EFFECT OF CONDUCTIVE MECHANISM ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS

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May-2003

CERTIFICATE

This is to certify that this Dissertation entitled **"EFFECT OF CONDUCTIVE MECHANISM ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS"** is a bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. MSHM0103).

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CERTIFICATE

This is to certify that this Dissertation entitled **"EFFECT OF CONDUCTIVE MECHANISM ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS"** has been prepared under my supervision and guidance. It is also certified that this Dissertation has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

This Dissertation entitled **"EFFECT OF CONDUCTIVE MECHANISM ON DISTORTION PRODUCT OTOACOUSTIC EMISSIONS"** is the result of my own study under the guidance of **Mr. Animesh Barman** Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore and not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysore,

May, 2003 Reg. No. MSHM0103

Dedicated to

My Family & Teachers

... my sources of inspiration

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INTRODUCTION

One of the most exciting advances in understanding of hearing process during recent years is the discovery of otoacoustic emissions (OAEs). OAEs can be defined as "sound generated within the cochlea, by the outer hair cells, which can be detected at tympanic membrane by a miniaturized sensitive microphone"(Norton & Stover, 1994). The otoacoustic emission phenomenon is based on an active mechanism in the cochlea and was first described by Kemp (1978). With the discovery of OAEs, the cochlea is considered now to be a sophisticated organ with bi-directional transduction properties (Kemp, 1997).

OAEs can be broadly classified into two types (1) spontaneous OAEs which occur in the absence of any external stimulation, (2) evoked OAEs (EOAEs) which occur during or after acoustic stimulation. There are several subclasses of EOAEs based primarily on the stimuli used to evoke them. They include:

1) Transient evoked otoacoustic emissions (TEOAEs): There are frequency dispersive emissions occurring in response to transient acoustic stimuli such as click or a tone burst.
2) Distortion product otoacoustic emissions (DPOAEs): These are generated in response to two continuous pure tones closely separated in frequency by a prescribed differences (in Hz) and presented simultaneously to the ear.
3) Stimulus frequency otoacoustic emissions (SFOAEs): These occur as a synchronous response to a continuous tonal stimulus and are at the same frequency as the stimulus.

The OAEs as a clinical tool, provides several advantages, hitherto not possible using other contemporary tools for the purpose (Martin, Probst & Lonsbury-Martin, 1990). First this test is objective in nature and does not require patient co-operation for it to be administered. Also, DPOAEs are emitted at a known frequency related to the stimuli; it helps in determining the exact place on the basilar membrane, which responds to two known stimuli.

But there are various factors which influence OAEs. Some factors include: stimulus parameters, patient variables and age and gender effects (Hall, 2000). Among patient variables, external and middle ear characteristics are most important. The ear canal and middle ear transmission system contain mechanical and acoustic elements that are, compliance, mass and friction. Compliance and mass susceptance vary as a function of frequency. When the admittance of the middle ear is measured using a low frequency probe tone, the compliance or stiffness elements are the primary contributors to the admittance measured in the ear canal; the middle ear transmission system, therefore, is described as stiffness controlled at low frequencies. When there is increased stiffness, it will have greatest effect on low frequency signals. (Shanks & Shelton, 1991).

In contrast, when admittance is measured using a high frequency probe tone, the mass elements are the primary contributors to the admittance measured in the ear canal; the middle ear is described as mass controlled at high frequencies. If the mass of the middle ear increases, hearing will reduce in the high frequencies (Shanks & S helton, 1991).

When stiffness susceptance and mass susceptance are exactly equal, then the middle car transmission is said to be in resonance. Normal middle ear resonance falls between 800Hz and 1200Hz. The middle ear is stiffness dominated below resonant frequency and mass dominated above the resonant frequency (Shanks & Shelton, 1991).

In addition ear canal volume also affect resonant frequency and sound pressure level in the canal. A smaller ear canal volume results in a higher stimulus sound pressure and a higher ear canal resonant frequency (Margolis, 2000).

As the DPOAEs are recorded in the ear canal, effective reverse transmission is needed lo transmit the OAEs from the inner ear to the ear canal (Margolis & Trine, 2000). Hence, middle ear conditions directly influence OAE measurements. Although the middle ear can transmit sound bidirectionally the forward transmission characteristics and backward characteristics are different.

Forward transmission through the middle ear determines the effectiveness of the evoking stimulus that reaches the cochlea. The tympanic membrane and ossicular chain produces a sound pressure gain that has often been described as a transformer action. The effect of ear canal volume between the probe and the tympanic membrane also influences forward transmission (Margolis, 2000).

Backward transmission through the middle ear is less efficient than forward transmission. In the reverse direction, there is a sound pressure loss, as energy is transmitted by the cochlea, through the ossicular chain and into the ear canal

(Margolis, 2000). Puria and Rosowski (1996) measured the backward transmission loss in human cadavers. The loss was around 22dB and increased at lower and higher frequencies. The mechanical vibrations of the ossicular chain set the eardrum in motion, producing an airborne pressure wave in the ear canal. As ear canal volume affects the intensity and spectrum of the stimulus, it also influences the characteristics of the response, thus contributing to the backward transmission characteristics. The sound pressure that is produced in the ear canal is inversely proportional to ear canal volume (Kemp, 1980)

Therefore studies have been carried out to investigate the influence of external or middle ear characteristics on OAEs. Middle ear pressure and ear canal pressure have very similar effects on middle ear function. Even a mild degree of middle ear pressure could significantly reduce measured TEOAE and DPOAE amplitude (Owens, McCoy, Lonsbury-Martin & Martin, 1992). Kemp (1980) showed that sound pressure produced in the ear canal is inversely proportional to the ear canal volume. So, the OAE amplitude is also expected to be inversely proportional to the ear canal size.

Wada, Ohyama, Kobayashi, Sunaga and Koike (1993) investigated relationships between TEOAEs and middle ear dynamic characteristics. They concluded that TEOAEs are most distinctly detected at the middle ear resonant frequency and in normal subjects whose middle ear mobility is normal.

Gvelcsiant, Gunenkor and Tarankialaze (2000) studied the influence of age and external and middle ear resonance on TEOAEs and DPOAEs. Result demonstrated that assessment of resonance properties of external ear canal and middle ear could be a valuable tool in understanding of age related changes in OAE parameters.

Need for the study

Thus it is clear that stimulus presented to elicit OAEs can be changed due to ear canal and middle ear resonant properties, causing increase or decrease in DPOAE amplitude.

OAEs generated in the inner ear can change its spectrum on the way traveling through the middle ear and measured in ear canal due to resonance properties of ear canal and middle ear. Not only this, the ear canal volume also can change the measured sound pressure level in the ear canal. The ear canal volume is inversely proportional to the resonance frequency, hence lesser the volume more the sound pressure level thus resulting in increased resonance.

Mobility of the middle ear can also act like a filter and allow specific frequencies to pass through and attenuate other frequencies. This will change the OAE spectrum. When there is increased stiffness it will have greatest effect on low frequency signals, thus modifying the DPOAE spectrum depending upon the mobility of the ear.

Moreover most of the studies have been focused on TEOAEs (Kemp, 1980; Wada, Ohyama, Sunaga, Kobayashi & Koike, 1993). Hence, the present study has been taken up to study the effect of external ear, middle ear resonance and also the mobility of the middle ear on DPOAE spectrum.

Aim of the study

The present study has been taken up to investigate,

the influence of middle ear resonance on the DPOAE amplitude and signal to noise ratio (SNR).

the influence of external ear resonance on the DPOAE amplitude and SNR.

the effect of mobility of the middle ear (static compliance) on amplitude of DPOAE.

REVIEW

Otoacoustic emissions have provided hearing researchers with new insights into the micro mechanical workings of the cochlea. The OAEs first described by Kemp (1978), represent acoustic energy presumed to be generated by the stimulus-induced, motile activity of the outer hair cells.

One of the two major classes of OAEs consists of evoked OAEs. Depending on the parametric features of the eliciting sound, stimulated emissions can be further separated into three subclasses consisting of transiently evoked otoacoustic emissions (TEOAEs), stimulus frequency otoacoustic emissions (SFOAEs) and distortion-product otoacoustic emissions (DPOAEs) (Martin, Probst & Lonsbury-Martin, 1990).

DPOAEs have been investigated as the basis of an objective test of hearing since 1988. Although a limited amount of information is available concerning the normal properties of DPOAEs, initial results in both normal and hearing impaired ears, indicate that DPOAEs like TEOAEs, can form the basis of an objective hearing test (Lonsbury-Martin, Harris, Hawkins, Stagner & Martin, 1990).

