EFFERENT SYSTEM FUNCTIONING IN PAEDIATRIC POPULATION

USING DPOAE INPUT OUTPUT FUNCTION

Priya Abdul Khader, M. T.

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MAY, 2019

CERTIFICATE

This is to certify that this dissertation entitled '**Efferent System Functioning in Paediatric Population using DPOAE Input Output Function'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 17AUD029. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2019

Dr. M. Pushpavathi
Director
All India Institute of Speech and Hearing,
Manasagangothri, Mysuru-570 006

CERTIFICATE

This is to certify that this dissertation entitled '**Efferent System Functioning in Paediatric Population using DPOAE Input Output Function'** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2019

Dr. Sreeraj Konadath
Guide
Assistant Professor in Audiology
All India Institute of Speech and Hearing,
Manasagangothri, Mysuru-570 006

DECLARATION

This is to certify that this dissertation entitled **'Efferent System Functioning in Paediatric Population using DPOAE Input Output Function'** is the result of my own study under the guidance a faculty at All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
May, 2019

Registration No. 17AUD029

Dedicated to Ma, Pa, Muthoos, Anu and Kasi

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Abstract

Objective: *The present study aimed to investigate the characteristic of DPOAE I/O function in a normally functioning cochlea in paediatric population. The two objectives were to find the effect of contralateral noise on the slope and area of DPOAE I/O function and to find the DPOAE I/O function characteristics at different test frequencies.*

Method: *Thirty three typically developing children with normal hearing sensitivity in both the ears participated in the study with an age range of 6-12 years. DPOAE measurements were done at 6 frequencies 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz by changing the L1 and L2 levels from 65dB SPL to 45 dB SPL keeping the ratio of f1 and f2 constant, 1.22. This procedure was done in 4 conditions: in quiet and in the presence of 40 dB SPL, 50 dB SPL and 60 dB SPL contralateral white noise. The slope and area of the DPOAE I/O function was determined from the data obtained from the DPOAE measurements.*

Results: *The results showed an increase in slope and area of the DPOAE I/O function as the frequency increases. The area of the I/O function reduced with the increase in the level of contralateral white noise, whilst the slope of I/O function did not show any significant difference in the presence of contralateral white noise. The slope of the DPOAE I/O function increased as the test frequency increased with a statistical significance except from 2 kHz to 3 kHz. Similarly, the area of the I/O function also increased with the frequency in all the conditions tested.*

Conclusions: *This study shows that the area of DPOAE I/O function can be used as an effective measure to assess the efferent system in paediatric population. Also, it is found that the area of the DPOAE I/O function did not show any significant difference between 50 dB SPL and 60 dB SPL white noise.*

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Chapter 1

Introduction

Evoked otoacoustic emissions (OAE) are low level acoustic signals produced by a normally functioning cochlea. There are different types of OAEs depending upon how they are stimulated and recorded such as spontaneous OAEs (SOAEs), stimulus frequency OAEs (SFOAEs), transient evoked OAEs (TEOAEs) and Distortion product OAEs (DPOAEs).

Distortion product otoacoustic emissions (DPOAE) were introduced by Kemp in 1978. He recorded an acoustic response from the external auditory canal 5 ms post the stimulus presentation. Also, suggested that this slowly decaying acoustic response is a result of non-linear mechanism which is originating from the cochlea. He also noticed that these responses were absent in the ears with cochlear damage.

It is postulated that the DPOAEs are the result of intermodulation distortion produced by the non-linear cochlear processing in response to two pure tone stimuli that are close in frequencies, presented simultaneously (Martin & Theodore, 1997). The DPOAEs that reflect the functioning of an essential element of peripheral sound processing enable a reliable estimation of cochlear hearing threshold up to hearing losses of 50 dB HL without any statistical data (Boege & Janssena, 2002). A significant correlation was found between DPOAE threshold and pure tone threshold using input–output functions of DPOAE. Thus, DPOAEs make a useful clinical tool to predict the pure tone threshold of an individual reliably.

DPOAEs also provide information about the rate of growth of cochlear responses. They are dependent on the level of presentation of the tones, and an input-output (I/O) function can be obtained by keeping the stimulus frequency and frequency ratio constant. The relation between these two measures becomes stronger depending on the frequency of the signal (Rasetshwane, Neely, Kopun, & Gorga, 2013). Information about cochlear function may be obtained by quantifying characteristics of DPOAE input/output (I/O) functions.

Conventionally DPOAE make use of a lower frequency pure tone which is referred to as f1 and a higher frequency tone referred to as f2. The intensity levels of f1 and f2 are L1 and L2 respectively. The pure tones are related in such a way that, their ratio gives a value of 1.22 (f2/f1). The most measured DPOAE is at the 2f1-f2 frequency as it is the largest measurable in human ears. It can be detected in almost all normal human ears with an approximate sound pressure level of 5-15 dB. Kummer, Janssen, & Hulin (2000) found the optimal L1-L2 primary tone levels to attain maximum DPs from a typical human test frequency range of 1 kHz to 8 kHz for f2 frequency. Their data shows that optimal stimulus levels can be approximated by the linear equation L1 = 0.4 L2 + 41 dB SPL, for clinical application, for the levels of L2 between 20 and 65 dB SPL.

Normal properties of DPOAEs have been studied extensively in humans and other animals using I/O function (Probst, Lonsbury-Martin, & Martin, 1991); Lonsbury-Martin & Martin, 2007) and the features observed are qualitatively similar to those observed in invasive measurements of cochlear-response properties in lower animals. For example, I/O functions derived from direct basilar membrane (BM) measurements (Ruggero, Robles, & Rich, 1992; Recio, Rich, Narayan, & Ruggero, 1998; Rhode, 2007) are similar to DPOAE I/O functions (Mills & Rubel, 1994). The input-output function slope obtained for different input levels, is directly reliant on cochlear health and therefore gives a picture of the supra-threshold nonlinear characteristics of the cochlea.

Several quantitative features of emitted responses can be determined from the resulting curves of I/O function, such as detection thresholds, maximum amplitude, dynamic range, slopes which relates to the rate at which emission grows as a function of increased primary tones (Lonsburry-Martin & Martin, 1990).

Contralateral suppression of DPOAE is a procedure in which the amplitudes of these emissions are reduced followed by the presentation of a signal apart from the stimulus, in the contralateral ear. This suppression of amplitude reflects the functioning of efferent system in the particular individual. There are numerous studies which describe efferent effect on all different types of OAEs. The effects of contralateral stimuli on DPOAEs appear more variable than for TEOAEs with reports of both increases and decreases in DPOAE amplitude with presentation of contralateral stimuli (Chery-Croze, Moulin, Collet, 1993; Moulin, Collet, Duclaux, 1992, Moulin, Collet, & Morgon, 1993). Suppression variation in DPOAEs may be related at least in part to the specific effects on various components of the DP fine structure in which peaks and valleys of fine structure are differentially affected (Williams & Brown, 1997; Long, Shaffer, Dhar, & Talmadge, 2000; Sun, 2008). Yet, there are also studies which show suppression of DPOAEs. Characteristic features of contralateral suppression were identified with an acoustic stimulus applied intermittently to the contralateral ear with an onset latency of 43ms. Magnitude of suppression increased with contralateral stimulus intensity (James, Mount, & Harrison, 2002). Moulin et al, 1993 found that DPOAEs recorded from 500 Hz to 5000 Hz was suppressed by contralateral broad-band noise (BBN). Also, the magnitude of effect of efferent system was significantly larger at low intensities of primary tones compared to high intensity levels likewise the suppression was more at mid frequency region compared to other frequencies.

