# EFFECT OF AGE AND EAR CANAL RESONANCE ON CLICK EVOKED OTOACOUSTIC EMISSIONS IN TODDLERS WITH 1 TO 2 YEARS OF AGE

Indukala K V

**Register No: 11AUD011**

A Dissertation Submitted in Part Fulfillment for the Degree

Master of Science (Audiology),

University of Mysore,

Mysore.

**ALL INDIA INSTITUTE OF SPEECH AND HEARING**

**NAIMISHAM CAMPUS, MANASAGANGOTHRI**

**MYSORE-570006**

**MAY, 2013.**

## CERTIFICATE

This to certify that this dissertation entitled **" Effect of Age And Ear Canal Resonance on Click Evoked Otoacoustic Emissions in Toddlers With 1 To 2 Years Of Age "** is the bonafide work submitted in part fulfillment for the degree of Masters in Science (Audiology) of the student **(Register No. 11AUD0011).** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for award of any other Diploma or Degree.

**Dr. S. R. Savithri**
**Director**
All India Institute of Speech and Hearing
Manasagangothri, Mysore -570 006.

Mysore

May, 2013

# CERTIFICATE

This is to certify that this dissertation entitled **" Effect of Age And Ear Canal Resonance on Click Evoked Otoacoustic Emissions in Toddlers With 1 To 2 Years Of Age "** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any Diploma or Degree.

Mysore

May, 2013

**Ms. Mamatha N M**

**Guide**

Lecturer in Audiology

All India Institute of Speech and Hearing

Manasagangothri, Mysore - 570 006.

# DECLARATION

This dissertation entitled **" Effect of Age And Ear Canal Resonance on Click Evoked Otoacoustic Emissions in Toddlers With 1 To 2 Years Of Age "** is the result of my own study under the guidance of Ms. Mamatha N. M., Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other university for the award of any Diploma or Degree.

Mysore **Reg. No. 11AUD0011**

May, 2013

## ACKNOWLEDGEMENT


"You don't choose your family. They are God's gift to you, as you are to them"

-Desmond tutu

Nothing in this world could express how much thankful I am to my wonderful family.

To my **father,** my first teacher…Acha, your fingers were a strong pillar of support right from my very first footsteps. As I stepped on further, you made my ways clear and planted perseverance and will power in me ☺

The more I grow, The more I realize that my **mother** is the best friend that I ever had. Amma, listening to your voice makes me feel light and seeing your smiling face can bring the best in me. ☺

**Jinuuu**…my adorable brother..Your tactic of converting any complex situations in to the most funny ones had definitely helped me a lot. Even though you say strong advices, you are still that naughty young boy in my eyes.

"We enjoy the best days of our lives because of the past struggles of our ancestors"

To my **grandfather**..Though you are not there with us now, each time I think of you I can feel a transient vibration in the air around me which eventually renews the spirit in me ☺ To my grandmother, **Ammamma** your blessings had always worked for and I know it will work further too.

I extend my very sincere gratitude to my guide **Mamtha mam**. Maam, I am highly indebted to you for providing me an anchor through your excellent guidance, support and encouragement. I appreciate the interest involvement and commitment shown by you at all stages of the study which persuaded me to work at the same phase and finish my work on time.

I take immense pleasure in thanking **Dr.S.R.Savithri** the director of AIISH, Mysore for having permitted me to carry out my dissertation. I would like to thank HOD audiology **Dr. Animesh Barman** and all the faculty and staffs of Audiology for their support and valuable suggestions.

Now, to my dissertation partner, A very special thanks to you **Baljeet**. Without you my data collection would have been a very tiring process and I still remember those funny incidents and moments were we go hunting for our "guinea pigs" and successfully mastering the tactic of making them fall asleep so professionally. ☺☺

And to my special sister **Vishnupriya**, Veepee you were more than a sister to me ☺ Thanks for your company when my eyes were droopy doing the work!! You were always there with me with your crazy advices even at midnight 3:00 (its not early morning for us).Thanks for being the person you are ☺☺

To my chweetheart **Aswathi,**You made my days in AIISH so colourful as your profile picture :D You should thank me for tolerating all your blunders. Okay now don't tell I did not thank you, thanks to you too ☺

**Akbar** and **Astha**.. my chweet buddies ..... your 1000 watts smile brings happiness all the while ☺☺

This would go incomplete without mentioning the most happening names of my AIISH life. **Greeshma** chechi,a big thanks for the sunshine days we spent together .**Kirti,Amrutha,Margaret** and **Nisha,**having juniors like you and teasing and fighting with each other is the one among the major crazy things that I have done here.

**Sabarish**, thank you for your constant moral support and for being there reminding me of dissertation work everyday. **Nikhil**, a very special thanks for your gift, the alarm clock which triggered me to do my work on time. ☺

**Aparna** chechi, thank you for all the valuable guidelines and help whenever I was in need of it. Thanks to Sreelakshmi and Nandu for those beautiful moments spent together.

I must say a very big thanks to **Ceana,Shilpa** and **Thulasi**, my wonderful neighbours. Seeing you people also doing the work was seriously a relief for me ☺☺

Ajay... thanks for everything in my life...

I really wish to thank each and everybody individually, but if I do so the timely completion of this dissertation would be in dream ... I am sorry that I have not been able to thank so many people.

Each one we meet in our life definitely has a role in our life. Some hurts you and some loves you. Some stays back and some leaves for ever. Thanks to all the wonderful people in my life.. u made my life blissful and stronger... and special thanks for all those difficult people too... for they made me bolder. Life gets harder as we progress.. and sometimes the most beautiful relation does not need a daily conversation..a glimpse makes it all…and I believe at the end we sit back in our easy chair seeing the beautiful portrait and then close your eyes and believe strongly "if its meant to be, It will be" !!

## CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER-1

# INTRODUCTION

Otoacoustic emissions (OAEs) are a form of energy leakage from cochlea through the middle ear to the ear canal during the active process of stimulus by the outer hair cells (Kemp, 1986). The emissions are low intensity sounds that are detected in the external canal by a microphone**.** The OAEs are the basis for understanding of how auditory system is able to respond to the minute energy levels that are required to reach the threshold of perception of humans. OAE has major clinical applications in pediatric audiometry as it can be recorded from sleeping or sedated children and requires relatively less time (Hall, 2000). OAEs assess cochlear function specifically and gives frequency specific information.

Probst (1990) classified OAEs as Spontaneous OAEs (SOAEs), Transient Evoked OAEs (TEOAEs), Stimulus Frequency OAEs (SFOAEs), Distortion Product OAEs (DPOAEs) depending on the stimulus used. The presence of evoked OAEs (EOAEs) is an evidence of normal cochlear function and its absence can be because of the conductive pathologies or cochlear hearing loss. According to Cope and Luteman (1988), 80-90% of normal hearing ears produce EOAEs. They also observed that it is seldom present in persons with hearing loss exceeding 30-40 dB HL. So it can be considered as a good indicator of normal hearing sensitivity.

Bray and Kemp (1987) also found higher click evoked OAE (CEOAE) level in children aged between 6 and 13 years than adults. Norton and Widen (1990) found significant differences in CEOAE levels in subjects in the age groups of 0.0–9.9, 10.0–19.9 and 20.0–29.9 years. Kapoor and Panda (2006) reported higher mean amplitude in neonates compared to infants and children and also comparatively a lower SNR was found. The explanation for the differences in OAE characteristics could be an immature cochlea. Although the histological development of the human cochlea seems to be completed at about 26 weeks of post conception, there are still incomplete ultra-structural processes.

**Need for the study**

Click evoked otoacoustic emissions (CEOAEs) have been widely used to assess the functioning of cochlear outer hair cells. Since the click stimulus has a broad spectrum, and it can consequently stimulate a broad frequency region of the cochlea in a single measurement, CEOAE measurement has been widely applied as a general tool in universal neonatal hearing screening (UNHS) programs. It is a well-supported fact that OAEs are affected by age. Differences in OAE characteristics across the age can be explained based on immature cochlea, or histopathological changes. Hall (2000) reported that the neonatal middle ear development can influence the measurement of OAE due to various factors like dissipation of middle ear mesenchymal tissues, improved middle ear transmission efficacy, increase in areal ratio of tympanic membrane to stapes footplate, decrease in tympanic membrane thickness and improvement in ossicle lever function.

The necessity to develop OAE clinical norms in pediatric population is suggested by different authors. Prieve and Fitzgerald (1991) reported higher CEOAE levels in children less than 1 year old compared to 12–17 year old and adults. The different properties of the external and middle ear like ear canal volume, ear canal resonance frequency, middle ear resonance frequency etc affects OAE measurement. The ear canal resonance frequency for adults is between 3500-4000Hz and in children the resonant frequency will be higher as the length of EAC is short. Cauto and Carvello (2009) reported that the response levels for both transient and distortion product otoacoustic emissions are influenced by the middle ear resonance in adults. The concentrations of TEOAEs were more at middle ear resonance frequency which was close to 1 kHz. Wada et al. (1993) stated that the external and middle ear resonance has an important role in transmission, and is easily detected. Otoacoustic emissions are best detected at the middle ear resonant frequency and in subjects with moderate middle ear mobility.

According to Keefe and Leve (1996) the external and middle ear systems vary significantly in their acoustic response properties over the first 2 years after birth. During this period, the external auditory meatus increases in size, the orientation of the tympanic membrane changes, and the middle ear mass decreases. Holte et al. (1991) reported that the external auditory meatus wall and middle ear mobility change in the first 4 months of life, as do the tympanometric characteristics. These authors also have reported that, because the middle ear of children is a mass-dominated system, the resonant frequency will be lower in children compared to normal adults whose middle ear system is stiffness dominated.

Studies support that significant differences in weight, length and head circumferences are reported among babies according to ethnicity. The head growth for children in the first 2 years of the life increases drastically (Ying et al. 2007). Janssen, Thiessen, Klein, Whitfield and Ying (2007) reported that South Asian and Chinese babies had similar mean head circumferences at 40 weeks but European babies exhibited a larger head circumference. This suggests that there is a need to develop norms for different ethnic groups.

It is clear that the ear canal resonance and middle ear resonance changes over age which has a significant effect on OAEs. Also studies have reported change in head circumference across different ethnic groups, which might also affect the ear canal length and volume. All these factors influence the OAE measurement. Chandni and Mamatha (2012) observed a significant difference in absolute amplitude and SNR for click and tone burst evoked OAEs across different age group in infants less than 1 year of age in Indian population. Hence the current study was conducted to see the age and ear canal resonance frequency related changes on CEOAEs in the age range of 1 to 2 year toddlers in Indian population since there are exhibited changes in head circumference and ear canal volume.

**Aim of the study**

The aims of the present study were,

- To know the spectrum change of CEOAEs with age.
- To investigate the effect of ear canal resonance on CEOAEs.
- To see is there any relationship between head circumference and CEOAEs.

# CHAPTER 2

## Review of literature

Otoacoustic emissions (OAEs) are sounds which arise in the ear canal when the tympanum receives vibrations transmitted backwards through the middle ear from the cochlea. According to Kemp (2002) these vibrations occur as a by-product of a unique and vulnerable cochlear mechanism which is known as the 'cochlear amplifier' and this contributes greatly to the sensitivity and discrimination of hearing. OAEs arise because some of the energy generated by outer hair cells leaks back into the ear canal. The detected emissions are low in intensity and detected in the external canal by a microphone**.** Depending on the presence or absence of an external stimulation, otoacoustic emissions (OAEs) may be classified in two main categories: spontaneous OAEs (SOAEs) and evoked OAEs (EOAEs).