DPOAE testing has several advantages over the use of TEOAEs. In particular, because of the continuous, short latency nature of DPOAEs, essentially any frequency, between approximately 1 and 8 kHz, can be tested intentionally. Also, the reasonably wide dynamic range of DPOAEs in terms of growth of response amplitude as a function of stimulus level permits a complete evaluation of cochlear function at both "threshold and suprathreshold" levels of stimulation (Lonsbury-Martin & Martin, 2000).

The information gathered regarding DPOAE has been classified under the following titles:

1) Site and mechanism of origin

2) Characteristic features and Normative findings

3) Factors, which influence the DPOAE response

1) Mechanism and site of origin

Distortion-product generation represents a nonlinear phenomenon that is characteristic of many physical systems. Such responses are generated by elements that modify the signal, thereby creating additional frequencies (Martin, Probst & Lonsbury-Martin, 1990).

Wilson (1980) suggested that hair cells or supporting cells underwent volume changes when stimulated by sound. This could be due to the movement of ions and gave the cochlea its bi-directional transduction property.

Brownell (1983) demonstrated that the outer hair cells have elecromotile properties. It was observed that the actin and myosin filaments in the stereocilia interact under electrical stimulation and set the outer hair cells to oscillate at audible frequencies.

The presence of distortion products in the human auditory system has been known for many years (Helmholtz, 1870; Bekesy, 1934, cited in Martin, Probst & Lonsbury-Martin, 1990). Helmholtz (1870), thought that this distortion was generated from the middle ear. Over-driving the mechanical-conduction system at excessively high levels can generate distortion in the auditory system (Bekesy, 1934; Wever, Bray & Lawrence, 1949, cited in Martin, Probst & Lonsbury-Martin, 1990).

However, later, the results of a number of psychoacoustic experiments (Plomp, 1965; Goldstein, 1967; Wenner, 1968) demonstrated the existence of distortion product and thus, of non-linear elements in the auditory system, at medium levels of stimulation. Goldstein (1967), provided the first clear evidence of inner ear as the locus for the generation of distortion products.

Also, numerous observations done by Siegal and Kim (1982) which support the site of generation of OAE s are:

The emissions are independent of synaptic transmission and are preneural. When the auditory nerve activity was blocked chemically or physically by severing it, otoacoustic emission which could be measured through neural responses to sound were absent.

Otoacoustic emissions are unaffected by stimulus rate, unlike neural responses.

Evoked otoacoustic emissions are frequency dispersive, ie, the higher the emissions frequency, the shorter the latency, which is consistent with coding along the basilar membrane. Their amplitude also grows non-linearly with stimulus level.

Otoacoustic emission tuning or suppression curves are similar to psychophysical tuning curve.

The emissions are vulnerable to various agents such as ototoxic drugs, intense noise and hypoxia, which are known to affect cochlea.

They are absent in frequency regions with cochlear hearing losses exceeding 40-50dBHL and present when hearing sensitivity is normal.

To summarize, otoacoustic emissions are generated due to the electro motile properties of the outer hair cells.

2) Characteristic features and normative findings

There is growing evidence that DPOAEs are a property of all normally hearing human ears (Furst & Lapid, 1988). Kemp and Chum (1980) reported the presence of DPOAEs in all fourteen ears they examined. Other similar findings indicate that DPOAEs can be recorded in well over 90% of normal ears (Harris, Lonsbury-Martin, Stagner, Coats & Martin 1990; Martin, Probst & Lonsbury-Martin, 1990). The frequency range within which acoustic distortion products are reliably detected is between 1 and 8kHz with respect to the geometric mean of f1 and f2 (Martin, Probst & Lonsbury-Martin, 1990).

Detection "thresholds" for DPOAEs depend almost entirely on the noise floor and the sensitivity of the measuring equipment. Martin, Probst and Lonsbury-Martin (1990) reported detection thresholds that were 3dB above the noise floor at about 35-45 dB SPL for DPOAEs between l-8kHz. However, much lower "thresholds" down to 5dBSPL, have been determined when measuring near or at strong fixed-place emission frequencies (Wilson, 1980).

The latency of DPOAEs can be defined by phase measurements. A systematic relationship between phase and f2/fl ratios was noted by Wilson (1980) and Kemp and Brown (1984) in that the latency was much shorter with high rather than with low ratios. Wilson (1980) reported a latency of <2msec for f2/fl ratios of 1.3 and around 3ms for ratios of 1.1.

Acoustic distortion products are methodologically difficult to measure in human ears because of their relatively small amplitudes. The small amplitudes are probably one reason why DPOAEs have not been examined in humans as extensively as the other classes of OAEs. An additional difficulty is represented by the multitude of parameters that need to be considered and that can be varied. For example, the frequency ratio of the primaries, their levels, the particular distortion product frequency to be measured, and the frequency range where the primaries, the distortion product, and the distortion product site are located need to be considered (Martin, Probst & Lonsbury-Martin, 1990).

Distortion products in human ears have been almost exclusively measured at the frequency of 2fl-f2 (Zwicker, 1955, cited in Martin, Probst, Lonsbury-Martin, 1990; Goldstein, 1967; Hall, 1972; Smorenburg, 1972; Weber & Mellert, 1975, cited in Martin, Probst, Lonsbury-Martin, 1990; Zurek & Leshowitz, 1976; Humes, 1980). The amplitude of the combination at 2fl-f2 shows a variability of 10-20dB and is dependent on the relationship of frequencies and levels of the two primaries. Small frequency ratio of O/fl, elicit combination tones that are generally louder than those evoked with widely spaced primaries (Martin, Probst & Lonsbury-Martin, 1990). Additionally, the loudest tones are obtained when the level of the lower primary frequency (f1) is 5-10dB higher then that of the higher frequency primary (f2). Also when equilevel primaries are used, the loudness growth function generally grows linearly with a slope of approximately 1, up to stimulus level of 60-70dBSPL. Saturation occurs in most cases when higher stimulus levels are used. Nonmonotic individual loudness/growth functions are sometimes measured, especially with f2/fl ratios > 1.25. Finally combination tones are detected in most normally hearing subjects, in the frequency range of 0.5-5kHz, with a maximum incidence between 1 and 2kHz.

Norton and Widen (1990) in a survey of literature, summarized the findings with regard to developmental changes in EOAEs:

i. The amplitude reduces with age.
ii. The energy spectrum tends to shift to lower frequencies with age.
iii. The latency tends to increase with age.

3) Factors affecting evoked otoacoustic emissions

There are various factors, which might affect DPOAEs. In the present review the studies have been mentioned in the following sequence:

a) Stimulus parameters

- Frequency
- Intensity

b) Subject parameters

- SOAEs
- Gender differences
- Ear differences
- Diurnal effects
- Genetics
- Temperature
- Body position
- Age
- Ear canal and middle ear pressure
- Ear canal and middle ear resonance

a) Stimulus parameters: The amplitude of DPOAEs is dependent on several parametric factors including the level and frequency of the primaries, their frequency separation or ratio, and the innate properties unique to each ear (Martin, Probst & Lonsbury-Martin, 1990).

Frequency: If, the DPOAE frequency coincides with an SOAE or a dominant TEOAE frequency, the amplitude of the DPOAE can be relatively large (Wilson, 1980; Scholith, 1982, cited in Hall, 2000). Through enhancement by the presence of these other emissions, the amplitudes of DPOAE can reach unusual level that are only 10-20dB less than those of primaries.

The frequency distance between the two primaries is crucially important. Wilson (1980) demonstrated that the largest amplitudes occurred with f2\fl ratios between 1.1 and 1.2.A similar ratio of 1.22 was reported by Harris, Lonsbury-Martin, Stagner, Coats and Martin (1989) as the most effective stimulus for eliciting DPOAEs from 1 to 4kHz.

Intensity: The levels of fl compared to f2 have been thoroughly examined in human ears. There are two possible ways, i.e., two primary stimuli have equal intensity (Ll = L2) or intensity for higher frequency primary (f2) is lower than that of the lower frequency primary (fl), i.e., L1>L2 (Hall, 2000). For both conditions (Ll= L2 and L1>L2), at low to moderate absolute levels, the tail of the fl primary extends towards base of the cochlea and into the region of f2 excitation. However the amplitude of basilar membrane vibration at the f2 place will be even greater as the fl intensity is increased. Decreasing the f2 primary level may reduce the overlap, with a reduction in DPOAE amplitude (Whitehead, Stagner, Lonsbury-Martin & Martin, 1995). For equally intensities primaries (Ll= L2) at low to moderate intensity levels, the site of maximum vibration on the basilar membrane is presumably closer to the geometric mean between two frequencies (Hall, 2000).

b) Subject parameters: DPOAE amplitude varies with subject variables like age, gender, etc (Hall, 2000).