Bassim, Miller, Buss, and Smith (2003) concluded that the average DPOAE suppression was 1.1 dB after contralateral stimulation with a BBN of 60 dB SPL. A study done by Moulin et al (1992) found a notch in the DPOAE I/O function with the presence of contralateral BBN. They also found that the contralateral BBN effect is stronger in the vicinity of an SOAE frequency.

Contralateral acoustic stimulation (CAS) of 60 dB SPL broad band white noise significantly affects the amplitude of DPOAE I/O function in neonates. Even though statistically not significant, the slope of DPOAE I/O slope was also altered (Campos, Hatzopoulos, Kochanek, Sliwa, Skarzynski, & Carvallo, 2011). These findings reflect the nature of CAS, suggesting that it might be primarily a linear phenomenon, deprived of the cochlear compression and non-linear components seen in the healthy cochlea.

1.1.Need for the study

By relating the DPOAE level and growth rate of DPOAE I/O-functions to pure-tone threshold, a correlation much stronger than reported before can be found (Janssen, Kummer, & Arnold, 1998; Kummer, Janssen, & Arnold, 1998) when using an optimum primary tone level setting.

Several studies have shown that there is significant effect of age in otoacoustic emissions. Characteristics of DPOAE as a function of age was also studied and results showed that DP emissions decrease as age increases (Lasky, Perlman, & Hecox, 1992; Norton, Bargones, & Rubel, 1991). The human cochlea is generally thought to reach complete structural maturation in the last trimester of pregnancy (Bredberg, Engstrom & Ades,1965). However, the ear canal continues to mature in child up to 7 years of age and functional changes may occur in a period after birth also, in the human organ of corti and that changes may influence the evoked emissions (Saunders, Kaltenbach, & Relkin, 1983).

Campos et al (2011) assessed the effects of contralateral acoustic stimulation (CAS) on DPOAE I/O function at two frequencies (2000 Hz & 4000 Hz) in neonates. They found that there was reduction in I/O function amplitudes as a result of contralateral suppression and they also observed a slight alteration in the slope of DPOAE I/P function. There are no similar studies which have attempted to study the role of efferent auditory system on DPOAE input-output functions in children (regarding the slope and area).

This study can give rise to a way to assess the efficacy of efferent system in typically developing paediatric population through DPOAE I/O function and to find the optimum intensity level of contralateral noise for suppression of otoacoustic emissions.

1.2. Aim of the study

The study examines the efferent system functioning in typically developing children using DPOAE I/O function characteristics (Slope of the curve and area under the curve).

1.3. Objectives of the study

- To find the DPOAE input/output function characteristics of a normal functioning cochlea in paediatric population.
- To find the effect of white noise on the slope and area of DPOAE I/O function at different intensity levels (40 dB SPL, 50 dB SPL and 60 dB SPL)

- To check DPOAE I/O function characteristics at different test frequencies (1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz, 4000 Hz, and 6000 Hz) with and without contralateral noise.

1.4. Null hypotheses

The null hypotheses were framed based on the objectives of the study.

1. There is no significant difference in the slope of DPOAE I/O function with and without the presence of noise.
2. There is no significant difference in the area of DPOAE I/O function with and without the presence of noise.
3. There is no significant difference in the slope of the DPOAE I/O function at different frequencies
4. There is no significant difference in the area of the DPOAE I/O function at different frequencies

Chapter 2

Review of literature

DPOAEs are the small amplitude emissions from the ear which represents the nonlinear properties of cochlea and can be detected in almost all the ears with normal hearing sensitivity. Many studies have demonstrated the importance of DPOAEs in evaluating the auditory system. Apart from giving an insight to the hearing sensitivity of an individual, DPOAEs have been proved to be sensitive to the efferent system functioning as well which is assessed by the suppression characteristics of the emissions.

2.1. DPOAEs in paediatric population

Prieve, Fitzgerald, Schulte, and Kemp conducted a study in 1997 to determine the DPOAE characteristics of young population. The experiment was carried out on 196 subjects with the age range of 4 weeks to 29 years and they were divided into 7 groups based on the age of the subjects to find the effect of age. Their findings showed that there was a significant difference between the groups in terms of DPOAE amplitude and the difference was dependent on the frequency regardless the stimulus intensity. The infant group exhibited approximately 10 dB higher DPOAE level compared to all the other groups at most of the frequencies tested. The authors attribute the differences between the groups to the maturation of auditory system throughout these age range.

In contrast to the above mentioned study, Groh, Pelanova, Jilek, Popelar, Kabelka, and Syka in 2005 found that the average amplitude of DPOAEs was uniform across the age groups for all the frequencies tested except at the highest frequency (6.3kHz) from their study where they have taken children and adolescents between 6 to 25 years and categorized into 4 age groups. The youngest group had statistically higher average DP amplitude from that of the older groups at 6.3 kHz. They concluded that the decrease in the OAE responses at mid frequencies as the age increases reflects the deterioration in high frequency hearing which begins early in life.

A clinical study was done by Brook, Trussell, Hilton, Forsyth, and Pizer (2001) to find the normal values for DPOAE amplitude in children. They observed an inverse relationship between the DPOAE amplitude and the age although the DPOAE amplitude was only consistently greater at all frequencies for subjects below 8 years old. Also, there was a large intra and inter subject variation in DPOAE amplitudes which resulted in a large overlap of DPOAE amplitude between different age groups.

A comparison between children (4- 10years old) and young adults (22-29 years old) shows a qualitatively similar data of DP-grams for both the groups (Spektor, Leonard, Kim, Jung, & Smurzynski, 1991). However, the emissions of children were approximately 5 dB higher than that of adults in all stimulation levels, although both the groups reached saturation at 70 dB SPL stimulation level, above which any increase in stimulation did not induce any increase in the level of emissions. In the same study, the authors attempted to find a correlation between the DPOAE amplitudes and audiometric thresholds at specific frequencies by including children with mild high frequency hearing loss. A notable decrease in the amplitude of DPOAE was seen in the 6 kHz - 8 kHz region corresponding to the frequency region which had pure tone thresholds greater than 15 dBHL.

Owens, McCoy , Lonsbury-Martin, and Martin (1993) conducted a study on children in the age range of 4-13 years to determine the efficacy of otoacoustic emissions in paediatric population. They compared the values between 2 groups, in normal hearing children and children with middle ear disorders which is confirmed by tympanometry. Similar to previous studies they have found that the mean DPOAE amplitude in children is greater than that of the adults. But, the comparison between normal hearing children and children with middle ear disorders, showed a markedly reduced amplitude or absence of DPOAE in the diseased ears. This study suggests that the OAE measurement is helpful in determining the normalcy of middle ear.

An extended high frequency DPOAE measurement was done on children with a mean age of 6.3 years by Kei, Brazel , Crebbin , Richards , and Willeston (2006) in 3 different groups, they were, 'pass' immittance group 'fail' immittance group and an 'undetermined' group (children who failed in either tympanometry or immittance). Their results show that the fail immittance group had significantly lesser amplitude and SNRs of DPOAE compared to other 2 groups. But this trend was not seen in the extended high frequency region from 9 kHz to 16 kHz except at 13 kHz. This finding supports the use of DPOAE measurements in the children with middle ear dysfunction in the extended high frequency which is difficult with the conventional frequency range.

A paediatric normative study was done by O'rourke, Driscoll, Kei, and Smyth (2001) in 1003, 6 year old school going children to learn the ear effect, gender effect and the effect of history middle of ear infections. Their results show greater DPOAE amplitude and a better SNR in the right ear compared to that of left ear. This ear effect was more evident in high frequency region than low frequency. When evaluating the gender effect, they found a greater amplitude and better SNR in females compared to males. The resulted age and gender effect was in contradiction with the results of previous studies, for which the authors justifies with the large number sample size.

The effect of history of middle ear infection correlates well with other studies, that is, the DPOAE amplitude and SNR was better in the group with negative history of ear infection than the group with positive history of ear infection.

