MULTIFREQUENCY, MULTI-COMPONENT TYMPANOMETRY: NORMATIVE IN KINDERGARTEN AND PRESCHOOL CHILDREN (3-6 YEARS)

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Register no: 07AUD015

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MAY 2009.

To,

The Lord Almighty

And

My Beloved Parents

Certificate

This is to certify that this dissertation entitled **“Multifrequency, Multi-component Tympanometry: Normative in Kindergarten and Preschool Children (3-6 years)”** is a bonafide work in part of fulfillment for the degree of Master of Science (Audiology) of the student Registration no: 07AUD015.This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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Declaration

This is to certify that this master's dissertation entitled **"Multifrequency, Multi-component Tympanometry: Normative in Kindergarten and Preschool Children (3-6 years)"** is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

MYSORE Registration no:

May 2009 07AUD015

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"If any of you lacks wisdom, let him ask of God, who gives to all liberally and without reproach, and it will be given to him"

(James 1:5)

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1. Introduction

Tympanometry is one of easy, safe and quick method for assessing middle ear function. From the pioneering work of Terkildsen and Thomson (1959), tympanometry performed using a low probe tone frequency, has proven its validity in identifying a variety of middle ear disorders (Lilly, 1984). However, it has been reported that standard low frequency tympanometry often fails to distinguish normal middle ears from some middle ear pathologies which affect middle ear sound transmission (Colletti, 1976, 1977; Hunter & Margolis, 1992; Lilly, 1984). It is possible that low frequency tympanometry may fail to reveal distinct patterns for many middle ear pathologies, because the status of the tympanic membrane dominates the tympanograms and thus effectively overshadows conditions affecting more medial structures. Several studies have discussed the possible advantage of using probe tone frequencies closer to the resonance of middle ear (ME). Recent studies suggest that identification of otosclerosis and other middle ear pathologies can be substantially improved using measures derived from multifrequency, multi-component tympanometry or by combining tympanometric variables in specific way (Margolis & Shanks, 1991; Shanks & Shelton, 1991).

As recommended by American Speech and Hearing association (ASHA 2004 & 2007), till today, the admittance measure for age above 24 months is done using regular 226 Hz tympanometry. But it has been shown that abnormality of ME can be prominently identified at the probe tone frequency which is very close to or at resonant frequency (Margolis & Shanks, 1991; Shanks, 1984; Shahnaz & Polka, 1997) and the impact of ME pathology on static immittance will be greater at the frequency close to resonant frequency (RF) (Liden, Harford, & Hallen, 1974). Thus studying the admittance parameter close to resonant frequency might give a better picture about the ME transmission of sound in both normal and pathological ME. This may also help in better diagnosis of ME pathologies. Multiple-frequency tympanometry seems to be a useful method for determining the effect of various middle-ear pathologies on the mechano-acoustical status of the middle-ear system (Kontrogianni et al., 1996).

In 1984 Funasaka, Funai, and Kumakawa have described a sweep frequency procedure by which we can obtain the RF and admittance parameters such as susceptance (B), conductance (G), admittance (Y), phase angle (θ) across frequencies 250 to 2000 Hz and at RF, by providing clear picture of ME sound transmission across frequencies . The efficacy of this procedure was studied on clinical population and it was found useful in differentiating ME pathologies (Funasaka & Kumakawa, 1988; Wada, Koike, & Kobayashi, 1998).

According to Shahnaz and Polka (1997), the admittance phase angle corresponds to 45° at frequency where $\Delta B=\Delta G$ or $B=G$. It was noted that phasor angle admittance at 45° was significantly affected in otosclerotic ears. However application of F45° in other pathologies is not mentioned in literature and there are very few studies regarding ΔY (peak to tail difference in acoustic admittance) at resonant frequency (RF) in normal and pathological middle ears. Parameters ΔY, ΔG (peak to tail difference in acoustic conductance), $\Delta\theta$ (peak to tail difference in phase angle) at RF, and RF at $\Delta B\approx 0$ (ΔB is the peak to tail difference in acoustic susceptance) are important in differentiating, describing, studying the mechano- acoustical transformation of middle ear system.

Otitis media (OM) is a frequent middle ear disorder in children. The prevalence of otitis media in Indian children varies in different studies. Jacob, Rupa, and Joseph (1997) reported predominant conductive hearing impairment in 10.9% of the children in 284 children in the age range of 6-10 years. Otitis media was seen in 17.6% of children, whereas, 91.2% of children with hearing impairment had associated middle ear disease. Rupa, Jacob, and Joseph (1999) reported a prevalence rate of Chronic Suppurative otitis media (CSOM) in 5.7% of the preschool children of aged 2 to 5 years whereas the prevalence of CSOM in 6 to 10 years old children was found to be 6.2 % in Indian children.

Multifrequency tympanometry (MFT) records changes in the middle ear after acute otitis media, that 226 Hz tympanometry is unable to detect, implying persistence of pathology. It has also been concluded by the authors that more extended research will illuminate the clinical value of this method in the follow-up of acute otitis media (Ferekidis et al., 1999). The MFT is a better tool in the diagnosis of otitis media with effusion and adhesive otitis media and has better performance in reflecting middle ear pathology with an efficacy of 100% in the diagnosis of otitis media with effusion and 70% in the diagnosis of adhesive otitis media (Abou-Elhamd, Abd-Ellatif, & Sultan, 2006).

MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry. Moreover, it has been shown that conventional 226 Hz tympanometry is unable to detect sequelae and subtle changes in middle-ear mechanics following OM; however, MFT appears to be sensitive to these changes (Hanks & Robinette, 1993; Margolis, Hunter, & Giebnik, 1994; Vlachou, Ferekidis, Tsakanikos, Apostolopoulos, & Adamopoulos, 1999; Vlachou, Tsakanikos, Douniadakis, & Adamopoulos, 2001). Harris, Hutchinson and Moravec (2005) evaluated the effectiveness of conventional 226 Hz and MFT tympanograms in detecting middle ear effusion in 21 children prior to myringotomy. They reported that all abnormal cases identified by conventional 226 Hz tympanometry were also identified by MFT; however, three abnormal cases that were identified as normal by 226 Hz tympanometry were correctly identified as abnormal by MFT. It is concluded that MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry.

In a systematic study of tympanometry using probe tone frequencies ranging from 200 Hz to 2000 Hz proved to be far more sensitive method for checking small changes in transmission characteristics of tympano-ossicular system than the single frequency traditional analysis (Colletti, 1976). According to Vlochou et al., (2001) the acoustic admittance phase angle is efficient in identifying children suffering from acute otitis media (AOM). Several studies noted the importance of resonant frequency (RF) on identifying middle ear pathologies like ossicular fixation, AOM in children as well as adults (Funasaka & Kumakawa, 1988; Margolis et al., 1985; Holte, 1996; Shahnaz & Polka, 1997). Colletti (1975) has stated that multi frequency tympanometry could be useful in differential diagnosis of middle ear pathologies with normal otoscopic findings.

Literature review shows that the RF and ΔG have clinical significance in differentiating a normal ear from otosclerotic ear in adults and ΔG also has a high correlation with the RF i.e., higher RF values corresponded to lower G values (Miani et al., 2000).

Abou-Elhamd et al., (2006) evaluated the diagnostic value of multifrequency tympanometry in otitis media with effusion and adhesive otitis media. Results indicated that resonant frequency proved to have the best performance in reflecting middle ear pathology.

Need for the study

- Even though the prevalence of ME pathologies like Acute Otitis Media (AOM) is very high in children between the age groups of 2-5 years and 6-11 years, in most of the audiology clinics acoustic immittance measures are done with standard 226Hz probe tone (Martin & Sides, 1985). The information on the usefulness of the high probe tone frequencies, multifrequency, multi-component tympanometry in infants and preschool age children for differential diagnosis of ME pathology is not adequate.

- Studies have also shown that there is statistically significant decrease in both RF values and change in phase angle in ears with OME compared to normal ears (Kontrogianni et al., 1996). However, normative data for RF at $\Delta B \sim 0$, ΔY, ΔG,$\Delta \theta$ at RF and F45°, which could be of diagnostic significance, are not available for population between the age group of 3-6 years.

- Wong, Lena, Joyce, and Wan (2008) reported significant difference in Chinese children aged between 6 and 15 yrs from that of white children in four tympanometric variables [peak, compensated static acoustic admittance (peak Ytm); equivalent ear canal volume (V_{ec}); tympanometric width (TW) and tympanometric peak pressure]. Since the normative value may vary from race to race, there is a need to establish a separate normative for, RF at ΔB~0, ΔY, ΔG, Δθ at RF and F45° for Indian population.

- Present data can be used in checking incidence, prevalence and also in identifying and ME pathologies which affects ossicular chain like otosclerosis and ossicular chain discontinuity in children between age group of 3-6 years, as multifrequency is a better indicator for these pathologies.

Thus normative needs to be obtained in order to use it for clinical population.

Objectives

- To provide normative data for, RF at ΔB~0; ΔY, ΔG, Δθ at RF and F45° for children from 3-6 years of age.
- To study the RF at ΔB~0; ΔY, ΔG, Δθ at RF and F45° across the age groups from 3-6 years.
- To study the ear differences for RF at ΔB~0; ΔY, ΔG, Δθ at RF and F45° across 3-6 years of age.
- To study the gender differences for RF at ΔB~0; ΔY, ΔG, Δθ at RF and F45° across 3-6 years of age.

2. Review of Literature

2.1 Definition

The middle ear transmission system is made up of membranes, ligaments, muscles, bones and trapped air. Each of these components has susceptance and conductance characteristics, and together they make up the input acoustic admittance of the middle ear that is measured with tympanometry (Lilly, 1972).

Tympanometry is defined as the dynamic measure of acoustic immittance in the external ear canal as a function of changes in air pressure in the ear canal (ANSI, S3.39-1987), which refers to measure of acoustic admittance that are taken at various pressure points.

2.2 Types of tympanometry

2.2.1 Low probe tone frequency tympanometry

The simplest and most commonly used tympanometric procedure involves the recording of a single immittance component, acoustic admittance (Y_a) using a single probe tone frequency, typically 226 Hz. The low probe tone frequency has clinical value. For the low probe tone frequency, primarily the stiffness characteristics of the middle ear transmission system are assessed. Static admittance, peak pressure and ear canal admittance are used routinely in interpreting standard low frequency tympanograms. In addition to these measures, tympanometric width is also used for clinical application.

The peak compensated static acoustic admittance (Ytm) describes the height of the tympanogram measured at the plane of the tympanic membrane. This measure is useful because certain disease can increase or decrease the normal height of the tympanogram (Fowler & Shanks, 2002).

Tympanometric peak pressure (TPP) refers to the position of the tympanometric peak on the pressure axis (Figure 1) and is measured in deka Pascal (daPa). This measure provides an estimate of the pressure within the middle ear space (Fowler & Shanks, 2002).

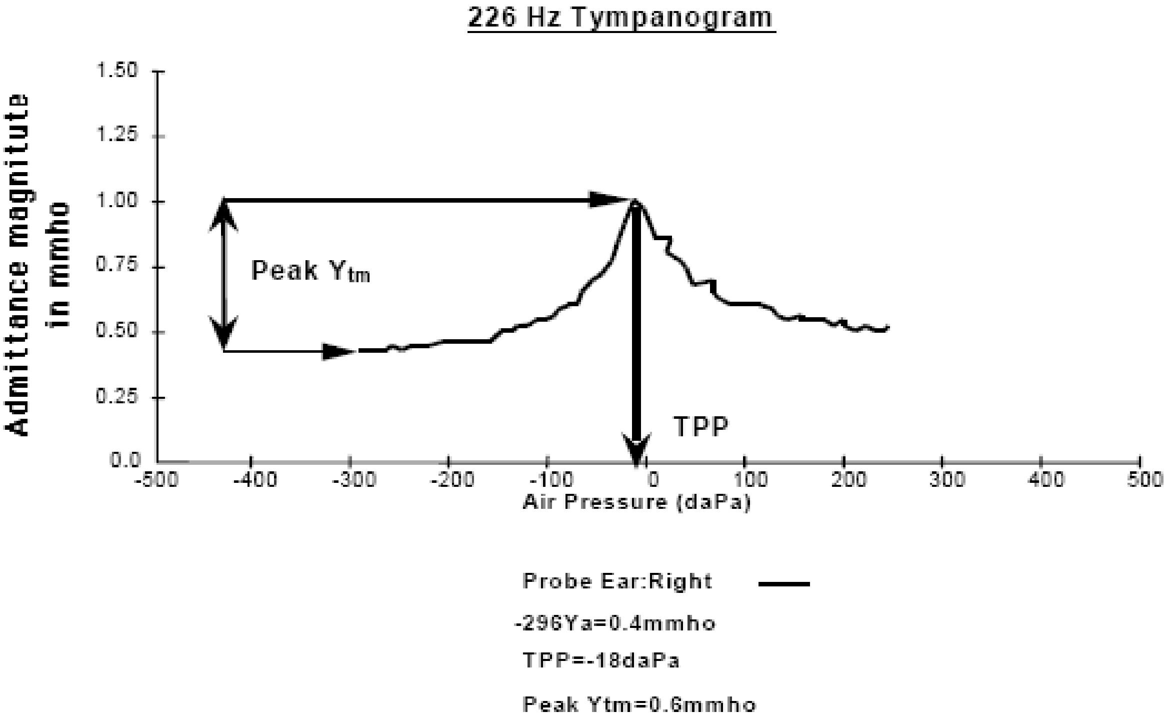

Figure 1. Tympanogram showing the peak pressure and the admittance at peak pressure (Ytm)

Equivalent ear canal volume (V_{ea} or V_{ec}) is an estimate of the volume of air medial to the probe, which includes the volume between the probe tip and the tympanic membrane if the tympanic membrane is intact, or the volume of the ear canal and middle ear space if the tympanic membrane is perforated (Fowler & Shanks, 2002). The estimate of ear canal volume is useful for two reasons. First, an accurate determination of the compensated static admittance (Ytm) depends on an accurate estimation of the ear canal volume. If the ear canal volumes are overestimated, then the static admittance will be underestimated. Second, in case of flat tympanograms, the estimation of ear canal volume can provide a clue to the cause of the flat tympanogram, whether it is due to artifact/due to tympanic membrane perforation or middle ear effusion.