Spontaneous OAEs (SOAEs) are obtained without any sound stimulation. They are narrow band signals, single or more often multiple, unilateral or bilateral. They can be measured in 40% to 70% of normal ears. EOAEs are subdivided into stimulus frequency OAEs (SFOAEs), transient evoked OEAs (TEOAEs), & distortion product OAEs (DPOAEs) depending on the characteristics of stimulus used. SFOAEs are obtained for continuous sonorous stimuli. TEOAEs are obtained for clicks or tone-bursts, and are known as cochlear, or Kemp, or transient echoes. Distortion products OAEs (DPOAEs) are obtained for the simultaneous presentation of 2 sound stimuli (f1& f2 of ratio 1:1.2 ), or primary tones, bound together by a frequency relationship; These emissions consist of different frequencies with respect to primary stimuli resulting from the combination of f1 and f2 as a result of either their difference or summation.

TEOAEs are the best known otoacoustic emissions and it has gained an importance in clinical application since the early 1980s. TEOAEs are present in 98% to 100% of the normal hearing individuals, independent of sex and age with a good morphologic stability and reproducibility. However great differences may be found among individuals as well as between the ears of the same individual.

Though OAEs are not important for measuring the degree of hearing, it is important for research and diagnostics purposes as it provides a means of examining the health of innermost parts of the cochlea from outside (Kemp, 2004). OAEs are dependent on outer hair cell (OHC) integrity and it assesses the cochlear function specifically. It also helps in differentiation of cochlear vs. retro cochlear auditory pathology. In combination with ABR, OAEs clearly distinguish sensory from neural pathologies. OAEs are used in monitoring ototoxicity as ototoxic drugs exert their effect on OHC function. OAEs are also used in monitoring music and noise induced hearing loss since OAEs are site specific for cochlear dysfunction.

OAE being a physiologic test has major clinical applications in diagnosing pediatric population as it does not depend on subject’s behavioral responses. It assess cochlear function specifically and can be recorded from sleeping or sedated children, requires relatively less test time. It provides ear specific and frequency specific information with good reproducibility.

One of the major applications of OAE is in new born hearing screening. Johnson et al. (1983) reported that TEOAE waveforms are unique in neonates. The latency of the first TEOAE "burst" was shorter and the amplitude measured was higher in neonates than adults. Average TEOAE levels evoked by clicks of 80 dB pSPL in neonates are approximately 20 dB SPL. In 1993, the National Institute on Deafness and Other Communication Disorders, part of the National Institutes of Health (NIH), advocated the use of TEOAEs in combination with auditory brainstem response (ABR) to screen all newborns for hearing loss. Soon after, OAEs were recommended as appropriate screening tools by the Joint Committee on Infant Hearing (1994, 2000) and the American Academy of Pediatrics (1999).

The measurement of OAEs are affected by different factors which can be non pathological or pathological. Kalfa and collet (1996), Penner et al. (1993) reported about the ear effect wherein the amount of response varies in left or right ear. The SOAE amplitude is typically greater for right than left ear in children and adults (Penner et al. 1993). The asymmetries in efferent system innervations and function results in SOAE difference. Kalfa and Collet (1996) described more efferent system activity for right side of medial olivo cochlear system in right handed adults.

Robinette (1992), Hall and Baer (1994) suggests that TEOAE amplitude is slightly more prominent in right versus left ear in adults and children. The ear difference found in TEOAE was may be due to the contribution of SOAEs. These authors reported that TEOAE amplitude was larger for the right ear when SOAEs were present in that ear, and vice versa for the left ear. Also it is said that efferent inhibition is relatively lesser in the right ear and in females than in left ears and males (McFadden, 1993).

The effect of age is another important factor in OAE measurement. Burns et al. (1992) reported that SOAE amplitude decreases with developmental age from infancy to adulthood and tend to be most pronounced for the higher frequency SOAEs. For example, the amplitude decrease may be over 15 dB for frequencies about 3000 Hz and about 10 dB for frequencies from 1000 to 2000 Hz region. There was a general shift observed for SOAEs from higher to lower frequencies during childhood and into adulthood.

TEOAEs are also affected in a similar way. Kok et al. (1993) reported that the TEOAEs in infants had an overall amplitude of 30 dBSPL in contrast to typical adult whose amplitude was about 8 to 12 dBSPL. Other TEOAE parameters also show age effects for the response spectra. Neonates had a flat spectral response and children and adults had progressively less high frequency energy and there was development of multiple notches of reduced amplitude. The effect of age on TEOAEs are discussed later in detail in this chapter. DPOAEs are highest for infants less than 1 year, with amplitude decreasing during 1 to 3 years of age range, and decreasing even further for older children and teenagers until adult values are reached. Thus larger DPOAE amplitudes are obtained for children compared to adults (Bonfils et al. 1992). Explanations offered for the age effects on OAE amplitude and frequency includes developmental changes in external and middle ear resonance during infancy (Burns et al. 1994). However effects secondary to maturation of the efferent system must also be considered (Mc Fadden, 1993). The effect of ear canal resonance is discussed in detail in this chapter later.

Effect of gender on OAEs is studied by different authors. Zurek (1981) reported that SOAEs were higher in both prevalence and amplitude in females compared to males. TEOAE amplitudes and reproducibility values are significantly higher in females than males (Robinette, 1992). Explanations for the gender difference in OAEs include an anatomical difference in the size of cochlea with females typically having a shorter cochlear length. (Sato et al. 1991), more number of OHCs (Wright et al. 1987), slightly better hearing sensitivity (McFadden & Mishra, 1993) and possibly smaller ear canal volume (Martin et al, 1987).

Several investigators have examined the effect of body position on OAEs. Data from these studies suggest that TEOAE latencies decrease from the upright (90 degree) position to supine (0 degree) or head hanging positions. Changes in body position altered oval window pressure. At high negative and positive middle ear pressures the middle ear is stiffened whereas in the upright position the middle ear is mass dominated. When the normal impedance matching of middle ear to cochlea is disturbed, energy produced by the cochlea may be reflected back to the cochlea where it can interfere with and alter the ongoing active process.

Placement of probe tip is another important factor. A well designed probe tip contributes immensely to successful OAE measurement. In addition to selecting the appropriate sized probe tip, appropriate depth of insertion is also important. As a rule deeper probe tip insertion is better as it attenuates more ambient noise. The probe tip is placed directly into the ear canal, so that stimulus is delivered towards the center of canal, rather than diagonally towards the canal wall. A loose probe fit can produce an oscillation of meatal cavity in response to stimulus which produces a long ringing waveform. Stimulus spectrum shows sharp peak (2 kHz) and trough (4 kHz) with no low frequency energy below 1 kHz (due to leaking), poor reproducibility and response obscures by environmental noise.

Detection of OAE is very much affected by any other sound present in the ear canal during the measurement. The three general sources of noise are environmental, equipment related and physiological noise. The pathological factors which affect the OAE recordings are ototoxicity, sensorineural hearing loss, tinnitus, and other external and middle ear infections. These above discussed factors need to be considered while carrying out an OAE testing. The age of the subject and the external ear canal resonance properties has got significant effect in pediatric OAE measurement. The effect of age on ear canal resonance and its effect on OAEs are mentioned in details further in this chapter.

**2.1 Resonance property of the ear canal and its effect on OAEs**

The ear canal is acoustically considered to be a tube of about 2.3cm long which is closed at one end. Thus the resonant frequency of such a tube will be at wavelength four times the length of the tube. The resonant frequency of the ear canal is upto 3600 Hz (Wiener & Ross, 1946). The average ear canal length being 2.3 – 3cm, it resonates the sound with wavelength of about 10-12 cm. Since frequency is equal to velocity/wavelength, the frequency range will be between 3500-4000Hz. The shorter the length of EAC, greater will be the resonant frequency. In children the resonance frequency will be higher as the length of EAC is short. The gain given by the ear canal at resonance frequency is around 17 dB if the walls of the ear canal are rigid. But if the

EAC is not straight and also covered with the skin it absorbs some sound energy and it decreases the sound signal approximately by 15 dB. According to Dallos (1973), the resonance pattern will provide 10-15 dB amplification of sounds in children's ear canals. The sound pressure gain curve is slightly different when the pinna and concha are combined with the ear canal resonance. The concha resonance blends with the ear canal resonance producing a composite curve with two peaks one at 2700 Hz and the other at near 5000 Hz.

Weiner and Ross (1946) in their classical study placed a probe tube microphone at two locations in the ear canal, one near the tympanic membrane and the other halfway between the tympanic membrane and the concha. At these two locations, they measured sound pressure distribution in the ear canal from a free field sound presented at three angles of incidence: $0^0$, $45^0$ and $90^0$ in the horizontal plane. The pressure distribution in the ear canal at various frequencies varied, and the most obvious pressure gain was reported in the region of 2 – 4 kHz (10 – 15 dB) with a maximum increment of 17 to 22 dB at 3 kHz. The important findings were that the concha and ear canal acts as a resonator and the amount of resonance provided is up to 20 dB between 2 to 5 kHz. The sound source has a differential effect on the amount of pressure developed in the canal across frequencies. The gain for a $45^0$ angle being largest whereas $90^{0 \text{ and}}$ $0^0$ showed lesser gain.

OAEs are measured with a probe assembly placed into the ear canal of the Subject. The probe contains a miniature loudspeaker to generate sound stimuli and one more miniature microphone to measure the sound pressure. The dimensions of ear canals of infants and small children are substantially smaller than those of adults. In adults, the distance from the canal entrance to the umbo ranges from 22 to 31mm. The ear canal length is important because the OAE tests are most commonly done on infants and young children. As stated earlier the external and middle ear systems vary significantly in their acoustic response properties over the first 2 years after birth and the OAE responses vary depending on the external and middle ear resonance properties. Ear canal resonance frequency decreases progressively from about 6000Hz in neonates to about 4000Hz in infancy and downward to adult values of approximately 3000 Hz by 2 to 3 years of age.

Developmental maturation of efferent function is another anatomic factor that may contribute to changes in OAEs during infancy. Evidence exists that the efferent auditory system may not be fully matured until well after 1 year of age (Goforth, Hood & Berlin. 1998). Chandni and Mamatha (2012) studied the TEOAEs in infants of 0 to 1 years of age and observed higher SNR and amplitude at 2 kHz and 4 kHz with click stimuli. According to them, possible explanation for higher absolute amplitude at 2 kHz and 4 kHz is due to resonance frequency of the ear canal. Thus at higher frequencies the amplitude is more. As the age increases, the resonant frequency of the ear canal shifts towards the mid frequencies. This would have resulted in an increase in the amplitude at 1 kHz with increase in age. The reduction in amplitude at other frequencies with increasing age could be attributed to the fact that, with the increase in age, ear canal volume increases. As the sound pressure level measured inside the cavity is inversely proportional to the volume, it leads to the decrease in amplitude with increase in age.

## 2.2 Effect of Age on Ear Canal Characteristics and OAEs

As age related factors influence the OAE responses, some factors need to be considered in pediatric OAE recording. The important consideration for pediatrics is the status of the external and the middle ear factors like ear canal length, ear canal resonant frequency and middle ear resonant frequency. The volume of head increases as the age increase and thus the ear canal length and its resonance changes. Hence there can be a change in pattern of OAE response with the change in age. These effects are significant upto 2 years of age.

