fluid, which makes sound waves in air ineffective in setting the fluid into motion. Second, effective stimulation of the cochlea depends on the pressure difference between the oval and round windows, which cannot be adequately achieved if sound is directly transmitted to the inner ear. Due to this impedance mismatch between air to cochlear fluid ($T = \frac{4r}{(r+1)2}$), approximately 99.9% of sound energy would be reflected at the air–fluid interface, with only a minimal amount of energy being transmitted into the cochlea. These challenges are efficiently overcome by the middle ear, which functions as an impedance transformer. The middle ear matches the low impedance of air to the high impedance of cochlear fluid, thereby enhancing the efficiency of sound transmission (Møller, 1974).

The middle ear is a mechanical system comprised of mass, stiffness, and resistance components, all of which influence the sound transmission properties (Van camp, Margolis, Wilson, Creten & Shanks; 1986). Here the contribution of stiffness and mass component of sound transmission is frequency dependent, whereas resonance properties of middle ear is thought to be independent of frequency. The efficiency of the middle ear as an impedance transformer is majorly therefore frequency-dependent. At low frequencies, stiffness is the dominant factor and restricts movement, resulting in reduced low frequency sound transmission. At high frequencies, mass becomes dominant and similarly limits the movement hence it leads to inefficient transmission of high frequency acoustic signals. Due to these factors, it is not sufficient to describe the transformer action of the middle ear using a single value; instead, it must be represented as a frequency-dependent transfer function.

Clinically, middle ear function is commonly assessed using tympanometry, which measures acoustic impedance or admittance and provides information about middle ear status and air pressure within the middle ear cavity based on the single frequency sound reflectance (impedance) or absorbance (admittance) capacity. Conventional tympanometry typically uses a single probe tone; however, the impedance characteristics of the middle ear would vary across frequencies with changes in mechanical properties of the middle ear. Interpreting the middle ear status based on single frequency (226 Hz probe tone) measurement is like interpreting audiometric test results solely based on the information obtained from the audiogram at 250 Hz. A broadband assessment of middle ear function will offer a more comprehensive understanding of its acoustic response characteristics across a wide range of frequencies.

To overcome the limitations of single frequency tympanometry, multi-frequency tympanometry (MFT) is being used and is regarded as superior to conventional 226 Hz probe tone tympanometry, as it evaluates middle ear function across a broader frequency spectrum (226–2000 Hz). The use of multiple probe tone frequencies enhances its ability to detect high-impedance pathologies, including middle ear effusion, otosclerosis, and chronic otitis media. Consequently, MFT demonstrates greater sensitivity than single-frequency tympanometry in the identification of middle ear disorders. However, the clinical application of MFT is limited by several factors. At frequencies exceeding 1500 Hz, the occurrence of standing waves can result in significant sound pressure variability, thereby compromising measurement accuracy. Furthermore, the absence of standardized calibration protocols for higher probe tone frequencies may lead to unreliable assessments of middle ear function. These limitations increase the potential for diagnostic inaccuracies, including both false-positive and false-negative outcomes. Accordingly, there is a need for alternative diagnostic approaches that provide improved sensitivity and specificity, particularly for the detection of mild pathologies in the middle ear.

Wideband Tympanometry (WBT) is a new approach in this direction has gained popularity of late that helps to measure the transfer functions of the middle ear (J. B. Allen, 1986; Shahnaz & Bork, 2006). It facilitates this measurement by evaluating middle ear function over a broad frequency spectrum, thereby enabling a more accurate and sensitive assessment of its mechanical and acoustic properties.

The umbrella term *wideband acoustic immittance (WAI)* encompasses a range of acoustic measurement types, including energy or power reflectance, absorbance, conductance, and admittance. Among these, wideband absorbance (WBA) is particularly important, as it represents the proportion of sound energy absorbed across frequencies by the middle ear, thereby reflecting its transmission efficiency. It also provides a key parameter known as resonant frequency which indicates the balance between mass and stiffness components of the middle ear.

Various researches reveal several advantages of wideband tympanometry (WBT) over conventional 226 Hz and multi-frequency tympanometry in the assessment of middle ear function. It employs transient stimuli across multiple frequencies simultaneously, thereby minimizing the influence of myogenic noise caused by patient movement (Prieve et al., 2013). Additionally, WBT measurements can be obtained without changing pressure within the ear canal (Feeney et al., 2003; Huang et al., 2000; Keefe & Levi, 1996). Furthermore, WBT measurements are not significantly affected by the positioning of the probe tip within the ear canal (Keefe & Levi, 1996; Voss & Allen, 1994). In contrast, traditional tympanometric assessments are highly sensitive to probe insertion depth, which can influence tympanometric test results (Margolis et al., 1999).

Overall, WBT is increasingly recognized as a promising diagnostic tool for the detection of middle ear pathologies, offering high accuracy and has the potential to replace both single-frequency and multi-frequency tympanometry in clinical practice (Sanford et al., 2013).

1.1 Need for the study

Wideband absorbance (WBA) is becoming an important tool for evaluating middle ear function across a wide range of frequencies, with better diagnostic accuracy than the traditional 226 Hz tympanometry. However, it is not clear whether WBA results can be influenced by various physiological factors, including posture and intracranial pressure variations, which may cause confusion or misinterpretation if not carefully considered.

The auditory system is highly responsive to changes in intracranial pressure (ICP) as the cochlear aqueduct links the cerebrospinal fluid to the cochlear fluids. When ICP rises, it leads to elevated intracochlear pressure, causing outward displacement of the flexible oval and round windows. Such increases in ICP are primarily detected as a reduction in middle-ear sound transmission, due to increased stiffness of the annular ligament that anchors the stapes to the oval window (Büki et al., 2000, 2002). This stiffness effect is particularly evident at frequencies below the resonant frequency of the middle ear. This relationship between the middle and inner ear can be understood in terms of mechanical coupling at the stapes–cochlea interface. Lynch et al., (1982) characterized the cochlear input impedance and showed that the cochlea acts as a mechanical load on the stapes, thereby directly influencing middle-ear motion and sound transmission through animal experiment.

Intracranial pressure changes systematically with postural position (Sagirov et al., 2023a). Thus, changing postural position provides a method to induce changes in ICP. It is widely documented that posture affects auditory function, including thresholds, otoacoustic emissions, and middle-ear impedance (Buki et al., 2000). Thus, the relationship between posture and ICP could provide a mechanism to understand whether variations in pressure affect middle ear transformer action.

Effect of body position on ICP and in turn impact on middle ear function can be assed using either single frequency tympanometry or wideband tympanometry. Chatterjee et al (2017) found that tympanometric results, especially the pressure gradient, can shift when the head is kept in different positions for a long time (Chatterjee et al., 2017). In line with this, Torrecilla and Avan, (2021) observed that body tilt, along with the related changes in intracranial pressure, can alter wideband absorbance**,** particularly affecting tympanometric peak pressure.

More recently, Yücel et al., 2020 showed that changes in body posture can significantly influence tympanometric peak pressure and resonance frequency in wideband tympanometry, and these shifts also affect distortion product otoacoustic emissions at certain frequencies. However, it is not clear whether or not body position can alter the absorbance pattern across frequencies, which needs to be assessed systematically. Understanding the effect of body posture on wideband absorbance (WBA) has important clinical implications, particularly in populations where testing conditions vary and couldn't be systematically controlled. In routine clinical practice, patients are often assessed in different positions depending on age, medical condition, or testing environment—for example, infants are typically evaluated in the supine position, whereas adults are assessed in an upright posture. If posture introduces such variability in WBA measurements, this could certainly lead to misinterpretation of middle ear status, potentially affecting the diagnosis and management decisions.

Taken together, these studies make it clear that body position has a real and measurable impact on middle and inner ear function. Yet, there is limited research focusing specifically on wideband absorbance in clinically normal hearing individuals across common clinical postures (sitting, supine, prone, & lateral positions). Since WBA is increasingly incorporated into clinical practice, it is crucial to establish whether posture introduces significant variability in WBA measures.

Therefore, this study is needed to provide systematic evidence on the effect of body position on wideband absorbance. This will help to refine clinical interpretation of WBA findings which in turn helps to avoid false positives/negatives results. Furthermore, the findings could potentially contribute to the development of standardized testing protocols.

1.2 Aim of the study

This study aims to evaluate the effect of different body positions on wideband absorbance and resonant frequency of middle ear in normal hearing individuals.

1.3 Objectives of the study

1. To compare the absorbance patterns across body positions at each frequency both at tympanometric peak pressure (TPP)and ambient pressure (AP) condition.
2. To compare the absorbance between TPP and AP at each frequency at each body position.
3. To compare the middle ear resonant frequency across all body positions.

Chapter II

REVIEW OF LITERATURE

The mammalian middle ear plays a crucial role in hearing by acting as an impedance matching system that efficiently transfers sound energy from the air to the fluid-filled cochlea, thereby enabling effective auditory transduction. Traditionally, the middle ear was described as a simple lever system, amplifying sound via the combined effects of the eardrum's area advantage (with a ratio of 17.7:1), buckling effect (with a ratio of 2:1) and the lever action of the malleus-incus complex (with a ratio of 1.3:1). However, recent research has demonstrated that middle ear mechanics are more complex than this classical view, involving frequency-dependent synovial joint functions and multiple axes of ossicular rotation that enhance sound transmission across a wide frequency range (Ugarteburu et al., 2022). Experimental measurements and finite-element modelling studies have provided insights into the dynamic behaviour of the ossicular chain and tympanic membrane, revealing that the middle ear primarily functions to reduce acoustic impedance mismatch and minimize sound reflection rather than solely providing gain (Gan et al., 2002; Killion & Dallos, 1979).

Middle ear or immittance measurement is an essential physiological measure that provides an insight about the functioning of the middle ear (Hunter & Sehnaz, 2014). Although the assessment of middle ear function has undergone substantial evolution, beginning with early acoustic impedance measurements (Metz, 1946) and advancing through successive technological developments. Single-frequency tympanometry became widely adopted in clinical practice due to its simplicity and efficiency (Jerger, 1970). However, multi-frequency tympanometry, although offering improved diagnostic insight into middle ear mechanics (Margolis & Goycoolea, 1993a; Vanhuyse et al., 1975), has seen limited clinical use because of practical constraints such as increased test time, complexity, and the need for specialized training (Emanuel et al., 2012). More recently, wideband acoustic immittance has emerged as a comprehensive approach, enabling evaluation across a broader frequency range and providing more detailed information about middle ear function (Keefe et al., 1993; Margolis et al., 1999; Stinson et al., 1982).

Accordingly, the current literature review emphasizes the single frequency immittance measures to wide band middle ear absorbance along with different components of middle ear that contributes to the middle ear function and most importantly underlying principles of WBA tympanometry and examines the various sources of variability that can affect WBA measurements.

2.1 Acoustic Immittance Measures

Acoustic immittance is a broad term used to describe the transmission characteristics of sound energy through the middle ear system and encompasses both acoustic impedance and acoustic admittance. Acoustic impedance refers to the opposition offered by the middle ear to the transmission of acoustic energy, whereas acoustic admittance represents the ease with which acoustic energy is transmitted through the middle ear. These parameters are derived from the relationship between sound pressure and volume velocity at the tympanic membrane following the presentation of an acoustic stimulus into the ear canal. Impedance is mathematically expressed as the ratio of sound pressure to volume velocity ($Z = P/U$), while admittance is the reciprocal of impedance ($Y = 1/Z$). As both measures provide complementary information regarding middle ear mechanics, they are collectively termed acoustic immittance. Acoustic immittance measurements constitute the foundation of clinical procedures such as tympanometry, multifrequency tympanometry, and wideband acoustic immittance assessment, which are widely used in the evaluation of middle ear function. (Wiley & Stoppenbach, 2002).

2.2 Components of Acoustic Immittance

As mentioned above immittance is a generic term that involves both acoustic impedance and admittance. Impedance results from the combined interaction of three fundamental physical factors: mass, stiffness, and friction. Opposition to the flow of energy caused by the mass is known as mass reactance, which is directly proportional to the frequency ($X_m = 2\pi f M$) and the opposition caused due to stiffness is known as stiffness reactance, which is inversely proportional to the frequency ($Xs = S/ 2 \pi f$). And the third component generally develop due to the dissipation of energy through the friction is known as acoustic resistance (R). Similarly acoustic admittance is also influenced by three main components: compliance, mass, and friction. Admittance offered by the stiffness is called stiffness susceptance, which is reciprocal to the stiffness reactance ($B_s = 1/ X_s$) and admittance offered by mass is called mass susceptance, which is reciprocal to the mass reactance ($B_m = 1/ X_m$). Admittance due to friction is called Conductance and is reciprocal of resistance ($G=1/R$) (Gelfand, 2016).

2.3 Middle Ear Resonance

Resonance is a state where an oscillating force applied to an object closely matches the object's natural frequency and which depends upon the systems mass and compliance (Haughton, 2002). When the compliance and mass susceptance are equal, or when the total susceptance is equal to 0 mmhos, the middle ear system achieves resonance. Compliance and mass acoustic reactance change in reciprocal fashion as probe frequency is increased or decreased. As probe frequency decreases, the mass acoustic reactance decreases and the compliant acoustic reactance increases. Accordingly at some specific probe frequency two reactance will be equal because the two reactance are directly out of phase, they will cancel one another and the resultant total acoustic reactance will be equal to zero. Specifically, the addition of two equal but out-of-phase components will result in a total acoustic reactance of zero acoustic ohms. At this specific frequency, the system is said to be at Resonance and the frequency at which this occurs is termed as the resonant frequency of the middle ear. Because the total acoustic reactance is equal to zero acoustic ohms at the resonant frequency, the total acoustic impedance is equal to the acoustic resistance offered by the system. Only acoustic resistance contributes to the total acoustic impedance, at the acoustic impedance phase angle is equal to zero degree. At the resonant frequency, the acoustic impedance is at its minimal value and is equal to the acoustic resistance offered by the system under test.

So resonant frequency is directly proportional to square root of stiffness and inversely proportional to square root of mass (Wiley & Stoppenbach, 2002). The normal adult ear's resonance frequency can range from 630 Hz to 2000 Hz (Margolis & Goycoolea, 1993b).