In summary, the amplitude of the DPOAE is found to be higher in children compared to adults and higher in neonates compared to children. These differences in the DPOAE characteristics are attributed to the maturational changes in the auditory system of human beings by majority of the authors.

2.2 Effect of noise on DPOAE Amplitude

Contralateral suppression of DPOAE is reflected by an average of 1-4 dB decrease in DPOAE amplitude (Chery-Croze et al, 1993). Contralateral suppression of DPOAE is also used as an objective clinical tool for evaluating the auditory brainstem pathways and descending efferent pathways along with giving information about the site of generation of DPOAE.

Moulin et al (1993) used a broadband noise to study the suppressive effect on DPOAE. They found that DPOAE suppression was more effective in frequencies between 1 kHz and 3 kHz. Later studies also supported this view of maximum suppression at mid frequencies between 2 kHz and 4 kHz (Kummer et al, 1995).

Williams & Brown (1997) also shows a reduction in the DPOAE amplitude in the presence of 60dBSPL contralateral broad band sound in adult population. In correlation with other studies, their results also showed a frequency effect in the suppression, i.e., lower frequency DPOAEs were more affected by the presence of noise than the high frequency noise. Also, they found a negative correlation between the amount of suppression and the primary tone level. The suppression was greater for a low level primary stimulus compared to a high level primary stimulus.

Kummer et al (1995) studied the suppression tuning characteristics of DPOAE in normal hearing human subjects using ipsilateral suppressor tones. He concluded that the suppression of DPOAE was maximum when the frequency of suppressor tone was below the primary tone f2, and suppression was minimum when the frequency of suppressor tone was near or above f2. This confirmed the speculation that the generation of DPOAE is the f2 site. Kujawa, Glattke, Fallon, and Bobbin (1993) investigated the suppression of DPOAE by contralateral presentation of wide band noise in guinea pigs. Their results provide the evidence for the involvement of medial olivocochlear efferent system in contralateral suppression of DPOAEs.

Micheyl & Collet (1996) evaluated the functioning of efferent system by noting the thresholds of tones in the presence noise of 50 dB SPL. They observed an improvement in the threshold when contralateral noise of 30 dB SPL was given and it correlated with the best effective suppressive frequency of otoacoustic emissions. Hence it is suggested that the activation of efferent system steepens the rate intensity function for supra thresholds signals.

The study on effect of age on suppression of DPOAEs shows a decline of contralateral suppression of emissions with the age, from young adults to older individuals (Kim, Frisina, & Frisina, 2002). The middle aged group exhibited early functional decline of MOC, indicated by contralateral suppression, even when the audiometric thresholds were comparable with the young adult group. The difference in the amount of suppression between the middle aged group and older group was not as large as that of the young adult group and middle aged group. The older individuals also showed decreased absolute DP amplitude with reduced amount of contralateral suppression. The authors investigated frequency dependent aging effect on contralateral suppression of DPOAE in the same study. They found that, although there was a reduction in the DP amplitude in the presence of noise at all the frequency region tested, the maximum suppression was seen in 1 kHz - 2 kHz region. This frequency dependency was significantly different from young adults to the other two groups whereas the middle aged group and older group did not differ significantly.

Abdala, Ellen, and Sininger (1999) studied the maturation of medial efferent system function using contralateral suppression of DPOAE. They had 3 groups with different age range, young adults, term-born neonates and premature neonates. The contralateral presentation of broad band noise induced a reduction in amplitude of DPOAE in young adults as well as in term-born neonates at 1500 Hz and 3000 Hz but not at 6000 Hz. The magnitude of contralateral suppression of term-born neonates was comparable to that of young adults, whereas premature neonates showed a high variability in results. The DPOAE amplitude in premature neonates was equally likely to be suppressed or enhanced by the presentation of contralateral BBN. The authors suggest that this variation in premature neonates is the result of temporary immaturity of the MOC system.

The bipolar changes in DPOAE level (transition from enhancement to suppression) in the presence of contralateral and ipsilateral broad band noise were investigated by Muller, Janssen, Heppelmann, and Wagner (2005). They studied the changes in the DPOAE levels by changing the primary tone levels in normal hearing adult subjects. The results show that the large bipolar changes in DPOAE levels were present only in contralateral acoustic stimulation. Also, the bipolar effect was seen at the frequencies at which dips of DPOAE fine structure was seen.

The experiment done on guinea pigs to find the effect of contralateral white noise on DPOAE reveals the evidence of involvement of medial efferent system. the study results shows a significant reduction in the DPOAE amplitude in the presence of contralateral white noise which was completely cancelled out by the mid sagittal section of brainstem (Puel & Rebillard ,1990).

Giraud, Wable, Collet, & Chéry-Croze (1997) found the effect of contralateral broad band noise on the latency of DPOAEs. Their results show that the latency of DPOAE was shortened in the presence of noise. The effect was seen more on low frequencies followed by high frequencies and ceased in the mid frequency region especially around 4 kHz. The reduction in the latency was noticed only in the low primary stimulus levels. At high primary stimulus level, 65dBSPL, the trend was reversed, i.e., the latency became longer with the presentation of contralateral noise.

To concise, the contralateral presentation of noise alters the characteristics of DPOAE elicited in quiet. The major difference is seen as a reduction in the amplitude of DPOAEs. This contralateral suppression of DPOAE can be used as a measure of efferent system functioning of human auditory system. The frequency analysis of contralateral suppression indicates maximum suppression occurs at mid frequency regions.

2.4 DPOAE I/O function

Boege and Janssen (2002) derived DPOAE thresholds from DPOAE I/O functions that were extrapolated. They measured the cubic 2f1-2f2 distortion products and pure tone thresholds at f2 at different frequencies between f1=500 Hz and 8000 Hz up to ten primary tone levels between L2=65 dB SPL and 20 dB SPL in individuals with normal hearing and individuals with sensori neural hearing loss. They used a primary tone level setting of L1=0.4 L2+39 dB which accounted for nonlinear interaction of the two primaries at the DPOAE generation site. Linear regression yielded correlation coefficient higher than 0.8 in majority of DPOAE I/O function and they stated that linear behaviour was sufficiently fulfilled for all frequencies in individuals with normal hearing and individuals with hearing loss. This concludes that observed linear function dependency is quite general. They also state that there is a significant correlation between DPOAE thresholds and pure tone threshold. Thus, according to these authors DPOAEs that reflect the functioning of peripheral sound processing enable reliable information about cochlear hearing threshold up to hearing losses of 50dBHL without any statistical data.

Similarly, it is also found that the slope of DPOAE I/O function is the growth rate of DPOAE responses, and the slope value decreases with higher stimulus intensities especially in the range of 50-80 dB pe SPL, where the cochlear compression occurs. Hence the slope of DPOAE I/O function is a valuable measure of cochlear functioning (Campos et al, 2011).

Gates, mills, Nam, D'Agostino, and Rubel (2002) studied the relationship between input–output (IO) growth function of the distortion product (DP) otoacoustic emissions and behavioural hearing threshold levels (HTL) in normal hearing men and women and the effect of age on it. The results show a decline of area of DPOAE input output function and increase in hearing threshold levels as the age increases. They found that effect of age was significantly greater on the pure tone hearing threshold levels than that on the DPOAE input output function characteristics. Although the rate of change of behavioural thresholds with age was greater than that of the DP thresholds, it was only significant at 2 kHz for both the genders. They also concludes that the area function appears to be a more robust measure of the systematic change in the DPOAE input output than either DP threshold or the slope of the DP IO function, especially when the noise floor is high.

