Multifrequency, Multi-Component Tympanometry: Normative in Kindergarten and Preschool Children (3-6 Years)

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Abstract

The aim of the present was to provide a normative for RF at $\Delta B \sim 0$; ΔY, ΔG, $\Delta\theta$ at RF and F45° for children from 3-6 years of age and to study the effect of age, ear and gender effects on RF at $\Delta B \sim 0$; ΔY, ΔG, $\Delta\theta$ at RF and F45°. A sweep frequency method was used which 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 which needs to be calculated manually using the B and G values in the GSI tympstar immittance meter. The mean of RF for 3+ to 4 years was 1087.83 Hz, 4+ to 5 years with a mean of 1059.33 Hz and for 5+ to 6 years with a mean of 1049.50 Hz. The mean of compensated admittance (ΔY) for 3+ to 4yrs was 1.29 mmho, 4+ to 5yrs with a mean of 1.49 mmho and 5+ to 6yrs with a mean of 1.41 mmho. The mean of compensated conductance (ΔG) for 3+ to 4yrs was 2.12 mmho, 4+ to 5yrs with a mean of 2.64 mmho and 5+ to 6yrs with a mean of 2.72 mmho. The mean of phase angle (Δè) for 3+ to 4yrs was -26.36°, 4+ to 5yrs with a mean of -25.13° and 5+ to 6yrs with a mean of -31.13°. The mean of frequency at 45° (F45°) for 3+ to 4 years was 494.16 Hz, 4+ to 5 years with a mean of 497.50 Hz and for 5+ to 6 years with a mean of 465 Hz. 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.

Key words: Multifrequency- multicomponent tymanometry, Kindergarten.

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.

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

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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).

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.

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. 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 & Rose, 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 and concluded that MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry.

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; 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).

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 ΔB~0, ΔY, ΔG,Δθ 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.

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 1.

Table 1: 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 ΔB~0; (2) ΔY, ΔG, Δθ 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.

- 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.
- 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 Δθ (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 Δθ 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 Δθ 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, Δθ 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 ΔB ≤ ΔG. 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, Δθ 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. All the statistical analyses were done using SPSS 15 software.

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.

Mean and standard deviation for different multifrequency parameters

The mean and standard deviation (SD) 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 2.

Table 2: 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 2 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. 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.

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.

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.

The range of phase angle (Δè) 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.

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.

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 revealed 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 ($p<0.05$).

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 standard deviation (SD) 0.26, which is lower than the obtained values for 3-6 years of age in the present study. Calandruccio et al., (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 ($\Delta\theta$) 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 $\Delta\theta$ 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 $\Delta\theta$ in neonates at RF, where the reported mean RF value was 261.85 Hz. Hence $\Delta\theta$ value for both adults and neonates was taken at RF, and thus it can be compared. It can be seen that the $\Delta\theta$ 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 $\Delta\theta$ 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 $\Delta\theta$ 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. In 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 Δθ 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 Δθ are more sensitive in indicating the subtle age related changes in the middle ear.

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 3.

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.

Table 3: 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

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 4.

From Table 4 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.

Table 4: 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

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. 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.

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 5.

Table 5: Results of Correlation analysis for RF, ΔY, ΔG, Δθ 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, ΔY, ΔG, Δθ and F45° between the two measurements. Thus this shows that RF, ΔY, ΔG, Δθ and F45° measurements were reliable.

Thus, a normative data has been established for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° in 3 to 6 years of age. RF, ΔY, and F45° showed no significant differences across the age from 3 to 6 years. However, ΔG and Δθ 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.

Summary and Conclusions

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 6.

Table 6: 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

- ANOVA 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 (Δθ) 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 Δθ 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.

Future research and directions

Sensitivity and specificity of multifrequency tympanometry parameters RF, ΔY, ΔG, Δθ 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, Δθ and F45°.

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