2.5 Single Frequency Tympanometry

Tympanometry is an integral component of acoustic immittance assessment and is widely utilized in clinical audiology for the objective evaluation of middle ear function. It involves the systematic variation of air pressure within the external auditory canal while simultaneously measuring the acoustic admittance of the middle ear system. It basically comprises of the admittance contribution offered by the volume of air between the probe tip and the tympanic membrane. The procedure is based on the principle that the mobility of the tympanic membrane and ossicular chain changes as the air pressure on either side of the tympanic membrane is altered. Maximum admittance is obtained when the pressure within the external auditory canal approximates the pressure of the middle ear cavity, thereby reflecting optimal tympanic membrane compliance. Any deviation from this pressure equilibrium alters tympanic membrane compliance and consequently changes the admittance characteristics of the middle ear system. Clinically significant tympanometric parameters, including tympanogram peak pressure (TPP), peak compensated static acoustic admittance, ear canal volume and tympanogram width (TW). A 226 Hz probe tone is used for the clinical assessment of adults. The rationale for utilizing a low-frequency probe tone is based on the acoustic characteristics of the normal adult middle ear, which is predominantly stiffness controlled at lower frequencies. At 226 Hz, changes in middle ear stiffness significantly influence acoustic admittance, thereby allowing reliable identification of pathological alterations affecting tympanic membrane mobility and ossicular function. The contemporary immittance instruments primarily measure acoustic admittance rather than impedance because admittance more effectively represents the ease with which acoustic energy flows through the auditory system (Wiley & Stoppenbach, 2002).

2.6 Factors affecting Single Frequency Tympanometry

The middle ear conditions can be assessed by tympanometry. However, there are various subjective and procedural factors that can influences the tympanometric results. Subjective factors including age, gender, race and objective factors like pressure sweep rate and direction, middle ear volume etc. can influence the single frequency acoustic immittance measurement.

S. Sinha, A. Neupane, K. Gururaj (2021) & Khaleefah , R. R., Alsarhan, H. W., & Jwery, A. K. (2025). Studied the effect of aging on tympanometric findings. (Sinha et al., 2021) revealed significant difference for ear canal volume from 61 to 80 years. Whereas Khaleefah et al., (2025), found that in comparison to the younger group, the elderly population, those with 85 years of age and older showed noticeably higher tympanometric breadth and ear canal volume. The reason given for these changes is the soft tissue shrinking surrounding the ear canal and age-related decrease of skin elasticity.

Regarding ethnicity, the evidence on tympanometric parameters remains inconsistent. Lih et al., (2017) found no significant differences between Malay and Chinese participants among young adults. However, Shahnaz and Davies (2006) reported significant ethnic differences in several tympanometric measures between Chinese and Caucasian adults.

Chua, (2020) found that gender significantly influenced ear canal volume (ECV), while ethnicity marginally affected static admittance. The role of gender in affecting ECV is understood by the notion that males generally have a larger body size and hence a larger ear canal as compared to the females.

Feldman; Thomas.; Palfrey and Dellecker, (1984) demonstrated that faster air pressure change rates resulted in higher measured compliance and shifted maximum compliance points in both normal and pathological ears, affecting ~25% of impaired ear classifications. They correlated their findings with a study done by Williams (1976), where the author attributed the absence of a relationship between immittance and pressure sweep rate in ears with flaccid tympanic membranes by attributing it to hysteresis. Hysteresis refers to the delayed mechanical response of an object following changes in the force applied to it. This delay can occur during both increases and decreases in the applied force. In the context of tympanometry, hysteresis occurs when the tympanic membrane and middle-ear structures do not respond instantaneously to variations in ear-canal pressure.

Gaihede, (1999), through model experiments showed the effect of middle ear volume and pressure on tympanometric peak pressure. The author postulated that middle ear volume significantly affects tympanometric pressure measurements, with smaller volumes leading to more negative readings, and hysteresis contributes to numerical overestimation of pressure. Author has postulated that the middle ear tissues are viscoelastic, their movement does not occur instantly with pressure changes during tympanometry. Instead, there is a lag between the applied ear canal pressure and the actual movement of the tympanic membrane. This time-dependent lag causes the peak of the tympanogram to appear at a pressure value that is more extreme than the true middle ear pressure. As a result, negative pressures appeared more negative and positive pressures appeared more positive during tympanometric recording.

Wilson et al., (1984)demonstrated that the acoustic impedance of the ear decreases with consecutive tympanometric runs. This is attributed to alterations in the viscoelastic properties of the eardrum and middle ear with repeated pressurization.

Falk, (1983) identified sniffing-induced pressure changes and probe frequency as additional variables affecting results.

Mariyam, Alsarhan and Mohammed, (2025) examined Middle ear pressure in 162 ears at 2 different body positions i.e. sitting and supine. They found statistically significant differences in middle ear pressure when subjects moved from sitting to supine positions. Author postulated that this is because the supine posture has a higher jugular vein pressure than the erect posture, which causes congestion and increases the volume of the middle ear mucosa, which in turn affects the MEP. Chatterjee, Hembram, Shahi, Sinha, (2017) similarly reported that maintaining the head in a supine position for 10 minutes resulted in a significant decrease in the pressure gradient throughout the duration of the supine posture when compared with the sitting position.

2.7 Multifrequency, Multicomponent Tympanometry (MFT)

Multifrequency Tympanometry (MFT) involves measurement of more than one acoustic immittance components (e.g., admittance (*Y*a), conductance (*G*a), susceptance (*B*a), and phase angle ϕa using more than one probe tone frequencies. Compared to a single-frequency tympanometry, MFT offers a more comprehensive picture of the middle ear's admittance characteristics (Katz, 2016). The relation between admittance components varies as a function of frequency as described in 2.2, with rising frequency, total susceptance shifts from positive values associated with stiffness dominance, approaches zero at resonance, and eventually becomes negative when the system becomes mass dominated.(Shahnaz, 2014.). The method is particularly valuable in identifying ossicular chain abnormalities and differentiating stiffness-dominated conditions from mass-dominated pathologies. In normal ears, tympanometric patterns may transition from single-peaked to multipeaked responses as probe frequency increases, a phenomenon explained by the Vanhuyse model (Vanhuyse et al., 1975) . Furthermore, MFT facilitates the estimation of middle ear resonant frequency, which may shift to higher frequencies in disorders associated with increased stiffness, such as otosclerosis, and to lower frequencies in conditions involving increased mass, such as ossicular discontinuity (J. Shanks & Shelton, 1991).

2.8 Factors affecting MFT.

A recent study was done in 2023 by Mishal K et al., to find the effects of gender and ear difference of multi-frequency tympanometry in the Indian young adult population. The test results showed that the mean RF and F45 have no significant difference in left and right ears. Females have slightly better RF and F45 than males. Shahnaz and Davies (2006) found that Chinese adults show a significantly higher mean RF than Caucasian adults. This higher RF could be caused by increased stiffness in the ME transmission system of the Chinese group.

Shanks & Wilson, (1986) had measured the effect of the direction (ascending and descending) and rate (12.5, 25.0, and 50.0 daPa/s) of ear-canal pressure changes. They Found that a decrease in phase angle for ascending and for fast rates of ear-canal pressure change strongly indicates that peak static admittance was significantly affected by both the rate and direction of pressure change. Also, the rate of ear-canal pressure change increased so did the difference in peak pressure for the two-pressure change direction. A higher incidence of tympanometric notching and/or deepening of the notch has been reported for ascending than for descending pressure changes and for fast rates (> 30 daPa/s) of pressure change with high-frequency probe tones (678 or 800 Hz) (Creten & Van Camp, 1974).

Franco-Vidal et al. (2015) studied 20 volunteers (40 ears) using multifrequency tympanometry across three body positions to see the effect of changes in inner ear fluid pressure caused by body tilt on the results of multifrequency admittance tympanograms. They found conductance width increased from 141.7 daPa in vertical body position to 158 daPa (supine body position) to 184 daPa in Trendelenburg position (20 degrees), with resonance frequency also increasing in Trendelenburg position. Daniel, Hume, Givens and Jordan (1985), obtained susceptance tympanogram in five different body positions i.e. seated upright, supine, prone, lying flat on side on examining table with test ear down and lying flat on side of examining table with test ear up. The results of this study showed that the meatal air pressure corresponding to the point of maximum compliance in the susceptance tympanogram of the test ear shifted from approximately −15.97 mm H_2O in the upright position to approximately −2.50 mm H_2O across the other four positions, namely supine, prone, test-ear up, and test-ear down. The authors explained that the positive pressure shift at the point of maximum compliance could be due to intracranial labyrinthine fluid pressure and increased intracranial venous pressure affecting the mucosal lining of the middle ear cavity.

2.9 Wideband tmpanometry (WBT)

Wideband Reflectance is a relatively new tool to analyse the reflected or absorbed sound energy across a wide range of frequencies. A sound is presented and the amount of energy reflected back from the middle ear is calculated at the level of ear canal. Pressure reflectance refers to the comparison between the sound pressure of the incoming wave and that of the reflected wave. Energy or power reflectance (ER) is obtained by squaring the magnitude of pressure reflectance, represented as $R = [R(f)]^2$, and indicates the ratio of reflected acoustic energy to incident acoustic energy. An energy reflectance value of 0 indicates complete absorption of sound energy by the middle ear, whereas a value of 1 signifies total reflection of sound energy back into the ear canal. While reflectance represents the amount of sound pressure or energy reflected from the end of the wave pathway, absorbance refers to the portion of sound energy absorbed by the middle ear system. Absorbance is mathematically expressed as $A(f) = 1 - \Re(f)$ (Rosowski, J. J., Stenfelt, S., & Lilly, D, 2013.).

When a calibrated transient broadband stimulus is directed towards the tympanic membrane in a sealed ear canal, the amount of energy that is absorbed or reflected at the tympanic membrane is calculated across frequencies. This is known as Wideband Tympanometry (WBT). In WBT the factors measured are reflectance or absorbance, known as Wideband absorbance (WBA) or Wideband Reflectance (WBR) (Hunter & Sehnaz, 2014). Wideband tympanometry is a novel tool that assess how efficiently sound is transmitted through the middle ear across a range of frequencies rather than just one, providing a more comprehensive evaluation of middle ear function (Biswas & Dutta, 2018)

2.10 Wideband Absorbance: Normative data and Influencing Variables

Normative data for WBA in adults indicate that absorbance is generally lowest at the frequency extremes (below 500 Hz and above 4000 Hz) and peaks in the mid-frequency range between 1000 and 4000 Hz. Several studies have established robust normative ranges across different populations and measurement conditions (Rosowski et al., 2012; Feeney et al., 2003). Similary a study done on Indian Population by Karuppannan & Barman, (2021) reported that in the control group, maximum wideband absorbance (WBA) was observed at the mid frequencies of 1000 Hz and 2000 Hz, while lower absorbance values were noted at the extreme low and high frequencies. Collectively, these studies report mean absorbance values of approximately 0.2–0.3 at 500 Hz, rising to 0.7–0.85 in the 1000–4000 Hz range, before declining to 0.3–0.5 at 8000 Hz.

Similar to single frequency tympanometry or multifrequency tympanometry, there are several variables that can influence the WBA measures, including age, gender, ear canal volume, race/ethnicity, and measurement conditions and ear canal pressurization. Feeney and Sanford, (2004) reported significant effects of age on WBA. The older adults demonstrated decrease in reflectance from 800 to 2000 Hz but an increase near 4000 Hz. The findings imply that middle ear stiffness decreases with age advancement.

Shahnaz and Bork (2006), found differences in wideband energy reflectance between Caucasian and Chinese adults, particularly at low and mid-frequencies, attributed to anatomical differences in ear canal and middle ear characteristics.

2.10 Effect of Body Positions on Various Auditory Measures

2.10.1 Postural Effects on Auditory System

The study by Macrae (1972) examined how changes in body position influence auditory function, particularly auditory thresholds, acoustic impedance at the tympanic membrane, and middle ear muscle reflexes. The findings showed that shifting from an upright to an inverted position resulted in reduced auditory sensitivity and increased acoustic impedance, including both resistance and reactance components. These changes are thought to be largely due to increased hydrostatic pressure in the inner ear fluids, which affects sound transmission through the middle ear. Furthermore, the effects of middle ear muscle contractions on tympanic membrane compliance were found to be reduced in the inverted position, indicating that body posture can significantly influence auditory system behaviour and should be considered in acoustic measurements.

Allen & Habibi, (1962)), attributed the primary shift in threshold to an increase in the hydrostatic pressure of the cochlear fluids, produced by placing the cochlea near the bottom of the cerebrospinal fluid system in the inverted position. If this explanation is correct, a change of body position from upright to inverted should produce an increase in the acoustic impedance of the middle ear.

Sagirov et al., (2023) indicate that changes in body position—such as transitions between upright, supine, and head-down tilt—lead to gravity-dependent redistribution of blood and cerebrospinal fluid (CSF) within the craniospinal system. In upright posture, collapse of the internal jugular veins reduces cerebral venous outflow and shifts CSF toward the spinal compartment, resulting in decreased Intracranial Pressure (ICP), whereas head-down tilt produces venous engorgement, reduced venous flow velocity, and a corresponding increase in ICP. This finding is ascribed to communication between CSF and inner ear labyrinthine fluids. CSF pressure is easily transmitted to perilymph as the perilymph is continuous with CSF via the cochlear aqueduct).

Elevated perilymphatic pressure, as occurs with increased ICP in the recumbent position, is transmitted to the scala tympani and may cause outward displacement of the round window membrane. Since the round window membrane is the primary pressure relief valve for the incompressible cochlear fluids, its displacement alters the mechanical coupling between the middle ear and inner ear. Specifically, increased perilymphatic pressure increases the stiffness of the round window membrane, which may increase the overall stiffness of the middle ear-cochlear system and shift the middle ear resonant frequency accordingly (Densert et al., 1977; Reid et al., 1990).

Several pathological conditions associated with elevated ICP have been linked to characteristic Wideband immittance changes. Reid et al (1990), investigated the effect of hydrocephalus on auditory function by evaluating patients diagnosed with hydrocephalus using impedance audiometry techniques. The findings demonstrated abnormal tympanometric patterns, indicating that increased intracranial pressure in these patients influenced middle ear impedance characteristics.

Demir et al., (2020) performed WBT on 21 patients with unilateral Meniere's Disease. report that patients with MD show significantly lower resonance frequency (RF) and reduced absorbance at low frequencies (0.25–1 kHz) compared to normal ears, suggesting increased inner ear pressure due to endolymphatic hydrops.

These observations suggest that the physiological pressure transmission mechanism from ICP to the inner ear via the cochlear aqueduct is sufficiently potent to alter auditory function at the margins of normality, particularly when the system is sensitized by pathology.