Another study by Gorga, Neely, Dorn, and Hoover (2003) evaluated the effect of frequency on correlation of audiometric thresholds with DPOAE input output function. Estimation of audiometric thresholds was best accurate at 4 kHz with lowest standard errors. Poor performance was seen at low frequencies and 8 kHz. Additionally, altering the inclusion criteria associated with the linear regression and widening the stimulus levels resulted in slightly better correlation between the audiometric thresholds and DPOAE input output function.

Dorn, Konrad-Martin, Neely, Keefe, Cyr, and Gorga (2001) studied the DPOAE input output characteristics in normal hearing as well hearing impaired ears. Their major finding was the slope of the DPOAE I/O function was steeper in impaired ears compared to normal hearing ears. Also, the ears with normal auditory thresholds showed a compressive non-linear regions at moderate levels in the I/O functions at moderate levels, with more rapid growth at low and high stimulus levels. Likewise, the amount of compression and the range of levels over which compression occurs are reduced in ears with hearing impairment than that of normal hearing ears.

Abdala (2000) studied the DPOAE amplitude growth function in human neonates and adults changing the stimulus levels from 30 to 80 dB SPL in 5 dB steps. Majority of the term neonates and adults showed a non-monotonic growth function with a saturation of DPOAE amplitude. Another finding of this study was that the neonates showed a slightly elevated saturation thresholds compared to adults. Also, there was no age effect found on the slope of DPOAE function, yet the slope significantly increased with the frequency when the frequency ratio (f2/f1) increased from 1.14 to 1.35. The mean slope of overall growth function was found to be 0.89 at f2/f1=1.2.

Another study done in neonates to differentiate middle ear and cochlear disorders using DPOAE I/O function also reveals an increased slope of DPOAE I/O in functions at fixed L2 levels in middle ear and cochlear disorders (Janssen, Gehr, Klein, & Muller, 2005). although both the ears with middle ear disorder and cochlear disorder showed a similar slope of DPOAE I/O function, it was concluded that the difference between the estimated DPOAE threshold and the DPOAE detection threshold is able to differentiate between sound conductive and cochlear hearing loss Additionally, a significant difference in DPOAE levels of 2 kHz and 4 kHz was revealed which was approximately 10 dB when they compared the frequency specific characteristics of DPOAE I/O function. However, both I/O-functions exhibited the same compressive shape.

Abdala and Chatterjee (2003) conducted a study to evaluate the cochlear nonlinearity measured by suppression of DPOAE growth function in neonates and in adults. The mean slope of DPOAE growth suppression showed a frequency dependent suppression in adults. For high frequency suppressors, compression rate of suppression growth was lesser than that for the low frequency suppressors. In the other way, the suppression growth was less dependent on the level of tone suppressors. Additionally, the observed differences between the age groups were smaller at 1500 Hz compared to 6000 Hz, that is, the age effect was most evident when f2 was at high frequencies. The suppression growth of DPOAE was found to be shallower in neonates compared to adults; also the suppression thresholds were elevated when the suppressor tone was of lower frequency than the f2.

The DPOAE I/O function gives a number of parameters which are useful in predicting behavioural thresholds and differential diagnosis. Audiometric thresholds are well correlated with DPOAE thresholds which are extrapolated from the DPOAE

I/O growth function which makes it a useful tool in predicting behavioural thresholds. In the similar way, the changes in the slope of DPOAE I/O function with the hearing thresholds also helps to differentiate between normal hearing and hearing impaired ears. Few studies also concludes that DPOAE growth function helps to differentiate types of hearing loss by evaluating the difference between estimated and detected DPOAE threshold. These results put on a view that the DPOAE I/O function can be used as a clinical tool.

Chapter 3

Methods

This study was carried out with the main objective of finding the I/O function characteristics of DPOAEs in typically developing paediatric population in the presence and absence of contralateral noise. Additionally, to find out the effect of different levels of contralateral broad band noise on the slope and the area of the resulting I/O function in a normally functioning cochlea which in turn will be giving an insight towards the optimal level of contralateral noise for the effective suppression of DPOAEs in paediatric population.

3.1. Selection of Participants

A total of 33 randomly selected, typically developing children were considered for the study in the age range of 6-12 years.

3.1.1. Inclusion criteria: the participants meeting the following criteria were included in the study:

- Hearing sensitivity within normal limits (at frequencies 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz).
- Normal middle ear functioning.
- No retrocochlear pathology.
- No other cognitive or neurological complaints.
- Presence of DPOAE in both the ears.

Children who had pure tone average of more than 15 dB HL were not considered for the study. Likewise, the children who had a history of or an on-going otological problem were also excluded from the test procedures.

The demographic data of the participants included in this study is given in Table 1.1. The mean age of this group was found to be 9.6 years with a standard deviation of +/- 2.02. There were 18 male and 15 female participants.

Table 1.1

Demographics of the subjects participated in the study

Participant	Age (years)	Gender	Participant	Age (years)	Gender
1	12.0	male	18	6.7	female
2	11.5	female	19	7.5	male
3	10.6	male	20	12.1	female
4	9.2	male	21	11.9	male
5	10.8	female	22	12.0	male
6	9.7	female	23	12.5	male
7	9.6	female	24	10.3	male
8	9.2	female	25	11.4	female
9	9.10	male	26	6.2	male
10	9.1	female	27	7.5	female
11	8.9	male	28	6.1	male
12	7.4	female	29	8.9	male
13	8.2	female	30	12.1	female
14	7.2	male	31	12.2	male
15	8.6	female	32	11.8	female
16	8.4	male	33	11.3	male
17	6.3	male	-	-	-

3.2. Test environment

All the participants are subjected to tests in an acoustically treated room where the ambient noise level is within the permissible limits as specified by ANSI S3.1-1999 (R 2008).

3.3. Procedure

3.3.1. Preliminary evaluations. Initially pure tone thresholds of each subject was found out at all the octave frequencies (250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz) using modified Hughson and Westlake procedure (Carhart & Jerger, 1959) with a dual channel diagnostic audiometer in a sound treated room. Speech recognition thresholds were obtained using Kannada paired words and Speech Identification Scores (SIS) using Phonetically Balanced (PB) word lists in Kannada language (Vandana & Yathiraj, 1998). An immittance evaluation was performed to rule out any kind of conductive pathology. Acoustic reflex using 226 Hz probe tone at 500 Hz, 1 kHz, 2 kHz, and 4 kHz was assessed using GSI-Tympstar middle ear analyzer. OAE measurements were done through a calibrated Otodynamics ILO V6 Echoport system. DPOAEs were obtained for two tones, f1 and f2 (primaries), their ratio being 1.22, with intensities of 65 dB SPL and 55 dB SPL (L1 and L2) respectively. DPOAEs considered to be present only when the amplitude to noise floor ratio was > 3 dB at any three consecutive frequencies tested.Participants satisfying the above mentioned selection criteria were included for further evaluations.

3.3.2. DPOAE I/O function. DPOAE measurements were done using calibrated Otodynamics ILO V6 Echoport system in a sound treated room. DPOAEs I/O function of each subject was estimated for the frequencies 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz.

The I/O function was derived by changing the L1 and L2 levels keeping the ratio of f1 and f2 constant, 1.22. The levels of primary tones are changed according to the scissor paradigm given by Kummer et al, 2000 in which the difference between L1 and L2 increases with decreasing stimulus level. At high primary tone levels, L1 and L2 are equal. However, with lower stimulus levels the difference between L1 and L2 has to be increased using the formula $L_1=0.4L_2+39$ (with $f_2/f_1=1.2$)

The growth function was obtained for each of the above mentioned six frequencies at different intensity levels, 65 dB to 45 dB in 10 dB step size. The DPOAE amplitude at different intensity levels is measured along with the noise floor for all the six frequencies. The procedure was repeated for the following four different conditions:

Condition 1: without the presence of any contralateral stimuli

Condition 2: with contralateral presentation of 40 dB SPL white noise

Condition 3: with contralateral presentation of 50 dB SPL white noise

Condition 4: with contralateral presentation of 60 dB SPL white noise

Throughout the procedure OAE tip is kept stable without altering the placement and a rest period of 1 minute given in between each condition. The white noise is presented to the contralateral ear through ER 3A inserts from a dual channel clinical audiometer (Grason- Stadler 61) in a sound treated room.