During the development of the fetus, the skull is developed with fibers linking the cranial bones. A year after birth these fibers disappear and the cranial bones fuse together. In early infancy the skull bones are not fused together to allow for brain growth. The head grows rapidly in the first three months in the postnatal period. The rate of increase in head circumference is 3cm per month. The Head circumference (HC) is used as a surrogate measurement of brain size and brain growth. The head circumference is determined by measuring the greatest occipitofrontal circumference (from the occipital prominence to the frontal prominence taking the biggest of the three obtained measurement) (Bartam et al. 2005).

Various studies reveal the relationship between head growth and age, body weight, ethnicity etc. Janssen, Thiessen, Klein, Whitfield and Ying (2007) reports that South Asian and Chinese babies had similar mean head circumferences at 40 weeks but European babies exhibited a larger head circumference. Madan et al. (2002) reported that the size of head varies according to ethnicity and in turn the length and weight of the baby. The study was conducted among 4500 infants and were categorized according to their place of origin. Hanley et al. (2012) reports that ethnicity and nutrition also plays a major role in head growth. World Health Organization (2000) also provides an account for head growth in terms of child growth standards.

The human ear canal continues to mature after full-term birth. The canal is straighter and shorter in infants than in adults (Northern & Downs, 1984). The ear canal length is 1.68 cm in newborns, which is roughly two thirds of that in adults (Crelin, 1973). The canal wall of the newborn has no bony portion and consists of a thin, compliant layer of cartilage (Anson & Donaldson, 1981) and the tympanic ring does not completely develop until 2 years of age (Saunders et al. 1983). The adult canal has a bony wall in its inner two thirds and soft-tissue wall in the outer one third, whereas the canal in newborns is almost completely surrounded by soft tissue (McLellan& Webb 1957). The ear-canal diameter and length increases from birth till 24 months of age (Keefe et al. 1993). Human temporal bone data show maturational changes in the middle ear during childhood. The tympanic-membrane plane relative to the central axis of the ear canal is more horizontal in the newborn, with a more adult-like orientation by the age of 3 years (Ikui et al. 1997).

According to Keefe and Leve (1996), the external and middle ear vary significantly in their acoustic response properties over the first 2 years after birth. During this period, the external auditory meatus increases in size, the orientation of the tympanic membrane changes, and the middle ear mass decreases. Holte et al. (1991) reported that the external auditory meatus wall and middle ear mobility change in the first 4 months of life, as do the tympanometric characteristics. These authors also reported that, because the middle ear of children is a mass-dominated, the middle ear resonant frequency tends to be lower compared to normal adults, in whom the middle ear system is stiffness dominated. Hall (2003) reported that the resonance frequency of the adult ear canal is in the region of 2500 Hz to 3000 Hz region. For children it ranges about 4000 Hz to 4500 Hz. Also Hood (1998) provided the information that ear canal resonance frequency decreases progressively from about 6000 Hz in neonates to about 4000 Hz in infancy and downward to adult values of approximately 3000 Hz by 2 to 3 years of age.

Various studies reveal change in OAE characteristics as an influence of age. In neonates the change in OAE response can be due to an effect of middle ear and external ear developmental characteristics (Hall, 2000). Advanced age can lead to ganglion cell loss, strial atrophy and stiffness of the basilar membrane, which leads to hearing loss (Liu & Wang, 2012). Collet et al. (1991) reported reduction in OAE amplitude as the age increases. In neonates and infants the OAE amplitude were found to be larger.

Liu and Wang (2012) attempted to explore the role of age-related decline of cochlear outer hair cells by considering the total intensity and signal to noise ratio (SNR) of TEOAEs in various frequency bands. They reviewed various articles from 1990- 2010 and basically analyzed the effect of age on OAE amplitude and SNR. They concluded that TEOAE level increases in the first 2 months of age, decreases between 2 months and 6 years old, and decreases after 6 years old. They observed the most rapid decrease of TEOAE amplitude at 1 year old. The total TEOAE level decreased to about 4.25 dB SPL between 2 months to 1 year old, then about 0.26-0.52 dB SPL from 1 to 10 years old, about 0.23 dB SPL from 11 to 25 years old, and about 0.14 dB SPL from 26 to 60 years old. The signal-to-noise ratio in the frequency bands centered at 1.5, 2, 3 and 4 kHz decreased with increasing age after 2 months of age. The authors reported a significant negative correlation between the signal-to-noise ratio for frequency bands ranging from 1.5 kHz to 4 kHz.

Mazlan, Kei and Hickson (2007) and Thornton, Marotta and Kennedy (2003) reported that TEOAE levels increases in the first 2 months of life. Thornton, Marotta and Kennedy (2003) showed that the TEOAE level for click stimuli distinctly increases in the first 48 hours and slowly increases up to next 2 months of age. According to Liu and Wang (2012) these effects are not due to increased amount of OHCs or development of medial olivo cochlear bundles. Instead the reason could be due to the reduction in the middle ear effusion and the ear canal debris.

The low emission level recorded immediately after birth can be attributed to a transitory sound-conductive hearing loss due to residual amniotic fluid in the middle-ear cavity or due to Eustachian tube dysfunction. Doyle *et al.* (2000) found a higher incidence of middle ear effusion (22.7%) in neonates of 5 to 48 hours old (mean 25.7 hours). Out of 200 infants, 66 (33%) had effusion in at least in one ear, whereas 24 (12%) had bilateral effusion. Middle ear effusion will reduce emission energy below approximately 2 kHz and middle ear effusion decreased with increasing age, which may be the reason for the increase in TEOAE response in the first few days of life.

A decrease in TEOAE level was found between 2 months to 6 years of age. The primary reduction was visible at 2 to 3 months of age. The reduction cannot be attributed to cochlear maturation since the cochlea is matured at 40 weeks of gestation. It is more likely to be related to external and middle ear characteristics. Jupiter and Giacomazza (1998), Norton and Widen. (1990) reported that the decrease in TEOAE level depends on the anatomical changes of outer and middle ear. OAE levels were higher in small ear canals of neonates. As the length of ear canal increases with age the OAE amplitude is likely to be reducing. Keefe, Bulen, Arehart et al. (1993) reported that the external auditory canal elongates most rapidly from 6 to 12 months after birth, and then continues to increase in length until 6-7 years old.

Kapoor and Panda (2006) compared TEOAEs in 3 age groups i.e. neonates (0-1 month), infants (1 month-1 year), and children (1-6 years). Results showed that in neonates the mean amplitude is higher compared to the other groups whereas comparatively a lower SNR was also found. They did not find any difference between right v/s left ears in these age groups. The mean amplitude in neonates was significantly higher than the infants or children and the mean SNR for all the subjects were well above 3 dB at frequencies 1.5 k, 2 k, 3 k and 4 kHz. The neonates showed the lowest SNR ranging between 3.47 to 9.62 dB. The infants showed the highest SNR ranging between 6.13 to 13.11 dB. Moleti and Sisto (2007) mentioned that the latency was 2–3 ms shorter for CEOAEs for infants compared to adults in 1.5–2.5 k Hz frequency range, which could be explained by a reduced middle ear forward transmission.

After 6 year of age there was a slow decrease observed in OAE levels (Liu & Wang, 2012). Kon et al. (2000), Groh et al. (2006) observed TEOAEs in 4 age groups and found that the TEOAE response in the 16-20 year and the 21-25 year age group was significantly lower than the 6-10 year and 11-15 year old groups. Norton and Widen, (1990) and Satoh et al. (1998) reports similar findings. Since the ear canal length do not significantly change after 6 year of age, the changes in OAE may be related to cochlear micromechanics.

Liu and Wang (2012) reported that reduction of distortion-product otoacoustic emission was relatively consistent with outer hair cell (OHC) loss and age-related changes were predominantly determined by an otoacoustic emission generator system, i.e. at the level of the OHCs. According to Yu et al. (2009), 1% OHC loss results in a 0.24 dB SPL reduction in distortion-product otoacoustic emission levels. Seidman, Ahmad and Bai (2002) did histological analysis of presbycusis and found that the loss of inner hair cells ranged from 3.1% to 9.2%, while OHC loss ranged from 7.4% to 46.8% with increase in age. Inner hair cell loss was greatest at the upper apex, while OHC loss was greatest at the basal turn. General noise exposure in life is also attributed as a factor for OHC damage. Considering the various results, Liu and Wang (2012) suggests that children around 6 years old can suitably reflect a fully intact auditory periphery.

TEOAE being an effective diagnostic measure among otoacoustic emissions with good morphologic stability and reproducibility is considered for the present study. Various studies show changes in OAE characteristics from childhood to adulthood. As the infant grow older the head volume increases. As the head volume increases the properties of the ear canal alters. The external and middle ear systems vary significantly in their acoustic response properties over the first 2 years after birth. During this period, the external auditory meatus increases in size and the resonance of the external ear canal reduces from 7000 Hz to about 3000 Hz. Thus the present study was taken up to investigate the effect of frequency pattern shift in TEOAE parameters with click stimulus in toddlers in the age range of 1 to 2 years. The effect of ear canal resonance and head circumference on click evoked OAEs were also investigated.

# CHAPTER - 3

## Method

The aim of the present study was to investigate the effect of age on the pattern of frequency shift of click evoked otoacoustic emissions in toddlers. The effect of head circumference and ear canal resonance on signal to noise ratio (SNR) and absolute amplitude of click evoked otoacoustic emissions (CEOAEs) was investigated. The relationship between head circumference and CEOAE was also investigated. The following method was employed for the study.

### Participants

To accomplish the aim of the study, toddlers in the range of 1 to 2 years of age (mean age of 18 months) were taken. A total of 40 toddlers (80 ears) participated in the study. In order to see the age related changes, they have been further divided into two groups. Group 1 consisted of 20 children (40 ears) within the age range of 13 to 18 months. Group 2 consisted of 20 children (40 ears) within the age range of 19 to 24 months.

#### Participant selection criteria.

The subjects were selected based on the following criteria.

- Normal otoscopic examination indicating absence of external and middle ear pathology.
- Normal birth history (Full term normal delivery with no significant prenatal, perinatal, postnatal histories and any high risk factors).

- Healthy with no symptoms of cold or ear discharge at the time of assessment.
- No previous history of any middle ear infections or other otological complaints as reported by an ENT specialist.
- No complaint and history of any neurological symptoms.
- Age appropriate response at minimum levels to various auditory stimuli for either behavioral observation audiometry or visual reinforcement audiometry.
- Normal middle ear function revealed by tympanometry (A /As type tympanogram) and presence of acoustic reflex threshold using immittance measurements of 226Hz probe tone.
- Normal outer hair cell functioning ensured by recording of TEOAEs
- Normal hearing sensitivity ensured by recording of ABR with the presence of wave V till 30 dB nHL.

**Test environment**

All the testing was carried out in a sound treated room with the noise levels within permissible limits as per ANSI S3.1-1991 (R-2003).

