A Comparison of Distortion Product Otoacoustic Emissions in Children and Adults

Register No. M 9513

An Independent Project submitted as part fulfilment for the First Year M.Sc. (Speech & Hearing) to University of Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MYSORE - 570 006

May-1996

C E R T I F I C A T E

This is to certify that the independent project entitled **"A Comparison of Distortion Product Otoacoustic Emissions in Children and Adults"** *is a bonafied work done in part fulfilment for the first year degree of Master of Science (Speech & Hearing), of the student with Register No.M95813.*

Mysore
May 1996

Director
All India Institute of Speech and Hearing
Mysore - 570 006

C E R T I F I C A T E

This is to certify that the independent project entitled

"A Comparison of Distortion Product Otoacoustic Emissions in Children and Adults" *has been prepared under my supervision and guidance*.

Mysore
May 1996

Dr. (Miss) S. Nikam
Guide

DECLARATION

I hereby declare that this independent project entitled **"A Comparison of Distortion Product Otoacoustic Emissions in Children and Adults"** *is the result of my own study under the guidence of Dr.(Miss) S.Nikam,Professor and Head, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for any other Diploma or Degree.*

Mysore
May 1996

RegisterNo.M9513

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Reg. No. **M9513**

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INTRODUCTION

In humans, the role of the ear is extremely important. It is one of the most important links in the speech chain, which enables proper communication. Such enhanced communication skills, as seen in humans, have a momentous role in the existent structure of human society, as society is dependent upon verbal communication.

Since time immemorial, the ear has been recognized as the organ of hearing. It is known beyond doubt that the ear is the organ of hearing. However, only recently has it been demonstrated that the ear, besides, receiving sounds, also produces sounds (Kemp, 1978). Although these sounds are of very low intensity, they are loud enough to be reliably measured by instruments specifically designed for the purpose. These sounds, emitted by the ear are called Oto-acoustic emission (OAE).

The discovery of OAE led to a deluge of studies on the same. After over twenty years since its discovery, the OAE have been classified into the following two types.

I. Spontaneous Oto-acoustic emission **(SOAE)**

Those which are emitted spontaneously from the ear, in the absence of any external stimuli. These are seen in about 50% of the ears with normal hearing.

II. Evoked OAE

These are elicited in response to certain external stimuli. These may be of the following three types:

a. Transient Evoked Otoacoustic Emission (TEOAE)

Those which are emitted in response to externally given clicks as stimuli. This is seen in about 98% of the ear with normal hearing (Kemp, 1982; Elberling, 1982).

b. Distortion Product Otoacoustic Emission (DPOAE)

These are emitted in response to two simultaneously presented pure tones. These are characteristically found to occur at specific frequencies, which are related to the two stimulus frequencies. These are found to occur in all ears with hearing acuity levels within 25-30 dB HL (Ref. ANSI, 1969).

*

c. Stimulus Frequency Otoacoustic Emissions (SFOAE)

These are emitted in response to a continuous tone of a specific frequency. The emission resembles the stimulus in terms of the frequency.

The fact that OAE, are seen in all ears, as long as peripheral hearing is within normal limits, led to attempts to use these measures as being indicative of the presence or absence of hearing loss. These attempts did bear fruits (Jhonson, 1983; Tanaka et al., 1987; Bonfils et al., 1988; Stevens, 1988; Collet, 1989) and OAE was demonstrated to be a reliable tool for measuring hearing acuity (Harris, 1990). This development was further promoted by improvements in technology which made instruments much more inexpensive and thus more accessible.

The DPOAE, as a clinical tool, provides several advantages, hitherto not possible using other contemporary tools for the purpose (Martin et al., 1990). First, this test is objective in nature, and does not require patient co-operation for it to be administered. Thus, it may be conveniently used for measuring the hearing acuity of young children including neonates. Unlike BSERA, it does not require cumbersome procedures such as electrode placement and measurement of impedance at the electrodes. Nor does it require an airtight seal as is the case with tympanometry. While the time taken to test a patient using DPOAE varies with the exact procedure used for measurement, it is shorter than that required for BSERA measurements, but longer than that required for tympanometric measurements. Another major advantage is that DPOAE can give highly precise frequency specific information. (Anova et al., 1993). Since DPOAE 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. Such precise information cannot be obtained using BSERA, because the stimuli employed here are not pure tones.