3.3.3. Slope of the curve. The slope was calculated using the linear trend model. The linear functions are applied for the DPOAE I/O amplitude for the stimulus range from 65 to 45 dB SPL. Once a linear fit is obtained, the slope is estimated by considering 2 points of the x coordinate which corresponds to the intensity level of the primary tones, x1 = 45 dB SPL and x2 = 65 dB SPL. The slope of the fitted linear function is defined as b = (y2–y1) / (x2–x1), where y1 and y2 are the corresponding DPOAE amplitude of x1 and x2 respectively on y axis.

3.3.4. Area under the curve. The area under the curve was determined using the difference between the noise floor and the DP amplitude at all the 10 dB stimulus level steps from 65 dB SPL to 45 dB SPL. The responses are considered as valuable only if the amplitudes of DPOAEs are above the noise floor and further analysis was done. Gates et al (2002) proposed the procedure to find the area under the curve by calculating the cumulative amplitude of the DP responses above the noise floor at each of the intensity levels and multiplying it by 5 which is reported in $dBSPL^2$ ($area^2$). The square root of $area^2$ (i.e., area) is used for the analyses.

3.4. Statistical analysis

A Shapiro Wilk's test was done on the data to find the normality, and the result showed that the data was not normally distributed ($p < 0.05$). Therefore, non-parametric tests were chosen for further analysis of the data. Descriptive statistics were done to find the median, minimum and maximum for both the slope and area of DPOAE I/O function at all the 6 tested frequencies. To compare the within group data, Friendman test was administered and Wilcoxon signed rank test was done as post hoc analysis if a significant difference was revealed.

Chapter 4

Results

This study analyses the DPOAE I/O characteristics of a normally functioning auditory system in the presence of contralateral noise in children. Additionally, the slope and area of the I/O function is also studied across the different conditions, i.e., at different levels of noise presentation and at different test frequencies. All the data obtained was analysed in statistical package of social science (SPSS) software version 21. Shapiro Wilk's test was done to find the normality of the data and it was found to be non-normally distributed. Hence, non-parametric tests were used for data analysis.

The results of this study are given under the following sub headings based on the objectives of the study.

4.1 DPOAE I/O function characteristics

4.2 Effect of white noise on the slope and area of DPOAE I/O function

4.3 Effect of frequency on slope and area of DPOAE I/O function at different frequencies

4.1 DPOAE I/O function characteristics

To evaluate the DPOAE I/O function characteristics, descriptive statistics were done on the data to fulfil the first objective of the study. Table 4.1 shows the median, minimum and maximum of the slopes for all the six frequencies across all the 4 conditions, in the presence of no noise (0 dB SPL), 40 dB SPL, 50 dB SPL, and 60 dB SPL white noise. The slope of DPOAE I/O function at different frequencies shows no specific trend in the presence of different levels of noise. But, a general increase in the median values of slope was seen from 1 kHz to 2 kHz in all the conditions followed by a reduction of the same from 2 kHz to 3 kHz. Also, there was an increase in the median of slope observed from 4 kHz to 6 kHz. Among the six frequencies, 1 kHz showed the lowest and 6 kHz showed the highest median values of the slope of DPOAE I/O function.

Table 4.1

Median, minimum and maximum of the slopes across frequencies of DPOAE I/O function

Noise level	Median	Minimum	Maximum
1000Hz			
0 dB SPL	-.03	-1	1
40 dB SPL	.05	-2	1
50 dB SPL	-.05	-1	1
60 dB SPL	-.01	-1	1
1500Hz			
0 dB SPL	.19	0	1
40 dB SPL	.29	0	1
50 dB SPL	.16	-1	1
60 dB SPL	.17	-1	2
2000Hz			
0 dB SPL	.37	0	1
40 dB SPL	.39	0	1
50 dB SPL	.39	-1	1
60 dB SPL	.34	-1	1
3000Hz			
0 dB SPL	.27	-1	1
40 dB SPL	.28	0	1
50 dB SPL	.27	0	1
60 dB SPL	.33	0	1
4000Hz			
0 dB SPL	.29	0	1
40 dB SPL	.29	0	1
50 dB SPL	.25	-1	1
60 dB SPL	.27	-1	1
6000Hz			
0 dB SPL	.43	0	1
40 dB SPL	.39	-1	1
50 dB SPL	.44	-1	2
60 dB SPL	.44	-1	1

The Table 4.2 shows the median, minimum and maximum of the areas for all the 6 frequencies across all the four conditions, in the presence of no noise (0 dB SPL), 40 dB SPL, 50 dB SPL, and 60 dB SPL white noise. The median of area of

DPOAE I/O function increased with the frequency in all the conditions. In General, the median of area decreased with the level of contralateral noise presentation in all the frequencies except 1 kHz. A slight increase in the median of area was seen from 50 dB SPL noise to 60 dB SPL noise in 3 frequencies (1.5 kHz, 3 kHz, and 6 kHz).

Table 4.2

Median, minimum and maximum of the area across frequencies of DPOAE I/O function

Noise level	Median	Minimum	Maximum
1000Hz			
0 dB SPL	5.74	0	17
40 dB SPL	0.00	0	18
50 dB SPL	0.00	0	18
60 dB SPL	0.00	0	18
1500Hz			
0 dB SPL	14.25	0	23
40 dB SPL	10.90	0	21
50 dB SPL	10.18	0	20
60 dB SPL	10.27	0	19
2000Hz			
0 dB SPL	15.25	0	24
40 dB SPL	13.58	0	22
50 dB SPL	13.02	0	21
60 dB SPL	11.59	0	22
3000Hz			
0 dB SPL	16.18	0	24
40 dB SPL	14.87	0	23
50 dB SPL	13.56	0	23
60 dB SPL	13.96	0	22
4000Hz			
0 dB SPL	16.45	0	22
40 dB SPL	15.86	0	22
50 dB SPL	15.91	0	21
60 dB SPL	15.72	0	22
6000Hz			
0 dB SPL	16.72	0	23
40 dB SPL	16.26	0	22
50 dB SPL	15.81	0	22
60 dB SPL	15.96	0	22

Graphical representation of the slope (Figure 4.1) and area (Figure 4.2) across the frequencies for all the four conditions are given below.

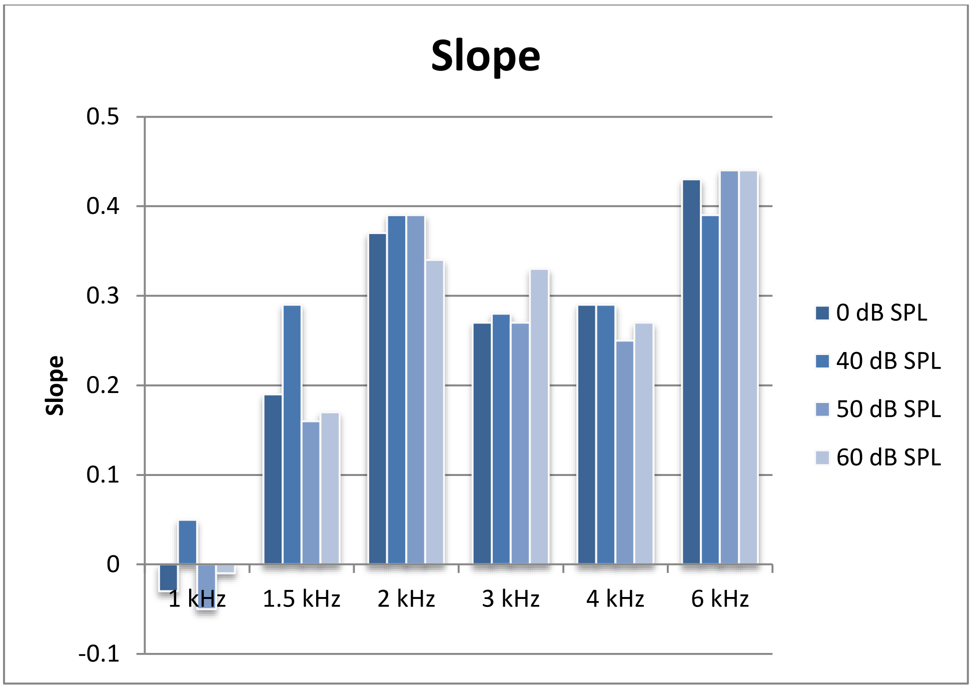

Figure 4.1 effect of noise on slope of DPOAE I/O function across six frequencies.