2.10.2 Studies on Postural Effects on Wideband Acoustic Immittance

Torrecilla and Avan (2021) investigated the relation between wideband tympanometry and intracranial pressure (ICP) in 41 healthy adult subjects (68 ears) by measuring energy absorbance (EA), ambient absorbance (aEA), peak absorbance (pEA), and tympanometric peak pressure (TPP) in different body positions including upright, supine, and head-down tilt. The authors found that tympanometric peak pressure (TPP) shifted progressively toward more positive values as body position increased intracranial pressure, with average TPP values changing from approximately 0 daPa in upright posture to +19 daPa in supine and +27 daPa in the head-down position. Despite these changes, the overall shape of the wideband absorbance pattern remained essentially unchanged and merely shifted along the pressure axis. The authors suggested that increased ICP alters the stiffness of the stapes–annular ligament system through pressure transmission from cerebrospinal fluid to the inner ear via the cochlear aqueduct. This increased stiffness reduces sound energy transmission, particularly at low frequencies. They further proposed that applying an appropriate ear-canal pressure during wideband tympanometry could counterbalance the effect of ICP on middle-ear mechanics, thereby restoring the absorbance pattern. Hence, the TPP was identified as the primary parameter reflecting intracranial pressure–related changes. The study highlighted the potential of wideband tympanometry as a non-invasive method for monitoring intracranial pressure.

Yücel et al. (2020) investigated inner ear pressure changes in 40 healthy individuals by utilizing wideband tympanometry (WBT) and distortion product otoacoustic emissions (DPOAE) in three postural conditions—sitting, supine, and Trendelenburg. Parameters such as resonance frequency (RF), tympanic peak pressure (TPP), and DPOAE signal-to-noise ratio (SNR) across frequencies (1–6 kHz) were recorded under ambient and peak pressure conditions. The results showed a significant decrease in RF and an increase in TPP with postural changes, along with a significant reduction in DPOAE SNR at 1 kHz, while higher frequencies (2, 3, and 6 kHz) showed increased SNR under ambient conditions.

Extensive studies on tympanometry revealed that several factors affect the tympanometric result. Similarly, it can also affect the WBT results as both reflects middle ear characteristics of sound transmission. Despite these findings in the field of WBT, the literature still remains thin, with most studies limited by lack of systematic comparison of multiple body positions. Most available studies have examined only two to three body positions (typically seated and supine) and have not provided comprehensive Wideband Acoustic Immittance data across the wide frequency spectrum . Resonant frequency as a specific outcome measure has received little attention in the postural Wideband Acoustic Immittance literature. Given RF's sensitivity to middle ear stiffness changes, it represents a potentially more sensitive marker of postural effects than the broadband absorbance alone. Therefore the dedicated investigation across body positions is essential. Hence, the proposed study addresses these gaps and have future insight to advance both the theoretical understanding of postural physiology and the practical standardization of WBA measurement protocols.

Chapter III

METHODS

3.1. Study Design

The objective of this study is to determine the effect of different body positions on Wideband Absorbance across frequencies and resonant frequency of the middle ear in normal hearing adults. The study required each participant to be evaluated several times with different body positions hence the research design adopted is a non-experimental within-subject repeated measures design.

3.2. Participants

A total of 30 individuals (15 males &15 females) in the age range of 18 to 45 years were included in this study. A structured case history was taken to rule out any history of ear pain, ear discharge, history of medically and surgically treated ear diseases and symptoms associated with outer and middle ear. The test procedures were clearly explained to the participants before the testing, and written informed consent was obtained from all the participants. The study followed the ethical guidelines described in *Ethical Principles for Bio-Behavioral Research Involving Human Subjects* (AIISH, 2023). Ethical clearance for the biobehavioural research was granted by the AIISH Institutional Review Board (IRB) (Reference No. SH/IRB/M.4/AUD.30/2025-26 dated). All procedures carried out in this study were non-invasive in nature.

3.3. Participant's Inclusion Criteria

Participants had to fulfil the following criteria to be considered for the study:

i. Participants with air conduction and bone conduction pure tone hearing thresholds of ≤15 dB HL at octave frequencies between 250 Hz and 8000 Hz for Ac and 250Hz to 4000Hz for BC (Clark, 1981).

ii. Participants who demonstrated an Uncomfortable Loudness Level (UCL) for speech greater than 100 dB HL.

iii. Participants who did not exhibit any symptoms associated with ear-related disorders.

iv. Individuals who did not present with any apparent neurological symptoms.

v. Participants who exhibited a type 'A' tympanogram and showed the presence of acoustic reflexes at 500 Hz and 1000 Hz for both ipsilateral and contralateral stimulations.

3.4. Test Environment

All test procedures were conducted in a soundproof room. The ambient noise levels in all test rooms conformed to the standards set by the American National Standards Institute (ANSI S3.1-1991). A double-room suite was utilized for pure tone and speech audiometry, while tympanometric evaluations and wideband absorbance measurements were conducted in a single-room setup. All rooms were adequately illuminated and air-conditioned.

3.5. Instrumentation

A GSI Audiostar Pro diagnostic audiometer with Radioear B-71 bone vibrator and Radioear 3045 supraaural earphones were used to obtain pure tone bone-conduction and air-conduction threshold, and uncomfortable loudness levels (UCL) for speech respectively. Tympanometric measures, including the wideband tympanometry, were accomplished using an Inter-acoustics Titan middle-ear analyser with Titan Suite software (Advance research module).

3.4. Calibration

Throughout the data collection phase, the audiological instruments, including the GSI AudioStar Pro™ dual-channel clinical audiometer and the Titan Suite IMP440 Ver 3.0, underwent calibration once in every three months in adherence to the ANSI S3.6-2004 (R2010) and ANSI S3.39-1987 (R2012) standards, as prescribed by ANSI (2010, 2012). The Titan Suite IMP440/WBT440 advanced research analyzer used to measure WBA required daily calibration, which was performed by positioning the probe assembly into a calibration unit with a standardized volume of 2 cc.

3.4. Test Procedure

To check for the eligibility criteria of the participants, they all underwent a preliminary evaluation before the experimental phase.

3.4.1 Preliminary evaluations

Structured Case History: A detailed case history was carried out to obtain information about each participant's hearing health and, their medical symptoms. This included common ear-related issues such as ear pain, a feeling of fullness, discharge, previous infections, itching in the ear canal, and tinnitus. Medical records were also reviewed and documented, with particular attention given to any confirmed diagnosis of external and middle ear related disorders by an otologist. Additionally, the chart review screened for neurological symptoms, including headaches, facial pain, numbness or weakness, tinnitus, dizziness or vertigo, difficulty swallowing, voice changes, double vision, and cognitive impairments to figure out any neurological issue is there or not.

Otoscopic Examination: All participants underwent an otoscopic examination to evaluate the condition of the external ear canal and the tympanic membrane. The goal of this assessment was to identify issues such as earwax or presence or absence of cone of light, visible external ear pathologies, tympanic membrane perforation, ear discharge, or the presence of foreign objects in the ear canal.

Pure Tone Audiometry: Each participant completed both pure tone and UCL for speech tests. Thresholds were estimated using modified version of the Hughson and Westlake method

(Carhart & Jerger, 1959) to determine air conduction thresholds at 0.25, 0.5, 1, 2, 4, and 8 kHz, and bone conduction thresholds at 0.25, 0.5, 1, 2, and 4 kHz.

Immittance Audiometry: Tympanometry was carried out using 226Hz probe tone as well as the measurement of acoustic reflex thresholds (ipsilateral & contralateral) at 0.5 and 1kHz, was done to know the status of the middle ear. Principal tympanometric parameters including ear canal volume, static admittance, and tympanometric peak pressure were recorded.

Based upon the results obtained from the preliminary examinations, the participants who fulfilled the selection criteria were selected for the main experimental procedure.

3.4.2. Experimental Test Procedure

Before beginning the measurement of WBA procedure, calibration of the Interacoustic Titan Suite IMP440/WBT440 was performed daily. The probe assembly was placed into a cylindrical shaped calibration cavity of a standardized volume of 2cc. Both source reflectance and incident pressure were systematically estimated to ensure precise WBA measurements.

It was ensured that the reflectance values remained below 15% up to 2 kHz and below 30% at higher frequencies, in accordance with the recommendations provided by the manufacturer (Interacoustics, 2016; Liu et al., 2008). The instrument used in the study consisted of receivers to present stimuli and a microphone for capturing the pressure of sound in the ear canal. To vary the ear canal pressure, a pressure pump was used. To create an air-tight seal in the ear canal, tips made of silicon material were used. Participants who satisfied the inclusion criteria were then subjected to the experimental procedures. The participants were explained the entire test

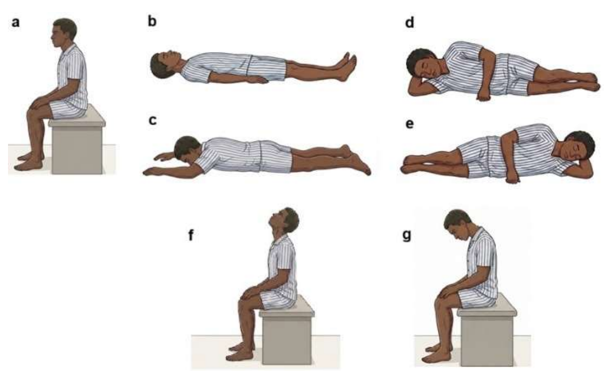
procedures and were asked to relax and not to move during the test. They were also briefed about the testing process, which involved the insertion of a probe tip into the ear canal to obtain an airtight seal, followed by pressure changes and the presentation of click stimuli. Additionally, participants were instructed to refrain from swallowing, coughing, or speaking while the test is in progress. A suitably sized probe tip was securely placed in the participant's ear canal, and a wideband click stimulus at 100 dBpeSPL was presented at rate of 21.1/sec (Interacoustics, 2017).

To modulate various body positions to study its influence on WBT findings, the tilting bed was used except for the body positions where the participants had to be in sitting position. For the sitting positions the participants were made to sit on an armed chair comfortably.

. Each subject was tested in a total of seven different body positions i.e with head upright position (seated), supine, prone, right lateral recumbent, left lateral recumbent, back head tilt (neck flexion) and front head tilt (neck extension) as shown in Figure 1.

The order of body positions was randomized across participants to counterbalanced the order effect. In each position, the participant was comfortably placed with appropriate head and body support to avoid probe displacement. The probe was refitted with every new position to measure WBA. The refitting of probe is not likely to affect the WBA measures, as the literature suggests that absorbance is relatively insensitive to depth of probe position within the ear canal (Stinson et al 1982; Voss et al 2010) and also, to ascertain dislodging of probe during movement of the body from one position to another.

Fig 3.1: *Different Body Positions at which WBA was measured.*



Note. (a) Seated, (b) Supine, (c) Prone, (d) Left lateral recumbent, (e) Right lateral recumbent, (f) Neck extension, and (g) Neck flexion.

WBT was performed at frequencies ranging between 250 to 8000 Hz. The air pressure was varied in the ear canal from +200 to -400 daPa. The instrument measured WBA simultaneously with the change in pressure in the ear canal for the click stimuli at $1/24^{th}$ octave band frequencies from 250 Hz to 8000Hz. The values were automatically recorded and displayed on the screen. However, WBA values were extracted at 1/3rd octave frequencies (16 frequencies) at both tympanometric peak pressure and ambient pressure. Measurements of absorbance was calculated automatically by the equipment at Tympanometric Peak Pressure (TPP) and Ambient Pressure (AP) across all body positions. Also, the change in resonant frequency at TPP with respect to different body position was also measured.

Each measurement was carried out minimum one minutes after the change of position as literature suggests that Intracranial Pressure (ICP) stablilizes approximately 30 seconds after the change in the body positions (de Kleine et al., 2001).

3.4.3. Test Retest Reliability Measures

The test retest reliability of the WBA was measured once again at those 16 frequencies by repeating the WBA measurement among the 10% of the participants on a later date. Thus, the Test–retest reliability was assessed using six ears, of the participants who were chosen randomly. The test-retest reliability was done after seven days following the initial measurement. To evaluate the consistency and reliability of WBA measures, both the initial and second measurements were compared.

3.5. Statistical Analysis

All the statistical analysis was done using SPSS version 26 (IBM SPSS Statistics, New York, USA). The Kolmogorov–Smirnov test was used to determine whether the WBA measures across 16 frequencies at different body positions along with resonant frequency data was normally distributed or not. It was done for 16 different frequencies both at TPP and AP conditions. Mean, standard deviation, median and interquartile range for absorbance at peak pressure and ambient pressure at all frequency and body positions and also for the resonant frequency were evaluated by doing descriptives analysis. As majority of the data were not normally distributed (table 3.1), nonparametric inferential statistics were carried out to compare and arrive at the objectives. To compare the data from the two ears Mann Witney U was performed at each frequency and pressure condition. There was no significant difference ($p > 0.05$) between the findings of the two ears hence the data for the two ears were combined. The Friedman test was employed to compare wideband absorbance values obtained at both peak pressure and ambient pressure across all tested frequencies among the seven different body positions. In addition, the Friedman test was also used to evaluate differences in resonant frequency measured at peak pressure across the seven body positions. This non-parametric statistical test was selected as the study involved repeated measurements obtained from the same participants under multiple body position conditions. Further Wilcoxon Signed rank test was used for pairwise comparison to establish whether or not there exists any significant difference.