SOAEs: There is a long standing suspicion that OAE energy is present with in the ear canal at all times (SOAE) that might contribute to, or enhance OAEs in the ear canal following the presentation of an appropriate stimulus. The SOAE contribution to DPOAEs is, to some extent, a "hit or miss" proposition. That is, the frequency of SOAEs needs to fall with in narrow band near the 2f1-f2 regions that is spectrally analyzed in distortion product measurements. An SOAE occurring precisely at the frequency of one primary (f1 or f2) could either enhance or minimize DP measurements, but the odds of these coinciding frequencies for a single subject are presumably low (Koilawiec & Orlando, 1995). Some investigators also have suggested that DPOAE amplitudes are enhanced in the frequency region of SOAE (Kemp, 1979; Furst, Rabinowitz & Zurek, 1988; Prieve, Filzgerald, Schulte & Kemp, 1997). Generally, the effect of SOAE decreases when the DPOAE frequency is more than 50Hz away from the SOAE frequency (Frust, Rabinowitz & Zurek, 1988)

DPOAE was also examined for a group 43-young adult (19-43years) subjects who showed SOAEs in only one ear. Amplitudes for DPOAEs evoked by stimuli with in the intensity range of 40-65dBSPL were higher for ears with SOAEs than for ears without SOAE. The difference in DPOAE amplitude between groups was 6-7dB at lower intensity levels and decreased at 2-3 dB for higher intensity levels. This suggests that DPOAE sensitivity to cochlear influences increases as stimulus intensity reduces (Ozturan & Oysu, 1999).

Gender differences: Gender differences are found almost for all measures of peripheral and central auditory function and it also exists for DPOAE response measures. Kimberly, Brown and Eggermint (1993) reported longer DPOAE latency values for males than females for selected frequency regions. Larger amplitudes have also been reported for females in comparison to males, again for some, not all frequencies (Gaskill & Brown, 1990; Lonsbury-Martin, Cutler & Martin, 1991). Reasons for these gender effects are unknown. Some explanations offered are endocronologic factors affecting neurotransmission (Hall, 2000).

One of the fascinating observation is seen in click-evoked OAEs for heterosexuals versus homosexuals (McFadden & Pasanen, 1998, cited in Hall, 2000) and in opposite sex dizygotic twins, or non-twins (McFadden & Loehlin, 1995). OAE amplitude is significantly larger for heterosexual females than heterosexual males. In addition, homosexual and bisexual females yielded smaller OAE amplitude values than heterosexual females (McFadden & Pasanen, 1998, cited in Hall, 2000). Possible explanation is that prenatal exposure to higher than normal levels of androgens in homosexual females produced a partial masculinization in both their peripheral auditory system and some brain structures involved with sexual orientation (McFadden & Pasanen, 1998, cited in Hall, 2000).

Ear differences: Hearing surveys of large numbers of apparently normal hearing persons have repeatedly shown slightly poorer hearing for the left versus right ear, especially for higher frequencies (Axelson & Lindgren, 1981). Most of the ear differences studies are on TEOAE and not on DPOAE. Reports have shown that amplitude is slightly higher in right ear then left ear in adults (Robinettee, 1992) and in children (Glattke and Pafitis 1995, cited in Hall, 2000). Whereas Robinette (1992) did not see any clear differences between right and left ears in DPOAE amplitudes.

Diurnal effects: Biologically controlled rhythms throughout the course of a day may influence SOAEs when interacting with other nonpathologic subject factors, such as body temperature and gender (Bell, 1992; Haggerty, Lusted & Morton, 1993). Diurnal (time of the day) effects do not have much effect on DPOAE amplitude especially during waking hours (Cacace, McClelland, Weiner & McFarland, 1996).

Genetics: Studies concerning the role of genetics is more in terms of TEOAEs than DPOAEs. It is observed that some families with more SOAEs would tend to show larger TEOAEs (McFadden, 1998, cited in Hall, 2000). He also said that this heritability of SOAEs, could, to some extent, be applied to other types of OAEs.

Temperature: OAEs are also influenced by temperature (Eatock & Manley, 1981, cited in Hall, 2000; Manley & Koppel, 1994). Cacace, McClelland, Weiner and McFarland, 1996, failed to demonstrate a relation among oral temperature, resting pulse and DPOAE amplitude. On the other hand, Khvoles, Freeman and Sohmer 1998, (cited in Hall, 2000) investigated the effect of temperature on TEOAEs & DPOAEs in rats. TEOAEs and DPOAEs amplitudes remained constant within the temperature range of 33°C to 39°C. Amplitudes for both types of OAEs were markedly reduced above and below these limits, especially for lower intensity stimuli.

Body position: The possible effects of body position on OAEs are evaluated in many studies. Johnsen and Elberling (1982) found emissions to be unaffected by posture changes in a group of healthy adults (21 to 42 years). Antonelli and Giandoni (1986) studied the influence of the relative position between the head and the body on the responses (sitting down on a chair, and lying onto a reclinable bed at angles 0, -20 and -40 degrees, with respect to the horizontal plain). The response amplitudes were reduced when the subjects were held in reclining positions. The latency of the response was greater in the reclining position and it decreased in the order 0 to- 20 to -40 degrees. Wilson (1980) had also reported a decrease in amplitude and a time shift whenever the subjects' position was changed. However, the changes were noted in waveforms only if the new position was held for a time interval of convenient duration.

Age: Amplitude is unusually robust and reproducibility is higher in infants than older children and especially adults in both TEOAEs and DPOAEs (Norton & Widen, 1990; Kemp, Ryan & Bray, 1990; Thorten, Kim, Kennedy & Cafarclli-Dees, 1993; Smuzynski, 1994;). Amplitude values for DPOAEs are greater for preterm infants, DPOAEs are highest for infants less than one year, with amplitude decreasing during the 1 to 3 year age range and decreasing even further for older children and teenagers, until adult values are reached (Hall, 2000). DPOAEs decreased with increasing age, particularly at high frequencies. The differences were significant for most frequencies (Widen & Grady, 2000).

Reasons that contribute for these changes include anatomy of the ear canal, including volume, length, resonance properties and compliance of walls. Sound intensity is inversely related to the volume of cavity and this may influence OAE measurements (Hall, 2000).

Ear canal acoustics also changes as a function of age in young children. The resonant frequency for an adult ear canal is in the region of 2000-3000Hz whereas it is about 4000-4500Hz for children in the age range of l0days to 6months and over 6000Hz for neonates (Kruger, 1987; Upfold & Byrne, 1988, cited in Hall, 2000; Dempster & Mackenzie, 1990; Westbrook & Bamfold, 1992). The ear canal volume and resonance play a role in DPOAE outcome (Gvelesiani, Gunenkov & Tavartkiladze, 2000).

Ear canal & middle ear pressure: The ear canal pressure is seemed to have more effect on DPOAE amplitude compared to TEOAE amplitude. Osterhammel, Neilson and Rasmussen (1993) recorded DPOAEs for fl-f2 combinations that range in frequency from 1 and 8kHz. The effect of positive and negative pressure symmetrically reduce DPOAE amplitude by about 8dB for l00daPa and lldB for 200daPa at 1kHz. The effect of ear canal pressure on DPOAEs is the smallest around 2kHz, at higher frequencies the effect becomes more complex. Above 4kHz, negative pressure decreases DPOAE amplitude and positive pressure causes slight increase in amplitude. The effect on low-frequency emission is consistent with the increase in stiffness caused by ear canal pressure, which preferentially affects the low frequencies in both forward and backward transmission (Robinette, 1992). Middle ear pressure also has similar effects on OAEs. Even a mild degree of middle ear pressure could significantly reduce both TEOAE and DPOAE amplitudes (Owens, McCoy, Lonsbury-Martin & Martin 1992). Pressure changes in the external auditory meatus increase the stiffness of the middle ear and decrease the middle ear mobility.

Ear canal and middle ear resonance: Few studies have been done to find the effect of external and middle ear resonance on evoked OAEs. At the middle ear resonance frequency the eardrum vibrates with the largest displacement, and the sound energy coming into the external auditory meatus is transmitted effectively into the cochlea. Therefore, EOAEs, which are considered to originate from the outer hair cell movement and to be transmitted to the external auditory meatus in retrograde fashion, would be detected most distinctly at the middle ear resonance frequency. It was also seen that TEOAEs was also detected in normal subjects whose middle ear mobility was normal (Wada, Ohyama, Kobayashi, Sunaga & Koike, 1993).

Gvelesiani, Gunenkov and Tavartkiladze (2000) studied the influence of age and external and middle ear resonance on TEOAEs and DPOAEs. Results demonstrated that assessment of resonance properties of external ear canal and middle ear canal could be a valuable tool in understanding of age related changes in evoked OAE parameters.