The origin of the OAE is believed to be the hair cells, specifically the outer hair cells (OHC) (Davis, 1983; Zwicker, 1984). Many pathologies causing hearing loss, such as noise induced hearing loss (NIHL), ototoxicity, etc., are known to selectively damage the OHC. Hence, in these cases, a measure of DPOAE may indicate the severity of damage of OHC directly (Wier et al., 1988; Probst, et al., 1993) -This has opened up possibilities of using the OAEs to measure the place and extent of damage of OHC on the basilar membrane, such as in patients exposed to noise or those under medication with ototoxic drugs.

Thus, it is evident that the OAE has a very high potential as a clinical tool for assessment of hearing acuity. Since DPOAE is seen in all ears with normal hearing, it proves to be a good choice. The other major disadvantage is that of time required for testing. The best method of assessment would be to vary stimulus intensity and find the minimal intensity at which DPOAE can be recorded (DPOAE threshold). However, this procedure consumes a lot of time, which makes its clinical application limited, especially so with children and infants. Hence, an alternative method was devised. The DPOAE is measured at fixed stimulus intensity, usually 70 dB HL or 50 dB HL, and the intensity of the DPOAE is measured. A comparison of this with the normal range of DPOAE intensity would reveal if there is any hearing loss (Lonsbury-Martin, 1990). This procedure reduces the test time manifolds since the stimulus is presented only at one intensity.

The method described above, may be used only if there are norms or standard values expected from normal hearing people. These may be used as a reference to judge one's hearing acuity. Thus, establishing norms is essential. The normal values of DPOAE intensity may vary with the population studied, the age, and even with the instrument used (as the sensitivity of the instruments may vary). This study was thus, undertaken, with a view to creating such normative data for various age groups for the Indian population. This data may then be of use in clinical practice, where a patient's DPOAE may be compared with this data to determine whether or not he has hearing loss. This study, the first of its kind in India, may then form the basis of further studies.

This study also aims to investigate if there is any changes in the intensity of DPOAE with age, from early childhood to adulthood.

Purpose of the study

The study was taken up with the aim of achieving the following purposes:

1. To create a normative baseline for DPOAE amplitude for the Indian population, so as to enable the use of DPOAE measures to serve as a reliable clinical tool for measurement of hearing acuity. Use of data obtained in the study will be of use in routine clinical practice in order to ascertain presence or absence of hearing loss. It may also aid in monitoring effect of etiological factors such as noise and ototoxic drugs on the hearing sensitivity.

2. To obtain a set of DPOAE amplitude values, which may be used as a reference value, for any future studies on the DPOAE. The normative data generated by the study will enable future researchers to compare their data with the norms and draw appropriate conclusions.

3. To compare the DPOAE amplitudes in children and adults in order to ascertain if there is any significant differences between the two groups.

REVIEW OF LITERATURE

OAEs are defined as "sounds generated within the cochlea, by the outer hair cells, which can be detected at the tympanic membrane" (Norton and Stoves, 1994).

While the OAEs are a recent discovery, it was as early as 1948, when Gold proposed that "a purely passive basilar membrane filtering action was not sharp enough for frequency selectivity". He further suggested that an active bio-mechanical cochlear feedback was responsible for sharp frequency selectivity. This was the first suggestion towards explaining that the ear was not merely a passive organ.

However, the discovery of OAE is attributed to Kempt, at the Institute of Laryngology and Otology, London in 1978. He reported that on presenting brief broad spectrum sound stimuli to the ear, the ear emitted another sound of similar spectra but of very small intensity. Initially, these were thought to be the echos of the stimulus and were labelled as "Kemp's Echos". However, over the years, it has been confirmed that these sounds are not echos but sounds emitted from the ear. These confirmations have come after studying the latency of the reflected sound and the emissions.

The source of the OAE is believed to be the OHC, which were demonstrated to be electromotile (Brownell, 1983). Later, OHC were demonstrated to be motile to pharmacologic stimulation (Slepecky, 1988) and also to acoustic stimulation (Brundin et al., 1989).

The cause of such motility of the OHC was earlier believed to be due to the presence of actin and myocin in the stereocilia (Tilney, 1980; MacCartney, 1980). However, it has now been established that the mobility of the OHC is due to volume changes in the OHC by the movements of ions and not due to actin and myocin fibres (Wilson et al., 1980).