Table 3.1 *Shapiro- Wilk test statistical results for normality obtained for WBA across different body positions under Ambient Pressure.*

Frequencies		257.33	297.3	408.48	500	629.96	793.7	1000	1259.92	1587.4	2000	2519.84	3174.8	4000	5039.68	6349.6	8000
Neck Extension	Statistics	0.854	0.875	0.849	0.877	0.906	0.931	0.950	0.981	0.970	0.980	0.968	0.972	0.973	0.851	0.974	0.977
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.000	0.000	0.000	0.000	0.000	0.002	0.016	0.494*	0.140*	0.422*	0.118*	0.181*	0.194*	0.000	0.000	0.000
Supine	Statistics	0.751	0.738	0.805	0.956	0.955	0.956	0.967	0.982	0.9780.344	0.969	0.948	0.956	0.973	0.832	0.935	0.966
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.000	0.000	0.000	0.030	0.026	0.030	0.099*	0.526*	0.344*	0.135*	0.012	0.029	0.024	0.003	0.072*	0.093*
Neck Flexion	Statistics	0.831	0.928	0.933	0.948	0.938	0.940	0.970	0.986	0.974	0.970	0.957	0.961	0.954	0.833	0.900	0.979
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.000	0.002	0.003	0.012	0.004	0.005	0.147*	0.728*	0.237*	0.151*	0.035	0.055*	0.114*	0.000	0.000	0.370*
Seated	Statistics	0.919	0.882	0.889	0.840	0.871	0.928	0.960	0.981	0.974	0.960	0.955	0.960	0.968	0.934	0.964	0.950
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.001	0.000	0.000	0.000	0.000	0.002	0.047	0.459*	0.223*	0.049	0.027	0.045	0.205*	0.000	0.000	0.016
Prone	Statistics	0.673	0.671	0.803	0.932	0.970	0.980	0.961	0.986	0.981	0.978	0.956	0.966	0.973	0.848	0.987	0.964
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.000	0.000	0.000	0.002	0.140*	0.425*	0.053*	0.732*	0.412*	0.335*	0.030	0.093*	0.090*	0.000	0.326*	0.072*
RLR	Statistics	0.797	0.786	0.867	0.977	0.957	0.977	0.973	0.982	0.971	0.946	0.971	0.968	0.966	0.832	0.914	0.979
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	p value	0.000	0.000	0.000	0.032	0.035	0.329*	0.210*	0.529*	0.171*	0.011	0.161*	0.112*	0.202*	0.238*	0.093	0.406
LLR	Statistics	0.838	0.816	0.858	0.912	0.925	0.970	0.964	0.980	0.971	0.962	0.942	0.954	0.973	0.844	0.905	0.953
	Df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.000	0.000	0.001	0.148*	0.073*	0.428*	0.161*	0.058*	0.007	0.025	0.000	0.003	0.370*	0.022

*Note: * and shaded values represents normal distribution (p>0.05). RLR stands for Right Lateral Recumbent and LLR stands for Left Lateral recumbent body positions.*

Table 3.2 *Shapiro- Wilk test statistical results for normality obtained for WBA across different body positions under Peak Pressure.*

Frequencies		**257.33**	**297.3**	**408.48**	**500**	**629.96**	**793.7**	**1000**	**1259.92**	**1587.4**	**2000**	**2519.84**	**3174.8**	**4000**	**5039.68**	**6349.6**	**8000**
Neck Extension	Statistics	0.939	0.949	0.950	0.965	0.961	0.946	0.962	0.987	0.972	0.979	0.965	0.968	0.968	0.852	0.973	0.976
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.005	0.014	0.015	0.086*	0.050	0.010	0.058*	0.757*	0.181*	0.386*	0.081*	0.126*	0.121*	0.000	0.208*	0.280*
Supine	Statistics	0.860	0.895	0.912	0.931	0.956	0.954	0.942	0.980	0.965	0.970	0.946	0.973	0.973	0.831	0.939	0.964
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.000	0.002	0.029	0.025	0.007	0.414*	0.086*	0.140*	0.010	0.045	0.195*	0.000	0.005	0.072*
Neck Flexion	Statistics	0.778	0.864	0.887	0.916	0.947	0.942	0.981	0.985	0.982	0.970	0.968	0.952	0.952	0.830	0.904	0.974
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.000	0.001	0.011	0.007	0.459	0.685*	0.517*	0.154*	0.114*	0.134*	0.020	0.000	0.000	0.232*
Seated	Statistics	0.894	0.858	0.858	0.925	0.952	0.958	0.947	0.974	0.975	0.962	0.964	0.964	0.964	0.926	0.968	0.948
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.000	0.001	0.019	0.036	0.011	0.229*	0.253*	0.060*	0.078*	0.061*	0.073*	0.001	0.112*	0.012
Prone	Statistics	0.966	0.967	0.975	0.982	0.984	0.973	0.947	0.991	0.985	0.976	0.970	0.959	0.959	0.842	0.988	0.962
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.095*	0.101*	0.259*	0.508*	0.623*	0.193*	0.011	0.928*	0.667*	0.290*	0.140*	0.147*	0.000	0.000	0.832*	0.056*
RLR	Statistics	0.914	0.907	0.943	0.963	0.969	0.949	0.966	0.968	0.970	0.957	0.975	0.956	0.956	0.830	0.906	0.979
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.007	0.069*	0.128*	0.014	0.088*	0.117*	0.143*	0.035	0.253*	0.221*	0.044	0.000	0.000	0.394*
LLR	Statistics	0.878	0.874	0.943	0.926	0.951	0.970	0.962	0.978	0.968	0.957	0.943	0.959	0.959	0.843	0.901	0.950
	df	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	P value	0.000	0.000	0.007	0.001	0.018	0.139	0.061*	0.339*	0.120*	0.034	0.008	0.16	0.029	0.000	0.000	0.016

*Note: * and shaded values represents normal distribution ($p>0.05$). RLR stands for Right Lateral Recumbent and LLR stands for Left Lateral recumbent body positions.*

Chapter 4

RESULTS

The aim of this study is to compare the findings of WBA of seven different body positions across 16 frequencies in two different pressure conditions. To fulfil the objectives of the present study, the data were analysed quantitatively and are presented under the following headings:

1. Comparison of absorbance patterns of different body positions at each frequency under tympanometric peak pressure (TPP) and ambient pressure (AP) conditions.

2. Comparison of absorbance between Ambient Pressure and Tympanometric Peak Pressure across frequencies at each body position.

3. Comparison of middle ear resonant frequency across different body positions at Tympanometric Peak Pressure.

Shapiro Wilk test was carried out to check whether the data is normally distributed or not. The test revealed that the most of the data falls under non normal distribution.

Descriptive analysis had been carried out to calculate the mean, median, standard deviation and IQR values of the wideband absorbance (WBA) at each frequency across each body positions at both ambient pressure and peak pressure conditions are presented in Tables 4.1 and 4.2 respectively.

Table 4.1 *Mean, SD, Median and IQR of the WBA obtained at ambient pressure conditions across seven body positions.*

Frequencies		257.33	297.3	408.48	500	629.96	793.7	1000	1259.92	1587.4	2000	2519.84	3174.8	4000	5039.68	6349.6	8000
Neck Extension	Mean	0.164	0.195	0.272	0.336	0.434	0.547	0.633	0.655	0.539	0.474	0.588	0.615	0.608	0.648	0.535	0.457
	SD	0.075	0.105	0.138	0.159	0.19	0.19	0.168	0.139	0.188	0.239	0.201	0.176	0.148	0.178	0.134	0.137
	Median	0.149	0.1590	0.231	0.292	0.394	0.498	0.624	0.615	0.514	0.470	0.591	0.626	0.630	0.687	0.537	0.459
	IQR	0.1	0.11	0.18	0.20	0.23	0.31	0.30	0.17	0.25	0.35	0.31	0.26	0.25	0.13	0.17	0.24
Supine	Mean	0.181	0.208	0.285	0.365	0.444	0.565	0.64	0.615	0.533	0.489	0.608	0.625	0.611	0.659	0.541	0.4670
	SD	0.119	0.137	0.161	0.197	0.181	0.197	0.164	0.128	0.194	0.27	0.23	0.197	0.159	0.163	0.138	0.137
	Median	0.153	0.176	0.255	0.549	0.412	0.549	0.667	0.622	0.520	0.474	0.623	0.642	0.625	0.670	0.543	0.435
	IQR	0.09	0.10	0.14	0.34	0.23	0.34	0.28	0.18	0.26	0.46	0.44	0.35	0.24	0.14	0.14	0.25
Neck Flexion	Mean	0.145	0.171	0.245	0.299	0.406	0.523	0.619	0.625	0.586	0.553	0.648	0.665	0.645	0.663	0.519	0.425
	SD	0.089	0.086	0.126	0.147	0.194	0.207	0.187	0.147	0.203	0.26	0.196	0.184	0.183	0.201	0.16	0.158
	Median	0.1235	0.1530	0.224	0.286	0.359	0.445	0.638	0.627	0.171	0.549	0.677	0.693	0.685	0.719	0.544	0.410
	IQR	0.09	0.10	0.15	0.21	0.30	0.32	0.28	0.21	0.09	0.41	0.24	0.26	0.25	0.17	0.16	0.25
Seated	Mean	0.136	0.172	0.24	0.298	0.394	0.525	0.632	0.636	0.581	0.521	0.619	0.63	0.602	0.66	0.535	0.451
	SD	0.069	0.092	0.116	0.149	0.169	0.18	0.177	0.147	0.202	0.289	0.231	0.182	0.156	0.125	0.117	0.14
	Median	0.122	0.1530	0.225	0.286	0.370	0.484	0.645	0.655	0.153	0.495	0.623	0.659	0.613	0.672	0.532	0.437
	IQR	0.08	0.16	0.14	0.16	0.18	0.23	0.29	0.24	0.09	0.52	0.35	0.26	0.18	0.13	0.10	0.24
Prone	Mean	0.162	0.196	0.262	0.318	0.415	0.544	0.634	0.626	0.56	0.525	0.617	0.636	0.633	0.669	0.524	0.437
	SD	0.138	0.152	0.155	0.152	0.167	0.18	0.181	0.149	0.213	0.254	0.204	0.182	0.169	0.18	0.125	0.155
	Median	0.141	0.3080	0.235	0.308	0.404	0.535	0.684	0.614	0.565	0.534	0.665	0.632	0.657	0.702	0.525	0.408
	IQR	0.1	0.15	0.16	0.15	0.20	0.29	0.28	0.18	0.32	0.37	0.28	0.26	0.26	0.19	0.16	0.20
RLR	Mean	0.166	0.196	0.272	0.358	0.436	0.558	0.646	0.63	0.564	0.525	0.629	0.631	0.62	0.651	0.506	0.429
	SD	0.105	0.119	0.145	0.186	0.173	0.186	0.17	0.142	0.207	0.278	0.211	0.196	0.174	0.185	0.152	0.152
	Median	0.133	0.533	0.235	0.533	0.398	0.533	0.663	0.612	0.524	0.537	0.617	0.658	0.661	0.682	0.514	0.431
	IQR	0.10	0.30	0.19	0.30	0.23	0.30	0.26	0.17	0.30	0.50	0.36	0.31	0.26	0.17	0.15	0.25
LLR	Mean	0.158	0.187	0.253	0.325	0.436	0.564	0.648	0.64	0.583	0.557	0.66	0.672	0.65	0.664	0.498	0.399
	SD	0.095	0.114	0.139	0.159	0.172	0.184	0.153	0.136	0.196	0.27	0.22	0.186	0.167	0.187	0.151	0.173
	Median	0.1250	0.288	0.220	0.288	0.408	0.545	0.679	0.643	0.578	0.566	0.699	0.710	0.665	0.678	0.518	0.369
	IQR	0.12	0.18	0.17	0.18	0.16	0.28	0.25	0.17	0.26	0.44	0.37	0.27	0.23	0.17	0.14	0.24

Note: RLR stands for Right lateral recumbent and LLR stands for Left lateral recumbent body positions

Table 4.2 *Mean, SD, Median and IQR of the WBA obtained at Tympanometric Peak Pressure conditions across seven body positions.*

Frequencies		257.33	297.3	408.48	500	629.96	793.7	1000	1259.92	1587.4	2000	2519.84	3174.8	4000	5039.68	6349.6	8000
Neck Extension	Mean	0.183	0.213	0.301	0.378	0.497	0.62	0.68	0.629	0.547	0.465	0.573	0.608	0.603	0.647	0.534	0.457
	SD	0.073	0.094	0.127	0.152	0.188	0.189	0.142	0.133	0.189	0.238	0.209	0.178	0.15	0.177	0.134	0.137
	Median	0.171	0.206	0.292	0.353	0.443	0.61	0.703	0.703	0.514	0.447	0.588	0.626	0.630	0.689	0.537	0.456
	IQR	0.09	0.12	0.18	0.24	0.29	0.33	0.26	0.17	0.25	0.34	0.31	0.26	0.25	0.13	0.17	0.23
Supine	Mean	0.195	0.225	0.314	0.384	0.503	0.634	0.629	0.627	0.542	0.481	0.59	0.615	0.605	0.657	0.541	0.465
	SD	0.101	0.107	0.136	0.16	0.179	0.176	0.125	0.121	0.188	0.268	0.235	0.197	0.155	0.161	0.137	0.166
	Median	0.169	0.204	0.294	0.369	0.48	0.659	0.698	0.629	0.513	0.475	0.595	0.642	0.629	0.671	0.545	0.431
	IQR	0.13	0.13	0.17	0.22	0.29	0.28	0.19	0.18	0.30	0.46	0.44	0.35	0.23	0.14	0.15	0.26
Neck Flexion	Mean	0.176	0.2099	0.299	0.369	0.5	0.638	0.698	0.646	0.571	0.528	0.628	0.651	0.638	0.659	0.517	0.424
	SD	0.095	0.101	0.137	0.159	0.183	0.173	0.137	0.135	0.213	0.263	0.199	0.187	0.184	0.201	0.16	0.156
	Median	0.133	0.176	0.268	0.3335	0.474	0.659	0.723	0.652	0.560	0.251	0.677	0.673	0.683	0.717	0.541	0.410
	IQR	0.1	0.12	0.17	0.2	0.3	0.33	0.19	0.18	0.31	0.39	0.24	0.27	0.24	0.15	0.16	0.24
Seated	Mean	0.18	0.212	0.212	0.368	0.492	0.621	0.689	0.647	0.561	0.494	0.596	0.611	0.595	0.657	0.535	0.452
	SD	0.865	0.102	0.102	0.149	0.172	0.176	0.148	0.141	0.203	0.28	0.236	0.182	0.156	0.126	0.116	0.141
	Median	0.161	0.186	0.186	0.349	0.470	0.622	0.716	0.671	0.543	0.463	0.641	0.633	0.610	0.665	0.530	0.427
	IQR	0.1	0.11	0.11	0.22	0.25	0.29	0.23	0.2	0.32	0.49	0.27	0.26	0.17	0.12	0.10	0.24
Prone	Mean	0.179	0.214	0.301	0.381	0.512	0.651	0.7	0.638	0.55	0.507	0.598	0.625	0.627	0.667	0.522	0.436
	SD	0.075	0.098	0.122	0.152	0.187	0.175	0.149	0.141	0.209	0.255	0.21	0.184	0.167	0.179	0.123	0.154
	Median	0.173	0.198	0.288	0.369	0.494	0.686	0.717	0.619	0.533	0.523	0.585	0.625	0.646	0.701	0.521	0.410
	IQR	0.1	0.13	0.19	0.23	0.27	0.29	0.2	0.21	0.25	0.37	0.38	0.25	0.22	0.19	0.15	0.20
RLR	Mean	0.178	0.212	0.296	0.377	0.506	0.642	0.702	0.646	0.564	0.512	0.614	0.625	0.617	0.648	0.505	0.428
	SD	0.082	0.096	0.127	0.149	0.176	0.173	0.132	0.139	0.207	0.269	0.21	0.194	0.169	0.184	0.151	0.15
	Median	0.155	0.178	0.28	0.357	0.504	0.668	0.716	0.626	0.525	0.483	0.617	0.641	0.659	0.681	0.512	0.433
	IQR	0.1	0.14	0.19	0.21	0.26	0.3	0.18	0.2	0.29	0.49	0.36	0.32	0.26	0.17	0.14	0.24
LLR	Mean	0.18	0.215	0.302	0.385	0.508	0.643	0.697	0.644	0.573	0.547	0.652	0.672	0.641	0.663	0.498	0.399
	SD	0.096	0.11	0.138	0.166	0.18	0.163	0.121	0.128	0.196	0.278	0.22	0.186	0.168	0.188	0.15	0.172
	Median	0.167	0.186	0.273	0.341	0.469	0.639	0.703	0.646	0.589	0.566	0.699	0.714	0.648	0.680	0.511	0.369
	IQR	0.1	0.12	0.2	0.27	0.25	0.23	0.16	0.16	0.31	0.47	0.37	0.26	0.24	0.18	0.15	0.24