In conclusion, the review of literature brings to light the various parameters that affect DPOAEs. Subject parameters including external and middle ear factors play a very important role and should be kept in mind while interpreting the evoked OAEs.

METHOD

The aim of the present study was to investigate the effect of conductive mechanism on DPOAEs.

Subjects: Forty-four subjects were considered for the study and were categorized into three groups as follows: -

Group 1 included 11 subjects in the age range of 4.0 to 7.0 years. This group represented for smaller middle ear and ear canal volume, Bopanna (1995).

Group 2 included 15 subjects in the age range of 9.0 to 12.0 years. Since several studies have shown that OAE amplitude does not change after 8 years of age, (Norton & Widen, 1990) this age group was taken.

Group 3 included 20 subjects in the age range of 18.0 to 24.0 years. This group represented for normal shape and size of the external ear and middle ear.

Three different age groups was taken as there will be variation in external canal volume, length and middle ear size resulting in variation in resonance frequency.

Subjects who participated in the study met the following criteria:

Normal external auditory canal on otoscopic examination.

Normal tympanic membrane and middle ear on ENT evaluation.

No history of middle ear pathology

No other otological history

Middle ear pressure within +10 to -30daPa

Normal hearing, pure tone threshold with in normal limits (-10 to 25dB,Goodmans, 1965) with in the frequency range of 250Hz and 8000Hz

A type tympanogram with acoustic reflexes present

Instrumentation

- A Clinical audiometer (Madsen OB822), coupled to acoustically matched earphones (TDH-39) with MX-41AR ear cushions and a bone vibrator (Radio earB-71) was used to assess the hearing sensitivity at different frequencies.
- A microprocessor based automatic immitance meter with a visual display (Grason-Stadler GSI-33, version 2), middle ear analyzer was used to rule out middle ear abnormalities, to obtain tympanogram, middle pressure, static compliance, acoustic reflex threshold and also middle ear resonant frequency.
- Phonix 6500C was used to estimate external ear resonance in both occluded and unoccluded condition.
- GSI-60 DPOAE analyzer was used for the DPOAE measurement.

Calibration of all the instruments was ensured prior to use as specified by the manufacturer.

Test environment

Testing was carried out in a sound treated room. The ambient noise was within permissible limits, as recommended by ANSI (1991, cited in Wilber, 1994).

Procedure

1) Pure tone testing

To ensure that the subjects had normal hearing, pure tone testing was carried out for all the three groups. Pure tone thresholds for air conduction and bone conduction were obtained for the frequencies from 250Hz to 8kHz and 250Hz to 4kHz respectively.

2) Immittance screening

To rule out middle ear pathology immitance assessment was carried out. Subjects who had A type tympanogram with acoustic reflexes present were considered for the study. Static compliance and middle ear pressure was noted for each subject.

3) External ear resonance estimation

The external ear resonance was estimated using Phonix 6500C. This was done in occluded and unoccluded condition. In the occluded condition the ear was occluded using insert receiver. The insert receiver was then connected to the Phonix from where composite signal at intensity 60dBSPL was presented to the ear. In the unoccluded condition, a composite signal was presented through the loud speaker at an angle of 45° facing the subject at an intensity of 60dBSPL. The peak value of real ear measurement was considered as external ear resonance under both the conditions.

4) Middle ear resonance estimation

Middle ear resonance was estimated using GSI-33 (version 2) immittance meter. This was done using frequency sweep method. Probe tone was swept from

200Hz to 2000Hz in 50Hz steps at 200daPa pressure. The susceptance value and phase angle measured at 200daPa for different frequencies was then stored in the memory. Tympanogram for admittance was recorded to obtain peak pressure using 226Hz probe tone. A second sweep was run at peak pressure to measure susceptance (B) and phase measurement (θ). This value was compared to that of values stored before. The change in susceptance (B) and phase value (θ) was then displayed. The frequency, at which change in susceptance was zero and phase was minimum was considered as resonance frequency.

5) DPOAE testing

DPOAE testing was carried out using GSI-60 analyzer. The subjects were made to sit comfortably and also instructed not to move or talk during the test. The probe was inserted gently into the ear canal with an appropriate probe tip. Probe fit was ensured to check adequate fitting of the probe into the ear canal. Once the probe tip was fitted, it was not removed till the completion of the test. A ratio of 1.22 between fl and f2 was used to elicit DPOAE. The intensity levels of f1 and f2 were 65dBspl(Ll) and 55dBspl(L2) respectively. Emissions were measured at 8 points/octave. The amplitude at various 2fl-f2 and f2 frequency and signal to noise ratio was noted down. Values were considered when the reproducibility was more than 90% at all the frequencies.

Scoring and analysis

Amplitude and signal to noise ratio of DPOAE, middle ear resonance, external ear resonance and static compliance was tabulated. This was subjected to suitable statistical analysis for comparison.

RESULTS

The purpose of the present study was to investigate the influence of the external ear and middle ear resonance on the DPOAE spectrum. The study was also aimed to find out the existence of relationship, if any, between the mobility of middle ear (static compliance) and the amplitude of DPOAE.

Altogether 92 ears were tested and all the ears had detectable DPOAE responses. The results have been explained in the following categories:

a) Effect of middle ear resonance on absolute DP amplitude and signal to noise ratio (SNR) :

The mean and standard deviation of the middle ear resonance maximum amplitude at 2fl-f2 frequency and f2 frequency was estimated and is as given in table 1.

	MER		Maximum amplitude 2f!-f2		Maximum amplitude at f2	
	Mean	SD	Mean	SD	Mean	SD
Group 1	904.54	145.5	2182.14(max) 1078(2nd highest)	375.53 353.5	2847.27(max) 2682.3(2nd highest)	567.54 367.5
Group2	885	228.62	1099.7	399.51	1678.67	589.00
Group 3	1073.75	238.31	1110.62	454.8	1688.6	680.23

Table-1: The mean and standard deviation of middle ear resonance (MER), maximum DP amplitude at 2fl-f2 frequency and f2 frequency in hertz.

It is seen from the table that middle ear resonance is 904.54Hz for the younger children (group 1) and is around 885 and 1073 Hz for the older children (group 2) and adults (group3) respectively. The maximum DPOAE amplitude or SNR obtained at 1000Hz of 2fl-f2 frequencies for adults and older children that is approximately the same as the middle ear resonance frequency (1073Hz and 885Hz) than the f2 frequency that is thought to be the prime origin for DPOAEs. For younger children the second highest peak was seen at around 1000 Hz of 2fl-f2 that was also closer to the middle ear resonance (904Hz). This can be understood better from the graph 1,2 and 3.

	2fl-f2	f2
Group 1	65%	17.5%
Group 2	70%	10%
Group 3	54.5%	9.09%

Table 2 : The percentage of individuals for whom the middle ear resonance correlates with the maximum absolute DPOAE amplitude or SNR at 2fl-f2 and f2 frequency.

A good agreement between the middle ear resonance and maximum DPOAE amplitude or SNR was obtained at DP frequency of 2fl-f2 in comparision to f2 frequency. It was observed that 65% of the younger children, 70% of older children and 54.5% of adults had maximum DP amplitude at 2fl-f2 frequencies that correlated with middle ear resonance and very less percentage of agreement was seen with the f2 frequency. The percentage of individuals for whom the middle ear resonance was correlating with 2fl-f2 and f2 in all the three age groups is shown in table 2.

b) Effect of external ear resonance on absolute DP amplitude and SNR :

The mean and standard deviation of external ear in both occluded and unoccluded condition was estimated and is depicted in table 3.