Tympanometric width (also referred to as tympanometric gradient) refers to the width of tympanogram (in daPa) measured at one half the compensated static admittance. This measure provides an index of the shape of the tympanogram in the vicinity of the peak. It also quantifies the relative sharpness (steepness) or roundness of the peak. A large tympanometric width is measured when the tympanogram is rounded and a small tympanometric width results when the tympanogram has a sharp peak (Fowler & Shanks, 2002).

Tympanometry performed at a low probe tone frequency of 226 Hz has proven its validity in identifying various disorders of the middle ear (e.g., effusion or abnormal air pressures within the middle ear cavity), tympanic membrane abnormalities (e.g., atrophic scarring, retraction, or perforation) and Eustachian tube malfunction (Lilly, 1984). Estimating the air medial to the probe tip has also contributed to the interpretation of abnormal tympanograms. However, standard tympanometry may fail to reveal these pathologies as they involve structures that are medial to the tympanic membrane. The status of the tympanic membrane dominates the tympanogram and therefore can overshadow conditions affecting more medial structures (Lilly & Shanks, 1981; Lindeman & Holmquist, 1982).

Increase or decrease in the stiffness or mass of the middle ear system by different pathologies results in an increase or decrease of the middle ear resonant frequency. For this reason, tympanometry performed at standard low probe tone frequency is not sensitive to all middle ear pathologies, because the probe tone frequency is far lower than the middle ear resonant frequency and is not consistently affected by many changes in the mass or stiffness of the middle ear system (Shanks, 1984).

2.2.2 High frequency tympanometry

High frequency tympanometry involves use of higher probe tone frequency. Commonly used high probe tones include 660 Hz, 678 Hz, 880 Hz or 1000 Hz. Recently, research has focused on a 1000 Hz probe tone which is currently the highest frequency available on commercial clinical tympanometers (Purdy & Williams, 2000). This stimulus has been shown to be more valid than other high-frequency probe tones such as 660 Hz and 678 Hz (Baldwin, 2006; Rhodes et al., 1999; Williams, Purdy, & Barber, 1995).

Several normative studies on 1000 Hz tympanometry have been published. Tympanometry with a 1000 Hz probe tone was successfully obtained on 47 out of 52 ears, resulting in a success rate of 90.4% for young infants in a clinical setting (Kei et al., 2003; Margolis et al., 2003; Mazlan et al., 2007). Both the Joint Committee on

Infant Hearing (2007) and the American Speech-Language Hearing Association (2004) recommend high-frequency tympanometry for infants from birth to six months of age.

2.2.3 Multi frequency, Multicomponent tympanometry

Multi-frequency tympanometry refers to the procedure in which the tympanogram is measured at two or more probe frequencies, and it is done in order to measure the admittance characteristics of the ear across broad spectral range. The broad range, determined by more than one probe tone frequency enables the measurement of potential changes in mass and stiffness components of the acoustic admittance.

The low probe tone frequency, 226 Hz, used in standard tympanometry was originally selected partly for ease of calibration and not because it necessarily provided the most clinically useful information (Terkildsen & Thomson, 1959). With the appearance of commercially available computer based tympanometry instruments, it is now possible to record multiple tympanograms at different frequencies. It is also possible to record separate tympanograms for the admittance rectangular components, susceptance and conductance, at different frequencies. It is known that in normal ears, a low probe tone frequency tympanogram has a single peak. In contrast, tympanograms recorded at higher frequencies often have multiple peaks. Vanhuyse, Creten, and Van Camp (1975) examined tympanometric patterns at various probe tone frequencies and developed a model which predicts the shape of susceptance (B) and conductance (G) tympanograms at 678 Hz in normal ears and in various pathologies.

Later, this model was extended to higher probe tone frequencies (Margolis & Goycoolea, 1993). This model can be explained with reference to the relationship between susceptance and conductance tympanograms as probe tone frequency increases.

The Vanhuyse model categorizes the tympanograms based on the number of peaks or extrema on the susceptance (B) tympanogram and the conductance (G) tympanogram and predicts four tympanometric patterns at 678 Hz. The patterns are denoted by the number of extrema on the B and G tympanograms as shown in Figure 2. These patterns include the following:

a. 1B1G pattern (Figure 2A) has one peak on the susceptance tympanogram and one peak on the conductance tympanogram. The 1B1G pattern occurs when the middle ear is stiffness dominated and the absolute value of susceptance is greater than conductance at all ear canal air pressures, i.e., when the admittance phase angle is between 90° and 45°. In normal ears, the standard low frequency tympanometry yields a 1B1G pattern.
b. 3B1G (Figure 2B), which has three extrema on the susceptance (B) tympanogram (two peaks on the side of a notch in the middle) and has a single peak on the conductance (G) tympanogram. The admittance tympanogram will also have one peak. When this pattern is observed, the ear is either stiffness dominated or at resonance, i.e., the admittance phase angle is between 45° and 0°. In this pattern susceptance is still larger than conductance at extreme pressures; however, this relationship is reversed near the peak pressure. The central notch on the susceptance tympanogram occurs at the pressure

corresponding to the peak value on the susceptance tympanogram. The middle ear is stiffness controlled when the central notch on the susceptance tympanogram is above either the positive or the negative tail, depending on which extreme is chosen to estimate ear canal volume.

c. 3B3G (Figure 2C) pattern, the susceptance and the conductance tympanograms each have three peaks. The admittance tympanogram will also have three peaks, i.e., it will have a notch. When this pattern is observed, the ear is either at resonance or is mass dominated, i.e., the admittance phase angle is between 0° and -45°. This in turn results in a deep notch on the susceptance tympanogram. The middle ear is at resonance when the central notch on B tympanogram is equal to either the positive or the negative tail as this indicates that susceptance is zero, whereas it is mass controlled when the central notch falls below either the positive or the negative tail as this indicates that susceptance is negative.
d. 5B3G (Figure 2D) the susceptance tympanogram has five peaks and the conductance tympanogram has three peaks. The admittance tympanogram will also have three peaks. In this pattern the ear is mass dominated and admittance phase angle is between -45° and -90°.

The sequence of patterns described in the model is seen as frequency is increased, in both normal and abnormal middle ears (Margolis et al., 1985). However, with pathologies the probe frequency at which each pattern occurs may be shifted higher or lower compared to normal ears. For example, in a stiffening pathology such as otosclerosis in which the resonant frequency is shifted upward, each of the various patterns can be expected to occur at higher frequencies compared to normal ears.

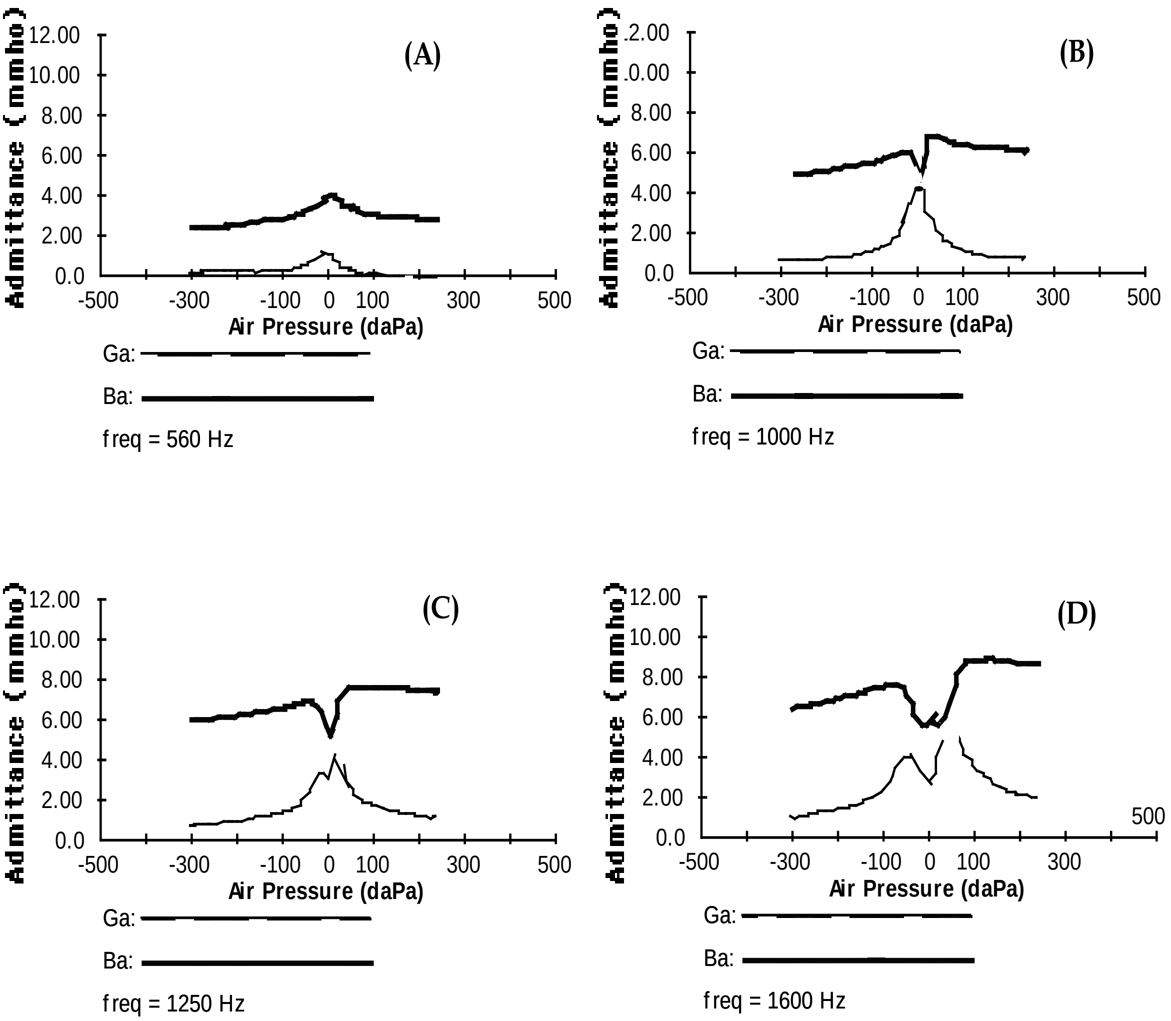

Figure 2. Vanhuyse et al. (1975) model showing four patterns for susceptance (B_a) and conductance (G_a) tympanograms, 1B1G (A); 3B1G (B); 3B3G (C); and 5B3G (D)

The Vanhuyse model is based on the sweep pressure method of multifrequency, multicomponent tympanometry. With the sweep pressure method, ear canal air pressure is continuously changed while probe tone frequency is held constant. This is the traditional way of recording a tympanogram. Therefore, to obtain multifrequency information, multiple sweep pressure recordings at different probe tone frequencies are needed.

Funasaka et al. (1984) described the sweep frequency method of multifrequency, multicomponent tympanometry. With the sweep frequency method, ear canal air pressure is altered in discrete pressure intervals. At each successive pressure setting, a series of probe tones which increase from low to high frequency is presented. In this way, tympanometric data are obtained at multiple frequencies with a single positive to negative (or negative to positive) pressure change. In this procedure one can either choose to measure the admittance or its rectangular components (B and G) along with admittance phase angle. These measures are conducted at an extreme ear canal pressure (positive or negative depending on the user preferences) and at a peak pressure (which is automatically derived by running a 226 Hz "Y" tympanogram) while the probe tones frequency is swept from 250 - 2000 Hz in 50 Hz steps. These component values (ΔY, ΔB, or ΔG) and phase angle values ($\Delta\theta$) are compensated for canal admittance by computing the difference between their value at extreme pressure and their value at peak pressure. The compensated values are plotted as a function of probe tone frequency (250-2000 Hz) to determine resonant frequency (Funasaka et al., 1984).

The instrumentation of sweep frequency tympanometry as given by Funasaka et al. (1984) is shown in the Figure 3.