OHCs contract and elongate at rates which no muscle fibre is capable of. This has been confirmed by studying the changes in OHC following electrical stimulation (Ashmore and Brownell, 1986). Further, OHC movement occurs as a direct conversion of electrical potential energy to mechanical energy. This was demonstrated by the presence of OHC movements even after the depletion of cellular stores of "Adenosine Triphosphate" (ATP) (Brownell and Kachar, 1986). Thus, it has been suggested that if the OHC length changes - are rapid enough, they may be responsible for the OAE (Davis, 1983; Schloth and Zwicker, 1984).

Distortion product OAE arises due to the fact that the ear is not a linear system. Distortion is generated by non-linear elements in the processes involved with the ear

(Bekesy, 1960). The presence of a distortion product was first postulated by Hall (1974). However, for a number of years, it was not realized that these distortions could be picked up at the tympanic membrane (Kemp, 1984).

DPOAE are emissions seen due to the interaction of two tones, separated in frequency by a given number, presented simultaneously (Kemp, 1981). Based on high level stimulation, the optimal ratio, i.e., the ratio of primaries yielding the maximum distortion product is found to be 1.22 (Harris, 1989; Loonsbury-Martin et al., 1989). However, the most sensitive threshold appears to be approximately 1.15 (Brown and Norton, 1990). As of now, there is no clear consensus as to what the best parameters for clinical use are (Norton and Stover, 1994). Beyond an optimal ratio, the intensity of the DPOAE falls at a very rapid rate (Gaskill, 1990)

The intensity of the primaries, L1 and L2 also affect the DPOAE. Lower levels of the primaries elicit a local response and thus gives frequency specific information. At higher levels, the response is more complex and non-local (Avans, 1993). The exact role of relative intensities of L1 and L2 is not clear. A few studies report that maximum DP amplitude occurs when L1 is greater than L2 (Gaskill, 1990). Others report that the effect of relative intensity of primaries varies with the geometric mean of the primary frequencies. For primaries with -geometric mean of 1000 Hz and 2000 Hz, the L1 should be greater than L2 by 10 dB, to give maximum DPOAE (Hanser, 1991). Certain other studies have found the L1 -*L2* differences to have a minimal effect on DPOAE amplitude. Maximum DPOAE amplitude was found when L1 = L2 except at 8000 Hz (Rasmussen, 1993).

Irrespective of the controversies regarding the best parameters for obtaining DPOAE, it is well established that it promises to be an excellent clinical tool for audiological evaluations. An elevated behavioural threshold corresponds to a reduced DP amplitude if the stimulus parameters are kept constant (Harris, 1990; Lonsbury-Martin, 1990). It can thus, differentiate between normal hearing and hearing loss patients (Martin, 1990; Smurzynski, 1990). DPOAE may indicate hearing difficulties, which may go undetected by conventional audiometry (Gaskill and Brown, 1992).

Well developed DPOAE have also been observed in neonates (Smurzynski, 1990). It may thus be useful for pediatric audiological evaluation. Lonsbury-Martin (1990) collected pediatric measures of DPOAE. The average threshold of DP elicitation was found to be 35-45 dB SPL. The dynamic range between DP elicitation and saturation was found to be approximately 40 dB SPL. The DPOAE responses of neonates were found to be higher than their transient evoked OAE responses (Bonfils et al., 1992). Thus DPOAE may be a better tool than the TEOAE.

Audiological assessment of infants and young children may be confounded by neurological and neuromaturational disorders. In such cases, also, DPOAE has been found to be an effective audiological assessment tool (Stoch, Wolf and Blard, 1993).

DPOAE is found to be more resistant to cochlear damage, and may be seen in the ears with behavioural thresholds upto 50 dB (Harris, 1990). It may thus be more useful in monitoring cochlear changes clinically, than the other OAEs.

DPOAE has been found to correspond well with behavioural audiometric thresholds (Harris, 1990; Probst and Harris, 1993). However, the efficiency of DPOAE in differentiating between normal hearing.and hearing impaired subjects is high at frequencies above 1000 Hz (Gorgan et al., 1993). Also, the presence of DPOAE elicited by high stimulus intensity was not found to be as reliable a measure of hearing loss, as that elicited by low stimulus intensity (Harris, 1991).