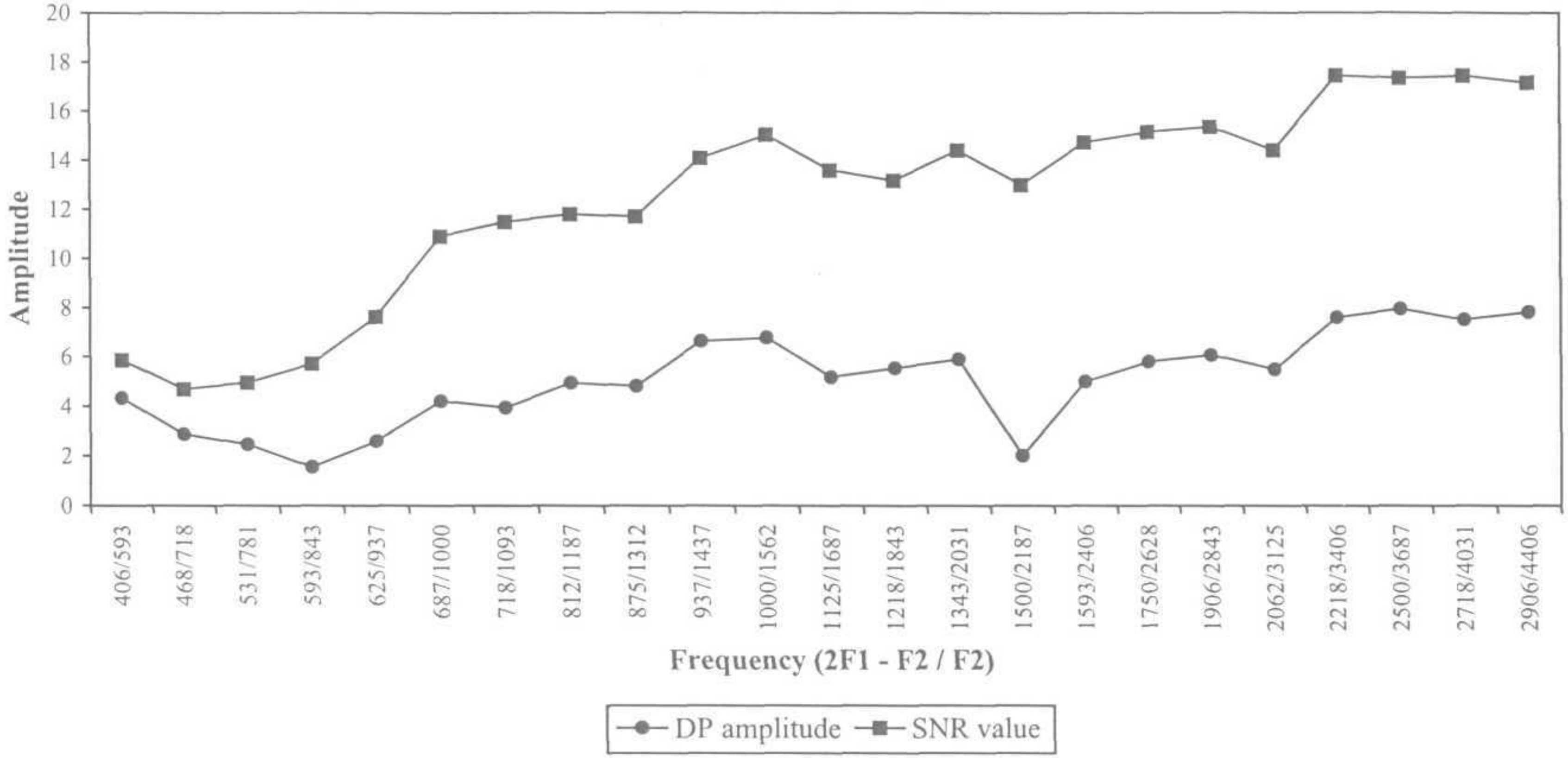
	EER (o)	EER (o)	EER (uo)	EER (uo)
	SD	Mean	Mean	SD
Group 1	366.95	1981.81	2993.18	359.32
Group2	366.95	1991.81	2935	320.87
Group3	293.67	1747.5	2926.25	145.43

Table 3 : The mean and standard deviation of external ear resonance in occluded condition (EERo) and unoccluded condition (EERuo) in hertz.

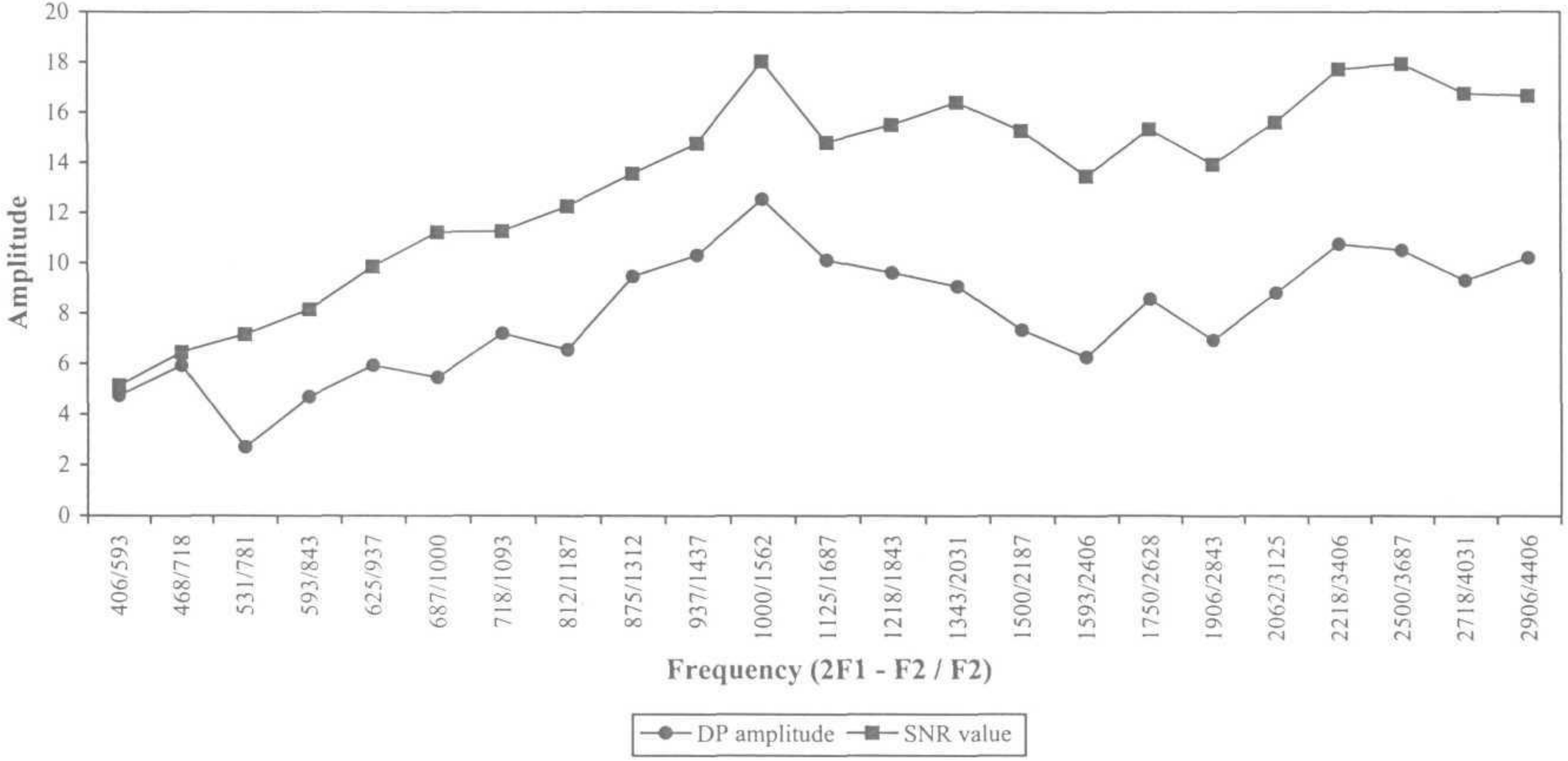
From table 3 it is evident that the external ear resonance in occluded condition is lesser than that of unoccluded condition. In occluded condition it is 1981 Hz for younger children and 1991.81 and 1747Hz for the older children and adults respectively. On the other hand it is around 2993 Hz for younger children and 2935 and 2926 Hz for the older children and adults in unoccluded condition.

It is evident from graph 1,2 and 3 that the two groups had second maximum DPOAE amplitude or SNR, at higher 2fl-f2 DP frequencies which is closer to the external ear resonance. The second highest peak for adult and older children was seen at around 2218Hz and for younger children the maximum amplitude was seen at around 2218Hz of 2fl-f2 frequencies. The frequency at which the second highest DP amplitude was seen, is more closer to the occluded ear canal resonance than the resonance frequency obtained during unoccluded condition which can be observed in the table 3.