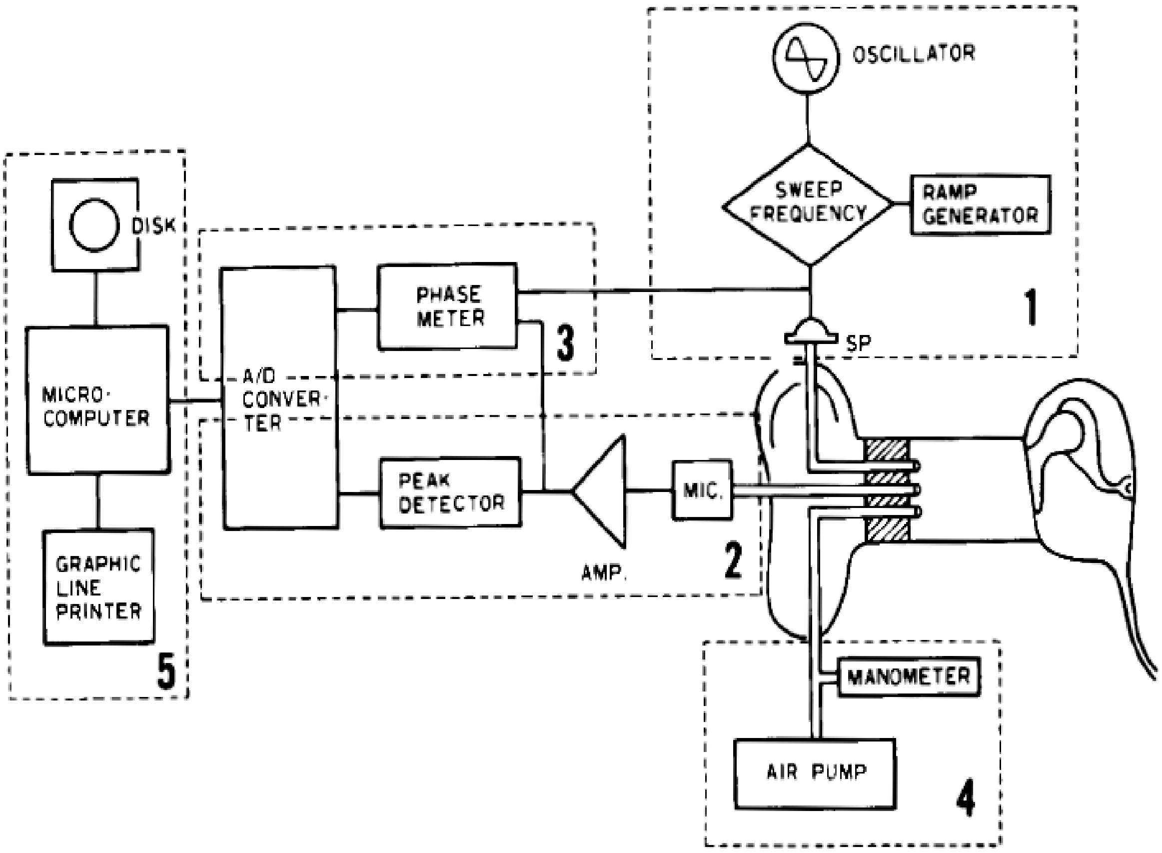

Figure 3. Block diagram showing system for sweep frequency testing (Funasaka et al. 1984). Block 1: Sweep-frequency probe tone generator; Block 2: Peak detector for sound pressure measurement; Block 3: Phase meter for phase measurement; Block 4: Air pump to produce air pressure of -200 and 0 mm H_2O in the ear canal; block 5: Microcomputer system for data processing and plotting

The Figure 4 represents the graph displayed in a GSI-Tympstar immittance meter. Recording of B and G (in mmho) at +250 daPa and at peak pressure while the probe tone frequency was swept from 220 to 2000 Hz in 50 Hz intervals (sweep frequency recording). The difference between B/G at +250 daPa and peak pressure (referred to as ΔB/ΔG) will be computed at each probe tone frequency. This ΔB/ΔG is essentially a compensated B and G measure. The ΔB and ΔG was then plotted as a function of frequency (in Hz). The frequency at which ΔB is closest to 0 corresponds to the resonant frequency of the middle ear system. The frequency at which ΔB is closest to ΔG corresponds to admittance phase angle of 45°.

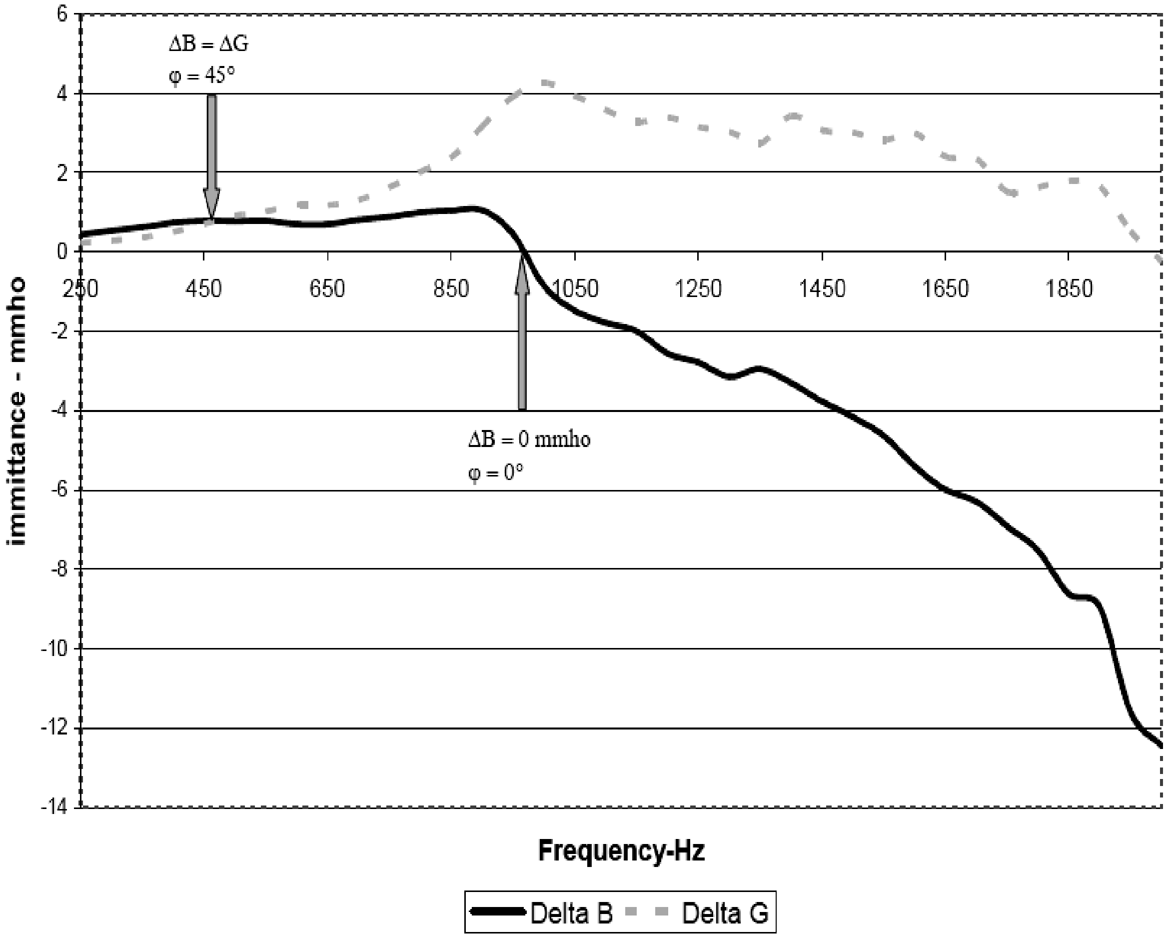

Figure 4. Peak compensated Static acoustic susceptance and conductance plotted as a function of probe frequency from 250 Hz through 2000 Hz. Points corresponding to the resonant frequency, where ΔB = 0, and frequency at 45°, where ΔB= ΔG are shown (Shahnaz, 2007)

Margolis and Goycoolea (1993), studied both sweep frequency and sweep pressure methods to record susceptance and conductance tympanograms with 20 probe tone frequencies between 250 and 2000 Hz (1/6 octave step intervals). They found two patterns in their normative data. First, resonant frequency was consistently lower when derived from the sweep pressure recordings rather than the sweep frequency recordings. They attributed these differences are likely due to the faster rate of pressure change used in the sweep pressure recording method. Compensated susceptance has been shown to be higher (Shanks & Wilson, 1986) and the notch on the susceptance tympanogram to be deeper (Creten & Van Camp, 1974) when a faster rate of air pressure change is used. This effect produces a lower estimate of resonant frequency for faster rates of pressure change. A low estimate of resonant frequency with the sweep pressure recording method may also have been observed because this method requires greater tympanometric runs than does the sweep frequency method (Margolis & Goycoolea, 1993). Acoustic admittance has been shown to be higher with multiple consecutive tympanometric runs which may result in an earlier notch on the susceptance tympanogram and may therefore, produce a lower estimate of resonant frequency (Osguthorpe & Lam, 1981; Vanpeperstraete, Creten, & Van Camp, 1979; Wilson, Shanks & Kaplan, 1984).

A second finding reported was that the resonant frequency estimates were higher when negative tail (rather than positive tail) compensation was used. As mentioned earlier, this effect is due to the asymmetry in the tympanogram at extreme positive and negative pressures (Margolis & Smith, 1977) and its effect on compensation for ear canal volume.

In examining the distribution of the various resonant frequency estimates as well as data on test retest reliability, Margolis and Goycoolea (1993), drew two conclusions concerning the clinical application of resonant frequency. First, they concluded that compensation at +200 daPa for ear canal admittance was preferred for estimation of the resonant frequency because this compensation method produced lower inter-subject variability and better test-retest reliability compared to other compensation methods. Second, they suggested that the sweep pressure recording is preferred for detecting pathologies that will produce an abnormally high resonant frequency such as otosclerosis whereas sweep frequency is preferred for identifying pathologies that will produce an abnormally low resonant frequency. This is because the upper limit of resonant frequency derived from sweep frequency recording extends to the maximum available probe tone frequency (2000 Hz) in the current available immittance systems. Thus, they concluded that ceiling effects are likely to limit the ability to measure abnormally high resonant frequencies using the sweep frequency procedure. Resonant frequency derived from sweep pressure recordings tends to produce relatively low resonant frequency values, suggesting that this method may be less sensitive to pathologies that lower resonant frequency.

Sweep frequency method is less time consuming as compared to sweep pressure method, as for the sweep pressure method, B, G and Y tympanograms should be done at each frequency separately. And the middle ear transmission characteristics can change due to the increased number of pressure changes as the parameters are got for each frequency (Wilson et al., 1984).

Another multifrequency multicomponent is the F45°. Estimate of frequency corresponding to 45º phase angle is taken as the lowest frequency at which compensated conductance first becomes equal or larger than compensated peak susceptance i.e. where $\Delta B \leq \Delta G$. This parameter has also shown to have diagnostic significance in distinguishing normal middle ear from that of abnormal middle ears (Shanks, Wilson, & Palmer, 1987).

2.3 Prevalence of middle ear disorders in children

Several studies have been presented on the prevalence of different middle ear disorders in children. A preliminary evaluation of the paediatric cholesteatoma in 26 patients (19 males and 7 females) for a total of 27 operated ears, the age of presentation of the disorder averaged eight years (range 2-15 years). The most common presenting symptoms were otorrhea (11/26), hearing loss (4/26) and tympanic membrane perforation (3/26). Five patients had congenital cholesteatoma (Vastola, 1993).

Stangerup, Arnesen and Larsen (1994) estimated the prevalence of different types of eardrum pathology in a cohort of children and teenagers up to the age of 16 years. At age 5 years, pathology of the eardrum was found in 19% of ears examined. At succeeding follow-ups until the age of 16 years, the prevalence of eardrum pathology increased to 33%. The tympanometric profile improved significantly from 49% of children with negative middle ear pressure at age 5 years to 4% at age 16 years.

Jacob et al., (1997) reported predominant conductive hearing impairment in 10.9% of the Indian children, Otitis media in 17.6% of children whereas 91.2% of children with hearing impairment with associated middle ear disease in 284 children in the age range of 6-10 years.

Odabasi et al., (1998) aimed at studying the incidence of silent otitis media in day care centre and to determine the pre-disposing and risk factors of middle ear disease. 213 children in the age range from 3-6 years were screened using otoscopy, pneumatoscopy, tympanometry and X-ray for sinus pathology. Results revealed that 43 out of 213 children had middle ear pathology. 39 of them were diagnosed by tympanometry. Results also revealed that children without any risk factors also develop middle ear problems and 81.4% of parents were unaware of the problem.

A cross-sectional survey on prevalence of chronic suppurative otitis media (CSOM) in rural South Indian children was conducted among 914 children (484 boys and 430 girls) from four primary schools and 12 nurseries (Rupa, Jacob, & Joseph, 1999). The preschool children were aged 2–5 years, while the ages of the primary school children ranged from 6 to 10 years. The overall prevalence rate of CSOM was found to be 6%. The disease was equally prevalent in preschool children (5.7%) and primary school children (6.2%). Cholesteatomatous ear disease was observed in 1.2% of children, those of the older age group having a slightly higher prevalence rate (1.5%) than the younger age group (0.7%).

Cowan and Makishima, (2006) reported that otosclerosis was most common between the age range of 15-45years, youngest presentation being seven years. Congenital stapes fixation was seen with 25% of other congenital anomalies and this can be detected during the first decade of life.