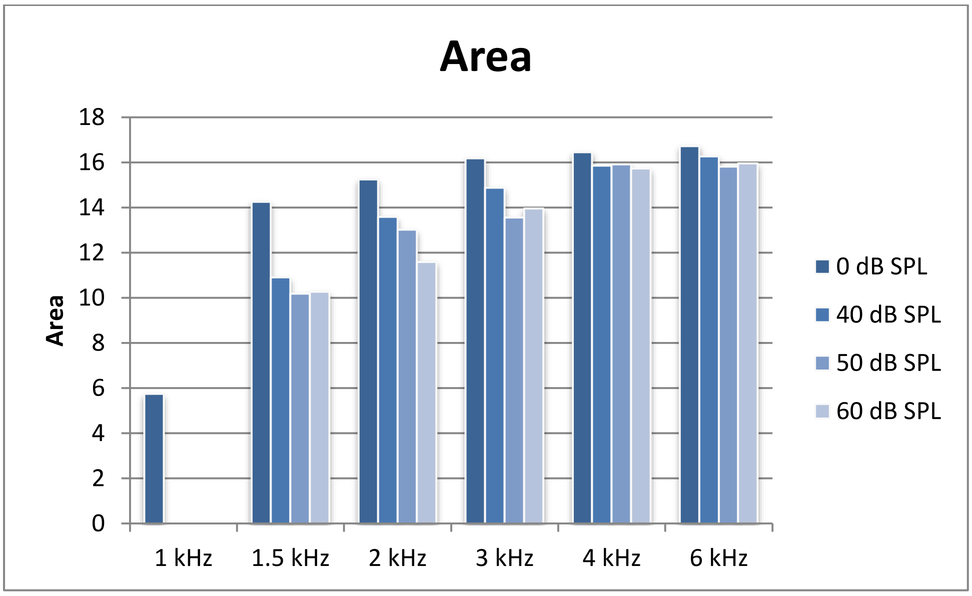

Figure 4.2 effect of noise on area of DPOAE I/O function across six frequencies.

4.2 Effect of white noise on the slope and area of DPOAE I/O function

This category of results address the second objective of this study, i.e., to find the effect of noise on the slope and area of DPOAE I/O function across frequencies. Friedman's test was done to find if there is a significant difference between the conditions. The results showed that there was no significant difference in the slope of the function in the presence of noise at any of the tested frequencies ($p > 0.05$). Test statistics are given in the Table 4.3.

Table 4.3

Test statistics of Friedman's test on the slope of DPOAE I/O function across conditions

	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	6 kHz
Chi-Square	3.791	4.525	4.473	3.467	.345	2.454
p value	.285	.210	.215	.325	.951	.484

In contrast, there was a significant difference in the area in the presence of different levels of noise at all the 6 frequencies tested ($p < 0.05$). The results are shown in table 4.4.

Table 4.4

Test statistics of Friedman's test on the area of DPOAE I/O function across conditions

	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	6 kHz
Chi-Square	22.412	39.740	55.966	55.189	16.542	13.014
p value	.000	.000	.000	.000	.001	.005

Post hoc analysis was done on the area of DPOAE I/O function using Wilcoxon's Signed Rank test to compare between the conditions. The area decreased significantly from no noise condition to 40 dB SPL contralateral white noise at all frequencies except at 4 kHz. Similarly, there was a significant reduction in the area when the noise level was presented at 50 dB SPL and 60 dB SPL from the baseline ($p < 0.05$) at all frequencies tested. In general, the area of DPOAE I/O function decreased as the level of contralateral white noise was increased at almost all the frequencies. There was a significant difference between and across all the different levels of noise seen only at 3 kHz ($p < 0.05$). Another trend which can be seen is that the amount of reduction in the area also decreased as the differences in the noise levels between the conditions decreased except for one instant at 6 kHz. The maximum difference in the areas was seen between the 0 dB SPL noise level and 60 dB SPL noise level at all the frequencies. There was no significant difference in the area between the levels of 50 dB SPL and 60 dB SPL noise at any frequency except for 3 kHz ($p > 0.05$). Table 4.5 gives the test statistics for effect of noise on area of DPOAEI/O function at different frequencies.

Table 4.5

Test statistic of Wilcoxon Signed Rank test of area of DPOAE I/O function for different frequencies (only significant comparisons)

1000 Hz				
Pair compared*	40 - 0	50 - 0	60 - 0	60 - 40
Z value	-2.173	-3.381	-4.275	-2.752
p value	.030	.001	.000	.006

1500Hz					
Pair compared*	40 - 0	50 - 0	60 - 0	50 - 40	60 - 40
Z value	-3.889	-4.837	-5.172	-2.561	-2.437
p value	.000	.000	.000	.010	.015

2000Hz				
Pair compared*	40 - 0	50 - 0	60 - 0	60 - 40
Z value	-4.806	-5.073	-5.847	-2.644
p value	.000	.000	.000	.008

3000Hz						
Pair compared*	40 - 0	50 - 0	60 - 0	50 - 40	60 - 40	60 -50
Z value	-4.594	-4.681	-5.664	-1.992	-3.218	-2.184
p value	.000	.000	.000	.046	.001	.029

4000Hz		
Pair compared*	50 - 0	60 - 0
Z value	-2.768	-3.618
p value	.006	.000

6000Hz			
Pair compared*	40 - 0	50 - 0	60 - 0
Z value	-2.227	-3.745	-2.876
p value	.026	.000	.004

* values in dB SPL

4.3 Effect of frequency on slope and area of DPOAE I/O function at different frequencies

The third objective of this study was to find the DPOAE I/O function characteristics at different test frequency with and without the presence of contralateral noise. To find the effect of frequencies on the slope and area of DPOAE I/O function Friedman's test was administered. Both slope and area showed a significant difference across the frequencies for all the 4 conditions ($p < 0.05$). Table 4.6 and Table 4.7 show the result of Friedman's test on slope and area of the DPOAE I/O function respectively.

Table 4.6

Test statistics of Friedman's test on the slope of DPOAE I/O function at different frequencies

	0 dB SPL	40 dB SPL	50 dB SPL	60 dB SPL
Chi-Square	73.826	39.075	53.957	58.354
Significance	.000	.000	.000	.000

Table 4.7

Test statistics of Friedman's test on the area of DPOAE I/O function at different frequencies

	0dBSPL	40dBSPL	50dBSPL	60dBSPL
Chi-Square	114.956	100.577	119.582	109.622
Significance	.000	.000	.000	.000

As the Friedman's test revealed significant difference across the frequencies, Wilcoxon Signed Rank test was done as a post hoc analysis to compare the differences across the frequencies. The test statistics are given in Table 4.8 and Table 4.9 for slope and area of DPOAE I/O function respectively.