While research on the effect of ototoxicity and aging on the DPOAE is much limited, as compared to that on

TEOAE, early results tend to indicate that these factors lead to a reduction in DPOAE amplitude (Lonsbury-Martin, 1991). It may thus be used for monitoring the effects of these factors on the cochlea. A change in DPOAE amplitude of greater than 6 to 9 dB SPL, depending upon stimulus conditions indicates a change in the cochlear status, provided that the conductive and middle ear status is the same (Roede, 1993).

DPOAE is affected by spontaneous OAE and by Stimulus Frequency OAE (SFOAE). If the DPOAE lies within the frequency region of SOAE or SFOAE, then the amplitude of the DPOAE may be increased so that it lies only 10-20 dB SPL lower than the intensity of the eliciting stimuli (Wit et al., 1981; Schloth, 1982; Furst et al., 1988).

Thus, the DPOAEs hold promise as an excellent clinical tool for audiological assessment, and may be used along with conventional audiometry. The ability of DPOAE to selectively test specific frequency regions on the basillar membrane makes it highly suitable for studying effects of external noise, ototoxins, aging, viral and bacterial pathologies, etc. on the cochlea (Martin, 1980). The DPOAE proves to be an efficient, cost effective, objective, non-invasive, tool for audiological assessment which is also speedy.

METHODOLOGY

This study was taken up with an aim of establishing a normative baseline for Distortion Product Otoacoustic emissions in children and in adults and comparing the two, to establish the differences in them, if any.

I- Subjects

The subjects for the study are grouped into:

Adults - 30 volunteers aged 17 to 28 years, both male and female (mean age - 20.5 years) . . .

Children - 25 children aged 2 to 12 years, both male and female (mean age - 7.7 years)

All subjects had pure tone hearing thresholds in the frequency range 250 Hz to 8000 Hz, less than 20 dB HL. This was ascertained using a two-channel clinical audiometer (Orbiter-922).

All subjects also had normal middle ear function. This was ascertained by using the Immitance audiometer. All subjects had "A type" tympanograms and had normal reflexes, on screening.

None of the volunteers reported of any audiological symptoms (hearing loss, tinitus, giddiness, etc.), and had audiometric thresholds lesser than 20 dB HL at all frequencies between 250 to 8000 Hz with an "A type tympanogram" and normal reflexes.

Equipment

The following equipments were used in the study:

a. Pure tone audiometer

A two channel clinical audiometer (Orbitar 922) was used to assess the behavioural thresholds of all the subjects. The audiometer was calibrated prior to the study as per the recommendations of the manufacturer (Appendix I).

b. Immitance audiometer

An immitance audiometer (GSI-33) was used to assess the middle ear function of the subjects. The audiometer was calibrated as per recommendations of the manufactrer (Appendix II).

c. DPOAE measuring system

The DPOAE measuring system is a computer-based OAE measuring system. This computer is being used as a dedicated system and is used only for the measurement of Otoacoustic emissions. The software being used for the purpose is the "Scoutplus Version 3.2".

Using a computer-based instrument gives the OAE measurement immense flexibility. The system allows for the user specifications to be used in testing for a number of parameter. With reference to the study the following values were set up.

1. **Display type** - The "display type" controls the pattern of the measurement. Since one of the basic purposes of the study was to get a normative baseline which can be then used for clinical purposes, the display was set to "DP Gram". This setting plots the DPOAE on a frequency vs. intensity graph, similar to an audiogram.

2. Frequency begin/Frequency **end** - This determines the range of frequencies being tested. This was set to 500 Hz and 8000 Hz respectively, since this range would encompass the frequencies tested in routine audiological evaluations.

3. **F /F, ratio** - The ratio of stimulus frequencies (primaries) at which the distortion product occurs has been determined by several previous studies. The maximum distortion is produced at F2/F1 ratio of about 1.22. As reported in the literature, studying a F2/F1 ratio from 1.15 to 1.25 gives clinically useful results (Loonsbury-Martin, 1993). Hence a F2/F1 ratio of 1.20 was set.

4. **L1 and L_2 level** - This refers to the intensities of the stimulus frequencies. It has been clearly established that very high level of stimulus gives a

"non-local response", i.e., the distortion product does not correspond to a specific area on the basilar membrane (Avans, 1993). However, at a slightly higher intensity, people with a mild hearing losses may also show some DPOAE (Harris, 1991) .

Keeping these observations in mind, each subject was tested twice, once with a stimulus level of 70 dB and again with a 50 dB stimulus level.