**Instrumentation**

The following instruments were used for the study

1. An otoscope to observe the status of external auditory canal and tympanic membrane.

2. A calibrated two-channel diagnostic audiometer Madsen Orbiter-922 (version 2) with impedance matched loudspeakers to present stimuli for both behavioral observation audiometry (BOA) and visual reinforcement audiometry (VRA).
3. A calibrated GrasonStadler Inc.-Tympstar middle ear analyzer (GSI Tympstar, version 2) to obtain tympanogram and to measure acoustic reflex threshold.
4. A personal computer based Intelligent Hearing Systems (IHS) Smart EP version 3.94 evoked potential system to record auditory brainstem response (ABR).
5. A calibrated Fonix 7000 hearing aid analyser to measure the ear canal resonant frequency
6. A calibrated otoacoustic emission system ILO version 6 software (Otodynamics Ltd., UK) to record TEOAEs for click stimuli.
7. A standard flexible non-stretchable plasticized measuring tape to measure the head circumference.

## Procedures

The procedure involved two phases.

### Phase I.

It included the detailed case history of the toddlers about pre natal, peri natal and post natal medical conditions. It also included following preliminary tests to confirm normal hearing sensitivity and therefore to select the participants for the main study.

**1.** High Risk Register (HRR) checklist: A modified HRR checklist developed by Anitha and Yathiraj (2001) to rule out the high risk factors in toddlers.

**2.** Otoscopic examination: Visual examination of ear canal and the tympanic membrane was done using a hand held otoscope to rule out the presence of wax, foreign bodies and any other ear related pathologies in the ear canal and tympanic.

**3.** Tympanometry and reflexometry: To record the tympanogram, the air pressure was varied from +200 daPa to -400 daPa, at a rate of 200 daPa/sec for 226 Hz probe tone frequency. Ipsilateral acoustic reflex thresholds were obtained at 500 Hz, 1 kHz and 2 kHz by varying the intensity of stimulus in 5 dB steps by observing changes in acoustic admittance. A minimum change in acoustic admittance value of 0.03ml was considered as presence of acoustic reflex thresholds recommended by ASHA (2004)

**4.** Behavioral Observation Audiometry (BOA): The testing was carried out in a sound treated room when the baby was active and alert. Warble tones (from 500 to 4000 Hz) were presented in ascending order and the appropriate responses from the child was observed. The lowest levels of presentation of each of the stimuli at which the toddler exhibits some kind of auditory behaviour, was considered as response and noted down the value (Northern & Downs, 1984).

**5.** Visual Reinforcement Audiometry (VRA): VRA was carried out in sound treated two-room situation. An audiometer housed in the tester room was used to deliver warble tones (500Hz to 4000 Hz) while the loud speaker was in the subjects room. The toddler was seated comfortably on the caregivers lap at a distance of 1 meter from the loudspeakers at an azimuth of 45 $^{0}$. The examiner was seated in front of the child. Reinforcement was provided through the LCD TV monitor placed at 1 meter disatance to the loudspeakers which delivered the test stimuli. The infant's attention was drawn to the midline by the examiner as and when it was required. Operant conditioning techniques were used to reward the infant's natural response to the sound that is a head turn in the direction of the sound source. A response was defined as a head turn towards the reinforcement stimuli or the LCD TV monitor which should occur within 3 seconds of stimulus presentation. Thresholds were obtained for the warble tones at octave frequencies from 500Hz to 4000Hz (Northern & Downs,1984).

**6.** Auditory Brainstem Response (ABR):.Initially electrode sites were cleaned and electrodes were placed on the scalp along with conduction gel at three locations. The non-inverting electrode was placed on high forehead (Fz), inverting electrode on the test ear & the ground electrode was placed on the lower forehead (Fpz). The recording was done using a click stimulus starting at 70dBnHL, with 11.1/sec repetition rate. The number of sweeps used were 1500, and the filter settings was at 30Hz to 3 kHz. The intensity was reduced in 10 dB steps and the presence of wave V was till 30 dB nHL was considered as normal hearing sensitivity.

**Phase II.**

The participants who were passed in preliminary tests of phase I were considered to have normal hearing sensitivity and selected for the evaluations in phase II. The phase II consisted the measurements of head circumference, ear canal resonance and TEOAE for clicks.

1. Head circumference measurement: The head circumference measurement (in cm) was obtained with a flexible non-stretchable plasticized measuring tape. Head circumference or OFC (occipital frontal circumference) was measured over the most

prominent part on the back of the head (occiput) and just above the eyebrows (supra orbital ridges). Re measurements were taken three times and the largest measure was considered (Bartam et al, 2005).

2. Ear canal resonance frequency measurement: Ear canal resonance measurement was carried out using a calibrated Fonix-7000 hearing aid analyzer. Participants were seated in the chair at 45 $^{0}$azimuth and 1 feet distance from the loud speaker of the hearing aid analyzer. First levelling of the system was done. The probe tube was marked first for the correct insertion depth of attached microphone.). The standard insertion depth from the intertragal notch given by Moodie et al. (1994) for children is 20-25 mm. The probe was inserted to the ear canal of the participant's test ear using digi speech at 60 dBSPL as stimuli. The real ear unaided gain curve was obtained with frequency (in Hz) on X axis and gain (in dB) on Y axis. External ear resonance was noted by considering the frequency belonging to the greatest peak point on the graph.

3. Transient evoked Otoacoustic emissions (TEOAEs): Click evoked OAEs were recorded using ILO- V6 system. Subjects were tested while in natural sleep or in a quiet state. The probe was inserted gently into the ear canal with an appropriate sized probe tip and adequate fitting of the probe was ensured to get a smooth, rounded curve in the stimulus spectrum. The probe fit was evaluated visually ensuring that the spectrum across the click frequency range (500 – 4000 Hz) was flat and "ringing" of the stimulus did not exceed 2 ms. The "nonlinear" mode of stimulus presentation was used to reduce the stimulus artifact. The TEOAEs were recorded for click stimuli at an intensity of 80dBpeak SPL. The number of stimuli used were 256 clicks at a rate of 50 stimuli/sec.

The time window used was 20 msec with amplification of 100-10,000 times and band a pass filter of 300-400Hz.

Nonlinear protocol includes trains of 4 biphasic clicks of 80 µsec i.e. three clicks of positive polarity followed by a 4th click of an inverse polarity with a relative magnitude of 9.5dB (3times) higher than the corresponding positive clicks (Kemp et al., 1986; Bray, 1989). The responses were recorded by means of buffer A and buffer B. Overall TEOAE levels were calculated by the ILO software using a cross-spectrum analysis using "A+B" and overall noise levels reported are the "A–B" measure. In order to ensure a significant artifact rejection, the first 2.5 ms of the recording was eliminated. On termination of the test, the OAE response data that is obtained is averaged and an OAE waveform is displayed in the time domain. A Fast Fourier Transform (FFT) is performed on the OAE response spectrum and the OAE and noise energy are displayed in a frequency spectrum (Hall, 1986; Norcia, Sato. Shinn &Mertus. 1986: Hall. 1992). The TEOAE response and noise levels were analyzed in half-octave bands centered at 1000, 1414, 2000, 2828, and 4000 Hz. OAEs are considered as present when the difference between OAE amplitude and noise floor is $\geq$6 dB SPL and reproducibility of greater than 70% (Prieve et al, 1993). The responses noted were the signal to noise ratio (SNR) and the absolute amplitude in the specified half octave bands.

**Analysis**

Appropriate statistical analysis was carried out using SPSS software version 17. For each of the subject, the values considered were SNR and absolute amplitude measures at frequency bands of 1000 Hz, 1500Hz, 2000 Hz, 3000 Hz, and 4000 Hz. The ear canal resonance frequency and head circumference were also measured for comparison with CEOAE. These values were considered and compared for the two mentioned groups and the analysis was done using appropriate statistical procedures.

# CHAPTER - 4

## Results & discussion

The present study investigated the effect of age on the pattern of frequency shift of click evoked otoacoustic emissions (CEOAEs) in toddlers in the age range of 1 to 2 years. Study was done in total 40 subjects (80 ears). The subjects were divided into 2 age groups i.e. group I from 13 months to 18 months and group II from 19 months to 24 months. The SNR and absolute amplitude of OAEs were taken at the frequency bands of 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, and 4 kHz. The measures of head circumference and external ear canal resonance frequency were also taken from each subject to investigate the effect of these parameters on OAEs. To analyze the data Statistical Package for the Social Science Version 17 was used. Various statistical analyses were carried out for both within groups and between group comparisons. The statistical tools used were:

- Descriptive statistics to calculate the mean, standard deviation (SD) and range of absolute amplitude and SNR of CEOAEs for the frequency bands of - 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz, head circumference and ear canal resonance frequency across both the age groups.
- Mixed analysis of variance (Mixed ANOVA) was done to study the main effect of age and frequency on the absolute amplitude and SNR for CEOAEs.
- Bonferroni pairwise comparison was done to see between which two frequencies of absolute amplitude or SNR differ significantly from each other, whenever mixed ANOVA had shown significant main effect of frequency.

- Repeated measure ANOVA was done to study the effect of different frequencies on each age group.
- Karl pearson's product moment correlation was done to find the correlation between ear canal resonance frequency and SNR, and correlation between head circumference and OAE.

### 4.1 Absolute amplitude, SNR, Ear canal resonant frequency and Head circumference across age groups

The mean, standard deviation, and range of absolute amplitude and SNR of OAEs, ear canal resonant frequency and head circumference were calculated for both group I and II and are depicted in the Table 4.1 and 4.2 respectively. The Figure 4.1 and 4.2 represents the mean absolute amplitude and mean SNR at various click frequencies for both the groups respectively.

Table 4.1

*Mean, standard deviation, and range for absolute amplitude and SNR of CEOAEs, ear canal resonant frequency and head circumference for group 1.*

| Group I (13 months to 18 months) | | | | |
|---|---|---|---|---|
| | | Mean<br>N = 40 | SD | Range |
| Age in months | | 15.67 | 1.77 | 13.00 - 19.00 |
| SNR (dB SPL) | 1 kHz | 10.12 | 4.01 | 0.4 - 17.6 |
| | 1.5 kHz | 11.33 | 4.40 | 0.1 - 18.9 |
| | 2 kHz | 14.48 | 4.24 | 5.7 - 24.4 |
| | 3 kHz | 16.67 | 3.55 | 6.7 - 21.3 |
| | 4 kHz | 17.12 | 4.03 | 9.0 - 27.1 |
| Absolute amplitude (dB SPL) | 1 kHz | 6.32 | 5.08 | -4.1 - 17.0 |
| | 1.5 kHz | 7.99 | 4.27 | -1.1 - 17.3 |
| | 2 kHz | 11.20 | 4.35 | 2.1 - 22.4 |
| | 3 kHz | 13.34 | 3.67 | 4.3 - 18.9 |
| | 4 kHz | 14.17 | 4.05 | 5.9 - 20.9 |
| Ear canal resonant frequency (kHz) | | 5.42 | 0.63 | 4.3 - 7.1 |
| Head circumference (cm) | | 44.85 | 1.77 | 41.3 – 48.3 |