Kavitha, Jose, Anurudhan, and Baby (2009) conducted a study to assess the hearing status of 339 preschool children attending six kindergarten schools in

Mangalore, India. Audiological examination revealed 37 (10.91%) children were found to have conductive hearing loss and none had sensorineural hearing loss. Out of the 31 children with middle ear disease, only 11 (35.48%) were detected to have hearing impairment. Prevalence of hearing impairment and otitis media was higher in rural school children than in urban schools. The prevalence of chronic suppurative otitis media was found in 9.09% (7 out of 77) of the rural school children and in 0.76% (2 out of 262) of the urban school children.

Table 1 shows the complied data of incidence and prevalence of otitis media in both children and adults across the countries by Daly (1991). Only data of Children are taken from the complied data and presented in the following table.

Table 1.

Summary of otitis media incidence and prevalence studies in childhood

Investigator, Country and year	**No. of subjects**	**Method of diagnosis ***	**Age (years)**	**OM incidence**	**OM prevalence**
Teele (US) 1989	877	1,2	0-7	62%	-
Kaplan (US) 1973	643	1,3	3-5	-	31%
Griffth (US) 1979	274	1	3-11	-	6-18%
Nelson (US) 1984	15890	1,2,3	4-14	-	2%
Casselbrant (US) 1985	103	1,2	2-6	53-61%	5-33%
Pederson (Greenland) 1986	86	1,4	3-4	-	18%
Nieto (Spain) 1984	5950	1,2	4-9	-	9%
Van Cauwenberge (Belgium) 1984	2069	1,2	2-6	-	12%
Okeowo (Nigeria) 1985	764	1	3-11	-	6%

******Note.* 1: Tympanometry; 2: otoscopy; 3: Audiometry; 4: Oto-microscopy

2.4 Normative studies on multifrequency tympanometry

Multifrequency tympanometry (MFT) consists of tympanography using probe tone frequencies ranging from 200 to 2000 Hz. This procedure improves the study of acoustic transmission through the tympano-ossicular system since it can separately assess the two components of admittance, conductance and susceptance. The resonance frequency is the frequency at which mass and spring elements of the middle ear cancel each other out, leaving only the friction component. This measurement has been found to be more sensitive to the presence of pathologies that affect the tympano-ossicular system, such as otosclerosis and rheumatoid arthritis. It is necessary to know normal patterns of tympanometric parameters to improve the study of these diseases (Margolis & Goycoolea, 1993).

Margolis and Goycoolea (1993) recorded MFT from 56 ears of 28 normal-hearing adults to obtain normative data and to determine abnormal criteria for tympanometric measures. Static admittance, tympanometric width, and tympanometric peak pressure at 226 Hz were analyzed along with eight different estimates of the resonant frequency of middle ear. Based on test-retest reliability and normal distribution characteristics, preferred methods for clinical estimation of resonant frequency were determined. They concluded that sweep pressure mode is preferred for detection of abnormally high resonant frequencies. The sweep frequency mode is preferred for identification of abnormally low resonant frequencies.

Multifrequency tympanometry was performed on 136 patients, 91 women and 45 men, age range 11-78 years by Lechuga et al., (2000). The mean resonant frequency of the middle ear was 1132.33 Hz, mean static admittance 0.76 daPa, and mean tympanometric amplitude 94.31 mmhos. Age showed no systematic effect on any of these measures in this population, and no significant association was found between static admittance and tympanometric amplitude and resonance frequency.

Hocke et al., (2000) presented experimental data on the evaluation of middle ear resonances by MFT. MFT of 18 normally hearing subjects were recorded with a frequency resolution of 15 Hz. The finer middle ear mechanism variation found in the

MFT patterns was compared with findings in the literature. They conclude that the concept of the middle ear ossicular resonance which can be even higher than 1000 Hz has to be reviewed by further studies MFT.

MFT data were measured multiple times between the ages of four weeks and two years from 33 infant/toddlers (Calandruccio, Fitzgerald, & Prieve, 2006). Tympanograms were also measured from 33 adult participants. Tympanograms recorded with five probe tone frequencies (226, 400, 630, 800, and 1000 Hz) were classified using the Vanhuyse model classification system. Admittance at +200 daPa Y (200) and middle ear admittance Y (ME) were calculated. The results showed that the proportion of Vanhuyse patterns in infants/toddlers were different than adults, especially at younger age. Y (ME) and Y (200) both increased with age. Y (ME) and Y (200) data for infant/toddler were significantly lower than adult values at all probe tone frequencies.

Megha and Kumar (2008) provided a normative for the multifrequency parameters RF, ΔG, and Δθ in neonates from birth to one month. The mean value of RF, ΔG, and Δθ was 261.85 Hz, 0.38 mmho and -35.73° respectively.

However, there is lack of normative studies in age range of 3-6 years for the multifrequency tympanometric parameters RF, ΔY, ΔG, Δθ and F45°.

2.5 Race variations in tympanometric parameters

There are a number of studies stating the variations in tympanometric results in different ethnic groups. Daly (1991) has stated that it is important to study different ethnic groups in the same environment in order to control for the large number of factors that may influence the prevalence of OME in a community.

The results of Rushton et al. (1997) suggest that the prevalence of OME is lower amongst Chinese School children than school children of other ethnic groups attending the multicultural schools in Hong Kong.

Reports on the prevalence of OME in African Children were also lower than expected in a study by Okeowo (1985) which was 4.9 per cent and in another study by Halama et al. (1986) it was 3.8 per cent. In both these reports the socio-economic and living conditions were poor and this low incidence of OME was ascribed to genetic factors. There was quick resolution in the high incidence of children with unilateral OME at presentation which indicated that these patients were in the resolving phase at the time of initial screening. Another factor that Rushton et al. (1997) quote is about the sensitivity and specificity of the 226 Hz tympanometry. Although 226 Hz tympanometry has shown to be an effective and objective means for the diagnosis of middle ear pathology (Paradise et al., 1976; Fiellau-Nikolajsen, 1986; Maw & Herod, 1986; Zeilhuis et al., 1990), Margolis et al. (1994) suggest that multifrequency tympanometry is more sensitive to the mechanical disturbances related to OME and should be used in future studies to improve the diagnostic sensitivity and specificity for OME.

Shahnaz and Davies (2006) examined differences between a group of normal-hearing Caucasian and Chinese young adults on six tympanometric parameters. Tympanometric data were obtained on a clinical immittance machine, the Virtual 310 and four of the parameters static admittance (SA), tympanometric width (TW), tympanometric peak pressure (TPP) and ear-canal volume (ECV) was measured automatically at a standard 226 Hz frequency. The two parameters resonant frequency (RF) and SA up to 1200 Hz were measured by multifrequency, multicomponent tympanometry. The results showed that Chinese group had significantly lower SA, wider TW, more positive TPP, and lower ECV than their Caucasian counterparts. The parameter SA up to 1200 Hz showed a significant group effect (Caucasian versus Chinese) until 900 Hz in the male group and up to 1120 Hz in the female group. The Chinese group had significantly higher RF than the Caucasian group. Thus, it was concluded that overall test performance may be improved by using a more homogenous norm when testing the Caucasian or Chinese individuals.

Wong et al. (2008) investigated the tympanometric characteristics of Chinese school-aged children with normal middle ear function. Measurements were made for four tympanometric variables [peak compensated static acoustic admittance (peak Ytm); equivalent ear canal volume (Vec); tympanometric width (TW); and tympanometric peak pressure] from 278 Chinese children aged between 6 and 15 yrs. The results showed that developmental pattern in tympanometric variables found with the Chinese school aged children in the study was similar to that found with white children in Western studies. The lower limit of peak Ytm 90% range of the Chinese school-aged children in the study was lower and their TW values were wider than those of white children. Age-specific data also suggested that the upper Vec limits of children between 6 and 7 yrs of age differed from those of older children.

Racial differences in peak Ytm and TW values were noted, which showed that the Chinese school-aged children had a lower peak Ytm limit and wider TW values than white children. The authors conclude that the use of ASHA, 1997 guidelines for identifying ears for referral with respect to Chinese school-aged children may therefore not be highly sensitive and specific.

2.6 Efficacy of multifrequency tympanometry in diagnosis of different middle ear pathology

The development of multifrequency, multicomponent admittance devices has made it possible to record admittance across a wide range of probe tone frequencies and to derive its polar components (admittance magnitude and its phase angle) or rectangular components (susceptance and conductance). There are many useful parameters that can be derived from multifrequency, multicomponent tympanometry. Some of them being an estimate of the middle ear resonant frequency, compensated susceptance, compensated conductance, phase angle, frequency at 45° and compensated admittance. The efficacy of MFT has been proven by various studies (Hanks & Rose, 1993; Margolis et al., 1994; Vlachou et al., 2001 and others).

2.6.1 Multifrequency tympanometry in identifying otitis media with effusion

Infection of the middle ear (especially OM) is the most common childhood disease. If left untreated, OM may result in permanent hearing loss or other medical complications that may cause damage to the structures of the middle ear (Berman, 1995; Roark & Berman, 1996). Otitis media with effusion (OME) is one of the most prevalent illnesses among children all over the world (Friel-Patti et al., 1982; Hubbard et al., 1985; Northern & Downs, 2001). Many researchers have tried out to seek the most efficient clinical strategies for early diagnosis and management of this condition.

Hanks and Rose (1993) studied multifrequency tympanometry using sweep frequency method in children between the age range of 6 to 15 years for both normal children and children with sensorineural hearing loss. Results showed that the mean RF value for all children was 1003 Hz (650 to1400 Hz range) and phase angle, $\Delta\theta$ had a mean of 31^0 (14^0 to 54^0 range). It was concluded form this study that if the parameters of MFT are used appropriately, they aid as a better tool in identifying middle ear disorder in children.

Margolis et al. (1994) evaluated the middle ear function using 226 Hz tympanometry (Static admittance, tympanometric width, tympanometric peak pressure and equivalent volume) and MFT from 226 Hz to 2000 Hz (Vanhuyse patterns across frequencies) in 98 ears. They found that tympanometric peak pressure is not related to presence or absence of middle ear effusion. Equivalent volume was found to be good predictor of perforation or patulous Eustachian tube patency in the absence of middle ear inflammation. MFT results showed 63% normal, 26% irregular, 11% low resonant frequency from children with otitis media histories. At the time of testing all the children had normal hearing and normal 226 Hz tympanograms and no visual evidence of active middle ear disease. Thus, MFT was found to be more sensitive to mechanical disturbances related to OM that are not detected by 226 Hz tympanometry and audiometry.

Kontrogianni et al. (1996) Multifrequency tympanograms were recorded from 76 ears of 43 children affected by otitis media with effusion (OME) and 90 ears of normal hearing children to obtain data for resonance frequency (RF) and changes in phase angle. There was found to be a statistically significant decrease ($p < 0.01$) in both RF values and change in phase angle in ears with OME compared to normative data. This decrease may be interpreted by considering OME as a mass pathology. Multiple frequency tympanometry seems to be a useful method for determining the effect of various middle-ear pathologies on the mechano-acoustical status of the middle ear system.

Margolis, Schachern, and Fulton (1998) created specific middle ear lesions in chinchillas and compared the results of conventional 226 Hz tympanometry and MFT. They reported that static admittance had a sensitivity of 73% and a specificity of 75% for detecting significant middle ear pathology while tympanometric width was not an effective diagnostic test. Combinations of MFT parameters such as low RF or irregular patterns had a sensitivity and specificity of 91% and 100%, respectively. They concluded that MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry. Moreover, it has been shown that conventional 226 Hz tympanometry is unable to detect sequelae and subtle changes in middle ear mechanics following OM; however, MFT appears to be sensitive to these changes (Hanks & Robinette, 1993; Margolis et al., 1994; Vlachou et al., 1999; Vlachou et al., 2001).

Ferekidis et al. (1999) studied the use MFT to collect information about the mechanoacoustical changes occurring to the middle ear system after acute otitis media and to compare it with the results of conventional, low probe-tone tympanometry. Children with acute otitis media were followed up with both methods for 1 month after an episode of acute infection. Also, children with normal hearing were studied to establish normative data. Resonant frequency of the middle ear was found to be lower than normal even one month past the initial episode, for all types of 226 Hz tympanograms. MFT seemed to record changes in the middle ear after acute otitis media that 226 Hz tympanometry was unable to detect, implying persistence of pathology.

Vlachou et al. (2001) studied how Acute Otitis Media (AOM) affects the middle ear system and to evaluate the change in phase angle ($\Delta\theta$) provided by an automated tympanometer using the sweep frequency technique. MFT and conventional tympanograms were obtained from 70 children suffering from AOM. Changes in the mechanical status of the middle ear after AOM are reflected in abnormal values, despite the normal findings in conventional tympanometry. Abnormal values coexisted with abnormal values of resonance frequency.

More recently, Harris, Hutchinson, and Moravec (2005) evaluated the effectiveness of conventional 226 Hz and MFT tympanograms in detecting middle ear effusion in 21 children prior to myringotomy. They reported that all abnormal cases identified by conventional 226 Hz tympanometry were also identified by MFT; however, three abnormal cases that were identified as normal by 226 Hz tympanometry were correctly identified as abnormal by MFT.