There are conflicting reports in literature as to the ratio of intensities of the two primaries which gives maximum DPOAE, while some studies show that a difference in L1 and L2 elicits greater DPOAE amplitude (Gaskill, 1990). Other studies either question these results entirely (Rasmussen, 1993) or suggest that the differences in intensity of primaries has different roles at different frequencies (Hanser, 1991). Thus for this study the intensities of both the primaries in each test condition were kept equal, i.e., 70 dB for both primaries in one test and 50 dB for both primaries in another test.

5. **Points per octave** - Determines the number of points tested per octave. Since during pure tone audiometry, the test is carried out at one point per octave, the same was done here.

6. Point time limit - It refers to the maximum artifact-free averaging time per data point. Variation in this changes the overall test time, but trades off with the averaging out of noise. It was set to 25 seconds which is also the default setting.

7. **S/N ratio** - It is one of the criteria for determining when to stop averaging a frequency. If the signal to noise ratio (i.e. the ratio of DPOAE level to the noise level) is greater than that specified, then the test frequency is plotted. This was set to +30 dB.

8. **Overall noise level** - Being another criteria for stopping test at a frequency this value specifies an intensity level. If the noise floor lies below this level the testing is stopped at that frequency and the test proceeds to the next frequency. This was set to -30 dB.

9. **Token buffer size** - This was set to 2048, which is also the default testing.

10. **Noise side bands** - It refers to the bandwidth of noise measured. It was set to '0', which indicated that the noise was measured only at the frequency of the DPOAE.

11. DP frequency - It refers to the frequency of emission. It was set to 2F1 -F2 which is known to have maximum distortion. It is also the computer default setting.

With these above mentioned parameters, two DPOAE protocols were generated. These protocols, IPl.LST and

IP2.LST varied only in terms of the stimulus intensities, 70 dB and 50 dB respectively.

Test environment

The tests were carried out in a sound treated room where the ambient noise level measured was within specified limits. (Appendix III). The test room had adequate lighting and was at a comfortable temperature.

The subjects were provided with a comfortable chair to sit on during the test. Since this is an objective test, the subjects were not required to do any task.

Test procedure

All volunteers were first screened for their pure tone thresholds in both ears using a two channel clinical audiometer (Orbitar 922). The frequencies tested were 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. Any volunteer with thresholds greater than 25 dB HL at any frequency were rejected.

Subjects who had thresholds within 25 dB HL were then tested for tympanograms and reflexes in both ears using an immitance audiometer (GSI-33). Only subjects who had A-type tympanograms and normal acoustic reflexes were tested further.

Subjects who fulfilled both these criteria were studied for their Distortion Product Otoacoustic Emissions. Each ear was tested twice, once each with the two protocols described earlier. Thus, four tests were done on each subject, two on each ear.

Each test consisted of three phases, which was done in the following order.

I. Checkfit - In this phase, a transient stimulus (frequency sweep) is presented to the ear and the measured response is displayed as a spectrum and a waveform. A correct probe fit would give a waveform as shown in Figure 1. If such a waveform was not obtained, the probe was taken out, checked for debris and refitted. The "checkfit" phase is redone to obtain correct fit.

II. Calibration - After obtaining a correct fit, the stimulus sources were calibrated. In this phase the system response of each of the two loudspeakers necessary to provide the stimulus are measured and displayed. If the responses of the two overlapped, then it is calibrated.