Table 4.2

*Mean, standard deviation, and range for absolute amplitude and SNR of CEOAEs, ear canal resonant frequency and head circumference for group II.*

| Group II (19 months to 24 months) | | | | |
|---|---|---|---|---|
| | | Mean<br>N = 40 | SD | Range |
| Age in months | | 20.75 | 1.690 | 19.00 – 24.00 |
| SNR (dB SPL) | 1 kHz | 10.60 | 3.71 | 3.2 – 17.6 |
| | 1.5 kHz | 12.96 | 3.67 | 5.3 – 18.9 |
| | 2 kHz | 15.56 | 3.97 | 4.6 – 23.9 |
| | 3 kHz | 16.45 | 3.55 | 8.9 – 22.0 |
| | 4 kHz | 14.18 | 5.03 | 0.0 – 21.1 |
| Absolute amplitude (dB SPL) | 1 kHz | 6.11 | 5.08 | -8.8 – 13.3 |
| | 1.5 kHz | 9.07 | 3.76 | 2.0 – 16.2 |
| | 2 kHz | 11.13 | 3.78 | 1.3 – 18.9 |
| | 3 kHz | 13.33 | 3.88 | 2.6 – 19.7 |
| | 4 kHz | 11.25 | 4.36 | -1.1 – 17.2 |
| Ear canal resonant frequency(kHz) | | 4.71 | .43 | 3.8 – 5.6 |
| Head circumference (cm) | | 50.81 | 1.22 | 48.2 |

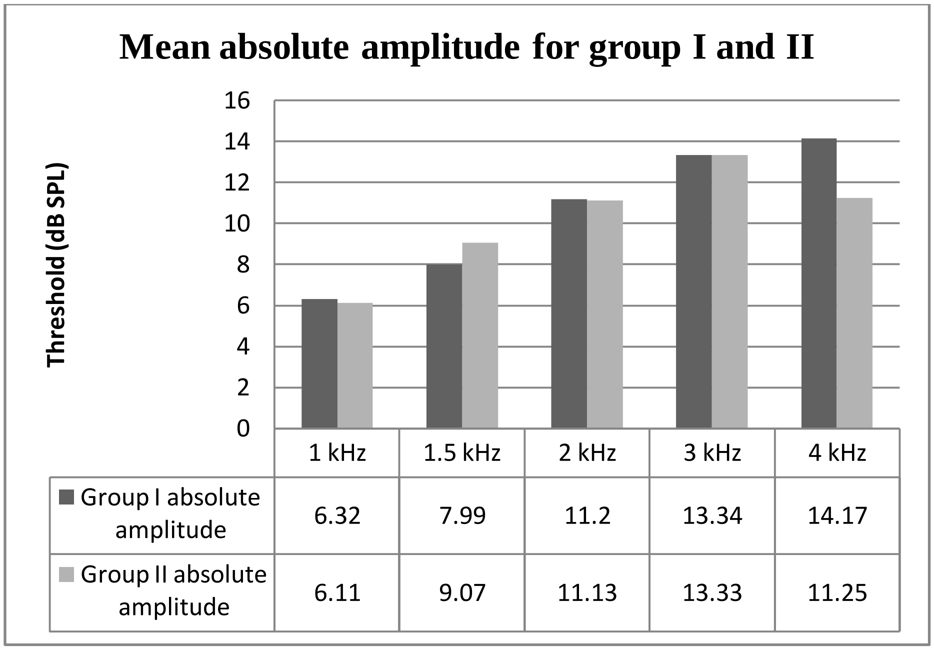


*Figure 4.2.*Mean absolute amplitude of CEOAEs at various frequencies across age groups

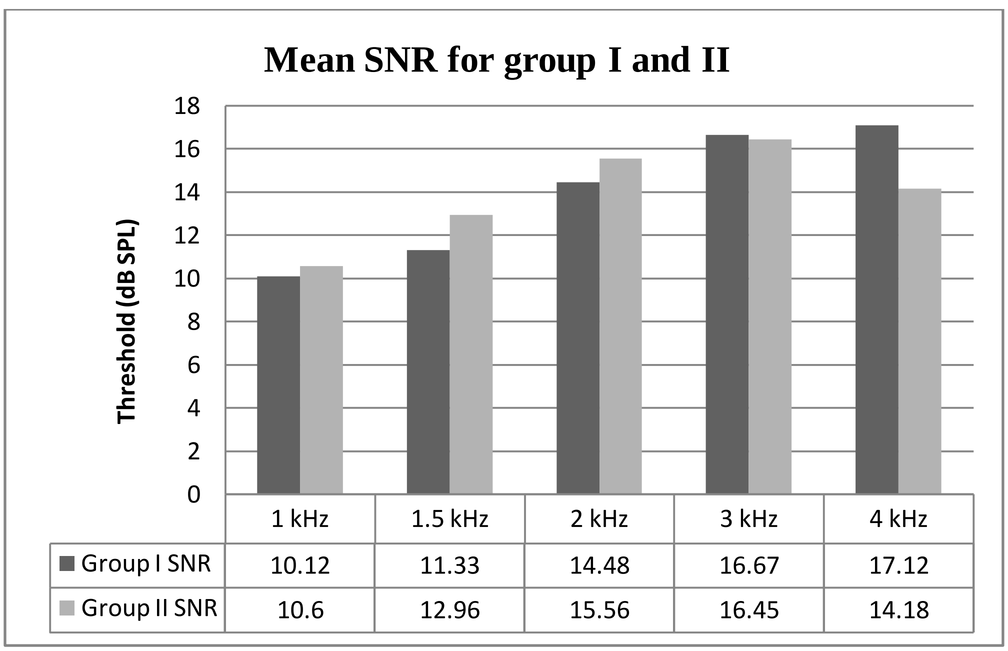


*Figure 4.1.*Mean SNR of CEOAEs at various frequencies across age groups

From the Figures 4.1 and 4.2 it can be inferred that, in group I, the SNR and absolute amplitude increases with increase in frequency. In group II also SNR and absolute amplitude increases with increase in frequency. At 2 kHz, the absolute amplitude increased with increase in age and reduced at 4 kHz in group II. Whereas, SNR increases at low frequency with increase in age except at 4 kHz which has shown to reduce with age. The mean ear canal resonant frequency is 5.4 kHz for group I. As the age increased the ear canal resonant frequency reduced to 4.5 kHz in group II. The mean head circumference in the group I is 44.8 cm and it increases to 50.8 as the age increases from 13 months to 24 months.

The present study showed that the click evoked OAEs are present in good amplitude even in toddlers. The study revealed higher TEOAE levels in toddlers in terms of both SNR and absolute amplitude. Also higher levels of amplitude and SNR were present at higher frequencies in younger toddlers and as the age progresses from 1.6 to 2 years the changes are seen and the higher levels of OAE shifts slightly towards mid frequency regions. These results are in agreement with Kapoor and Panda (2006) who reported mean amplitude of 18.86 dB at 1 kHz which increases upto 23.30 dB at 4 kHz in children of 1 to 6 years old. They also reported a high mean SNR of 11.93 at 3 kHz. Various other studies have reported higher levels of TEOAEs in infancy and childhood. Stevens et al. (1987); Johnsen et al. (1988); Bonfils et al. (1988) reported that the TEOAEs are detected in normal hearing infants or children in proportions that are similar to those observed in adults. The infants group had a higher level compared to children. Further, the amplitudes of TEOAEs in infants may be larger than adults under comparable recording conditions (Bray & Kemp, 1987) and the main frequency components may be higher (Johnson et al.1989; Kemp et al. 1990). Collet et al. (1993) reported that TEOAEs decrease with increasing age and that TEOAEs in elderly subjects are of relatively lower amplitude, with a spectrum shifted towards lower frequencies. Konet al. (2000) reported that the decrease of TEOAE amplitude in the first 6 years of life is rapid. At later ages, the decrease of TEOAE amplitude continues more slowly. They reported mean amplitude of 15.80 dB SPL in children with an age range of 1 to 3 years. Kapoor and Panda in (2006) reported that neonates showed lowest SNR whereas infants upto 1 year old showed higher SNR values. Liu and Wang (2012) observed that TEOAE level increases in the first 2 months of age, decreases between 2 months and 6 years old, TEOAE level decreases after 6 years old. SNR changes with age. They reported, for neonates and infants, the maximum SNR was centered at 3.2 kHz or 4 kHz. For children, the maximum SNR was centered at 2 kHz. For adults, the maximum SNR decreased to 1.5 kHz

In the present study, the absolute amplitude and SNR in both the groups were higher and it was found to be lesser in lower frequencies. A possible explanation for this could be due to interference of physiological noise which reduces the responses at lower frequencies. The increased amount of responses at higher frequencies can be due to the influence of external ear canal resonance.

**4.2 Comparison of absolute amplitude at different frequencies across age groups**

Mixed ANOVA was done to see the significant main effect of frequency and age on TEOAE amplitude and also the interaction effect of frequency and age. The results revealed are the following.

- A statistically significant main effect was found for the frequencies,

  [F (4,312) = 94.45 $p<0.05$].

- Statistically no significant main effect was found for age groups [F (1,78) = 0.297, $p > 0.05$].

- A statistically significant interaction effect was observed between the frequencies and age groups [F (4, 312) = 5.87, $p < 0.05$].

Since there was significant main effect on absolute amplitude across frequencies, Bonferroni pair wise comparison was carried out to know the significant difference between the frequencies. The results of Bonferroni pair wise comparison for absolute amplitude between the frequencies are depicted in Table 4.3

Table 4.3

*Results of Bonferroni's pair wise comparison for absolute amplitude between frequencies.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | p < 0.05 | p < 0.05 | p < 0.05 | p < 0.05 |
| 1.5 kHz | - | p < 0.05 | p < 0.05 | p < 0.05 |
| 2 kHz | - | - | p < 0.05 | p > 0.05* |
| 3 kHz | - | - | - | p > 0.05 * |

* not significantly different

From Table 4.3 it can be inferred that the absolute amplitude at 2 kHz, 3 kHz and 4 kHz followed a similar trend. The values of absolute amplitude in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the absolute amplitude values showed statistically significant differences between each others as depicted in Table 4.3.

Since there was an interaction effect between frequency and groups found in mixed ANOVA, further repeated measure ANOVA was carried out to see the significant differences across frequencies in each age group separately. In group I , there was a statistically significant difference found across frequencies [$F(4,156)= 55.048$ $p <0.05$].

Since there was a significant main effect of frequency on TEOAE amplitude, Bonferroni pair wise comparison was carried out to know the significant difference in absolute amplitude obtained between various frequencies. The result of Bonferroni pair wise comparison for absolute amplitude between the frequencies in group I is depicted in Table 4.4.

Table 4.4

*Results of Bonferroni's pair wise comparison for absolute amplitude between the frequencies in age groupI.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 1.5 kHz | - | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 2 kHz | - | - | $p < 0.05$ | $p < 0.05$ |
| 3 kHz | - | - | - | $p > 0.05$ * |

* not significantly different

From Table 4.4 it can be inferred that in group I the absolute amplitude at 3 kHz and 4 kHz followed a similar trend. The values of absolute amplitude in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the absolute amplitude values showed statistically significant differences between each others as depicted in Table 4.4.

Repeated measure ANOVA also showed a statistically significant main effect of frequencies on TEOAE amplitude for group II. [F (4,156) = 44.100 ($p < 0.05$)]

Since repeated measure ANOVA showed main effect of frequency, Bonferroni pair wise comparison was carried out to know the significant difference in absolute amplitude between various frequencies. The results of Bonferroni pair wise comparison for absolute amplitude between the frequencies for group II is depicted in Table 4.5.