Table 4.8

Test statistics of Wilcoxon Signed Rank Test for slope in different conditions

	0 dB SPL		40 dB SPL		50 dB SPL		60 dB SPL	
	Z	Sig.	Z	Sig.	Z	Sig.	Z	Sig.
1.5 kHz-1 kHz	-3.431	.001	-2.763	0.006	-3.424	0.001	-4.203	0.000
2 kHz-1 kHz	-5.213	.000	-4.294	.000	-5.280	0.000	-4.606	0.000
3 kHz-1 kHz	-4.661	.000	-3.258	0.001	-5.107	0.000	-5.519	0.000
4 kHz-1 kHz	-5.254	.000	-3.536	.000	-4.929	0.000	-5.088	0.000
6 kHz-1 kHz	-5.692	.000	-4.349	.000	-6.021	0.000	-5.604	0.000
2 kHz-1.5 kHz	-3.804	.000	-3.153	0.002	-3.450	0.000	-1.658	0.097
3 kHz-1.5 kHz	-2.258	0.024	-.562	0.574	-2.206	0.027	-1.859	0.063
4 kHz-1.5 kHz	-3.271	.001	-.774	0.439	-1.255	0.209	-1.156	0.248
6 kHz-1.5 kHz	-5.277	.000	-2.942	0.003	-3.587	0.000	-3.366	0.001
3 kHz-2 kHz	-1.386	0.166	-2.955	0.003	-1.712	0.087	-.234	0.815
4 kHz-2 kHz	-.754	0.451	-1.817	0.069	-2.092	0.036	-.776	0.438
6 kHz-2 kHz	-2.261	0.024	-.125	0.901	-1.185	0.236	-2.067	0.039
4 kHz-3 kHz	-.725	0.468	-.572	0.567	-1.216	0.224	-.866	0.387
6 kHz-3 kHz	-3.626	.000	-3.036	0.002	-3.054	0.002	-2.591	0.010
4 kHz-6 kHz	-3.038	0.002	-2.380	0.017	-3.744	0.000	-3.651	0.000

The slope of the DPOAE I/O function increased from 1 kHz to 1.5 kHz to 2 kHz consistently in all the conditions, also, from 4 kHz to 6 kHz. There is general decrement in slope observed from 2 kHz to 3 kHz in all the conditions even though it was not statistically significant except in the presence of 40 dB SPL white noise. There is significant difference in the slope of DPOAE I/O function at 1 kHz compared to slope at other five frequencies ($p < 0.05$). This result hold good in all the four conditions tested. Comparison of slope at 1.5 kHz with that of other frequencies reveals significant differences in slope of 1.5 kHz and 6 kHz at all conditions ($p < 0.05$). At 60 dB SPL noise, there was no significant difference in slopes across the frequencies 1.5 kHz to 4 kHz ($p > 0.05$). In contrast, a significant difference in slopes across the frequencies 1.5 kHz to 6 kHz was seen in quiet, 0 dB SPL noise ($p < 0.05$). Significant differences in the slope of 3 kHz and 6 kHz as well as 4 kHz and 6 kHz were seen in all the conditions ($p < 0.05$). Variable results were seen in the slopes between 2 kHz to 3 kHz, 4 k Hz and 6 kHz in different conditions. Also, there was no significant difference in slopes between 3 kHz and 4 kHz in any of the conditions tested ($p > 0.05$). The maximum differences in the slope were seen between 1 kHz and 6 kHz in all the conditions. These results are summarised in Table 4.8.

Table 4.9

Test statistics of Wilcoxon Signed Rank Test for area in different conditions

Pair compared	0 dB SPL		40 dB SPL		50 dB SPL		60 dB SPL	
	Z	Sig.	Z	Sig.	Z	Sig.	Z	Sig.
1.5 kHz-1 kHz	-5.725	0.000	-5.342	0.000	-4.944	0.000	-5.100	0.000
2 kHz-1 kHz	-6.811	0.000	-6.298	0.000	-6.183	0.000	-6.301	0.000
3 kHz-1 kHz	-6.935	0.000	-6.613	0.000	-6.661	0.000	-6.408	0.000
4 kHz-1 kHz	-6.674	0.000	-6.492	0.000	-6.754	0.000	-6.805	0.000
6 kHz-1 kHz	-6.494	0.000	-6.145	0.000	-6.504	0.000	-6.401	0.000
2 kHz-1.5 kHz	-3.431	0.001	-3.261	0.001	-3.532	0.000	-3.142	0.002
3 kHz-1.5 kHz	-3.238	0.001	-3.704	0.000	-4.594	0.000	-3.341	0.001
4 kHz-1.5 kHz	-3.565	0.000	-4.271	0.000	-5.290	0.000	-4.955	0.000
6 kHz-1.5 kHz	-2.725	0.006	-3.567	0.000	-4.409	0.000	-3.961	0.000
3 kHz-2 kHz	-.762	0.446	-2.072	0.038	-2.113	0.035	-1.462	0.144
4 kHz-2 kHz	-1.382	0.167	-3.016	0.003	-3.676	0.000	-3.539	0.000
6 kHz-2 kHz	-.461	0.645	-2.054	0.040	-2.290	0.022	-2.574	0.010
4 kHz-3 kHz	-.742	0.458	-1.659	0.097	-3.042	0.002	-3.364	0.001
6 kHz-3 kHz	-.227	0.820	-.502	0.616	-1.545	0.122	-2.211	0.027
4 kHz-6 kHz	-.676	0.499	-.872	0.383	-.461	0.645	-.174	0.862

Significant differences between the areas were observed across frequencies in all conditions with very few exceptions. In general, the area of the DPOAE I/O function increases as the frequency increases. A consistent and significant increase in the differences in the area between 1 kHz and the next four frequencies (1.5 kHz, 2 kHz, 3 kHz, and 4 kHz) are observed in all the conditions ($p < 0.05$). There is a decrement seen in the area between 1 kHz and 4 kHz to 1 kHz, and 6 kHz which was significant in all the conditions. Similarly, there is also a significant increase in the differences in the area seen between 1.5 kHz and 2 kHz, 1.5 kHz and 3 kHz and 1.5 kHz and 4 kHz ($p < 0.05$). Significant differences in the area between 2 kHz and 3 kHz were seen only in the presence of 40 dB SPL and 50 dB SPL noise. Yet, a significant difference in the area between 2 kHz and 4 kHz as well as 2 kHz and 6 kHz was seen in all condition except in the quiet (0 dB SPL noise). There were no significant differences between the area of 6 kHz with 3 kHz and 4 kHz in any of the conditions except a significant difference in the area between 3 kHz and 6 kHz in the presence of 60 dB SPL noise. The maximum differences in the area were seen between 1 kHz and 3 kHz in quiet (0 dB SPL noise) and in the presence 40 dB SPL noise and between 1 kHz and 4 kHz in the presence of 50 dB SPL and 60 dB SPL noise. Similarly, the minimum difference in the area was seen between 3 kHz and 6 kHz in quiet (0 dB SPL noise) and in the presence 40 dB SPL noise and between 4 kHz and 6 kHz in the presence of 50 dB SPL and 60 dB SPL. These results are summarised in the Table 4.9.

From the results above, it is suggested to:

1. Accept the null hypothesis which states there is no significant difference in the slope of DPOAE I/O function with and without the presence of noise.
2. Reject the null hypothesis which states there is no significant difference in the area of DPOAE I/O function with and without the presence of noise.
3. Reject the null hypothesis there is no significant difference in the slope of the DPOAE I/O function across different frequencies.
4. Reject the null hypothesis there is no significant difference in the area of the DPOAE I/O function across different frequencies.