Note: RLR stands for Right lateral recumbent and LLR stands for Left lateral recumbent body positions

Across all body positions under both ambient pressure and peak pressure conditions, absorbance values demonstrated a similar frequency-dependent pattern. Lower absorbance values were observed at low frequencies, followed by a gradual increase towards mid-frequency regions, having two to three peaks absorbance values at around 1000Hz, 2500 Hz and around 5000Hz in all body position and both at Tympanometric Peak Pressure and Ambient Pressure conditions. Subsequently, absorbance values demonstrated a declining trend at higher frequencies. Under peak pressure condition, absorbance values were generally higher compared to ambient pressure condition across low- and mid-frequency regions for most body positions. However maximum mean absorbance observed was different for different body position both for Tympanometric Peak Pressure and Ambient Pressure (Figure 4.1 to 4.2). Overall, supine, prone, and lateral recumbent positions demonstrated comparatively higher absorbance values across several mid frequencies when compared to seated and neck flexion positions under both pressure conditions.

Among all body positions, the highest absorbance value was observed in the right lateral recumbent position under Tympanometric Peak Pressure condition at 1000 Hz. Similar trends were also observed in prone, neck flexion, and left lateral recumbent positions as depicted in figure 4.1 and 4.2.

Fig 4.1. Mean WBA at ambient pressure across frequencies obtained between 7 different body positions

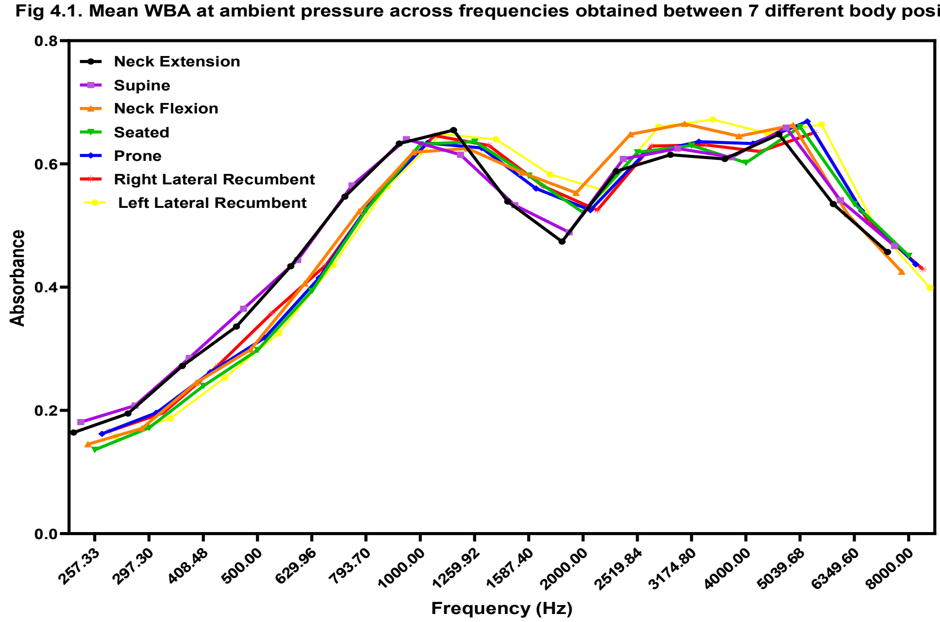
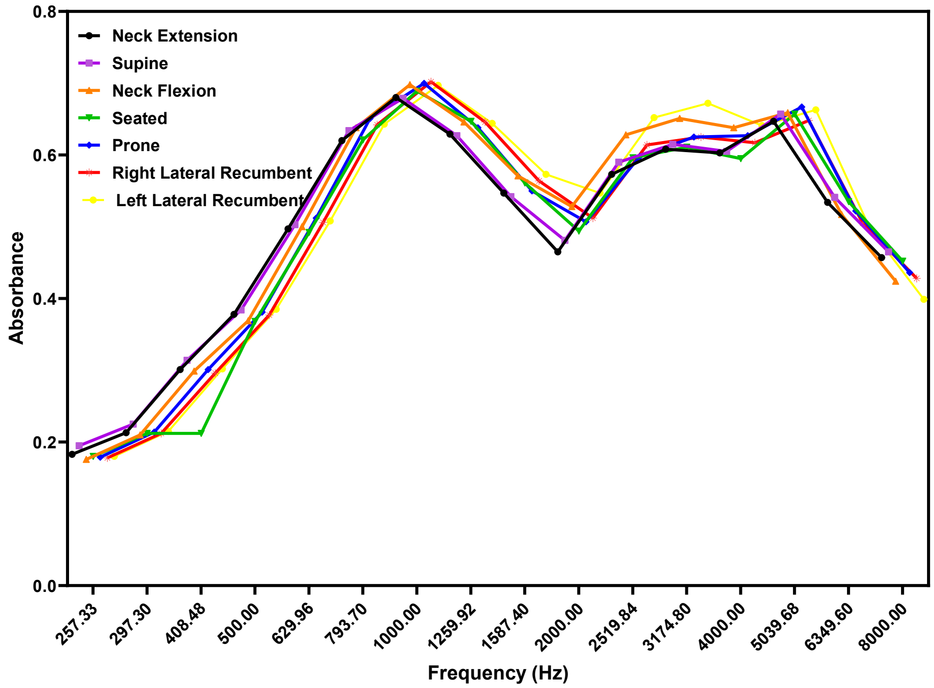


Fig 4.2. Mean WBA at peak pressure across frequencies obtained between 7 different body positions



The descriptive analysis has also demonstrated that there is difference in absorbance values across the frequencies. However, no inferential statistics was carried out to establish the difference in absorbance between any two frequencies because such differences is well established in the literature and also evident in the figure 4.1 and 4.2 and hence it is not taken as an objective in this study.

4.1 Comparison of Absorbance Across Body Positions at Each Frequency Under Ambient Pressure and Peak Pressure Conditions

As the test of normality report revealed that the data is not normally distributed. Hence, to compares absorbance patterns across the seven body positions at each frequency under ambient pressure (AP) and Tympanometric Peak Pressure (TPP) conditions, initially Friedman test was performed. The analysis revealed statistically significant effect of body positions at selected frequencies under both pressure conditions. Frequencies that demonstrated significant differences (< 0.05) under ambient pressure condition included 257.33 Hz, 408.48 Hz, 500 Hz, 629.96 Hz, 2000 Hz, 3174.8 Hz, 4000 Hz, 5039.68 Hz, and 8000 Hz. Under peak pressure condition, significant effect of body positions was observed at 408.48 Hz, 2519.84 Hz, 3174.8 Hz, 4000 Hz, and 8000 Hz. The details of the Friedman tests results are given in Table 4.3.

Table 4.3 *Friedman test results comparing absorbance across body positions under ambient pressure condition and Tympanometric Peak Pressure at different frequencies.*

Frequency	**Peak Pressure**					
	χ^2	**df**	**p value**	**χ^2**	**df**	**p value**
257.33	28.902	6	0.000*	7.727	6	0.259
297.3	7.801	6	0.253	2.205	6	0.900
408.48	13.559	6	0.035*	90.258	6	0.000*
500	172.826	6	0.000*	2.695	6	0.846
629.96	13.964	6	0.030*	6.884	6	0.332
793.7	6.853	6	0.335	3.244	6	0.778
1000	4.856	6	0.562	2.760	6	0.838
1259.92	5.440	6	0.489	4.061	6	0.668
1587.4	10.064	6	0.122	6.661	6	0.353
2000	13.962	6	0.030*	9.520	6	0.146
2519.84	10.904	6	0.091	14.123	6	0.028*
3174.8	19.562	6	0.003*	16.679	6	0.011*
4000	18.201	6	0.006*	21.641	6	0.003*
5039.68	9.370	6	0.154	7.545	6	0.273
6349.6	4.865	6	0.561	4.640	6	0.591

8000	22.239	6	0.001*	19.406	6	0.004*

*Note: * shaded area represents significant effect of body positions.*

Post hoc pairwise comparisons were subsequently carried out using Wilcoxon signed-rank tests for frequencies that demonstrated significant effect of body positions in Friedman test results. Bonferroni multiple correction was applied to control for multiple comparisons, and the adjusted significance level was set at $p < 0.0024$. Effect size for significant pairwise comparisons was calculated using the r value obtained from the formula $r = Z/\sqrt{N}$, where Z represents the Wilcoxon signed-rank test statistic and N represents the total number of observations. The magnitude of effect size was interpreted according to Cohen's (1988) classification criteria, where r values of 0.1–0.29 indicate small effect size, 0.30–0.49 indicate moderate effect size, and values ≥0.50 indicate large effect size. Significant pairwise differences were observed between selected body position combinations across specific frequencies are given in Table 4.4.

Table 4.4 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance between body positions under ambient pressure at 257.33 Hz with effect size.*

257.33 Hz at Ambient Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	Right Lateral Recumbent
Supine	NS					
Neck Flexion	NS	Sig (moderate, r=0.49)				
Seated	NS	Sig	NS			

		(moderate, r=0.49				
Prone	NS	NS	NS	NS		
Right Lateral Recumbent	NS	NS	NS	NS	NS	
Left Lateral Recumbent	NS	NS	NS	NS	NS	

Note: NS stands for no significant difference.

Under ambient pressure, at 257.33 Hz, Post hoc Wilcoxon signed-rank analysis demonstrated a significant difference between Neck Extension and Seated at 257.33 Hz , with a moderate effect size and for seated and supine positions with large effect size according to Cohen (1988). No other pairwise comparisons reached the Bonferroni-adjusted significance level as shown in Table 4.4.

Among the significant difference pairs, supine body positions have the higher value than both neck flexion and seated position.

At 408.48 Hz, significant difference was found only between Supine and seated body positions with supine position having higher value than the sitting position. Rest all pairs are not significant as depicted in table 4.5.

Table 4.5 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance between body positions under ambient pressure at 408.48 Hz with effect size.*

408.48 Hz at Ambient Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	Right Laeral Recumbent
Supine	NS					
Neck Flexion	NS	NS				
Seated	NS	Sig	NS			

		(Moderate, r=0.39)				
Prone	NS	NS	NS	NS		
Right Lateral Recumbent	NS	NS	NS	NS	NS	
Left Lateral Recumbent	NS	NS	NS	NS	NS	

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

At 500 Hz, significant difference was found between several pairs of body positions as shown in Table 4.6. Based on the descriptive analysis (Table 4.1), the highest absorbance values were observed in the supine position, followed by the right lateral recumbent, neck extension, seated, prone, and left lateral recumbent positions, whereas the least absorbance values were observed in the neck flexion position at this particular frequency.

Table 4.6 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance between body positions under ambient pressure at 500 Hz with effect size.*

500 Hz at Ambient Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	Right Lateral Recumbent
Supine	Sig (Large, r=0.83)					
Neck Flexion	NS	Sig (large, r=0.85)				
Seated	NS	Sig (Large, r=0.82)	NS			
Prone	NS	Sig	NS	NS		

		(Large, r=0.86)				
Right Lateral Recumbent	Sig (Large, r=0.78)	NS	Sig (Large, r=0.87)	Sig (Large, r=0.84)	Sig (Large, r=0.82)	
Left Lateral Recumebent	NS	Sig (Large, r=0.82)	NS	NS	Sig (Moderate, r= 0.41)	Sig (Large, r=0.81)

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

At 3174.8 Hz significant difference was found between Neck extension and left lateral recumbent body positions only and between these two body positions left lateral recumbent had higher absorbance value.

Table 4.7 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance between body positions under ambient pressure at 3174.8 Hz with effect size.*

3174.8Hz at Ambient Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	RLR
Supine	NS					
Neck Flexion	NS	NS				
Seated	NS	NS	NS			
Prone	NS	NS	NS	NS		
RLR	NS	NS	NS	NS	NS	
LLR	Sig (Moderate, r=0.40)	NS	NS	NS	NS	NS

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

At 8000 Hz, also significant difference found between Supine and left lateral recumbent body position only. Supine body position had higher absorbance value than lateral recumbent.

Table 4.8 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance between body positions under ambient pressure at 8000 Hz with effect size.*

8000 Hz at Ambient Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	RLR
Supine	NS					
Neck Flexion	NS	NS				
Seated	NS	NS	NS			
Prone	NS	NS	NS	NS		
RLR	NS	NS	NS	NS	NS	
LLR	NS	Sig (Moderate, r=0.42)	NS	NS	NS	NS

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

At frequencies 629.96, 2000 Hz, 4000 Hz and 5039.68 although the Friedman test revealed significant difference, but in post hoc analysis no significant difference found between any of the body positions analysed based on Bonferroni's correction.

Under peak pressure condition, as mentioned above significant differences across body positions were observed at 408.48 Hz, 2519.84 Hz, 3174.8 Hz, 4000 Hz, and 8000 Hz.

At 408.48 Hz, significant differences were observed between neck extension and seated, supine and seated, neck flexion and seated, seated and prone, seated and right lateral recumbent, and seated and left lateral recumbent body positions, as shown in Table 4.9. Based on the descriptive analysis (Table 4.1), the highest absorbance values were observed in the supine position, followed by right lateral recumbent, left lateral recumbent, prone, neck flexion, and neck extension positions, whereas seated position demonstrated the least absorbance values among the compared body positions.