Table 4.5

*Results of Bonferroni's pair wise comparison for absolute amplitude between the frequencies in group II.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 1.5 kHz | - | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 2 kHz | - | - | $p < 0.05$ | $p > 0.05$ * |
| 3 kHz | - | - | - | $p < 0.05$ |

* not significantly different

In group II the absolute amplitude at 2 kHz and 4 kHz followed a similar trend. The values of absolute amplitude in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the absolute amplitude values showed statistically significant differences between each others as depicted in Table 4.5.

### 4.3 Comparison of SNR at different frequencies across age groups

Mixed ANOVA was done to see the significant main effect of frequency and age on SNR and also the interaction effect of frequency and age. The results obtained for SNR are the following.

- A statistically significant main effect was found for the frequencies.

  [F (4,292) = 81.990, (p<0.05)]

- Statistically no significant main effect was found for age groups

  [F (1,75) = 0.068 , (p >0.05)]

- A statistically significant interaction effect was observed between the frequencies and age groups [F (4, 292) = 6.527, (p <0.05)]

Since there was significant main effect on SNR across frequencies, Bonferroni pair wise comparison was carried out to know the significant difference between the frequencies. The results of Bonferroni pair wise comparison for SNR between the frequencies are depicted in Table 4.6

Table 4.6

*Results of Bonferroni's pair wise comparison for SNR between the frequencies.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 1.5 kHz | - | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 2 kHz | - | - | $p < 0.05$ | $p > 0.05$ * |
| 3 kHz | - | - | - | $p > 0.05$ * |

* not significantly different

From Table 4.6 it can be inferred that the SNR at 2 kHz, 3 kHz and 4 kHz followed a similar trend. The values of SNR in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the SNR values showed statistically significant differences between each others as depicted in Table 4.6.

Since there was an interaction effect between frequency and groups found in mixed ANOVA, further repeated measure ANOVA was carried out to see the significant differences across frequencies in each age group separately. In group I, a statistically significant difference was found for SNR across frequencies [$F (4,156)= 55.048$ ($p <0.05$)]

Since there was significant main effect of frequency on SNR, Bonferroni pair wise comparison was carried out to know the significant difference in SNR obtained between various frequencies. The results of Bonferroni pair wise comparison for SNR between the frequencies for group I are depicted in table 4.7.

Table 4.7.

*Results of Bonferroni's pair wise comparison for SNR between the frequencies in group I.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 1.5 kHz | - | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 2 kHz | - | - | $p < 0.05$ | $p < 0.05$ |
| 3 kHz | - | - | - | $p > 0.05$ * |

* not significantly different

From Table 4.7 it can be inferred that in group I the SNR at 3 kHz and 4 kHz followed a similar trend. The values of SNR in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the SNR values showed statistically significant differences between each others as depicted in Table 4.7.

Repeated measure ANOVA also showed a statistically significant main effect of frequencies on SNR for group II $F(4,156)= 44.100$ ($p <0.05$)

Since the repeated measure ANOVA showed a main effect of frequencies in group II, Bonferroni pair wise comparison was carried out to know the significant difference in SNR between various frequencies. The results of Bonferroni pair wise comparison for SNR across the frequencies for group II are depicted in table 4.8.

Table 4.8

*Results of Bonferroni's pair wise comparison for SNR between the frequencies in group II.*

| | 1.5 kHz | 2 kHz | 3 kHz | 4 kHz |
|---|---|---|---|---|
| 1 kHz | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ | $p < 0.05$ |
| 1.5 kHz | - | $p < 0.05$ | $p < 0.05$ | $p > 0.05$ |
| 2 kHz | - | - | $p > 0.05$ * | $p > 0.05$ * |
| 3 kHz | - | - | - | $p > 0.05$* |

* not significantly different

From Table 4.8 it can be inferred that the SNR at 2kHz and 4 kHz followed a similar trend. The values of SNR in these frequencies did not differ significantly from each other. Whereas for all other frequency pairs the SNR values showed statistically significant differences between each others as depicted in Table 4.8.

The present study revealed statistically no significant main effect between group I and II. Statistically significant interaction effect was observed between frequencies and age groups. Overall the absolute amplitude followed a similar trend at 2 kHz, 3 kHz and 4 kHz. The SNR showed followed a similar trend at 3 kHz and 4 kHz across the age groups. The results of the present study are in agreement with Prieve et al. (1997). They measured TEOAEs in 7 age groups (1 year or less, 1 to 3 years, 4 to 5 years, 6 to 8 years, 9 to 11 years, 12 to 17 years, & 18 to 29 years). They considered narrower age ranges for the younger subjects because greater changes were expected to occur in a shorter period of time for them than for older children and adults. Results showed that greatest changes in TEOAE amplitude occurred at the younger ages. Children in the age groups 1 to 3 years and 4 to 5 years had TEOAE amplitudes similar to each other but higher than those of teens and adults. Clattke et al. (1995); Nozza et al. (1997); Oju et al. (1998); Spektor et al. (1991), Kon et al (2000) also reported about higher amplitude levels of TEOAEs in children. Spektor (1991) reported absolute amplitude of 14.80 dB SPL in children with a mean age of 6.2 years. Kon et al (2000) reported highest absolute amplitude of 15.80 dB SPL for 1 to 3 years of age, and 13.10 dB SPL for 4 to 6 years of age and 7 to 9 year old children. Norton and Widen (2000) reported mean amplitude of about 20 dB SPL in children (mean age: 3.4 years). Kapoor and Panda (2006) reported of a minimum SNR above 3 dB SPL in younger Indian children. The highest SNR was obtained in children (3 dB SPL to 13 dB SPL). The SNR values were lesser in infants compared to children. For infants the values ranged from 2 dB SPL to 9 dB SPL. A possible explanation given by the author is presence of high amount of biological noise. As they grow older the interference of such noises reduces. The study also reported the mean amplitude values ranging from 18dB SPL to 21 dB SPL in children and the highest SNR and amplitude values are obtained in frequency bands of 2 kHz and 3 kHz. Kapoor and Panda (2006) considered children from 1 to 6 year old with mean age of 3 years whereas the present study was done toddlers in the age range of 1 to 2 years. Thus a clear change in TEOAE characteristics as an effect of age could be seen here.

Prieve et al. (1997) in their study has taken narrower age range for assessing younger group since there were expected changes in TEOAE characteristics within shorter periods. These can be attributed to the changes in the ear anatomy in children (Keefe & Leve; 1996, Hall; 2002) During first 2 years the ear canal characteristics changes rapidly (Keefe & Leve ;1996). Thus it can be inferred that the size of ear canal and its resonance characters can affect OAE characteristics. As the age increases the changes are seen. Head circumference was taken as a measure of head growth with age and the ear canal resonance frequency was also measured. Comparison between ear canal resonance frequency and OAEs and head circumference and OAEs were also studied as given below.

### 4.4 Comparison between Ear canal resonant frequency and TEOAE across age groups

From Table 4.1 and Table 4.2 it can be noted that the mean ear canal resonant frequency reduces from 5.42 kHz to 4.71 kHz as the age progresses from group I to group II. The mean ear canal resonant frequency is relatively high in group I compared to group II. The Figure 4.3 and 4.4 depicts SNR and absolute amplitude of OAEs in group I and II respectively.

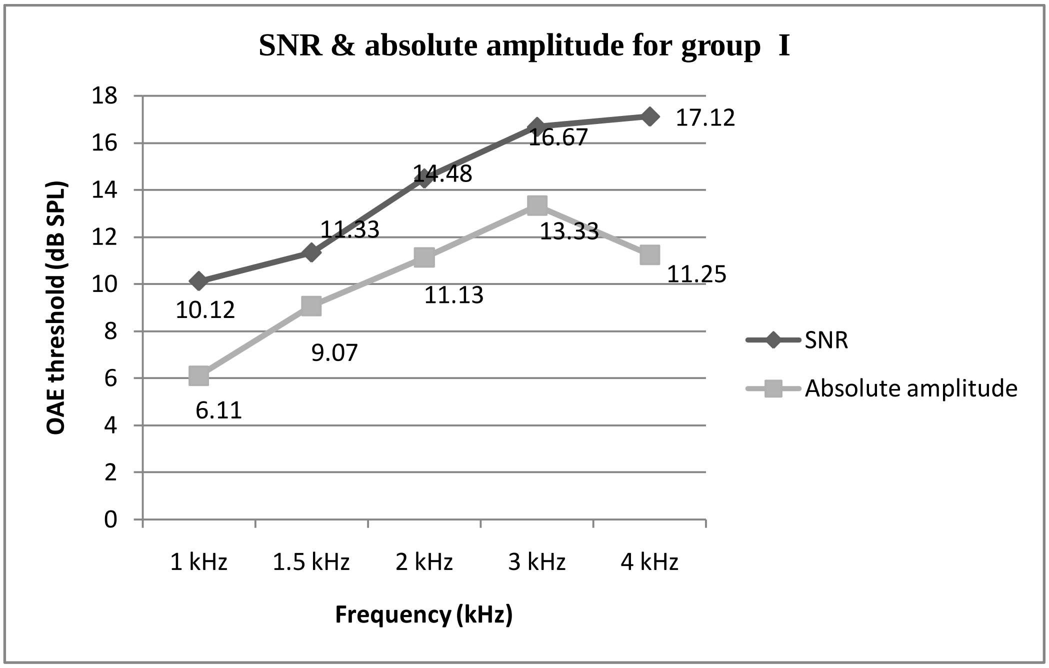


*Figure 4.3.*The mean SNR and absolute amplitude of CEOAEs across frequencies in GroupI

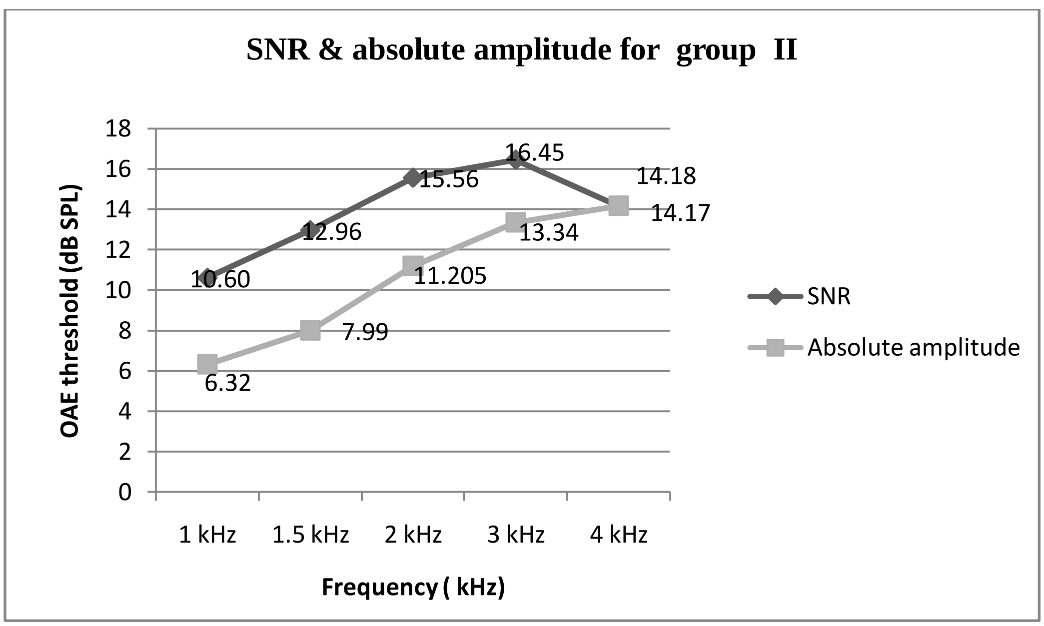


*Figure 4.4.*The mean SNR and absolute amplitude of CEOAEs across frequencies in group II

From Figure 4.3 and 4.4 it can be inferred that maximum SNR was obtained at 4 kHz for group I and at 3 kHz for group II. However such a relationship could not be obtained for absolute amplitude. Hence the SNR was considered for correlating with resonant frequency of ear canal.