In a study by in Abou-Elhamd et al. (2006) evaluated the diagnostic value of multifrequency tympanometry in otitis media with effusion and adhesive otitis media. 50 patients with long standing or recurrent attacks of otitis media with effusion were selected. A control group was also selected, consisting of 25 patients with normal hearing levels and with no history of Ear Nose and Throat problems. Complete audiological investigations in the form of pure tone audiometry, speech audiometry and immittance were done. Immittance included low probe tone frequency and multifrequency tympanometry. Each subject in the study group had undergone myringotomy and examination under microscope to decide if the case had either otitis media with effusion or adhesive otitis media. Results indicated that resonant frequency proved to have the best performance in reflecting middle ear pathology. It was lowest in otitis media with effusion with a mean value of 428 +/- 159 Hz and it was highest in adhesive otitis media with a mean of 1336 +/- 230 Hz. Thus is was concluded that MFT has an efficacy of 100% in the diagnosis of otitis media with effusion and 70% in the diagnosis of adhesive otitis media.

2.6.2 Multifrequency tympanometry in identifying ossicular chain abnormalities

The utility of multifrequency tympanometry to identify the stapes fixation which occurs in otosclerotic ears and other ossicular chain abnormalities have been studied by various researchers.

Lilly (1973) reported impedance values in polar and in rectangular form at five discrete probe tone frequencies between 125 Hz and 750 Hz for twenty-four patients with surgically confirmed otosclerosis. Results showed that in normal ears, the median impedance magnitude (at the plane of tympanic membrane) decreased by 2464 acoustic ohms as probe tone frequency increased from 125 Hz to 750 Hz. In contrast, in ears with stapes fixation the median impedance increased by 5489 acoustic ohms when probe tone frequency was increased from 125 Hz to 750 Hz. In addition, for normal ears the change in probe frequency from 125 Hz to 750 Hz resulted in a

38.6° change in median phase angle (from -80.2° at 125 Hz to -41.6° at 750 Hz). In contrast, for the ears with stapes fixation the change in probe frequency resulted in only a 10.4° change in median phase angle (from -83.6° at 125 Hz to -73.2° at 750 Hz). These differences in impedance magnitude and phase angle are consistent with reported increases in stiffness associated with otosclerosis. Thus, it can be concluded that, as the resonant frequency is higher in the otosclerotic ear, differential diagnosis should be facilitated by using a higher probe tone frequency.

Colletti (1975, 1976, & 1977) was one of the first to develop a system capable of recording multiple frequency tympanograms across a frequency range wide enough to observe immittance below and above the resonance of the middle ear. This system plotted the impedance values, thus the resulting tympanograms were inverted compared to the admittance tympanograms. Colletti (1975, 1976 & 1977) noticed that three distinct tympanometric patterns emerged as probe tone frequency was increased from 200 to 2000 Hz. The first pattern, recorded at low frequencies (<1000 Hz), was a V-shaped tympanogram (the inverse of an admittance pattern) which is consistent with stiffness controlled middle ear. The second pattern, recorded at mid frequencies (650-1400 Hz) and near the resonant frequency of the middle ear, was a W shaped or notched tympanogram. Colletti (1975, 1976 & 1977) reported that an impedance tympanogram would notch near the middle ear resonant frequency. Thus, the onset of the W pattern coincides with middle ear resonance which is consistent with the Vanhuyse model. The third pattern, recorded at high frequencies (>1400 Hz) where the middle ear is mass controlled, was an inverted V shape tympanogram. Colletti (1977) recorded multifrequency impedance tympanograms in patients with different middle ear pathologies and noted that the transition from V to the notched pattern and then to the inverted V pattern occurs at different frequencies for various middle ear conditions. He found that the transition to the W pattern (coinciding with middle ear resonance) was the easiest to identify. In patients with otosclerosis, the W pattern emerged between 850 and 1650 Hz (mean of 1300 Hz), indicating an increase in resonant frequency due to an increase in stiffness of the middle ear transmission system. Conversely, in patients with ossicular discontinuity, the W pattern emerged between 500 and 900 Hz, indicating a decrease in resonant frequency due to an increase in the mass or a decrease in the stiffness of the middle ear transmission system.

Zwislocki (1982) reported that at a probe tone frequency of about 700 Hz, reactance at the plane of tympanic membrane was negative (indicative of a stiffness controlled system) in subjects with otosclerosis and was approximately twice as large (i.e., more negative and thus much stiffer) than in normal ears. In addition, resistance (R) at 700 Hz was essentially the same in otosclerotic and normal ears.

With the advancements in commercially available computer based admittance devices, researchers have explored middle ear with these admittance devices. With each system it is possible to measure the admittance subcomponents, susceptance and conductance, at different probe tone frequencies. However, each of these systems uses different procedures to derive phase angle and estimate the resonant frequency. Several studies examining the clinical utility of resonant frequency have been reported using each of these newer admittance systems.

The estimation of resonant frequency in the GSI-33 is based on a procedure developed by Funasaka, Funai, and Kumakawa (1984). Using this procedure the mean resonant frequency measured in 50 normal ears was 1500 Hz whereas a resonant frequency of 850 Hz was measured for one subject with ossicular discontinuity and a resonant frequency of 2250 Hz was measured in one subject with otosclerosis.

Shanks, Wilson, and Palmer (1987) measured compensated static susceptance and conductance at probe tone frequencies between approximately 226-1800 Hz. From these data, the lowest frequency at which conductance first becomes larger than susceptance was determined for ten young, normal hearing subjects. This frequency corresponds to admittance phase angle of 45° and was on average 565 Hz for the normal subjects. Data were obtained from one patient with otosclerosis, and showed that the frequency corresponding to 45° phase angle was much higher (904 Hz). Interestingly, in this patient the resonant frequency was not markedly different from the normal ears. These preliminary findings suggest that the frequency corresponding to a 45° phase angle may be a better index than resonant frequency with respect to distinguishing normal and otosclerotic ears.

Funasaka and Kumakawa (1988) used the procedure developed by Funasaka et al. (1984) to compute resonant frequency in 50 normal ears and 40 patients with ossicular disorders. When normal resonant frequency was defined using a 95% confidence interval around the mean of the normal group, 10 out of 12 cases of ossicular discontinuity were correctly diagnosed (i.e., showed an abnormally low resonant frequency) and 5 out of 6 cases of malleus and/ or incus fixation were correctly diagnosed (i.e., showed an abnormally high resonant frequency). However, only 12 out of 22 ears with otosclerosis were correctly diagnosed (i.e., showed an abnormally high resonant frequency). Thus, this method of estimating resonant frequency revealed distinct differences between normal ears and ears with ossicular discontinuity and ears with fixation of the malleus or incus, but was less successful in distinguishing normal and otosclerotic ears. However, it was concluded that, their procedure should be useful in differentiating between ossicular discontinuity and otosclerosis since there was very little overlap between these two groups.

Colletti et al. (1993) examined resonant frequency in 73 surgically confirmed otosclerotic ears and 70 normal hearing individuals using the Virtual middle ear analyzer 310. Using a sweep frequency recording from 226 to 2000 Hz, resonant frequency was determined as the first frequency at which the “W” (notched) configuration occurred on a susceptance tympanogram. The median resonant frequency was 1000 Hz (range 630-1250 Hz) in normal subjects and 1400 Hz (range 710-1800 Hz) in otosclerotic ears, which was statistically different from normal ears.

Valvik, Johnsen, and Laukli (1994) measured the resonant frequency in 100 subjects with normal hearing and in several groups of subjects with different middle ear pathologies using the GSI 33 (Version 2). Resonant frequency was measured by calculating ΔB as a function of probe tone frequency as described above and finding the frequency at which ΔB has a value of zero. Mean resonant frequency for a group of normal ears was 1049 Hz with a markedly wide range of 350 Hz to 1750 Hz. A wide range of resonance frequencies was also found preoperatively in 38 ears with otosclerosis, with a mean of 1238 Hz (SD of 209). Thus, the mean resonant frequency was significantly higher in the otosclerotic ears than in normal ears, but there was a considerable overlap between the two groups. Recording of the resonant frequency in five otosclerotic ears was also done after surgery. The mean resonant frequency in this group ranged from 150 to 650 Hz (mean of 460 Hz). As expected, stapes surgery reduced the resonant frequency, indicating a reduction in stiffness and/or an increase in mass of the middle ear transmission system.

Shahanz and Polka (1997) evaluated alternative tympanometric parameters for distinguishing normal middle ears from ears with otosclerosis. A secondary goal was to provide guidelines and normative data for interpreting multifrequency tympanometry obtained using the Virtual 310 immittance system. Nine tympanometric measures were examined in 68 normal ears and 14 ears with surgically confirmed otosclerosis. No subjects in either group had a history of head trauma or otoscopic evidence of eardrum abnormalities. Two parameters, static admittance and tympanometric width, were derived from standard low-frequency tympanometry and two parameters, resonant frequency and frequency corresponding to admittance phase angle of 45^0 ($F45^0$), were derived from multifrequency tympanometry.

Differences between normal and otosclerotic ears were statistically significant only for resonant frequency and $F45^0$. Group differences in resonant frequency were larger when estimated using positive tail, rather than negative tail, compensation. Group differences in both resonant frequency and $F45^0$ were larger when estimated from sweep frequency (SF), rather than sweep pressure, tympanograms. Test performance analysis and patterns of individual test performance point to two independent signs of otosclerosis in the patient group,

- An increase in the stiffness of the middle ear, best indexed by $F45^0$ derived from SF recordings, and
- A change in the dynamic response of the tympanic membrane/middle ear system to changes in ear canal pressure, best indexed by tympanometric width. Most patients were correctly identified by only one of these two signs.

Thus, optimal test performance was achieved by combining $F45^0$ derived from SF recordings and tympanometric width. The findings confirm the advantage of multifrequency tympanometry over standard low-frequency tympanometry in differentiating otosclerotic and normal ears. The relationship among different tympanometric measures suggests a general strategy for combining tympanometric measures to improve the identification of otosclerosis.

Wada et al. (1998) aimed to develop a measuring apparatus that the ability to sweep both frequency and external auditory meatus static pressure and can display measurement results in a three dimensional expression and to measure the middle ear dynamic characteristics of normal-hearing subjects and of patients with this apparatus. 275 ears of normal hearing subjects and 72 ears of middle ear disease were taken. The results revealed that rate of correct diagnosis of ossicular chain separation is 84% and that of ossicular chain fixation is 74%.

Thus it can be summarized that multifrequency tympanometry is efficient in diagnosing middle ear disorders like otitis media and ossicular abnormalities.

Literature review also presents high incidence and prevalence of middle ear problems in children. Though there are several normative on multifrequency parameters, none have provided the normative for the resonant frequency, ΔY, ΔG, Δθ and F45° in the age range of 3-6 years. Thus there is a need to provide normative for all the above mentioned parameters for effective diagnosis of middle ear problems in children.

3. Method

To arrive at the normative data for RF at ΔB~0; ΔY, ΔG, Δθ at RF and F45° for children from 3-6 years of age, the following method was employed.

Participants

Ninety participants in the age group of 3-6 years were enrolled for the study. Participants were divided into three age groups. The mean age for each group with the age range is shown in Table 2 below.

Table 2.

Mean and age range for the three age groups

Groups	**Gender**	**Mean age (in years)**	**Range (in years)**
Group A: 3+ to 4 years	Male	3.65	3.2 to 3.7
	Female	3.48	3.3 to 3.6
Group B: 4+ to 5 years	Male	4.53	4.3 to 4.6
	Female	4.26	4.4 to 4.8
Group C: 5+ to 6 years	Male	5.42	5.0 to 5.7
	Female	5.34	5.2 to 5.6

Thirty participants were taken in each group.

The 10% of subjects from each group were retested to check the reliability of the obtained data within two months from the first testing.

Participant selection criteria

- A questionnaire consisting of questions which would rule out high risk factors as well as prior history of any middle ear disorder was prepared.
- Participants without any past history of middle ear disorders/problems were selected based on the data collected on this questionnaire.
- Pure tone audiometric thresholds of all participants for air conduction (AC) from 500 to 4000 Hz frequency range were ≤ 15 dB HL.
- Subjects who have normal acoustic reflex thresholds ≤ 100 dB HL (Wiley, Oviatt & Block, 1987) at frequencies 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz ipsilaterally were taken for study.

Instrumentation

- Calibrated two channel diagnostic OB 922 diagnostic audiometer with TDH 39 headphones with MX 14AR cushion.
- Calibrated GSI Tympstar middle ear analyzer version 2.0

Test environment

Both pure tone audiometry and tympanometric measurements were done in sound treated room with permissible noise levels (ANSI, 1991).

Procedure

1. Puretone thresholds for air conduction were obtained at octave intervals from 500 Hz to 4000 Hz.
2. Immittance audiometry with a probe tone frequency of 226 Hz was carried out. Ipsilateral acoustic reflexes thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at the peak pressure.
3. The procedure described by Funasaka, Funai and Kumakawa (1984) i.e., the sweep frequency method of multifrequency tympanometry was used in the current study to obtain the following data (1) RF at $\Delta B \sim 0$; (2) ΔY, ΔG, $\Delta\theta$ at RF and (3) F45°.

According to the sweep frequency procedure the frequency is swept twice from 250 to 2000 Hz at two different pressure i.e., +200 daPa and peak pressure.

1) At +200daPa, the vectors are measured as Y_{+200}, B_{+200}, G_{+200} with respect to selection of delta plots Y, B and G respectively .