Table 4.9 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance across body positions under Tympanometric Peak Pressure at 408.48 Hz with effect size.*

408.48Hz at Peak Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	RLR
Supine	NS					
Neck Flexion	NS	NS				
Seated	Sig (large, R=0.76)	Sig (Large, r=0.86)	Sig (Large, r=0.82)			
Prone	NS	NS	NS	Sig (Large, r= 0.79)		
Right Lateral Recumbent	NS	NS	NS	Sig (Large, r=0.79)	NS	
Left Lateral Recumbent	NS	NS	NS	Sig (Large, r=0.73)	NS	NS

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

At 2519.84 Hz, there is a significant difference only between neck extension and left lateral recumbent as shown in Table 4.10, out of which left lateral recumbent has more absorbance as compared to neck extension body position (Table 4.2).

Table 4.10 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in absorbance across body positions under Tympanometric Peak Pressure at 2519.84 Hz with effect size.*

2519.84 Hz at Peak Pressure	Neck Extension	Supine	Neck Flexion	Seated	Prone	RLR
Supine	NS					
Neck Flexion	NS	NS				
Seated	NS	NS	NS			
Prone	NS	NS	NS	NS		
RLR	NS	NS	NS	NS	NS	
LLR	Sig (Moderate, r=0.39)	NS	NS	NS	NS	NS

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

4.2 Comparison of Absorbance Between Ambient Pressure and Peak Pressure Conditions at Each Frequency Across Body Positions

Figures 4.11 given below give the birds eye view of how the mean absorbance values are varying between peak pressure and ambient pressure condition at each body position. However, as the nonparametric tests is used for the inferential statistics which considered the median values are given in Table 4.1 and 4.2.

Wilcoxon signed-rank test was performed to compare absorbance between ambient pressure (AP) and Tympanometric Peak Pressure (TPP) conditions at each frequency within individual body positions. The analysis demonstrated that the influence of tympanometric pressure condition on absorbance varied across body positions and frequencies as depicted in Table 4.11.

Table 4.11 *Difference between AP and* Tympanometric Peak Pressure *at several body positions across 16 frequencies.*

Frequencies	Neck Extension		Supine		Neck Flexion		Seated		Prone		right Lateral recumbent		Left Lateral recumbent	
	Z value	p value	Z value	p value	Z value	p value	Z value	p value	Z value	p value	Z value	p value	Z value	p value
257.33	-3.376[b]	0.001*	-3.303[b]	0.001*	-4.865[b]	0.000*	-5.848[b]	0.000*	-4.208[b]	0.000*	-4.444[b]	0.000*	-3.189[b]	0.001*
297.3	-2.965[b]	0.003*	-3.565[b]	0.000*	-4.927[b]	0.000*	-5.714[b]	0.000*	-3.840[b]	0.000*	-4.059[b]	0.000*	-3.292[b]	0.001*
408.48	-2.946[b]	0.003*	-3.577[b]	0.000*	-5.359[b]	0.000*	-4.007[c]	0.000*	-4.471[b]	0.000*	-4.038[b]	0.000*	-4.101[b]	0.000*
500	-3.685[b]	0.000*	-5.959[c]	0.000*	-5.380[b]	0.000*	-5.642[b]	0.000*	-5.317[b]	0.000*	-6.316[c]	0.000*	-4.199[b]	0.000*
629.96	-4.432[b]	0.000*	-4.636[b]	0.000*	-5.301[b]	0.000*	-5.879[b]	0.000*	-5.819[b]	0.000*	-5.213[b]	0.000*	-4.476[b]	0.000*
793.7	-4.293[b]	0.000*	-4.557[b]	0.000*	-5.233[b]	0.000*	-5.815[b]	0.000*	-5.655[b]	0.000*	-5.190[b]	0.000*	-4.506[b]	0.000*
1000	-3.282[b]	0.001*	-3.919[b]	0.000*	-4.082[b]	0.000*	-4.272[b]	0.000*	-4.510[b]	0.000*	-3.961[b]	0.000*	-3.368[b]	0.001*
1259.92	-.075[b]	0.940	-1.058[b]	0.290	-.984[b]	0.325	-1.032[b]	0.302	-.830[b]	0.407	-1.328[b]	0.184	-.085[b]	0.932
1587.4	-.056[b]	0.955	-.774[b]	0.439	-1.972[c]	0.049*	-2.431[c]	0.015*	-2.538[c]	0.011*	-2.724[c]	0.006*	-2.028[c]	0.043*
2000	-1.264[c]	0.206	-1.440[c]	0.150	-3.782[c]	0.000*	-3.278[c]	0.001*	-3.357[c]	0.001*	-2.805[c]	0.005*	-2.066[c]	0.039*
2519.84	-2.936[c]	0.003*	-3.557[c]	0.000*	-3.768[c]	0.000*	-4.228[c]	0.000*	-3.781[c]	0.000*	-3.508[c]	0.000*	-1.659[c]	0.097
3174.8	-2.176[c]	0.030*	-3.580[c]	0.000*	-3.915[c]	0.000*	-3.963[c]	0.000*	-3.098[c]	0.002*	-1.933[c]	0.053	-2.407[c]	0.016*
4000	-1.749[c]	0.080	-2.820[c]	0.005*	-3.476[c]	0.001*	-3.928[c]	0.000*	-2.827[c]	0.005*	-2.157[c]	0.031*	-3.464[c]	0.001*
5039.68	-.682[c]	0.495	-1.828[c]	0.068	-2.409[c]	0.016*	-1.666[c]	0.096	-2.481[c]	0.013*	-2.377[c]	0.017	-1.678[c]	0.093
6349.6	-.849[c]	0.396	-1.071[c]	0.284	-2.136[c]	0.033*	-.742[c]	0.458	-1.304[c]	0.192	-1.045[c]	0.296	-.420[c]	0.674
8000	-.358[b]	0.720	-1.654[c]	0.098	-.073[c]	0.942	-.571[b]	0.568	-.700[c]	0.484	-.658[c]	0.511	-.232[b]	0.817

*Note: * and shaded area illustrates the significant difference between the absorbance value at Ambient Pressure and Tympanometric Peak Pressure.*

Comparison between ambient pressure (AP) and Tympanometric Peak Pressure (TPP) conditions demonstrated statistically significant differences predominantly within the low-frequency region across all body positions, as illustrated in Figures 4.3 to 4.9. Significant AP–Tympanometric Peak Pressure differences were consistently observed from 257.33 Hz to 1000 Hz in all body positions, indicating greater pressure-related influence on absorbance within low frequencies. In addition, several body positions also demonstrated significant differences at selected mid frequencies, particularly at 1587.4 Hz, 2000 Hz, 2519.84 Hz, and 3174.8 Hz. Among all body positions, neck flexion demonstrated the greatest pressure-related influence, with significant Ambient Pressure–Peak Pressure differences extending from low frequencies up to higher mid frequencies including 4000 Hz, 5039.68 Hz, and 6349.6 Hz. Seated and prone body positions also demonstrated significant Ambient Pressure– Tympanometric Peak Pressure differences across multiple low- and mid-frequency regions, whereas neck extension and left lateral recumbent positions demonstrated comparatively fewer significant differences beyond 1000 Hz. No consistent significant Ambient Pressure– Tympanometric Peak Pressure differences were observed at higher frequencies across most body positions, suggesting relatively reduced pressure-related influence within high-frequency regions.

Fig 4.3 WBA at ambient and peak pressure across frequencies in Neck Extension Body Position

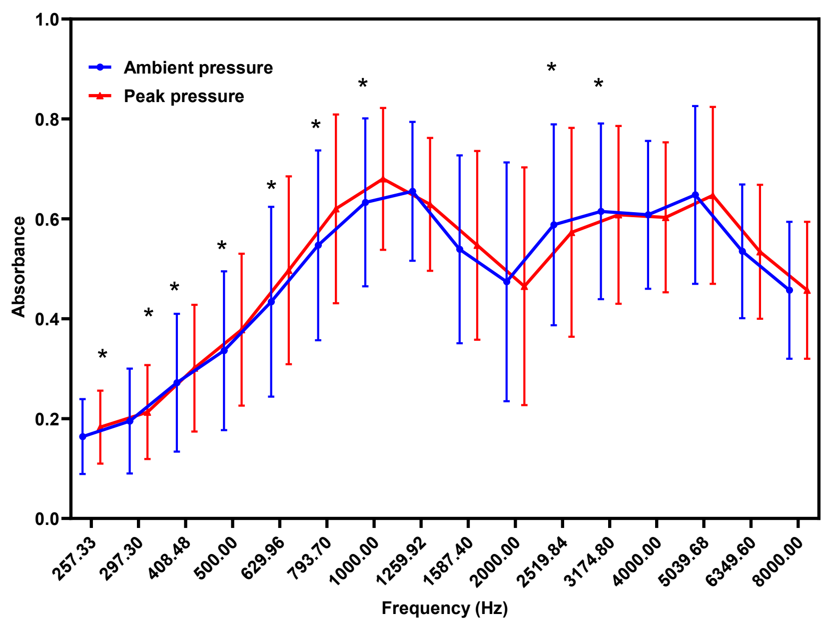


Fig 4.4 WBA at peak and ambient pressure across frequencies in Supine Body position.

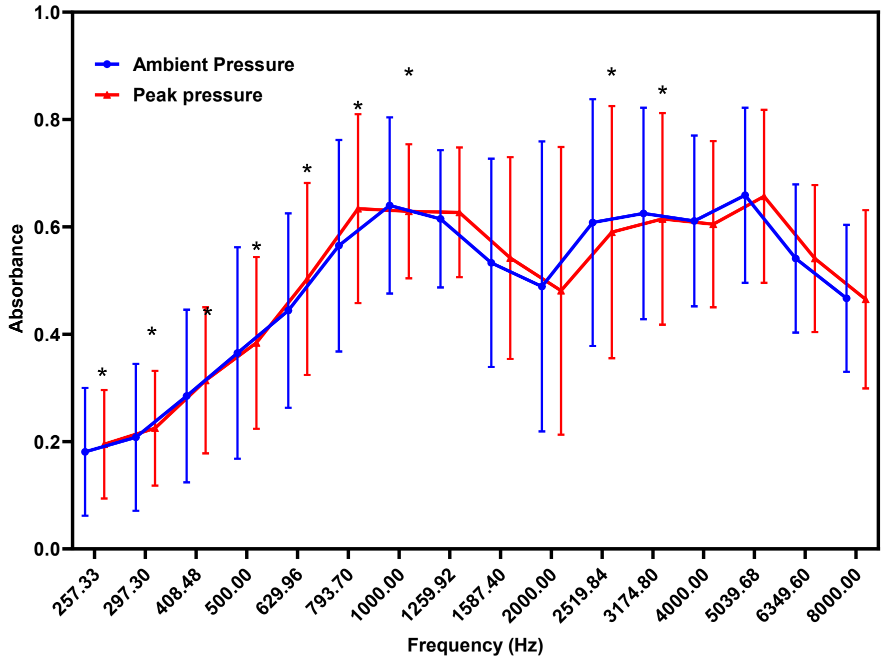


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Fig 4.5 WBA at ambient and peak pressure across frequencies in Neck Flexion Body Position

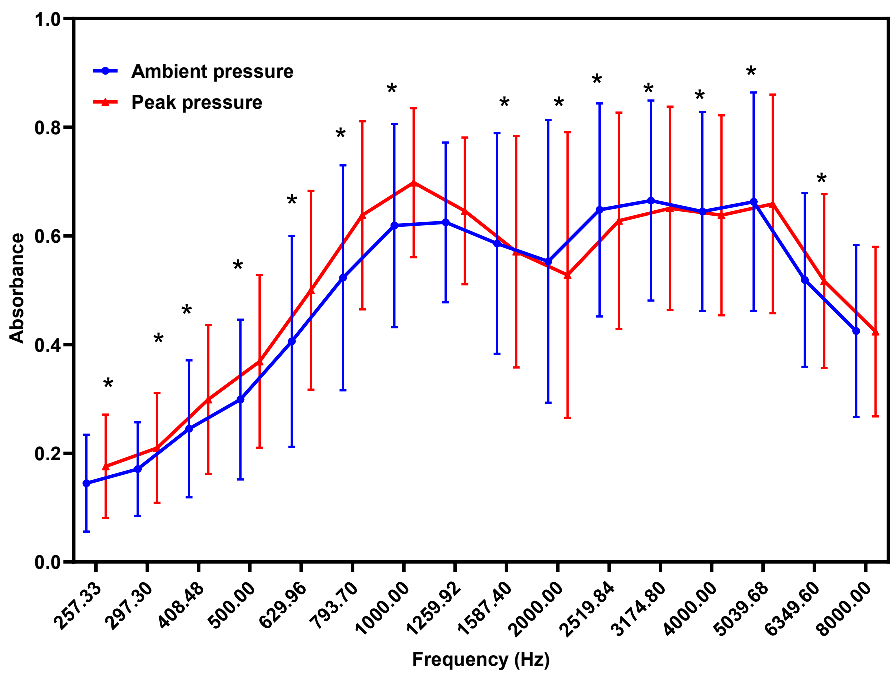


Fig 4.6 WBA at peak and ambient pressure across frequencies in Seated Body position.