Carl Pearson's product moment correlation (2 tailed) was carried out for finding the correlation between ear canal resonance, and OAEs. There was a moderate positive correlation between ear canal resonance frequency and OAEs (.486, $p<0.01$). The frequency at which the best SNR value was obtained and the ear canal resonance frequency have a moderate correlation between each other.

**4.5 Comparison between Ear canal resonance frequency, Head circumference and the OAEs**

The frequency at which the best SNR was obtained was compared with ear canal resonance frequency and head circumference. From the Figure 4.4 and 4.5 it can be depicted that the frequency at which best SNR obtained was at 4 kHz for group 1 and it reduces to 3 kHz in group II. Carl Pearson's product moment correlation (2 tailed) was carried to find the correlation between ear canal resonance, head circumference and SNR. The results of the Carl Pearson's product moment correlation (2 tailed) are the following.

- There was a high negative correlation of about 75 % between ear canal resonance frequency and head circumference (-.749, $p<0.01$) i.e. as the head circumference increases the ear canal resonance decreases frequency for both the groups.

- There was a significant negative correlation of about 76 % between age and ear canal resonance frequency (- .756, $p < 0.01$) i.e. as the age increases the ear canal resonance frequency reduces.
- There was a high negative correlation of about 77 % between head circumference and SNR (-.775, $p < 0.01$) i.e. as the head circumference increases there was a reduction in SNR values for both the groups.

The present study revealed a moderate positive correlation between ear canal resonant frequency and OAEs, a high negative correlation between ear canal resonant frequency and head circumference, and a high negative correlation between head circumference and OAEs.

Hall (2002) reported that OAE amplitude and its spectral parameters could be affected by external ear canal characteristics. Ear canal acoustics definitely changes as a function of age in childhood. The resonance frequency of the ear canal is in the region of 2500 Hz to 3000 Hz region for adults. For children it ranges about 4000 Hz to 4500 Hz. Hood (1998) also reported that ear canal resonance frequency decreases progressively from about 6000Hz in neonates to about 4000Hz in infancy and downward to adult values of approximately 3000Hz by age 2 to 3 years. The findings by Keefe and Leve (1996) supports that the external and middle ear systems vary significantly in their acoustic response properties over the first 2 years after birth. The ear-canal diameter and length each increases from birth through age of 24 months (Keefe et al. 1993).

Chandni and Mamatha (2012) investigated on the effect of click evoked TOAEs and tone busrt evoked TOAEs in the age group of 0 to 1 year old infants. They reported an increasing trend of SNR values across different frequencies of click stimulus across ages. A possible explanation given by them is the effect of external ear canal resonance frequency. As the child grows older the ear canal resonance frequency shifts to lower frequencies. The present study has also depicted the fact that the ear canal resonance frequency decreases as the age increases. A positive correlation was observed with head circumference and ear canal resonance frequency. However, this correlation can only be attributed to the age group of 1 to 2 years as the characteristics of ear canal become adult like by around 2 to 3 years of age (Keffe & Leve, 1996).

The higher SNR and absolute amplitude obtained in the present study may be due to the fact that the ear canal acoustics of children becomes adult like by the age of 2 years. The SNR improves in toddlers compared to younger groups is may be because the amount interference by physiological noise reduce as they grow older. In group I the best SNR is observed at higher frequencies and it well correlates with the ear canal resonance for the same group. Group I had ear canal resonant frequency about 5 kHz and the TEOAEs grows towards a higher frequency range. As the toddler grow older the ear canal acoustics become adult like and in group II the ear canal resonant frequency was found to be reduced to about 4 kHz, and the SNR grows till 3 kHz and reduces afterwards. These can be accounted to the fact that the OAE characteristics changes due to change in the ear canal acoustics. The ear canal resonance was found to be changing with head circumference as there was a high negative correlation.

# CHAPTER - 5

## Summary and conclusion

TEOAEs being the best known otoacoustic emissions present in 98% to 100% of the normal hearing individuals is widely used in hearing screening of infants and young children. TEOAEs when recorded with click stimuli (CEOAEs) have been used to assess the functioning of outer hair cells. Click stimulus has a broad spectrum, and therefore can consequently stimulate a broad frequency region of the cochlea in a single measurement. In young children the characteristics of OAEs varies rapidly across the age due to developmental changes occurring in the auditory system. The ear canal and middle ear resonant frequency changes with age and has a significant effect on OAEs. Also studies have reported change in head circumference across different ethnic groups, which might also affect the ear canal length and volume which again affects OAEs. Chandni and Mamatha (2012) observed a significant difference in absolute amplitude and SNR for click and tone burst evoked OAEs across different age groups in infants from 0 to 1 year of age in Indian population. Hence the current study was conducted to see the age and ear canal resonance frequency related changes on CEOAEs in the age range of 1 to 2 year toddlers in Indian population.

The aims of the present study were,

- To know the spectrum change of CEOAEs with age.
- To investigate the effect of ear canal resonance on CEOAEs.
- To see is there any relationship between head circumference and CEOAEs.

To accomplish the aim of the study, the absolute amplitude and SNR of CEOAE was measured at frequency bands centred at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz in 40 toddlers in the range of 1 to 2 years of age (mean age of 18 months). To know the age related changes, the groups were divided into two; 13 to 18 months (group I) and 19 to 24 months (group II). The ear canal resonant frequency and head circumference was also measured from the subjects.

To analyze the data Statistical Package for the Social Science Version 17 was used. Various statistical analyses were carried out for both within group and between group comparison.

The results of the present study can be summarized as follows.

**Absolute amplitude and SNR at different frequencies across age groups**

- An increase in mean SNR and absolute amplitude with increase in frequency was seen in group I. In group II also the SNR and absolute amplitude increased with increase in frequency. At 2 kHz, absolute amplitude increased with increase in age and reduced at 4 kHz in group II.
- Whereas, SNR increases at low frequency with increase in age, except at 4 kHz which has shown to reduce with age. Maximum SNR was obtained at 4 kHz for group I and at 3 kHz for group II. However such a relationship could not be obtained for absolute amplitude.
- The mean ear canal resonant frequency is 5.4 kHz for group I. As the age increased the ear canal resonant frequency reduced to 4.5 kHz in group II. The

mean head circumference in the group I is 44.8 cm and it increases to 50.8 as the age increases from 13 months to 24 months.

- There was no main effect found between the age groups for SNR and absolute amplitude.
- Statistically significant interaction effect was observed between absolute amplitude and age groups. Overall the absolute amplitude followed a similar trend at 2 kHz, 3 kHz and 4 kHz across age groups.
- Statistically significant interaction effect was observed between absolute amplitude and age groups. The SNR followed a similar trend at 3 kHz and 4 kHz across groups.

**Comparison between Ear canal resonant frequency and TEOAE across age groups**

- The mean ear canal resonant frequency is relatively high in group I compared to group II. The mean ear canal resonant frequency is 5.4 kHz for group I. As the age increased the ear canal resonant frequency reduced to 4.5 kHz in group II
- In group I the best SNR was observed at higher frequencies and it well correlated with the ear canal resonance frequency for the same group. Group I had an ear canal resonant frequency of about 5 kHz and the TEOAEs grows towards a higher frequency range. In group II the SNR grows till 3 kHz and reduces afterwards in the same group. The similar trend was not observed at 4 kHz for this group.
- Carl Pearson's product moment correlation showed moderate positive correlation of about 49 % between ear canal resonance frequency and SNR (.486, $p<0.01$).

The frequency at which the best SNR obtained and the ear canal resonance frequency have a moderate correlation between each other.

**Comparison between Ear canal resonance frequency, Head circumference and the OAEs**

- There was a high negative correlation of about 75 % between ear canal resonance frequency and head circumference (-.749, $p<0.01$) i.e. as the head circumference increases the ear canal resonance frequency decreases for both the groups.
- There was a significant negative correlation of about 76 % between age and ear canal resonance frequency (- .756, $p<0.01$) i.e. as the age increases the ear canal resonance frequency reduces for both the groups.
- There was a high negative correlation of about 77 % between head circumference and SNR (-.775, $p<0.01$) i.e. as the head circumference increases there was a reduction in SNR values for both the groups.

**Conclusion**

The higher SNR and absolute amplitude obtained in the present study may be due to the fact that the ear canal acoustics of children becomes adult like by the age of 2 years. The SNR improves in toddlers compared to younger groups is may be because the amount of interference by physiological noise reduces as they grow older. In group I the best SNR was observed at higher frequencies and it well correlates with the ear canal resonance for the same group. Group I had ear canal resonant frequency about 5 kHz and the TEOAEs grows towards a higher frequency range. As the toddler grow older the ear canal acoustics become adult like and in group II the ear canal resonant frequency was found to be reduced to about 4 kHz, and the SNR grows till 3 kHz and reduces afterwards. These can be accounted to the fact that the OAE characteristics changes due to change in the ear canal acoustics. The ear canal resonance was found to be changing with head circumference as there was a high negative correlation.

# References


Anson, B. J., & Donaldson, J. A. (1981). Surgical Anatomy of the Temporal Bone and Ear.Saunders, Philadelphia.

Baltimore., Williams., Wilkins.Ikui, A., Sando, I., Sudo, M., & Fujita, S. (1997). Postnatal change inangle between the tympanic annulus and surrounding structures," *Annals of Otology, Rhinology, Laryngology.106*,33–36.

Bonfils, P. Avan, P., Trotoux, J., & Narcy, P. (1992). Distortion-product otoacoustic emissions in neonates - Normative data. *Acta Otolaryngology 112*,739-744.

Bonfils, P., Uziel, A., & Pujol, R. (1988). Screening for auditory dysfunction in infants by evoked otoacoustic emissions.*Archives of Otolaryngology Head and Neck Surgery, 144, 887-890.*

Bray, P., & Kemp, D. T. (1987). An advanced cochlear echo technique suitable for infant screening. *Journal of Audiology, 21*, 191-204.

Burns, E. M, Campbell, S. L., & Arehart, K. H. (1994). Longitudinal measurements of spontaneous otoacoustic emissions in infants, *Journal of Acoustic Society of America,95*, 385-394.

Burns, E. M., Arehart, K. H & Campbell, S. L. (1992). Longitudinal measurements of spontaneous otoacoustic emissions in infants. *Abstract, Association for Research in Otolaryngology,15*,149.

Burns, E.M., Arehart, K. and Campbell, S.L. (1992) Prevalence of spontaneous otoacoustic emissions in neonates. *Journal of the Acoustical Society of America.91*, 1571-1575.

Chandni, M., & Mamata, N.M., (2012). Effect of age on spectral distribution of click and toneburst evoked otoacoustic emissions in infants. Dissertation submitted to the Univ. of Mysore, Mysore, as part fulfillment of M.Sc.(Aud).

Collet, L., Veuillet, E., Chanal, J. M., &Morgon, A. (1991). Evoked otoacoustic emissions-Correlates between spectrum analysis and audiogram.*Audiology 30*, 164-172.