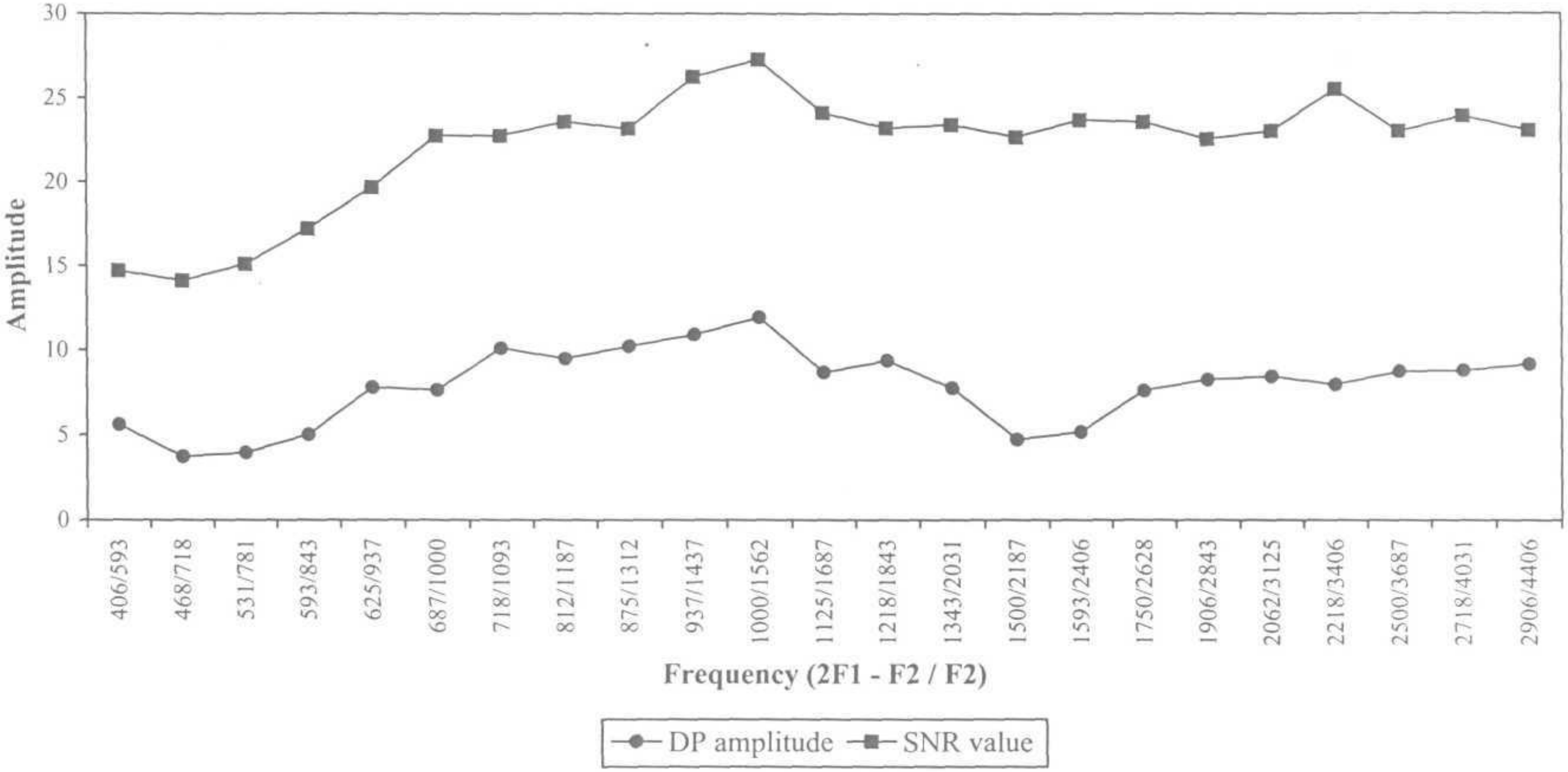
Graph 1 : Depicts the relationship between frequency vs
DP amplitude and SNR value for Group I



Graph 2 : Depicts the relationship between frequency vs DP amplitude and SNR value for Group II



Graph 3 : Depicts the relationship between frequency Vs DP amplitude and SNR value for Group III



c) Mobility of the middle ear and absolute DP amplitude :

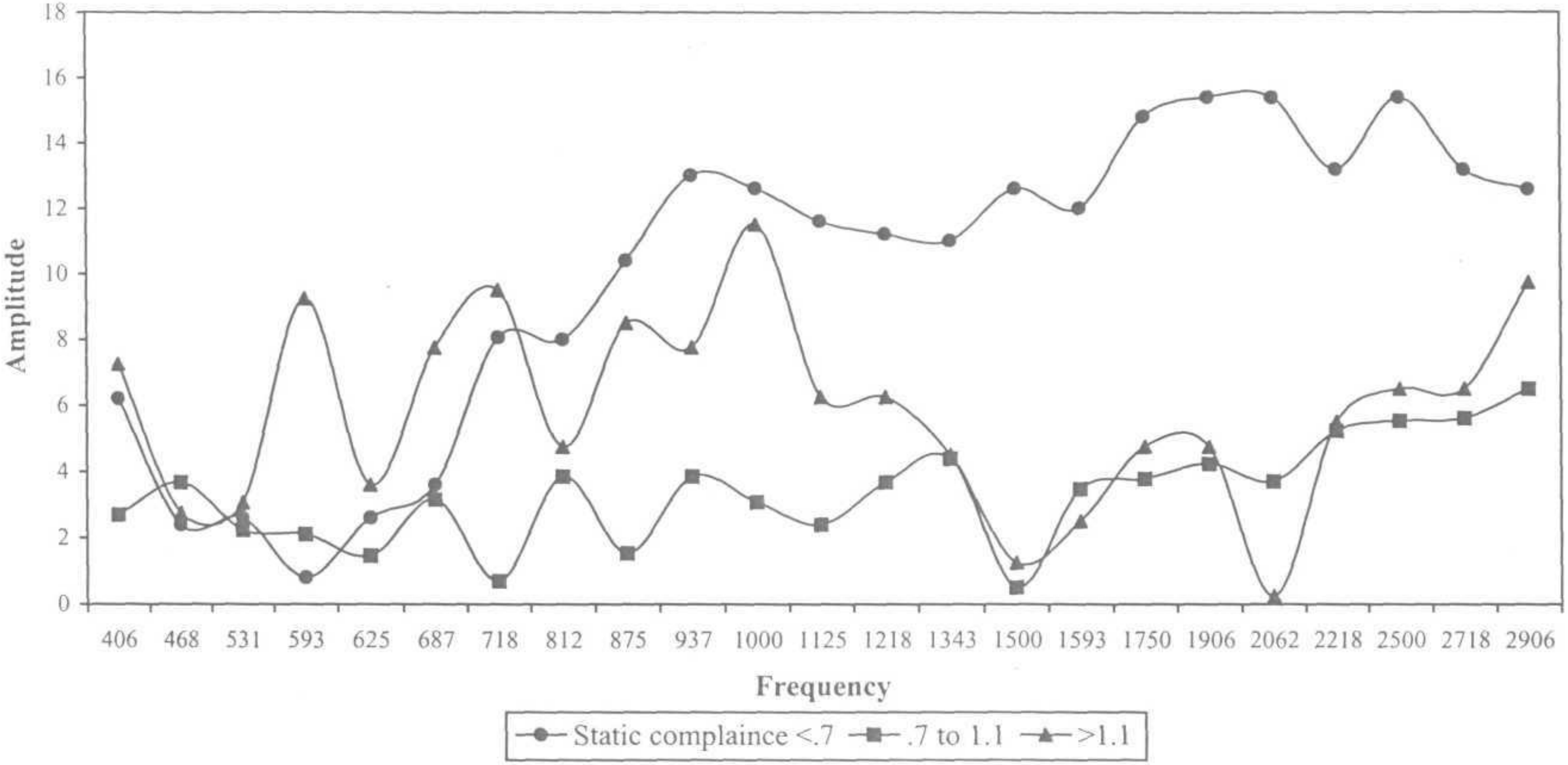
Mobility of the middle ear was assessed based on the static compliance obtained, i.e., lesser the static compliance lesser will be the mobility and vice versa. Subjects were divided into three categories based on the static compliance value obtained as,

- Subjects whose static compliance was less than 0.7ml were considered to have less mobile middle ear system.
- Subjects, whose static compliance was between 0.7 and 1.1 ml,were considered to have an optimum mobile middle ear system.
- Subjects whose static compliance was more than 1.1 ml,were considered to have a more mobile middle ear system.