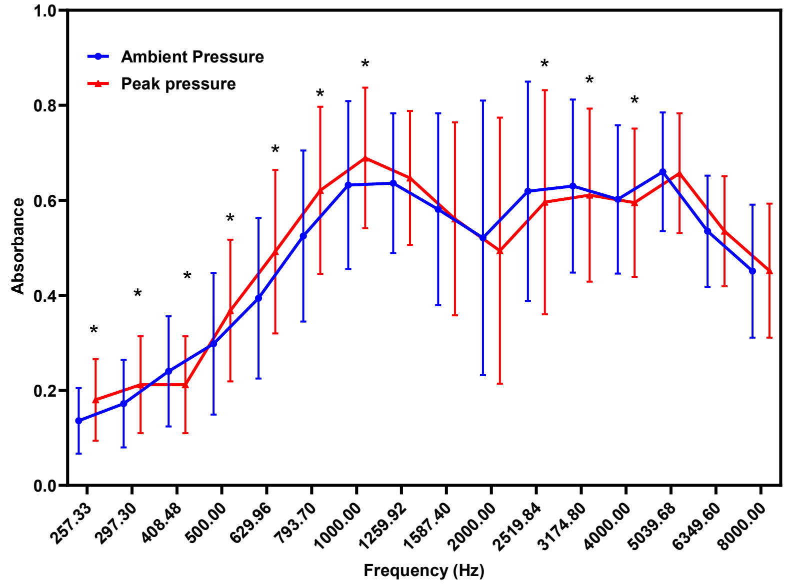


Fig 4.7 WBA at peak and ambient pressure across frequencies in Prone Body Position

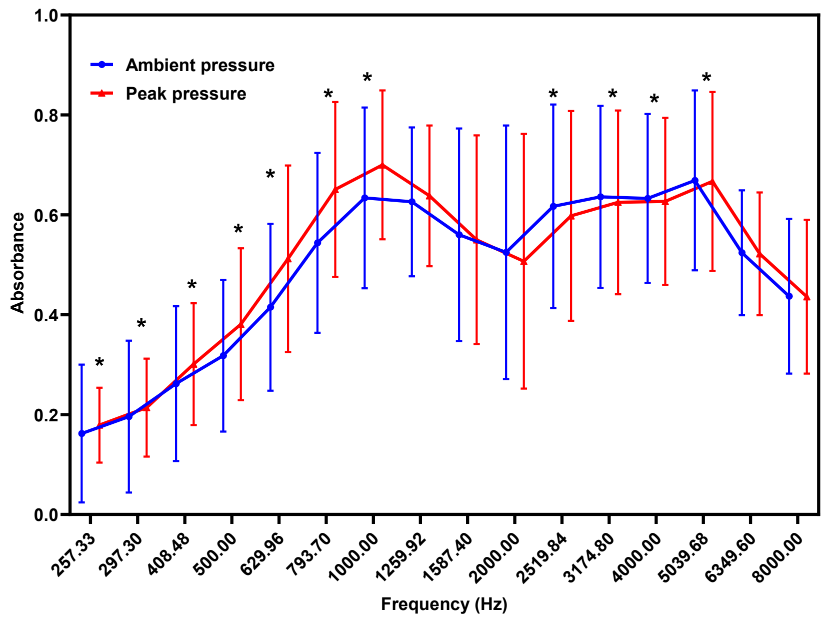


Fig 4.8 WBA at peak and ambient pressure across frequencies in Right Recumbent Body Position

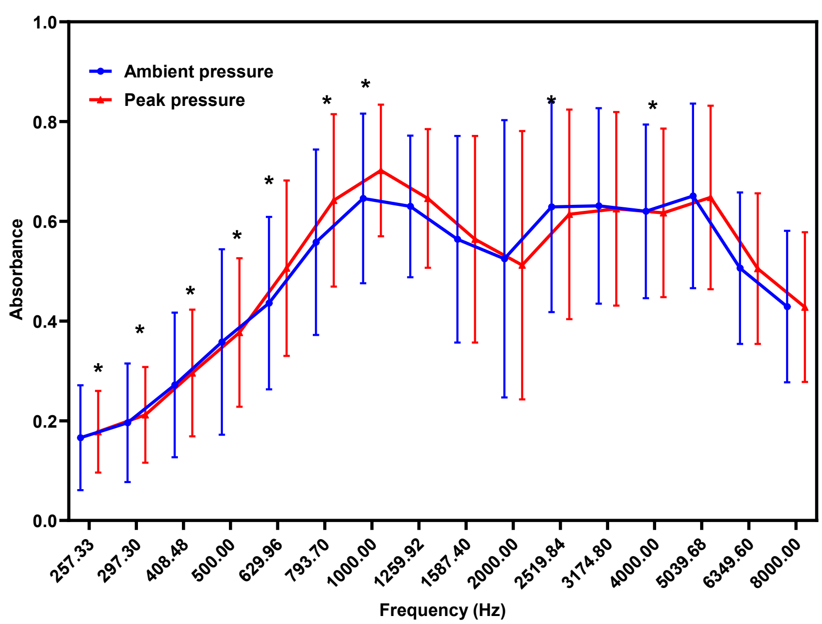
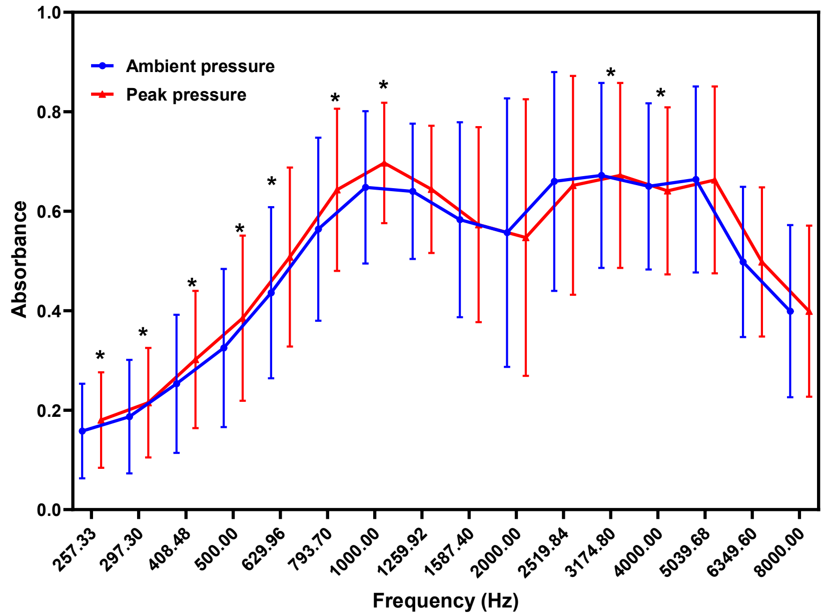


Fig 4.9 WBA at peak and ambient pressure across frequencies in Left Lateral Recumbent body position



Overall, body positions Seated and Prone body positions reflected greater pressure-related influence on absorbance measurements across frequencies, whereas Neck extension and left lateral recumbent demonstrated comparatively fewer pressure-related differences, particularly at mid- and high-frequency regions.

4.3 Comparison of Middle Ear Resonant Frequency Across Body Positions at Tympanometric Peak Pressure.

The mean, standard deviation, median and IQR of middle ear resonant frequency across the seven body positions is presented in Table 4.12. Among the seven body positions, the resonant frequency varied across body positions, with the highest mean values observed in the seated position (M = 862.73) and neck flexion (M = 859.43), followed closely by neck extension (M = 858.53). The supine position showed a slightly lower mean resonant frequency (M = 827.25), while the lateral recumbent positions demonstrated further reductions, with left lateral recumbent at 812.61 and right lateral recumbent at 808.00. The prone position exhibited the lowest mean resonant frequency (M = 796.91).

Overall, upright and neck-adjusted postures (seated, neck flexion, and neck extension) were associated with higher resonant frequencies, whereas recumbent and prone positions tended to show lower values. The standard deviation values across body positions remained relatively small, suggesting minimal variability in resonant frequency measurements among participants as shown in Fig 4.10.

Table 4.12 *Mean, standard deviation, median and Interquartile range of resonant frequency across seven body positions*

Body Positions	Mean	SD	Median	IQR
Neck Extension	858.53	21.38	809.00	218.00
Supine	827.25	20.53	806.50	237.50
Neck Flexion	859.43	22.61	836.50	194.50
Seated	862.73	21.86	832.00	216.25
Prone	796.91	19.06	783.00	190.75
Right Lateral Recumbent	808.00	20.36	777.00	223.75
Left Lateral Recumbent	812.61	19.89	790.00	197.25

The Shapiro Wilk test has been carried out to check for the normality of the data (Table 4.13). The results depict that most of the data were not normally distributed ($p>0.05$).

Table 4.13 *Shapiro Wilk Test of Normality for resonant frequency across 7 body positions.*

Body Positions	Statistic	df	Sig.
Neck Extension	0.937	60	0.004
Supine	0.953	60	0.021
Neck Flexion	0.961	60	0.056
Seated	0.944	60	0.009
Prone	0.910	60	0.000
Right Lateral Recumbent	0.950	60	0.015
Left Lateral Recumbent	0.929	60	0.002

Thus, to compare and see the influence of different body position on middle ear's resonant frequency at tympanometric peak pressure, Friedman test was applied. The test revealed that there is a significant effect of body positions (χ^2 (6) = 37.645, p < 0.001) in the resonant frequency across the seven body positions.

Further post hoc analysis was performed using Wilcoxon signed-rank test with Bonferroni correction (adjusted p < 0.0024). Significant differences in resonant frequency were observed between Neck Extension and Prone, Neck Flexion and Prone, Seated and Prone, Seated and Right Lateral Recumbent, and Seated and Left Lateral Recumbent. No statistically significant differences were observed between the remaining body position comparisons following Bonferroni correction. Effect size (r) was calculated using the formula r = Z/√N, where N = 60. Interpretation was based on Cohen's (1988) classification criteria: 0.1–0.29 = small, 0.30–0.49 = moderate, and ≥0.50 = large effect size.

Table 4.14 *Post hoc Wilcoxon signed-rank analysis showing significant pairwise differences in resonant frequency across different body positions.*

Body Positions	Neck Extension	Supine	Neck Flexion	Seated	Prone	RLR
Neck Extension						
Supine	NS					
Neck Flexion	NS	NS				
Seated	NS	NS	NS			
Prone	Sig (Moderate, r=0.41)	NS	Sig (Large, r=0.55)	Sig (Large, r=0.51)		
RLR	NS	NS	NS	Sig (Moderate, r=0.39)	NS	

LLR	NS	NS	Sig (Moderate, r=0.43)	Sig (Moderate, r=0.45)	NS	NS

Note: Sig stands Significant following Bonferroni correction (adjusted p < 0.0024); and NS stands for no significant difference.

Among the significant comparisons, the seated body position demonstrated a higher resonant frequency (Mean = 862.73) than both the neck extension position (Mean = 858.53) and the neck flexion position (Mean = 859.43). Neck extension also showed a higher resonant frequency (Mean = 858.53) compared to the left lateral recumbent position (Mean = 812.61). In the comparison between seated and prone positions, the seated posture exhibited a higher resonant frequency (Mean = 862.73) than the prone position (Mean = 796.91). Similarly, the seated position demonstrated higher resonant frequency than both the right lateral recumbent position (Mean = 808.00) and the left lateral recumbent position (Mean = 812.61). Overall, the seated posture consistently showed the highest resonant frequency across most of the significant pairwise comparisons. Effect size analysis for the significant post hoc Wilcoxon signed-rank comparisons demonstrated predominantly moderate to large effects across the compared body positions indicating substantial differences in resonant frequency between these body position combinations, suggesting a considerable influence of body position on resonant frequency measurements according to Cohen's (1988) classification criteria.

4.11 Test-Retest Reliability

Test–retest reliability was assessed using Spearman's rank correlation coefficient due to the non-normal distribution of the data. The findings demonstrated a strong positive correlation between the initial and repeated measurements, indicating good consistency and reliability of wideband absorbance measures across test sessions.

Chapter 5

DISCUSSION

The present study investigated the effect of seven different body positions on wideband absorbance across 16 frequencies under ambient pressure and tympanomeric peak pressure condition. It additionally examined how the resonant frequency varied across different body positions. The findings of this study provide important insight about the effect of change in body position on middle ear mechanics by measuring the energy transfer function of middle ear via wideband absorbance (WBA). It has a potential clinical implication for administration and interpretation of wideband acoustic immittance (WAI). The results are discussed below in reference to the existing literature. The result of the study has been discussed under the following headings:

1. General Pattern of WBA across frequencies.
2. Effect of Body Position on Wideband Absorbance.
3. Comparison of Absorbance Under Ambient Pressure and Tympanometric Peak Pressure.

Across all participants, a consistent pattern of absorbance value obtained irrespective of body position and pressure conditions. The pattern depicted low values at lower frequencies, a continuous increase towards mid frequencies and decline towards high frequencies. Peak absorbance was predominantly observed between 793.7 Hz to 5039.68 Hz which is in agreement with the well-established literature on the normative data of adults with normal functioning middle ear (Mazlan et al., 2015; Shahnaz et al., 2013). Similar findings have also been reported in the Indian population (Karuppannan and Barman, 2024). This pattern of max absorbance at the mid frequencies reflects the resonance properties of the middle ear system, where energy transfer is most efficient.

The similar frequency-dependent pattern observed across all seven body positions and under both pressure conditions indicates that WBA remains a reliable measure of middle ear function. These findings are clinically important because they support the use of WBA testing even when patients cannot be assessed in the standard sitting position, such as in paediatric populations or individuals with limited mobility.

Although the overall absorbance pattern remained stable, differences in WBA were observed at specific frequencies across body positions. These findings support the hypothesis that postural changes can influence middle ear sound transmission characteristics. One possible explanation for these changes is the alteration in intracranial pressure (ICP) and venous pressure associated with changes in posture. Previous physiological studies have shown that moving from an upright to a supine or head-down position causes redistribution of blood and cerebrospinal fluid, resulting in increased intracranial and inner ear fluid pressure(Holmlund et al., 2018) . Sagirov et al., 2023 has reported that recumbent and head-down positions increase venous congestion and intracranial pressure because of altered cerebrospinal fluid dynamics. Since the perilymphatic space communicates with cerebrospinal fluid through the cochlear aqueduct, these pressure changes can be transmitted to the inner ear.

Increased inner ear pressure may influence middle ear mechanics by altering the stiffness of the round window membrane and stapes-annular ligament system. Increased pressure in the peri lymphatic space pushes the stapes footplate out of the oval window and that the displacement of the incus by contraction of the stapedius muscle will depend on how much the stapes is pushed out of the oval window (Møller, 1983).

Similarly, Torrecilla and Avan, (2021), observed progressive shifts in tympanometric peak pressure with postural changes associated with increased intracranial pressure. The authors proposed that increased intracranial pressure alters the stiffness characteristics of the ossicular chain and annular ligament, thereby affecting sound energy transmission, particularly at low frequencies. The current findings are in agreement with these observations and suggest that posture-related pressure changes can subtly influence middle ear admittance characteristics.

5.2 Effect of Body Position on Wideband Absorbance

The Friedman test identified statistically significant differences in WBA across body positions at multiple frequencies. Under ambient pressure, significant differences were observed at 257.33 Hz, 408.48 Hz, 500 Hz, 629.96 Hz, 2000 Hz, 3174.8 Hz, 4000 Hz, 5039.68 Hz, and 8000 Hz. Under peak pressure, significant positional differences were confined to 408.48 Hz, 2519.84 Hz, 3174.8 Hz, 4000 Hz, and 8000 Hz. The greater number of significant frequencies under ambient pressure compared to peak pressure suggests that the influence of body position on WBA is more pronounced when middle ear static pressure is not compensated.