Collet, L., Gartner, M., Veuillet, E., et al. (1993). Evoked and spontaneous otoacoustic emissions A comparison of neonates and adults. *Brain Dev*,15(4), 249-252.

Collet, L.Gartner, M., Moulin, A., Kauffmann, I., Disant, F., Morgon, A. (1989). Evoked otoacoustic emissions and sensorineural hearing loss.*ArchOtolaryngol Head Neck Surg115*, 1060-1062.

Cope, Y., Lutman, M. E. (1988). Oto-acoustic emissions. In: Pediatric Audiology 0-5 years, B McCormick. London, Taylor and Francis, 221-245

Crelin, E. S. (1973). *Functional anatomy of the newborn*. New Haven and London: Yale UniversityPress.

Dallos, P. (1992). The active cochlea.*Journal of Neuroscience,12*, 4575-4585

Davis, A., Bamford, J. M., Wilson, I., Ramkalawan, T., Forshaw, M&Wright,S. (1997).A critical review of the role of neonatalscreening in the detection of congenital screening impairment.*Health Technology Assessment, 1*(1), 176.

Doyle, K. J., Burggraaff, B.,Fujikawa, S., (2000) external and middle ear effects on infant screening tests *Archives of Otolaryngology—Head & Neck Surgery,122*, 477-481

Gillian E. Hanley, PhD,1,2 Patricia A. Janssen,(2012). Ethnicity-Specific Growth Distributions forPrediction of Newborn Morbidity,*Journal of ObstetricsGynaecologyCanada*;*34(9*), 826–829.

Goforth l, Hood L J & Berlin C I (1998). Supression of transient evoked otoacoustic emission using frequency limited stimuli *Association for research in Otolarygology* abstracts 21, 153

Hall JW, Baer JE, Chase P A, & Schwaber MK (1994): Clinical application of otoacoustic emissions: What do we know about factors influencing measurement and analysis? *Otolaryngology Head Neck Surgery,110,* 22-38

Hall, J. W., (2000). *Handbook of Otoacoustic Emissions*. Singular Publishing Company, San Diego.

Hall, J. W., (2010). *Ojectiveasessment of hearing*Plural Publishing Company, San Diego.

Holte, L.A., & Margolis, R.H. (1991). Cavanaugh RM. Development changes tympanograms. *Audiology, 30, 1-24*

Holte, L., Margolis, R. L., & Cavanaugh, R. M., Jr. (1991). Developmental changes in multi frequency tympanograms. *Audiology, 30*, 1–24.

Janssen, P. A., Thiessen, P., Klein, M. C., Whitfield, M.F., & Ying, C. (2007).Standards for the measurement of birth weight, length and head circumference at term in neonates of european, chinese and south asian ancestry. *Open Medicine 1 (2) :e74-e88*

Johnsen NJ, Bagi P &Elberling C (1983): Evoked acoustic emissions from the human ear. Some results in neonates. *Scandinavian Audiology Abstract* 30:204.

Johnsen NJ, Bagi P &Elberling C (1983): Evoked acoustic emissions from the human ear. III. Findings in neonates. *Scandinavian Audiology* 12:17-24.

Johnsen NJ, Parbo J &Elberling C (1989): Evoked acoustic emissions from the human ear. V. Developmental changes. *Scandinavian Audiology* 18:59-62.

Johnsen, N.J. & Elberling, C. (1987a): Evoked acoustic emissionsfrom the human ear. I. Equipment and responseparameters. *Scandinavian.Audiology*.*11*, 3-12.

Johnsen, N.J. & Elberling, C. (1987b): Evoked acoustic emissions from the human ear. II. Normative data in youngadults and influence of posture. *Scandinavian Audiology*.*11*, 679-77.

Joint Committee on Infant Hearing.(1994). *Joint Committee on InfantHearing 1994 position statement*.*ASHA,36*,38-41.

Jupiter, T., & Giacomazza, S.(1998 The effect of middle ear resonant frequency, ear canal resonance, and ear canal volume on TEOAE ,*Journal of Acoustic Society of America*. *104*(3), 1800.

Kapoor, R., & Panda, N. K. (2006).Transient evoked otoacoustic emissions. *Indian Journal of Pediatric, 73,283-286.*

Keefe DH (1991) Effects of external and middle ear characteristics on otoacoustic emissions. *Abstract of International Symposium on Otoacoustic Emissions*, Kansas City, p38.

Keefe D H, Burns EM, Ling R & Laden B (1990). Chaotic dynamics of otoacoustic emissions. In: Mechanics and Biophysics of Hearing, P Dallos, CD Geisler, JW Matthews, MA Ruggero, CR Steele. New York, Springer-Verlag, pp194-201.

Keefe, D. H., & Levi, E., ( 1996). Maturation of the middle ear external ears: acoustic power-based responses and reflectance tympanometry. *Ear and Hearing, 17, 361-373*

Keefe, D. H., Bulen, J. C &Arehart, K. H.(1993). Ear-canal impedance and reflection coefficient in human infants and adults.*Journal of Acoustic Society of America, 94*(5*)*, 2617-2638

Kemp, D. T. (1986).Otoacoustic emissions, travelling waves and cochlear mechanisms. *Hearing Research*.*22*, 95–104.

Kemp, D. T., (2002) Otoacoustic emissions, their origin in cochlearfunction, and use .*British Medical Bulletin*, 63, 223–241.

Kemp, D.T. (1978). Stimulated acoustic emissions from within the human auditory system.*Journal Acoust Society of America*, *64*,386–1391

Kok MR, van Zanten GA, Brocaar MP, Wallenburg HCS (1993): Click-evoked oto-acoustic emissions in 1036 ears of healthy newborns. *Audiology32*, 213-224.

Liu, J &Wang, N (2012).Effect of age on click-evoked otoacoustic emission A systematic review, *Neural regeneration research*,*7*(11).

Liu, J. F., Wang, N. Y & Li JL.(2009). Frequency distribution of synchronized spontaneous otoacoustic emissions showing sex-dependent differences and asymmetry between ears in 2- to 4-day-old neonates.*International Journal of Pediatric Otorhinolaryngology, 73*(5), 731-736.

Madan B, Cnattingius S, Axelsson O.(1999) Outcomes of post-term births:the role of fetal growth restriction and malformations. *Obstetrics Gynaecology*, *94*, 758–62.

Martin GK, Lonsbury-Martin BL &Coats AC (1987): Alterations in behavioral thresholds, acoustic distortion products, and summating potentials following experimentally induced endolymphatichydrops in rabbit. *AbstractofAssociation for Research in Otolaryngology* 10:18.

Martin G. K., Probst. R, Scheinin. S. A., Coats A. C., &Lonsbury-Martin BL (1987): Acoustic distortion products in rabbits. Il. Sites of origin revealed by suppression and pure-tone exposures. *Hearing Research* 28, 191-208

Mazlan, R., Kei, J., Hickson, L, Stapleton, C, Grant, S., Lim, S. et al. (2007). High frequency immittance findings: newborn versus six-week-old infants. *International Journal of Audiology, 46*, 711-717.

McFadden D (1993): A speculation about the parallel ear asymmetries and sex differences in hearing sensitivity and otoacoustic emissions. *Hearing Research, 68*, 143-151

McFadden, D & Mishra, R.(1993). On the relation between hearing sensitivity and otoacoustic emissions.*Hearing Research, 70,* 170-182.

McLellan, M. S., & Webb, C. H. (1957).Ear studies in the newborn infant.*Journal of Pediatrics ,51*, 672–677.

Moleti, A &Sisto, R. (2007).Transient evoked otoacoustic emission latency and cochlear tuning at different stimulus levels. *Journal of Acoustic Society of America, 122, 2183-2190.*

Northern, J. L., &Downs, M. P. (1984).*Hearing in children* .

Norton S. J., &Widen J. E. (1990): Evoked otoacoustic emissions in normal-hearing infants and children: Emerging data and issues. *Ear and Hearing* 11, 121-127.

Norton, S. J., & Widen, J.E., (1990). Evoked otoacoustic emissions in normal-hearing infants and children: Emerging data and issues. *Ear and Hearing,11*(2), 121-127

Patricia A. Janssen., Paul Thiessen., Michael C. Klein., Michael F. Whitfield., Ying C. Macnab, Sue C., &Culliskuhl (2007). Standards for the measurement of birth weight, length and head circumference at term in neonates of European, Chinese and southAsian ancestry. Open Medicine, Vol 1, No 2.

Penner M. J., Glotzbach L & Huang, T. (1993).Covariation of binaural, concurrently-measured spontaneous otoacoustic emissions.*Hearing Research* 73:190-194

Prieve, B. A., & Fitzgerald, T. S. (1991). Basic characteristics of click evoked otoacoustic emissions in infants and children. *Journal of Acoustic Society of America,* 102, *2860- 2870.*

Probst, R., Coats, A.C., Martin, G. K., &Lonsbury-Martin, B. L., (1986). Spontaneous, click and tone burst evoked otoacoustic emissions from normal ears. *Hearing Research, 21,261-275.*

Probst, R., Coats, A. C., Martin, G. K., &Lonsbury-Martin, B. L. (1991).A review of otoacoustic emissions.*Journal of Acoustic Soceity of America, 89 , 2027-2067.*

Robinette, M. S. (1992). Clinical observations with transient evoked otoacoustic emissions with adults.*Seminar in Hearing 13,* 23-36.

Roeser, R. J., Valente, M., & Dunn, H. H. (2007).*Audiology: Diagnosis*. Thieme Publishers, New York.

Sato, H., Sando, I.,&Takahashi, H. (1991). Sexual dimorphism and developmentof the human cochlea.Computer 3-D measurement.*ActaOto-Laryngologica*.(Stockholm) 111, 1037–1040.

Saunders, J. C., Kaltenbach, J. A., &Relkin, E. M. (1983).“The structuraland functional development of the outer and middle ear,” In *Developmentof Auditory and Vestibular Systems*, edited by R. Romand and M.-R.Romand-Academic, New York_, pp. 3–25.

Siegel, J. J. H. (1994). Ear-canal standing waves and high-frequency sound calibration.

Sisto, R., and Moleti, A. (2007). Transient evoked otoacoustic emissionlatency and cochlear tuning at different stimulus levels,” *Journal of the Acoustical Society of America*. *122*, 2183–2190.

Stover, L., & Norton, S. J. (1993).The effects of aging on otoacoustic emissions.*Journal of Acoustic Society of America, 94, 2670-2681.*

Thornton, A. R., Marotta, N., & Kennedy, C. R.(2003). The order of testing effect in otoacoustic emissions and its consequences for sex and ear differences in neonates.*Hearing Research*, *184(1-2*), 123-130

Wada H., Ohyama K., Kobayashi T., Sunaga N., & Koike T. (1993). Relationship between evoked in otoacoustic emissions and middle ear dynamic characteristics. *Audiology, 32, 282-92.*

.

Weiner, F. M., & Ross, D. A. (1946).The pressure distribution in the auditory canal in a progessive sound field. *Journal of the Acoustic society of America*;18 (2) 401 408.

Wright, A. (1987). Dimensions of the cochlear stereociIia in man and the guinea pig.*Hearing Research*, *13,*89-98.

Zurek, P. M. (1981). Spontaneous narrowband acoustic signals emitted by human ears.*Journal of the Acoustical Society of America,62,*514-523