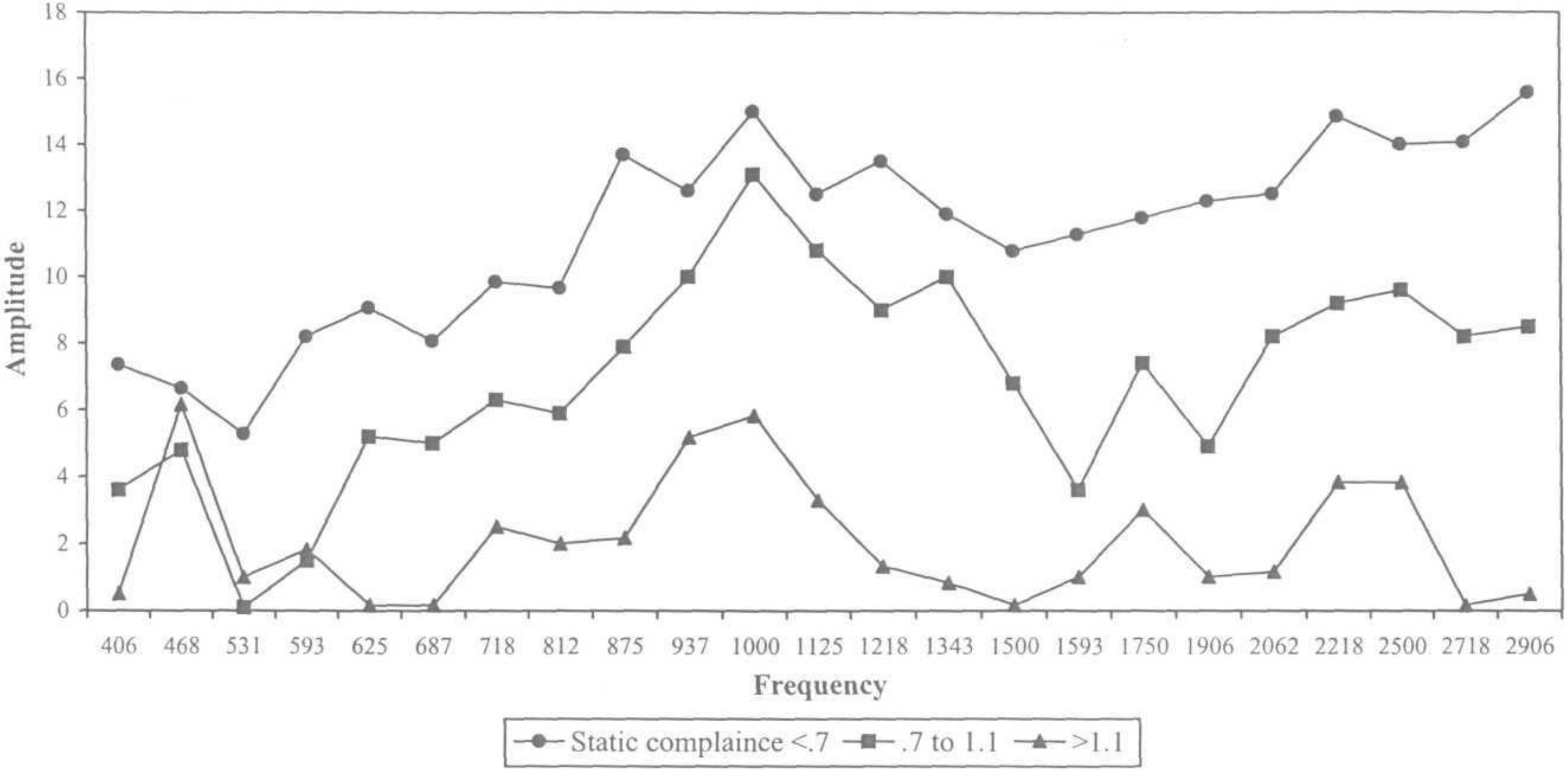
Graph 4,5 and 6 shows the relationship between the mean DP amplitude or SNR and mobility of the middle ear system at different 2fl-f2 DP frequencies for the different groups.

It is evident from the graph 4,5 and 6 that when static compliance is less (reduced mobility) DP amplitude was relatively higher at higher frequency than the lower 2fl-f2 frequencies for all the age groups. On the other hand subjects with relatively more mobile middle ear system showed better 2fl-f2 amplitude at lower frequency than the other two conditions. However this was more evident in case of younger children (Graph-4). Individuals with optimally mobile middle ear system had almost symmetrical DP amplitude having slightely higher amplitude around the middle ear resonance frequency across the 2fl-f2 frequencies which is more evident in graph 5 (group 2).

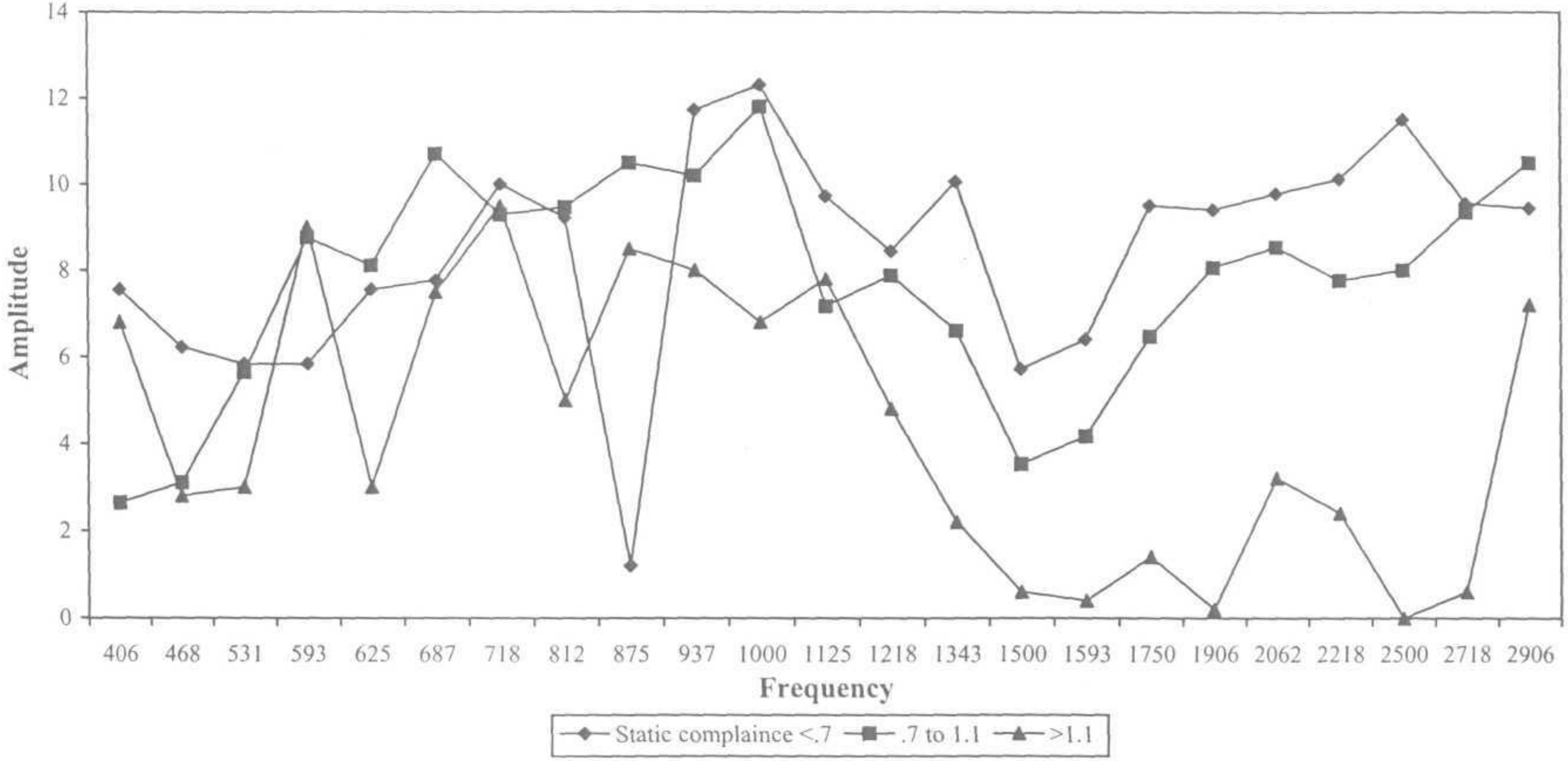
Graph 4 : Depicts the relationship between DP amplitude and frequency for Group I with static complaince less <0.7, 0.7-1.1 and >1.1 ml



Graph 5 : Depicts the relationship between DP amplitude and frequency for group II with static complaince <0.7, 0.7-1.1 and > 1.1 ml



Graph 6 : Depicts the relationship between DP amplitude and frequency for group III with static complaince <0.7, 0.7-1.1 and >1.1 ml



DISCUSSION

The otoacoustic emissions in normal individuals have been studied extensively, in both children and adults (Norten & Widen, 1990; Furst & Lapid 1988; Kemp & Chum, 1980). Additionally the influence of middle ear and external ear characteristics on TEOAE amplitude has been studied by many authors (Owens, McCoy, Lonsbury-Martin & Martin, 1992; Osterhammel, Neilsen & Rasmussen, 1993; Wada, Oyhama, Kobayashi, Sunaga & Koike, 1993). The present study also aimed at studying the effect of middle ear and external ear resonance on DPOAEs and the results are discussed below:

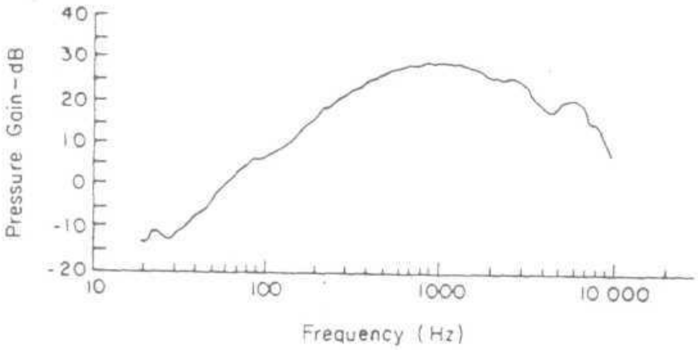
1) Effect of middle ear resonance on absolute DP amplitude and SNR:

In the present study the DPOAE amplitude and SNR of 2fl-f2 was estimated and found to have maximum amplitude at or near the middle ear resonance frequency for adults and older children. For group 1, the second highest peak of DP amplitude and SNR was obtained closer to the middle ear resonance.