The most extensive pairwise differences were observed at 500 Hz under ambient pressure condition where various body position pairs demonstrated statistically significant differences following Bonferroni correction. The concentration of significant positional effects in the low-frequency range is consistent with known physiological mechanisms. Body position modulates intracranial pressure (ICP), middle ear venous filling, and eustachian tube orientation, all of which influence middle ear stiffness. Since stiffness reactance is the dominant mechanical factor at low frequencies, postural changes are expected to exert their greatest influence in this frequency range, which is precisely what the present data demonstrate (Densert et al., 1977; Holmlund et al., 2018; Reid et al., 1990; Sagirov et al., 2023a; Voss et al., 2010).

Under ambient pressure, the supine position consistently yielded higher absorbance values than the seated position at several low frequencies, including 257.33 Hz, 408.48 Hz, and 500 Hz. This pattern possibly be attributed to the redistribution of venous blood volume toward the head and middle ear region in the supine posture, which alters tympanic membrane compliance and the mechanical loading of the ossicular chain (Sagirov et al., 2023a). The right lateral recumbent position similarly demonstrated comparatively elevated mid-frequency absorbance values relative to some upright positions. These observations align with tympanometric literature documenting postural influences on middle ear compliance and static pressure (Chatterjee et al., 2017; Mariyam et al., 2025)

Under peak pressure conditions, significant pairwise differences at 408.48 Hz were predominantly observed between the seated position and all other positions, with seated consistently showing lower absorbance. This may reflect the fact that at peak pressure, the differences in stiffness introduced by non-seated postures become more visible relative to the seated baseline, which exhibits relatively efficient middle ear mechanics under pressure compensation. This is because Sitting position ICP is likely to more (Holmlund et al., 2018) compare to any other position as the head is in upright position. Also, at the Tympanometric Peak Pressure this pressure variation likely to affect more due to middle er being maximum mobile at Tympanometric Peak Pressure. At higher frequencies specifically 3174.8 Hz, 4000 Hz, and 8000 Hz significant positional effects were observed under both pressure conditions, though the magnitude of differences was generally smaller than at low frequencies. At 8000 Hz under ambient pressure, the only significant post-hoc comparison was between supine and left lateral recumbent positions. The mechanisms underlying high-frequency positional differences remain less well characterised and may involve postural influences on mass loading of the ossicular chain or subtle shifts in cochlear impedance (Needham et al., 2005), neither of which has been systematically investigated across body positions in the existing literature.

5.3 Comparison of Absorbance Under Ambient Pressure and Tympanometric Peak Pressure.

Absorbance values recorded under Tympanometric Peak Pressure were consistently higher than those obtained under Ambient Pressure across low- and mid-frequency regions for all body positions. This observation correlates with the established principle that recording WBA at the pressure corresponding to maximum tympanic membrane compliance effectively eliminates the stiffening effect of any residual middle ear pressure differences, thereby enhancing energy absorption in the low and mid frequencies (Aithal et al., 2019; Liu et al., 2009).

However, the frequency extent and statistical significance of Ambient pressure and Peak pressure differences varied across body positions. Neck flexion demonstrated significant Ambient pressure and Peak pressure differences across the broad frequency range, extending from 257.33 Hz to 6349.6 Hz, encompassing frequencies well beyond those affected in most other positions. This may be attributable to the effect of neck flexion on venous drainage from the head, possibly through partial compression of internal jugular venous return, which could produce a greater deviation of middle ear static pressure from ambient levels (Sagirov et al., 2023a) resulting significant difference in most frequencies. Whereas at Tympanometric Peak Pressure stiffness being minimum, any alteration of pressure variation due to body position is likely to more impact on WBA at TPP condition. Thus, resulting in difference between the pressure condition.

In contrast, neck extension and left lateral recumbent positions exhibited significant Ambient Pressure–Peak Pressure differences over a comparatively narrow frequency range, largely confined to low frequencies below 1000 Hz. This pattern suggests that these positions possibly maintain middle ear static pressure in closer proximity to ambient level, reducing the magnitude of pressure-related absorbance changes. Seated and prone positions reflected significant Ambient Pressure–Peak Pressure differences across both low and upper-mid frequencies, including 1587.4 Hz, 2000 Hz, 2519.84 Hz, 3174.8 Hz, and 4000 Hz, indicating a broader pressure-sensitivity profile than neck extension or left lateral recumbent positions. Seated would increase pressure and prone would relatively decrease it. This effect is likely impact more for peak pressure condition that ambient pressure condition. Hence resulting in significant different in most of the frequencies (Yücel, Ardıç, Tümkaya, Kara, Topuz, 2020) and Sandra Gonzalez Torrecilla, Paul Avan. (2021).

Across all body positions, no significant Ambient Pressure–Peak Pressure differences were observed at 8000 Hz. This is consistent with the theoretical expectation that static pressure compensation has negligible influence on high-frequency absorbance, where mass reactance rather than stiffness reactance governs middle ear impedance. Mass reactance is not meaningfully altered by changes in static middle ear pressure, and the absence of significant Ambient Pressure–Peak Pressure differences at 8000 Hz across all positions provides further empirical support for this principle. (Rosowski, Stenfelt, Lilly, 2013).

5.4 Influence of Body Position on Middle Ear Resonant Frequency

Resonant frequency differed significantly across the seven body positions at tympanometric peak pressure. A consistent pattern emerged whereby upright and head-related postures were associated with higher resonant frequencies, and recumbent or prone postures with lower values. The seated position yielded the highest mean Resonant Frequency (862.73 Hz), followed by neck flexion (859.43 Hz) and neck extension (858.53 Hz). The prone position exhibited the lowest mean RF (796.91 Hz), with right lateral recumbent (808.00 Hz) and left lateral recumbent (812.61 Hz) occupying intermediate positions.

These findings are mechanically consistent with established models of middle ear acoustics. Resonant frequency is determined by the ratio of stiffness to mass within the middle ear system. Resonant frequency increases as stiffness increases and decreases as the mass increases and is highly sensitive to the balance between stiffness and mass components of the middle ear system (Shahnaz & Polka, 1997). Changes in resonant frequency observed in the current study may indicate posture-induced alterations in middle ear stiffness. Previous studies using multifrequency tympanometry have similarly reported postural effects on resonance characteristics. Victor Franco-Vidal et al., (2015), reported increased resonance frequency in the Trendelenburg position, which they attributed to elevated intracranial and inner ear pressure affecting middle ear mechanics. Likewise, Daniel and colleagues (1985) demonstrated positive pressure shifts and changes in susceptance tympanograms in recumbent positions. The current findings further support the concept that body posture can influence the stiffness properties of the middle ear system and thereby alter resonant frequency. The higher resonant frequency observed in the upright position may be attributed to posture-related alterations in intracranial and inner-ear pressures. Changes in body posture influence intracranial pressure (ICP), which in turn can affect inner-ear fluid dynamics through the cochlear aqueduct and other pressure transmission pathways. Increased inner-ear pressure may elevate the stiffness of the ossicular–cochlear system, thereby increasing the resonant frequency (Magnaes .1976). Conversely, in recumbent positions, relatively lower stiffness contribution within the middle-ear system may reduce resonant frequency values. Since resonant frequency is directly related to the stiffness-to-mass ratio of the middle ear, reductions in stiffness are expected to lower the resonant frequency (Carlborg, Densert, Densert, 1982).

The physiological mechanisms underlying these postural effects may involve several interacting factors. Changes in venous return and intracranial pressure in recumbent positions can increase mucosal congestion within the middle ear cavity, affecting tympanic membrane mobility and ossicular mechanics.

Based on the above discussion it is evident that body position of the participant would alter the absorbance values and also middle ear resonance frequency. This effect is more at low frequencies and less or no changes at high frequencies. This suggests that body position relatively alter the stiffness properties of the middle ear. It is also observed that absorbance values are more affected at Tympanometric Peak Pressure than the AP condition. This suggests that for the non-seated body positions Tympanometric Peak Pressure will provide more stable results as compared to the Ambient Pressure.

Normative reference data for WBA are predominantly derived from seated participants, and the present results indicate that absorbance values obtained in recumbent or prone positions may deviate from these seated norms particularly below 1000 Hz to a degree sufficient to affect clinical interpretation. Clinicians should therefore document body position at the time of testing and exercise caution when comparing measurements obtained in non-standard positions against seated normative benchmarks.

Chapter 6

SUMMARY & CONCLUSION

The present study was carried out to examine the effect of different body positions on wideband absorbance (WBA) and middle ear resonant frequency in adults with normal hearing sensitivity and normal middle ear function. WBA measurements were recorded under ambient and peak pressure conditions across seven body positions in order to understand whether postural changes influence middle ear sound transmission characteristics. To accomplish the objectives of the present study, 30 adults with normal hearing sensitivity, 'A' type tympanograms, and present acoustic reflexes were recruited. Wideband absorbance (WBA) measurements were obtained using the Titan IMP440/WBT440, version 3.1.024 by presenting click stimuli at 100 dB SPL. Measurements were recorded across 16 frequency points ranging from 257 Hz to 8000 Hz.

The results showed that the overall absorbance pattern remained similar across all body positions. In all positions, absorbance values were lower at very low and very high frequencies and higher in the mid-frequency range. This pattern was consistent with previous studies on normal WBA findings. Even though the general absorbance pattern remained stable, significant differences were observed at certain frequencies between body positions, suggesting that posture can influence middle ear mechanics to some extent. Maximum absorbance values were commonly seen between 1000 Hz and 4000 Hz under both pressure conditions. Comparatively higher absorbance values were observed in neck flexion, right lateral recumbent, and left lateral recumbent positions, especially within the mid-frequency region. Under ambient pressure condition, neck flexion demonstrated greater absorbance around 2000–4000 Hz, whereas under peak pressure condition, prone and right lateral recumbent positions showed relatively higher absorbance values between 1000 Hz and 3174.8 Hz. The increase in absorbance observed in certain recumbent and neck positions may be related to postural changes affecting middle ear pressure thus regulating the acoustic energy transmission through the middle ear system.

Differences were also observed between ambient-pressure and peak-pressure recordings. Peak-pressure measurements appeared to produce relatively higher absorbance values when compared to ambient-pressure recordings. Since the pressure in the external ear canal is adjusted to match the middle-ear pressure at the tympanometric peak pressure. This minimizes the impact of pressure-induced stiffness on middle-ear transmission by keeping the tympanic membrane and ossicular chain in their most flexible state. As a result, the middle ear transmits sound energy more reliably and effectively, which lowers absorbance measurement variability.

In addition, resonant frequency showed variation across body positions, indicating possible changes in the stiffness characteristics of the middle ear system with posture. Resonant frequency varied with body position, suggesting that posture may affect the middle-ear system's stiffness characteristics. Changes in posture can have an impact on intracranial pressure, venous pressure, and middle-ear pressure control, all of which can have an impact on the tension and compliance of the ossicular chain and tympanic membrane. Even minor posture-related changes in stiffness may cause detectable shifts in resonant frequency because resonant frequency is largely dependent on the balance between stiffness and mass components of the middle-ear system. Resonant frequency typically rises with increasing stiffness and falls with decreasing stiffness.

Conclusion

In conclusion, the findings revealed that changes in body position can influence absorbance measurements, particularly within the low- and mid-frequency regions, while relatively smaller variations were observed at higher frequencies. Maximum absorbance was commonly observed around 1000 Hz across most body positions. Comparatively greater absorbance values were noted in certain recumbent positions when compared to upright positions. The absorbance values recorded under peak pressure condition were generally higher than those obtained under ambient pressure condition. In addition, significant differences in resonant frequency across body positions were observed, indicating that postural changes may alter middle ear mechanics and acoustic energy transmission.

The findings of the present study may be explained by physiological changes associated with posture. Changes in body position can alter venous return, intracranial pressure, and inner ear fluid pressure. Since the inner ear communicates with the cerebrospinal fluid through the cochlear aqueduct, these pressure changes may influence middle ear mechanics and sound transmission. Increased middle ear mucosal congestion in recumbent positions may also contribute to these findings.

The study also highlights the possible relationship between posture-related physiological changes and middle ear mechanics. Since previous studies have suggested a connection between intracranial pressure and middle ear measurements, the present findings may support the future use of wideband immittance measures as indirect indicators of intracranial pressure-related changes.

6.1 Clinical Implications.

The findings of this study carry several implications for the clinical application of wideband acoustic immittance measures.

- Body position should be standardized during WBA assessment to reduce measurement variability.

- Low-frequency WBA findings should be interpreted cautiously, as they are affected by postural changes.
- Postural variation may influence WBA-based identification of otosclerosis, superior canal dehiscence, and peri-lymphatic fistula.
- TPP-based WBA recordings may be preferred clinically due to lower positional variability.
- TPP recordings may provide more stable absorbance measurements across different body positions.
- Body position should be considered while interpreting middle ear resonant frequency (RF).
- Use of upright normative RF values for non-upright testing positions may lead to inaccurate clinical interpretation.
- Position-specific RF normative data may improve diagnostic accuracy.

It also highlights the possible clinical utility of wideband acoustic immittance measures in monitoring physiological changes associated with intracranial pressure (ICP).

The findings of the present study add to the existing literature on factors affecting wideband acoustic immittance and may help in improving the clinical interpretation and standardization of WBA measurements across different body positions.

6.2 Limitations and Future Directions

There are several limitations of the present study. The study recruited adults with normal middle ear function, and the extent to which these findings generalise to clinical populations where pathological alterations in middle ear mechanics may interact with postural effects remains uncertain. Conditions such as otitis media with effusion, otosclerosis, or eustachian tube dysfunction may amplify or attenuate the positional effects on WBA observed in the current normative sample.

The study did not control for individual differences in eustachian tube function which may modulate the relationship between posture and middle ear pressure regulation.

From a methodological standpoint, future research should examine positional effects on WBA in clinical populations, with particular attention to conditions in which middle ear mechanics are known to be postural-sensitive, such as superior canal dehiscence, Ménière's disease, and perilymphatic fistula. Longitudinal designs tracking WBA changes across sustained postures or postural transitions would further explain the dynamic relationship between body position and middle ear acoustic mechanics. The development of position-specific normative databases would also represent a meaningful contribution to the clinical utility of wideband acoustic immittance measures.

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