2) At peak pressure, the vectors are measured as Y_{peak} B_{peak}, and G_{peak} with respect to selection of delta plots Y, B and G respectively.

The differences of the two vectors Y_{+200}, B_{+200}, G_{+200} and Y_{peak}, B_{peak} and G_{peak} are calculated by the middle ear analyzer as a function of frequency in step size of 10Hz. The admittance, susceptance, conductance parameters are represented as ΔY (the peak to tail difference in acoustic admittance), ΔB (the peak to tail difference in acoustic susceptance), ΔG (the peak to tail difference in acoustic conductance) are calculated as function of frequency, Similarly $\Delta\theta$ (phase angle difference between the admittance vectors at peak pressure and at +200daPa) is calculated simultaneously as function of frequency, where θ is angle between susceptance and conductance.

The ΔY, ΔB, ΔG and $\Delta\theta$ values are given by the automated subtraction of corresponding values at each frequency between first and second frequency sweep and graph of ΔY, ΔB, ΔG and $\Delta\theta$ are displayed across frequency. From these displays, RF was identified as the frequency where the value of ΔB reaches 0mmhos. The values of ΔY, ΔG, $\Delta\theta$ were taken at the resonant frequency.

Frequency at admittance phase angle of 45º (F 45º)

Estimate of frequency corresponding to 45º phase angle is taken as the lowest frequency at which compensated conductance first becomes equal or larger than compensated peak susceptance i.e. where $\Delta B \leq \Delta G$. This was accomplished by comparing the delta plot values of susceptance and conductance at each frequency from 250-2000 Hz in 50 Hz step.

Analysis of the obtained data was done to calculate the mean and standard deviation for resonant frequency, ΔY, ΔG, $\Delta\theta$ and frequency at 45°. Analysis was also done to study the age, ear, and gender differences. Correlation was done to check the reliability of the data.

4. Results and Discussion

The present study was conducted with an aim of establishing a normative data for resonant frequency (RF), compensated admittance (ΔY), compensated suspectance (ΔG), phase angle (Δθ) and frequency at 45° (F45°) across the three age groups of 3+ to 4 yrs, 4+ to 5 yrs and 5+ to 6 yrs. The present study also aimed at studying the age, ear, and gender differences in the three age groups.

The data obtained for all the above mentioned parameters was analysed using Statistical Package for the Social Sciences (SPSS) version 15 software. The following statistical tools were used to analyse the obtained data:

- Descriptive statistics to calculate the mean and standard deviation for RF, ΔY, ΔG, Δθ and frequency at 45°.
- Multiple analysis of variance (MANOVA) to study the overall age effects on RF, ΔY, ΔG, Δθ and frequency at 45° across the three age groups.
- Bonferroni Post Hoc analysis was done to study the pair wise comparison on RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups.
- Paired sample t-test was done to study the ear effects on RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups.
- Mann Whitney U test was done to study the gender effects on RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups (as sample size for males and females was unequal).
- Pearson’s Rank correlation to perform the reliability check.

4.1 Mean and standard deviation for different multifrequency parameters

The mean and standard deviation for RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups from 3+ to 4 yrs, 4+ to 5 yrs and 5+ to 6 yrs, with 30 subjects in each group (60 ears, N=60) is shown in Table 3.

Table 3.

Mean and SD for RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups

Age groups (years)	**RF (Hz)**		**ΔY (mmho)**		**ΔG (mmho)**		**Δθ (degree)**		**F45° (Hz)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
3+ to 4	1087.83	177.25	1.29	0.86	2.12	1.27	-26.36°	9.87	494.16	101.71
4+ to 5	1059.33	158.41	1.49	0.77	2.64	1.22	-25.13°	6.42	497.50	86.07
5+ to 6	1049.50	110.82	1.41	0.54	2.72	0.73	-31.13°	4.06	465.0	60.57

Note. RF- Resonant frequency; ΔY- compensated admittance; ΔG- compensated conductance; Δθ- phase angle; F45°- frequency at 45°

From Table 3 it can be seen that the multifrequency parameters vary across the 3 age groups. The mean and SD for resonant frequency decreases across the three age groups. Figure 5 shows the error bar comparing the mean and standard deviation for resonant frequency across the three age groups. The range of RF for 3+ to 4 years was 620 to 1390 Hz with a mean of 1087.83 Hz, which was less than the RF range of 4+ to 5 years (650 to1400 Hz with a mean of 1059.33 Hz); this was further less than the range of 5+ to 6 years, that is, 790 to 1260 Hz, with a mean value of 1049.50 Hz. This implies that the RF values decrease as the age increases from 3 to 6 years of age.

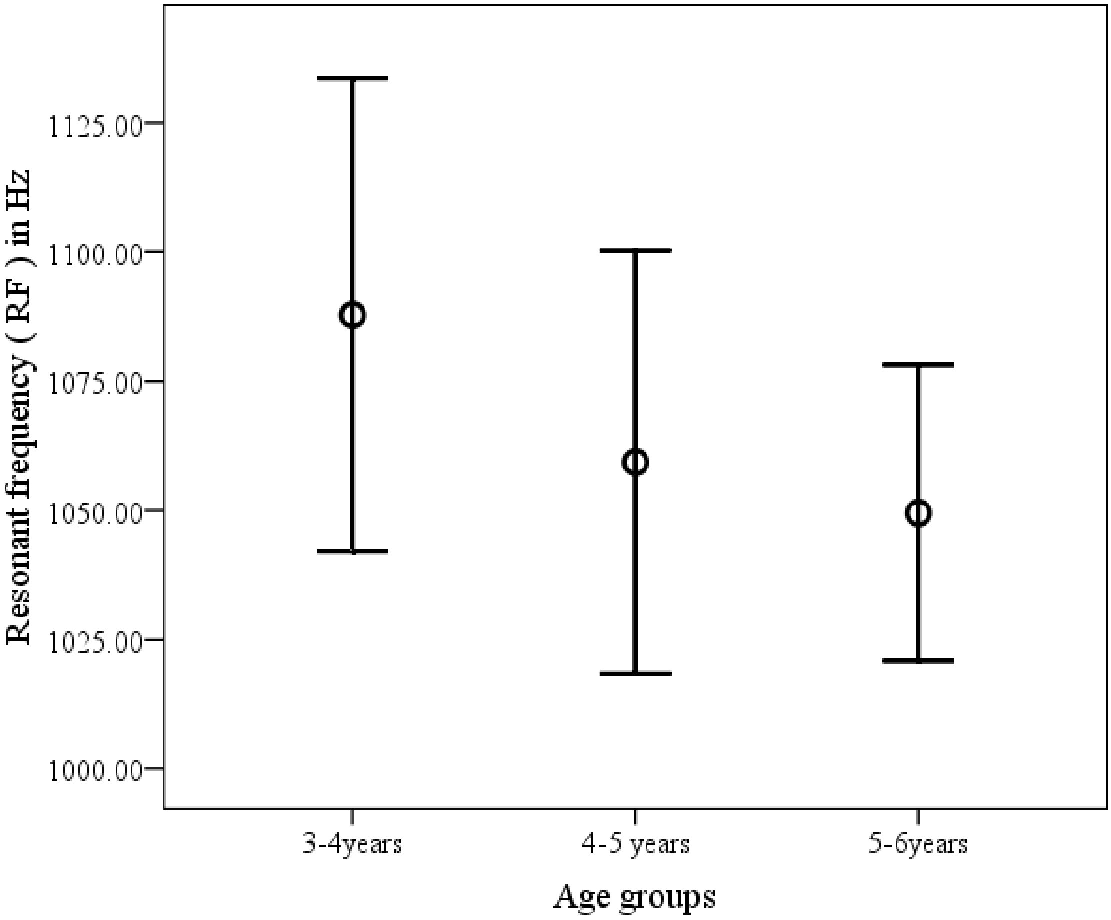

Figure 5. Error bar comparing the mean and standard deviation of Resonant frequency (RF) across the age groups

The range of compensated admittance (ΔY) for 3+ to 4yrs group was 0.21 to 3.65 mmho, with a mean of 1.29 mmho. This was less compared to that of 4+ to 5yrs and 5+ to 6yrs with range of 0.21 to 3.73 mmho (mean = 1.49 mmho) and 0.34 to 2.78 mmho (mean = 1.41 mmho) respectively. But there was no difference in mean values between 4+ to 5yrs and 5+ to 6yrs of age. The SD for ΔY decreased across the age groups, implying decreased variation in compensated admittance measures of children with in an age group, as they grew older. Figure 6 shows the error bar comparing the mean and standard deviation of compensated admittance (ΔY) across the age groups.

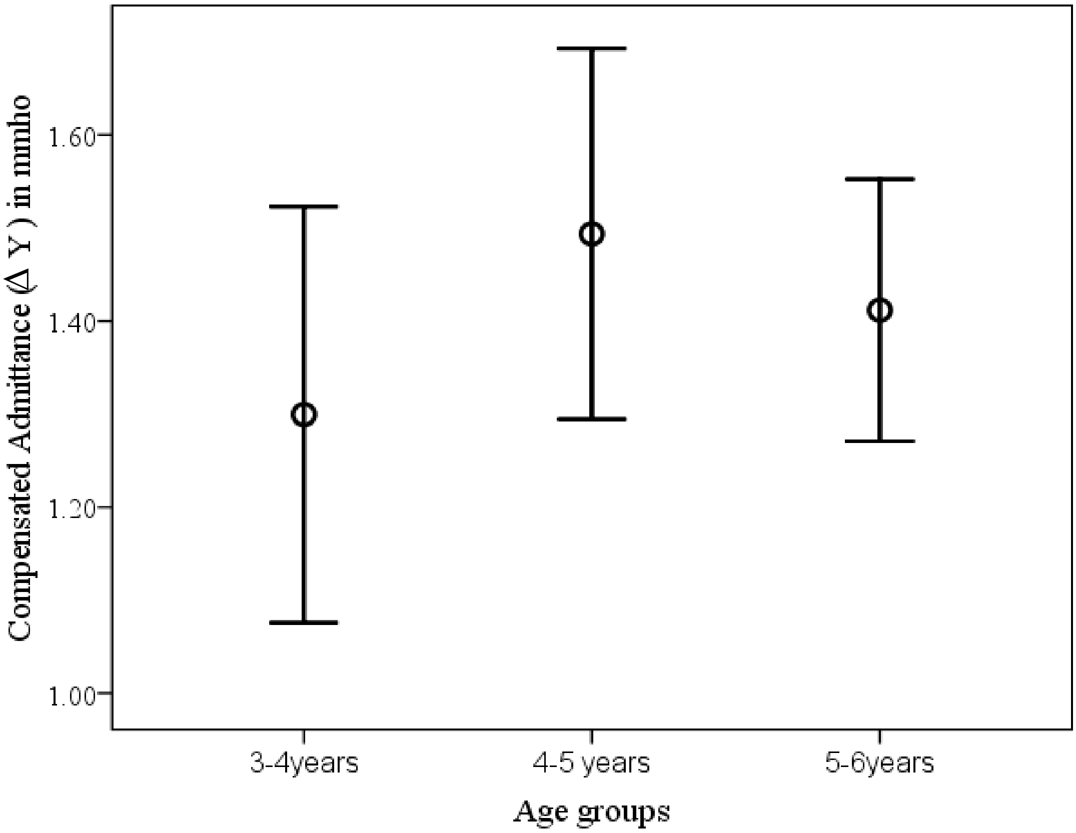

Figure 6. Error bar comparing the mean and standard deviation of compensated admittance (ΔY) across the age groups

The range of compensated conductance (ΔG) for 3+ to 4yrs group was 0.72 to 5.48 mmho with a mean of 2.12 mmho. This was less compared to that of 4+ to 5yrs and 5+ to 6yrs with range of 0.51 to 6.60 mmho (mean = 2.64) and 0.79 to 3.97 mmho (mean = 2.72) respectively. But there was little difference in mean values between 4+

to 5yrs and 5+ to 6yrs of age. The SD for ΔG decreased across the age group implying decreased variation in compensated conductance measures of children with in an age group, as they grew older. Figure 7 shows error bar comparing the mean and standard deviation of compensated conductance (ΔG) across the age groups.