Chapter 5

Discussion

The primary objective of this study was to find the DPOAE I/O characteristics of a normal hearing ear with and without the presence of noise. Additionally, the effect of contralateral white noise on the slope and area of the growth function was also evaluated along with characteristics across different test frequencies in the presence of noise.

5.1 DPOAE I/O function characteristics

The results of this study indicates that there is an increase in the slope of DPOAE I/O function as the f2 frequency increases from 1 kHz to 2 kHz which is in agreement with the previous studies done by Abdala (1999) and Probst et al (1993) where the results shows a similar trend of increase in the slope with the frequency. However, there was no consistent change in the slope seen with the presence of noise. A speculation for this finding is that, though the DPOAE amplitude is decreasing with the contralateral noise level, the reduction in DPOAE amplitudes in the presence of noise will be the same across the stimulus levels. The lowest and highest slope of the growth function was obtained at f2 = 1 kHz and f2 = 6 kHz respectively.

The increase in the f2 frequency resulted in increase in the area in all the conditions tested. This could be attributed to the increase in DPOAE amplitude with the frequency which is leading to the overall improvement in the area. The increase in the levels of DPOAE amplitudes across the frequencies in normal hearing individuals has described previously in the literature (Dorn, Piskorski, Keefe, Neely, & Gorga, 1998).

5.2 Effect of white noise on the slope and area of DPOAE I/O function

There was no significant effect of contralateral white noise on the slope of DPOAE I/O function seen in this study which is in contrast with previous studies which shows a decrement in the slope in the presence of high frequency tone suppressors (Abdala, 1998; Kummer et al, 1995; Gorga et al, 2002). The discrepancy in these results could be because of the different types of maskers being used.

The area of the I/O function reduced with the level of contralateral noise from no noise condition to 60 dB SPL noise. Many studies have found the effect of contralateral noise on the DPOAE amplitude (Chery-Croze et al, 1993; Moulin et al, 1993). This reduction in the amplitude of DPOAE from the contralateral suppression in turn could have led to the decrease in the area of the growth function. This trend of decrease in the area was not followed for the frequency 1 kHz in this study, as the median of area for 1 kHz was zero for all the conditions with presence of noise. Since the noise floor at low frequencies are in general higher, the reliability become doubtful at these frequencies, especially at 1 kHz in this study.

With the comparison of area across different conditions we can see the course of gradual decrease in the area of DPOAE I/O function with the increase in the contralateral noise which is a reflection of increase in the amount of suppression as the intensity of the masking noise is increased (James et al, 2002). Another interesting finding of this study is the release from suppression indicated by the slight increase in area observed in 3 of the test frequencies (1.5 kHz, 3 kHz, and 6 kHz) from the 50dB SPL noise to 60 dB SPL noise. However, there was no significant difference found between the area in the presence of 50 dB SPL and 60 dB SPL contralateral noise which is an indication of saturation from suppression at high intensity masker levels. This finding is consistent with the study by Veuillet, Duverdy-Bertholon, & Collet

(1996) where they have found an effective suppression of click evoked otoacoustic emissions (CEOAE) by contralateral acoustic stimulation at low to moderate levels of presentation compared to higher levels.

5.3 Effect of frequency on slope and area of DPOAE I/O function

Statistical analysis shows an increase in the slope of the DPOAE I/O function as the frequency increases, which is consistent with the results from previous studies by Abdala (1999) and Probst et al (1993). However, there is sudden reduction in the slope of DPOAE I/O observed from 2 kHz to 3 kHz. A speculation can be made by relating this result to the findings by Gorga et al(1993) which shows a reduction in the amplitude of the DPOAE level at 3 kHz compared to other lower and higher frequencies. Also, there was no significant difference seen in the slope at 3 kHz and 4 kHz in any of the conditions. Another finding of this study is that there was no significant difference in slopes observed across the frequencies in the presence of 60 dB SPL noise. This result could be because of the ineffective suppression provided by higher level contralateral stimuli.

Similarly, the area of DPOAE I/O function also increased with the frequency which is, as discussed earlier, a result of increase in the DPOAE amplitude with increase in frequency (Dorn et al, 1998). Yet there was no significant difference seen between the areas of 4 kHz and 6 kHz which could be because of contribution of lesser amount of suppression at high stimulus levels and the presence of maximum DPOAE suppression at low-mid frequencies (Abdala et al, 1999).

Chapter 6

Summary and Conclusions

The present study aimed to investigate the characteristic of DPOAE I/O function in a normally functioning cochlea in paediatric population along with other two objectives, first, to study the effect of contralateral noise on the slope and area of DPOAE I/O function, second, to find the DPOAE I/O function characteristics at different test frequencies. Thirty three typically developing children with normal hearing sensitivity in both the ears and without any otological problems participated in the study with an age range of 6-12 years. Preliminary evaluations including the audiometry, tympanometry, and immittance were done prior to the testing.

To find DPOAE I/O function, initially DPOAE measurements were done at 6 frequencies 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, and 6 kHz by changing the L1 and L2 levels from 65dB SPL to 45 dB SPL keeping the ratio of f1 and f2 constant, 1.22. This procedure was done in 4 conditions: in quiet and in the presence of 40 dB SPL, 50 dB SPL and 60 dB SPL contralateral white noise. The slope and area of the DPOAE I/O function was determined from the data obtained from the DPOAE measurements.

Results of this study show that, there is an increase in slope and area of the DPOAE I/O function as the frequency increases. Additionally, the area of the I/O function reduced with the increase in the level of contralateral white noise, whilst the slope of I/O function did not show any significant difference in the presence of contralateral white noise. The slope of the DPOAE I/O function increased as the test frequency increased with a statistical significance except from 2 kHz to 3 kHz.

Similarly, the area of the I/O function also increased with the frequency in all the conditions tested.

Hence, this study shows that the area of DPOAE I/O function can be used as an effective measure to assess the efferent system in paediatric population. Also, it is found that the effective level of contralateral noise is at a lower level as the area of the I/O function did not show any significant difference between 50 dB SPL and 60 dB SPL white noise.

6.1 Implications of the study

1. As the results show a clear effect of noise on area of the DPOAE I/O function, it can be used as an additional tool to assess efferent system functioning in paediatric population.
2. From this study it can be inferred that 50 dB SPL noise can be used as the optimum level of intensity for contralateral suppression of DPOAE in paediatric population.

6.2 Future directions

1. Measuring DPOAE I/O function characteristics across different age groups will give the maturational changes on slope and area of DPOAE growth function.
2. The same study can be done in the presence of different types of maskers to find the most effective suppressor of DPOAE.
3. Similar study can be done on adult population to find the effect of noise on slope and area of DPOAE growth function.

6.3 Limitations

1. This study could have been done on a larger sample size to reliably generalize the results to the population
2. The lax criteria (in terms of SNR and reproducibility) used to find the presence of DPOAE in this study led to the dilemma of very less or negative amplitude to noise ratio at low frequencies in the presence of contralateral noise which in turn hindered the analysis of area of the DPOAE growth function in presence of noise. Strict criteria would have allowed analysing the effect of noise more accurately at lower frequencies.

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Appendix 1

Test statistic of Wilcoxon Signed Rank test of area of DPOAE I/O function for different frequencies for which no significant differences was seen.

1000 Hz

Pair compared*	40-50	60-50
Z value	-1.682	-1.779
p value	.093	.075

1500Hz

Pair compared*	60-50
Z value	-.508
p value	.611

2000Hz

Pair compared*	50-40	60-50
Z value	-1.849	-1.172
p value	.064	.241

4000Hz

Pair compared*	40-0	50-40	60-40	60-40
Z value	-1.745	-1.518	-1.951	-1.358
p value	.081	.129	.051	.175

6000Hz

Pair compared*	50-40	60-40	60-50
Z value	-1.368	-.959	-.438
p value	.171	.338	.661