The robust amplitude at or near the middle ear resonance could be due to the forward and backward mechanism of OAEs generation, the stimulus used to elicit OAE gets enhanced while traveling from external ear to inner ear, due to the middle ear resonance, especially when fl frequency (which is more closer to the 2fl-f2 frequency) corresponds to the middle ear resonance. This increase in fl stimulus intensity in the cochlea could elicit more emissions, thus resulting in greater amplitude. Gaskill and Brown (1995) reported that when L1 is more than L2, DPOAE amplitude increases. During backward transmission, emissions elicited from the inner ear while traveling back towards the ear canal also will be enhanced due to the middle ear resonance. Thus when the emission frequency (2fl-f2) is near or at the middle ear resonance, it will lead to increase in DP amplitude.

The present study is in good agreement with studies done by Wada, Ohyama, Kobayashi, Sunaga and Koike, 1993; Gvelesiani, Gunenkov and Tavartkiladze, 2000 In their study EOAEs was detected most distinctly at the middle ear resonant frequency across age groups.

The absolute DPamplitude graph as seen in adults in the present study (graph 3) is very similar to that of curve representing the transfer function of middle ear. It is obvious from the graph that one can expect greatest transmission of sounds at around lKz (Nedzelnitsky, 1980), thus causing maximum DP amplitude around l000Hz for al most all the three groups.



The transfer function of the middle ear, according to Nedzelnitsky (1980)

It is evident from graph 1 that the maximum amplitude for younger children does not correlate with that of middle ear resonance i.e. the amplitude is more at higher frequencies. The probable reason for this could be a smaller ear canal volume resulting in increased DP amplitude at higher frequency (Margolis, 2000). Moreover 60% of this group had lesser middle ear mobility resulting in increased amplitude at higher frequencies amplitude.

Hence it can be concluded that the middle ear resonance has an influence on both absolute DP amplitude or SNR. At the middle ear resonant frequency the eardrum vibrates with the largest displacement and the sound energy coming into the external auditory meatus is transmitted effectively into the cochlea or back to the ear canal (backward transmission) (Wada, Ohyama, Kobayashi, Sunaga & Koike, 1993).

b) Effect of external ear resonance on absolute DPamplitude and SNR value:

As evident from the results, greater DP amplitude or SNR was seen at around external ear resonance in occluded condition for all the three groups. This also could be due to the same reason as explained before, i.e.,the effect of external ear canal resonance on forward and backward mechanism for the generation of OAEs, resulting in enhanced DP amplitude.

Another important feature that can be noticed from graph 1,2 and 3 is that the tendency to have greater DP amplitude at higher frequency for all the subjects. This may be because when the probe is inserted into the ear canal for DPOAE measurement, it will result in increase in ear canal pressure due to the trapping of air between the probe and tympanic membrane. Robinette (1992) reported that the positive pressure has a tendency to increase the emission level at higher frequency. Thus, there is an increased amplitude at higher frequencies and reduced amplitude at lower frequencies.

Secondly, it may also be that when the probe is inserted, it will reduce the ear canal volume and this in turn will increase the amplitude at higher frequency. This is because smaller ear canal volume results in higher stimulus sound pressure and thus increasing the high frequency amplitude (Margolis, 2000).

DP amplitude is lesser at low frequency when compared to that of the high frequencies. This may be mainly due of the physiological noise that is more concentrated at lower frequencies thus resulting in reduction in SNR at low frequencies, which is more prominent for younger children (Bright, 2000).

3) Mobility of the middle ear and DP amplitude:

It can be seen from the graph 4,5 and 6 that when static compliance is less (less mobile middle ear system) the DP amplitude for high frequencies was relatively better than the low frequencies and when static compliance is high (more mobile middle ear system); DP amplitude was seen to be more at low frequencies compared to the higher frequencies.

The possible explanation for this phenomenon is that compliance varies as a function of frequency. When middle ear mobility is reduced, it will attenuate the sigal at low frequencies and enhance at high frequency thus the high frequency transmission will be relatively better. On the other hand, when there is increased mobility, it will attenuate the high frequency signals and enhances the low frequency signals and thus the low frequency amplitude will be better (Shanks & Shelton, 1991).

Similar findings have been observed by Wada, Ohyama, Kobayashi, Sunaga and Koike (1993). They found that TEOAE is most distinctly detected when middle ear mobility is normal.

SUMMARY AND CONCLUSION

Researches carried out by several investigators have shown that the middle ear and external car factors have an affect on the OAE recording. The effect of middle ear pressure, ear canal pressure, resonance properties and mobility of the middle ear has shown to have an effect on sound transmission for eliciting TEOAEs (Osterhammel, Neilson & Rasmussen, 1992; Owens, McCoy, Lonsbury-Martin & Martin 1992; Wada, Ohyma, Kobayashi, Sunaga & Koike, 1993).

The present study was carried out to investigate the effect of external ear resonance and middle ear resonance on DPOAE spectrum. The study also aimed at studying the relationship between the mobility of middle ear and amplitude of DPOAE at different frequencies.

Forty-six subjects were taken who were divided into three groups. Group 1 was in the age range of 4.0-7.0 years. Group 2 and 3 were in the age ranges of 9.0 to 12.0 and 18.0 to 24.0 years respectively. None of the subjects had any history of middle ear pathology or any other otological history. They had normal hearing with A type tympanogram and reflexes present.

DPOAE testing at 8 points per octave was carried out in a sound treated room using GSI 60 DPOAE analyzer. The external ear resonance was estimated using Phonix6500C. The peak value of the real ear measurement was considered as external ear resonance. The middle ear resonance was assessed using GSI-33 (version 2) immittance meter through frequency sweep method. The frequency at which the susceptance was zero and phase angle was minimum was considered as the middle ear resonant frequency. The following comparisons were made with the data collected:

1) Influence of middle ear resonance on DP amplitude and SNR.
2) Influence of external ear resonance on DP amplitude and SNR.
3) Mobility of the middle ear and DP amplitude.

The data obtained was analyzed using mean and standard deviation. Results are as shown below:

DPOAE and SNR amplitude was maximum at or near the middle ear resonant frequency for adults and older children. For younger children the second maximum DP amplitude was relatively better at or near the middle ear resonant frequency.

DPOAE and SNR amplitude was maximum at or near the external ear resonance for younger children. The second peak in the DPOAE spectrum was seen at around external ear resonance for adults and older children.

The correlation of DPOAE and SNR with the middle ear resonance and external ear resonance was more at 2f1-f2frequency compared to f2 frequency.

DPOAE tends to increase at higher frequencies after having a peak at middle ear and external ear resonance and reduce at lower frequencies for all the three groups, i.e., adults, older children and younger children.

Mobility of the middle ear also affects the DPOAE spectrum. If the middle ear mobility was less, the amplitude was greater at high frequencies and when the mobility was more, the amplitude was relatively greater at low frequencies. This variation may be due to the filter action of the middle ear system.

Hence, from the above results it is clear that external ear resonance, middle ear resonance and mobility of the middle ear has an effect on the DPOAE spectrum. The sound transmission for eliciting DPOAEs might get enhanced at particular frequencies depending on the external ear resonance and middle ear resonance. Also the enhancement of the emitted sound may occur while traveling back to the ear canal (backward transmission).

The amplitude is also better at higher frequencies compared to the lower frequencies due to the pressure build up between the probe and the tympanic membrane.

It may thus be concluded that while interpreting the absence or presence of DPOAEs, all these factors, i.e., external ear resonance, middle ear resonance and mobility of the middle ear should be kept in mind. Reduced DPOAE amplitude may not be always due to the abnormality in the outer hair cells. The variation could also be due to the forward and backward mechanism of OAE generation. In addition it also gives an answer to the question of the integrity of outer hair cells and the poor agreement between the pure tone threshold and OAE threshold.

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