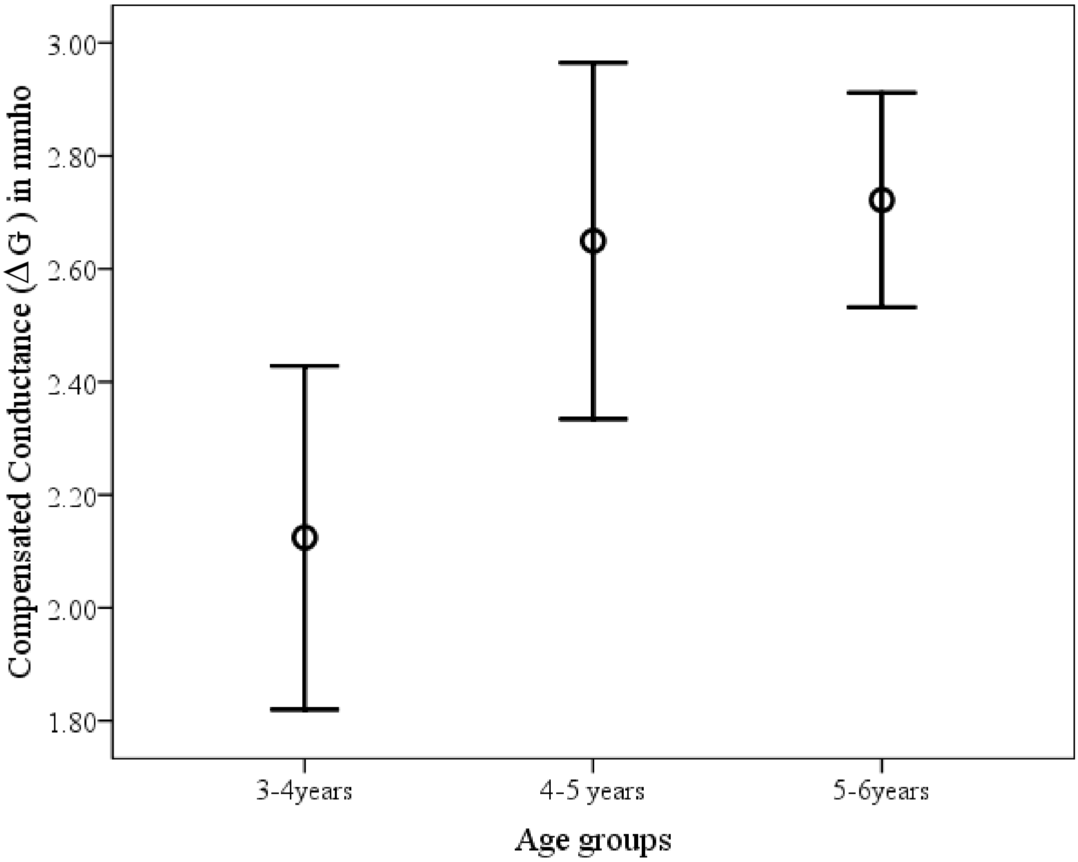

Figure 7. Error bar comparing the mean and standard deviation of compensated conductance (ΔG) across the age groups

The range of phase angle (Δθ) for the 3+ to 4yrs was -60° to -10° with a mean of -26.36° and for 4+ to 5yrs was -38° to -10° with a mean of -25.13°. These values were almost comparable. The range for 5+ to 6 yrs group was -39° to -22° with a mean of -31.13°, which was much lower than that of 3+ to 4yrs and 4+ to 5yrs of age. The mean SD of phase angle decreased across the age groups implying decreased variation in compensated phase angle measures of children with in an age group, as they grew older. Figure 8 shows the error plot comparing the mean and standard deviation of phase angle across the age groups.

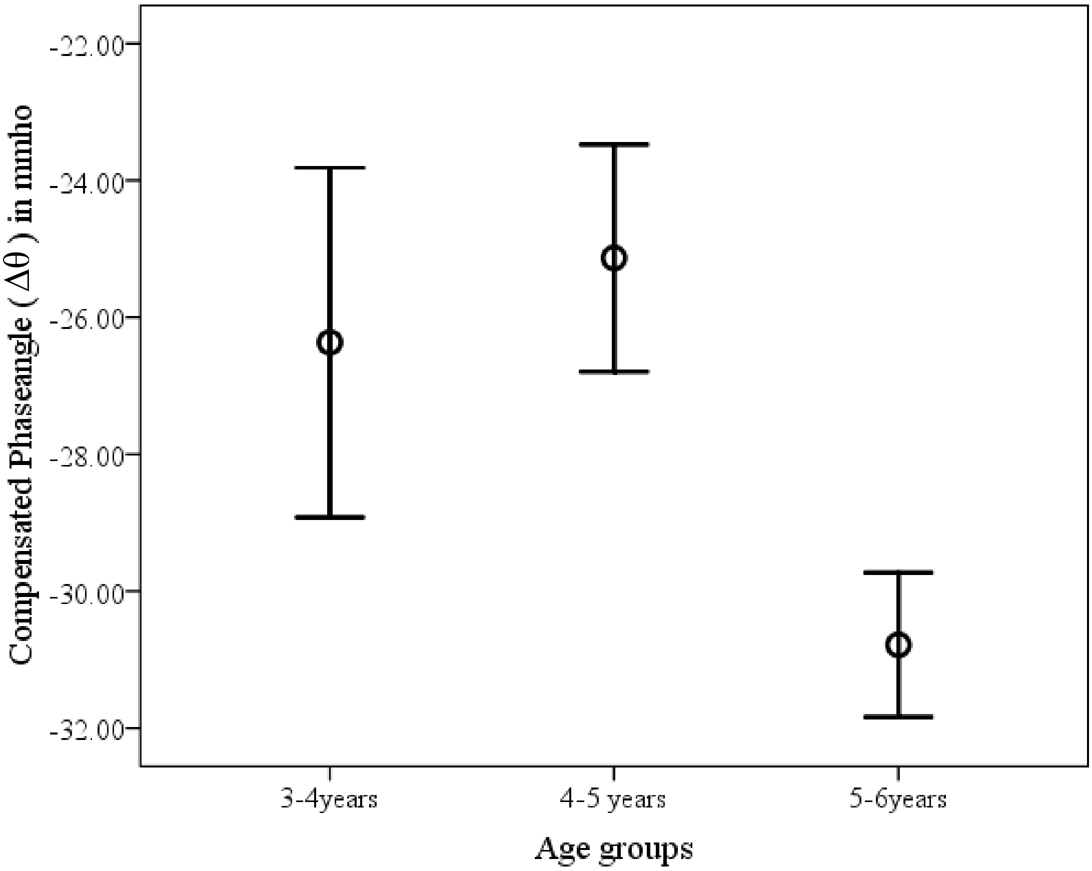

Figure 8. Error bar comparing the mean and standard deviation of phase angle (Δθ) across the age groups

The range for frequency at 45° (F45°) for 3+ to 4yrs was 350 to 750 Hz with a mean of 494.16 Hz and 4+ to 5yrs 350 to 700 Hz with a mean of 497.50 Hz, which were almost comparable. The range for 5+ to 6 yrs was 350 to 700 Hz with a mean of 465 Hz which was much lower than that of 3+ to 4yrs and 4+ to 5yrs of age. The mean SD of F45° decreased across the age groups, implying decreased variation in F45° measures of children with in an age group, as they grew older. Figure 9 shows the error bar comparing the mean and standard deviation of frequency at 45° across the age groups.

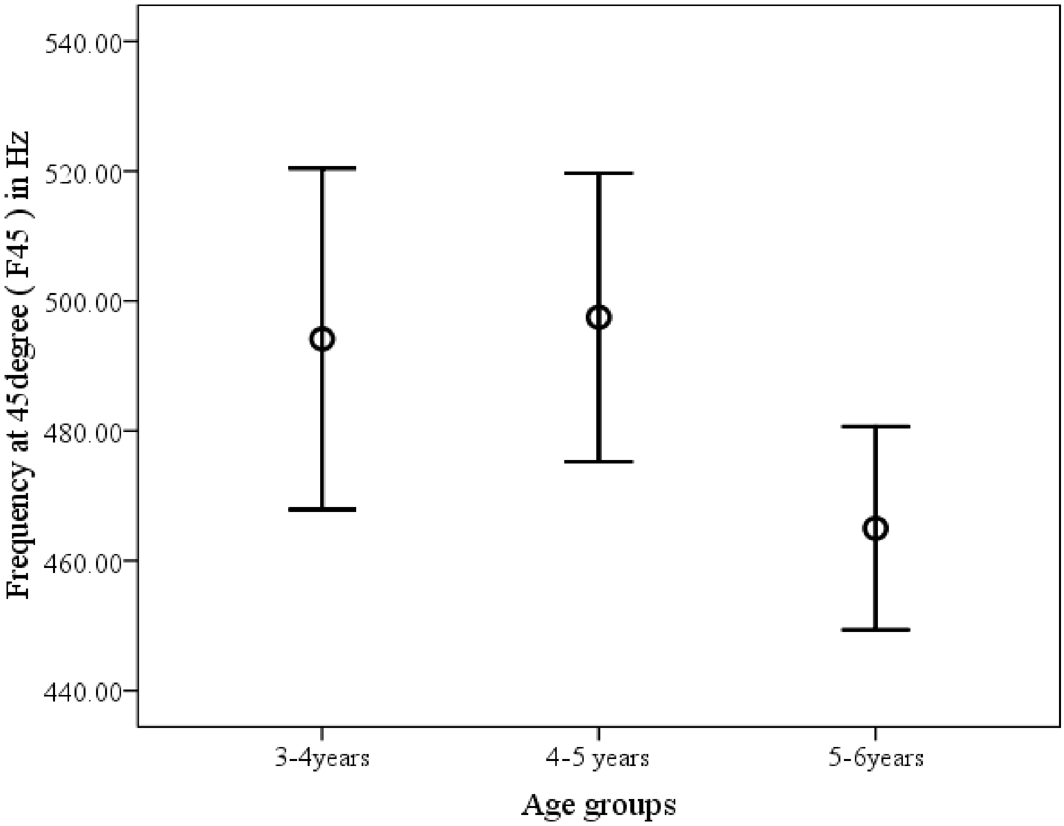

Figure 9. Error bar comparing the mean and standard deviation of frequency at 45° across the age groups

4.2 Comparison of multifrequency parameters across groups

Multiple analysis of variance (MANOVA) was done to compare the multifrequency parameters RF, ΔY, ΔG, Δθ and frequency at 45° across the age groups. The results showed that there was a significant difference in compensated conductance (ΔG) [F (2, 180) = 5.60, $p<0.05$] and phase angle (Δθ) [F (2, 180) = 10.21, $p<0.05$] across age groups. However RF, ΔY and F45° did not show any significant difference across the age groups.

The parameters which showed significant difference (ΔG and Δθ) were further analysed for pair wise comparison using the Bonferroni post hoc analysis test.

The results of Bonferroni post hoc test tabulated in the Table 4 reveal that there is significant difference in compensated conductance (ΔG) between the pairs 3+ to 4 years and 4+ to 5 years age groups ($p<0.05$) and also between 3+ to 4 years and 5+ to 6 years age groups ($p<0.05$).

Table 4.

The results of Bonferroni post hoc test

Parameter	**Age groups (years)**	**3+ to 4yrs**	**4+ to 5yrs**	**5+ to 6yrs**
Resonant Frequency (Hz)	3+ to 4		p>0.05	p>0.05
	4+ to 5	p>0.05		p>0.05
	5+ to 6	p>0.05	p>0.05	
Compensated Admittance (ΔY) mmho	3+ to 4		p>0.05	p>0.05
	4+ to 5	p>0.05		p>0.05
	5+ to 6	p>0.05	p>0.05	
Compensated Conductance (ΔG) mmho	3+ to 4		**p<0.05****	**p<0.05****
	4+ to 5	**p<0.05****		p>0.05
	5+ to 6	**p<0.05****	p>0.05	
Phase angle (Δθ) degree	3+ to 4		p>0.05	**p<0.05****
	4+ to 5	p>0.05		**p<0.05****
	5+ to 6	**p<0.05****	**p<0.05****	
F45° (Hz)	3+ to 4		p>0.05	p>0.05
	4+ to 5	p>0.05		p>0.05
	5+ to 6	p>0.05	p>0.05	

Note. ** Indicates significant difference between the pairs

Hanks and Rose (1993) reported that the mean value of RF as 1003 Hz with SD 216 in children from 6 years to 15 years which is consistent with the results of the present study. Margolis & Goycoolea (1993) reported mean RF of 1135 Hz in adults and similar results have also been found by Kumar and Adithya (2007) with a mean RF of 1051.53 Hz in adults. Megha and Kumar (2008) studied multifrequency parameters in neonates and reported the mean RF as 261.85 Hz. Thus it can be seen that there is an increase of RF from birth to childhood. However there is no change of RF in 3-6 years and is comparable to that of adults. This indicates that RF reaches adult like values by the age of 3-6 years of age.

Manuel (2004) reported that mean compensated admittance values in neonates as 0.74 mmho with SD 0.26, which is lower than the obtained values for 3-6 years of age in the present study. Calandruccio (2006) reported that admittance of the middle ear in 2 years at 1 kHz probe tone to be 2.46 mmho (median value) with range from 1.11 to 4.07 mmho and in adults 2.76 mmho (median) with range from 0.86 to 4.69 mmho which was not significantly different from that of 2 year old group. In the present study, the median values were 1.075, 1.46 and 1.25 in 3+ to 4 years, 4+ to 5 years and 5+ to 6 years respectively. However, these values were taken at the RF, and show no statistical significance across the age groups. Even though, there is a trend of successive increase of compensated admittance from birth to childhood, there is no change of compensated admittance in 3-6 years and is comparable to that of adults. This indicates that compensated admittance reaches adult like values by the age of 3-6 years of age.

Sabitha (1994) studied conductance at 1000 Hz across the age groups 8-12 years of age. The mean conductance value was 3.67, 3.99 and 3.74 mmho respectively for the three age groups. These results are similar to that of the adults. Kumar and Adithya (2007) reported mean ΔG of 3.58 mmho in adults and similar results have been found by Miani et al., (2000). Megha and Kumar (2008) reported mean ΔG for neonates to be 0.38 mmho. In this present study, the mean ΔG was 2.49 mmho for 3 years to 6 years old children. This was higher than the neonatal age group and lower than the adult age group. Thus it can be seen that there is a trend of successive increase of ΔG from neonate to childhood and reaches adult like value by 8 years of age.

The phase angle (Δθ) was significantly different between the age groups 3+ to 4 years and 5+ to 6 years age groups ($p<0.05$) and also between the age groups 4+ to 5 years and 5+ to 6 years ($p<0.05$). In adults the mean Δθ as reported by Kumar and Adithya (2007) was -26.77°, which was taken at RF, where the reported mean RF value was 1051.53 Hz. Similarly, Megha and Kumar (2008) reported a mean of -35.73° for Δθ in neonates at RF, where the reported mean RF value was 261.85 Hz. Hence Δθ value for both adults and neonates was taken at RF, and thus it can be compared. It can be seen that the Δθ value for a neonatal middle ear was low with a mean of -35.73° (Megha & Kumar, 2008) which was less than the adult mean values which was -26.77° (Kumar & Adithya, 2007). The present study showed significant difference in Δθ values between the age groups 3+ to 4 years and 5+ to 6 years and also between the pairs 4+ to 5 years and 5+ to 6 years age groups. Thus, these results show the developmental changes in the Δθ values.

Shahnaz and Polka (1997) studied F45° in adults and reported that the mean F45° to be 615 Hz (SD 148). In the present study, the mean F45° value for 3+ 4 years group to 5+ to 6 years group was 485.55 Hz. This is lower than the mean reported by Shahnaz and Polka (1997). In the present study, there was no significant difference across age groups for F45°. Even after taking into cognizance, Shahnaz and Polka (1997) used Virtual digital immittance instrument (model 310) where the values of F45° are calculated automatically by the instrument and in the present study used GSI Tympstar immittance meter where the experimenter has to manually calculate the

F45° values by considering the point where B and G values are equal and they reported for the western population. It appears that the F45° increases from childhood to adulthood, but may not be significantly increasing from 3-6 years of age. On the absence of studies of F45° values on younger children, it is difficult to remark on variation of F45° from birth to childhood.

The significant changes only in ΔG and $\Delta\theta$ may indicate that these parameters change with maturational changes in the middle ear. Eby and Nadol (1986) indicate that the formation of the middle ear is complete by 5 years. Lilly (1973) demonstrated that the first component of impedance to be affected by otosclerosis, in a subclinical stage is resistance (Conductance in case of admittance measures). More the increase in resistance, more the decrease in conductance. This is again shown in the recent years that ΔG and $\Delta\theta$ are more sensitive in detecting the subtle middle ear pathologies, which may go undiagnosed by the normal 226 Hz tympanometry (Kumar & Adithya, 2007). These findings are also in support with respect to the anatomical changes in the external ear and middle ear and also occurrence of tympanic membrane changes among school aged children (Haapaniemi, Suonpää, & Virolainen, 1995; Haapaniemi, Suonpää, Salmivalli, & Tuominen, 1995). Petrak (2002) reported that there are changes in the size of the external and middle ear cavity, orientation of tympanic membrane and tightening of the ossicular joints from birth to childhood till 2 years of age. Thus, this indicates that ΔG and $\Delta\theta$ are more sensitive in indicating the subtle age related changes in the middle ear.

4.3 Comparison of multifrequency parameters between the ears across age groups

Comparison of multifrequency parameters RF, ΔY, ΔG, Δθ and F45° were done to see the differences between the ears across the three age groups (N=90). The mean and standard deviation for right and left ears across the age are as tabulated in Table 5.

Table 5.

Mean and standard deviation for RF, ΔY, ΔG, Δθ and F45° for right and left ear across the three age groups

Age groups (years)		RF (Hz)		ΔY (mmho)		ΔG (mmho)		Δθ (degree)		F45° (Hz)	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
3+ to 4	**R**	1089.66	184.43	1.29	0.96	2.11	1.29	-25.70	10.74	493.3	108.8
	L	1086.00	172.91	1.32	0.76	1.32	0.76	-27.03	9.06	495	95.90
4+ to 5	**R**	1071.00	156.71	1.52	0.72	2.74	1.19	-25.56	5.94	501.6	88.55
	L	1047.66	161.90	1.46	0.82	2.55	1.25	-24.70	6.93	493.3	84.82
5+ to 6	**R**	1059.66	112.11	1.40	0.56	2.69	0.70	-30.30	4.34	465.0	68.41
	L	1039.33	110.48	1.42	0.53	2.75	0.77	-31.26	3.82	465.0	52.76

The mean values of multifrequency parameters RF, ΔY, ΔG, Δθ and F45° were comparable for both right and left ears across the three age groups. Paired sample t-test was done to compare the right and left ear values for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups (N=90).

Results of paired sample t-test showed no significant difference between the right and left ears for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups. This is in consistent with the results found by Hanks and Rose (1993) in 6-15 years group and Haapaniemi (1996) in adults. Thus confirming that there is similar middle ear mechanics taking place in both the ears.

The results of the paired sample t-test are as shown in the Table 6.

Table 6.

Results of paired sample t-test for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° for right and left ears across the three age groups

Age groups (years)	**Parameters**	**Df**	**t-value**	**Significance (2- tailed)**
3+ to 4	RF right- RF left	29	0.14	0.88
	ΔY right-ΔY left	29	-0.11	0.90
	ΔG right- ΔG left	29	-0.03	0.97
	Δθ right- Δθ left	29	1.07	0.29
	F45°right- F45°left	29	-0.13	0.89
4+ to 5	RF right- RF left	29	0.99	0.32
	ΔY right-ΔY left	29	1.35	0.18
	ΔG right- ΔG left	29	0.59	0.55
	Δθ right- Δθ left	29	-1.14	0.26
	F45° right- F45°left	29	0.79	0.43
5+ to 6	RF right- RF left	29	1.06	0.29
	ΔY right-ΔY left	29	-0.60	0.55
	ΔG right- ΔG left	29	-0.29	0.77
	Δθ right- Δθ left	29	1.78	0.08
	F45° right- F45°left	29	0.00	1.00

4.4 Comparison of multifrequency parameters RF, ΔY, ΔG, Δθ and F45° for boys and girls across the age groups

The mean and standard deviation for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups for boys and girls are shown in Table 7.

Table 7.

Mean and standard deviation for boys and girls for RF, ΔY, ΔG, Δθ and F45° across the age groups

Age groups (years)		**RF (Hz)**		**ΔY (mmho)**		**ΔG (mmho)**		**Δθ (degree)**		**F45° (Hz)**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
3+ to 4	**Boys(N= 20)**	1087.0	229.4	1.37	0.92	2.19	1.12	-25.10	8.24	492.50	93.57
	Girls(N= 40)	1088.25	147.95	1.26	0.84	2.08	1.17	-27.00	10.6	495.00	106.6
4+ to 5	**Boys(N= 22)**	1027.72	156.14	1.30	0.75	2.32	1.20	-23.18	6.22	470.45	89.52
	Girls(N= 38)	1077.63	158.87	1.60	0.76	2.83	1.20	-26.36	6.34	492.10	67.30
5+ to 6	**Boys(N= 28)**	1037.50	108.17	1.37	0.50	2.76	0.63	-23.18	6.22	470.45	89.52
	Girls(N= 32)	1053.12	111.77	1.43	0.58	2.70	0.82	-31.87	3.35	465.62	49.89

From Table 7 it can be seen that the mean values for both boys and girls were similar for all the multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups.

Mann-Whitney test was done to compare the boy and girl differences for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups. The results of the Mann-Whitney test are as shown in the Table 8.

Table 8.

Results of Mann- Whitney test for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° for boys and girls across the three age groups

Age groups (years)	**Parameters**	**Z**	**Significance (2-tailed)**
3+ to 4	RF boy - RF girl	-0.54	0.58
	ΔY boy - ΔY girl	-0.65	0.51
	ΔG boy - ΔG girl	-0.28	0.77
	Δθ boy - Δθ girl	0.00	1.00
	F45° boy - F45° girl	-0.17	0.86
4+ to 5	RF boy - RF girl	-1.12	0.25
	ΔY boy - ΔY girl	-1.24	0.21
	ΔG boy - ΔG girl	-1.43	0.15
	Δθ boy - Δθ girl	-1.95	0.51
	F45° boy - F45° girl	-0.80	0.42
5+ to 6	RF boy - RF girl	-0.75	0.44
	ΔY boy - ΔY girl	-0.51	0.60
	ΔG boy - ΔG girl	-0.08	0.93
	Δθ boy - Δθ girl	-1.63	0.10
	F45° boy - F45° girl	-1.48	0.13

As shown in the above Table 8, results of Mann-Whitney test showed no significant difference between boys and girls for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° across the three age groups. This is also consistent with the results by Hanks and Rose (1993) and Li (2006) who state that there are no gender differences in both sweep frequency tympanometry and normal 226 Hz tympanometry. This shows that the middle ear mechanism (stiffness and mass component) are same irrespective of the gender.

4.5 Reliability check

Reliability check was performed on 10% of the obtained data. The correlation analysis was done to check the reliability of the data. The results of Pearson’s rank correlation are as shown in the following Table 9.

Table 9.

Results of Correlation analysis for RF, ΔY, ΔG, $\Delta\theta$ and F45°

Parameters	**N**	**r**	**Significance**
Resonant frequency	20	0.95 ***	0.00 (0.001 level)
ΔY	20	0.90 ***	0.00 (0.001 level)
ΔG	20	0.97 ***	0.00 (0.001 level)
Δθ	20	0.48 *	0.03 (0.05 level)
F45°	20	0.57 **	0.00 (0.001 level)

Note. *** indicates high correlation, ** indicates positive correlation at 0.001 significance level, * indicates positive correlation at 0.05 significance

Pearson’s rank correlation results from the Table 9 indicate that there is correlation for RF, ∆Y, ∆G, ∆θ and F45° between the two measurements. Thus this shows that RF, ∆Y, ∆G, ∆θ and F45° measurements were reliable.

Thus, a normative data has been established for multifrequency parameters RF, ∆Y, ∆G, ∆θ and F45° in 3 to 6 years of age. RF, ∆Y, and F45° showed no significant differences across the age from 3 to 6 yesrs. However, ∆G and ∆θ showed variations across 3 to 6 years of age. There were no ear and gender effects seen in the groups for all the multifrequency parameters.

5. Summary and Conclusion

The study aimed at providing the normative data for multifrequency tympanometry parameters RF, ΔY, ΔG, Δθ and F45° using the sweep frequency method for the age range of 3-6 years. The sweep frequency method involves the probe tone frequency to be swept twice from 250 Hz to 2000 Hz at two different pressure i.e., +200 daPa and peak pressure and the F45° value needs to be calculated manually using the B and G values in the GSI tympstar immittance meter. Results were analysed using appropriate statistical tools like descriptive statistics, MANOVA, paired sample t-test, Mann Whitney test and correlational analysis. Results are summarized in Table 10.

Table 10.

Summary of mean values for RF, ΔY, ΔG, Δθ and F45° across the three age groups

Age groups (years)	**RF (Hz)**	**ΔY (mmho)**	**ΔG (mmho)**	**Δθ (degree)**	**F45° (Hz)**
3+ to 4	1087.83	1.29	2.12	-26.36°	494.16
4+ to 5	1059.33	1.49	2.64	-25.13°	497.50
5+ to 6	1049.50	1.41	2.72	-31.13°	465.0

- MANOVA and Bonferroni post Hoc tests revealed that there is significant increase in the values of compensated conductance (ΔG) between the pairs 3+

to 4 years and 4+ to 5 years age groups ($p<0.05$) and also between 3+ to 4 years and 5+ to 6 years age groups ($p<0.05$) and the phase angle ($\Delta\theta$) significantly increase between the pairs 3+ to 4 years and 5+ to 6 years age groups ($p<0.05$); also between the pairs 4+ to 5 years and 5+ to 6 years age groups ($p<0.05$). This can be due to the developmental changes in external and middle ear resulting in differences in ΔG and $\Delta\theta$ and indicate the maturational changes that is taking place in the middle ear across 3-6 years of age.

- However other multifrequency parameters like RF, ΔY and F45° did not show any change across the age groups indicating that they may be stabilized by 3-6 years of age.
- There was no effect of gender and ear differences in the age range of 3-6 years on the parameters studied.

Thus, the normative provided by this study can aid in assessing the middle ear functioning in clinical population and also to see the developmental trend of the middle ear across the age groups. However, further research can be conducted by comparing the obtained normative with the clinical population to establish the efficacy of these multifrequency tympanometric parameters in the age range of 3-6 years.

Limitations of the study:

- The study was not conducted on clinical population for validation purposes.
- Number of subjects considered was less (N= 30 in each group).
- The subjects considered were not homogeneous in terms of socio-economic status.

- The questionnaire administered to rule out the history of / presence of middle ear infections and medical problems was not a standardized questionnaire but it was more like general case history.

Future research and directions:

- Sensitivity and specificity of multifrequency tympanometry parameters RF, ΔY, ΔG, $\Delta\theta$ and F45° should be established by comparing the obtained normative with the data obtained from clinical population.
- Incidence and prevalence of middle ear disorders can be established using of multifrequency tympanometry parameters RF, ΔY, ΔG, $\Delta\theta$ and F45°.

6. References

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