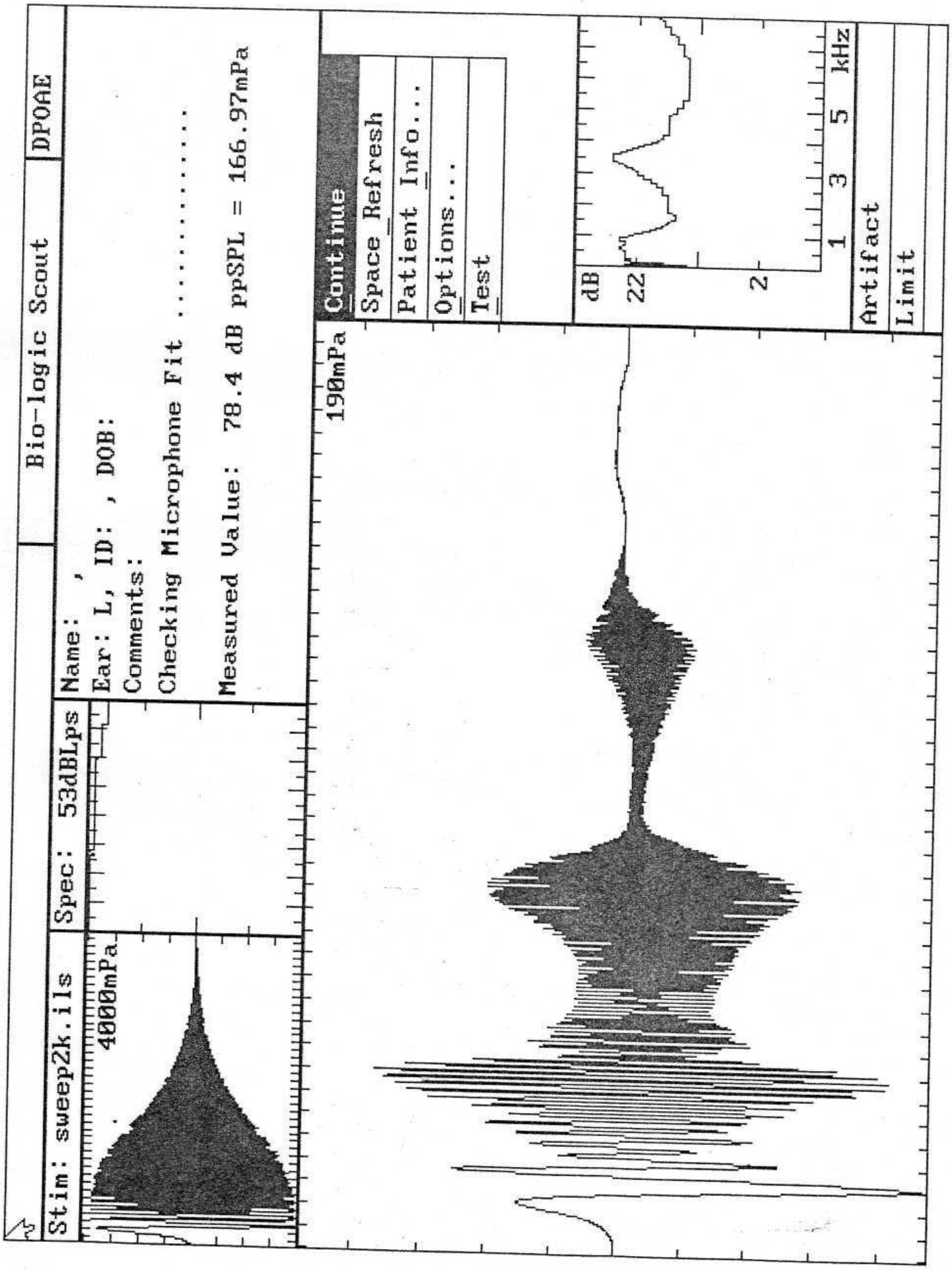
III. Measurement - In this main phase of the test, the-stimuli were presented and the DP emissions measured. The measures were done in accordance with the parameters, described earlier. The measures may then be displayed either as a DP-Gram in which the distortion product amplitude was shown as a function of frequency (Figure 3) or as a spectrum, where the final spectra of each test frequency may be viewed individually (Figure 4). Alternatively, the results may be studied as a "Report" which includes a DP-gram and the values for various stimulus and DPOAE parameters (Figure 5).

Analysis

The DP amplitude for each frequency tested, was studied for all the subjects. The emission frequencies obtained for the parameters selected were 450 Hz, 936 Hz, 1823 Hz, 3610 Hz and 7306 Hz. These frequencies correspond roughly with test frequencies employed for pure tone audiometry.

Statistical techniques were then applied to generate a normative range for DP amplitude in children and in adults, for both 50 dB and 70 dB stimuli. Further, statistical analysis was done to determine if a significant difference existed between the two groups. The statistical procedures used for generating the norms included calculation of the mean and standard deviati[ons for different test conditions. The procedures used for comparing the DPOAE in adults nad children involved using the "t-test".

Figure 1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Spec: 53dBLps
Bio-logic Scout
DPOAE
4000mPa
Name: ,
Ear: L, ID: , DOB:
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Measured Value: 78.4 dB ppSPL = 166.97mPa
190mPa
Continue
Space Refresh
Patient Info...
Options...
Test
dB
22
2
1
3
5
kHz
Artifact
Limit

Figure 2

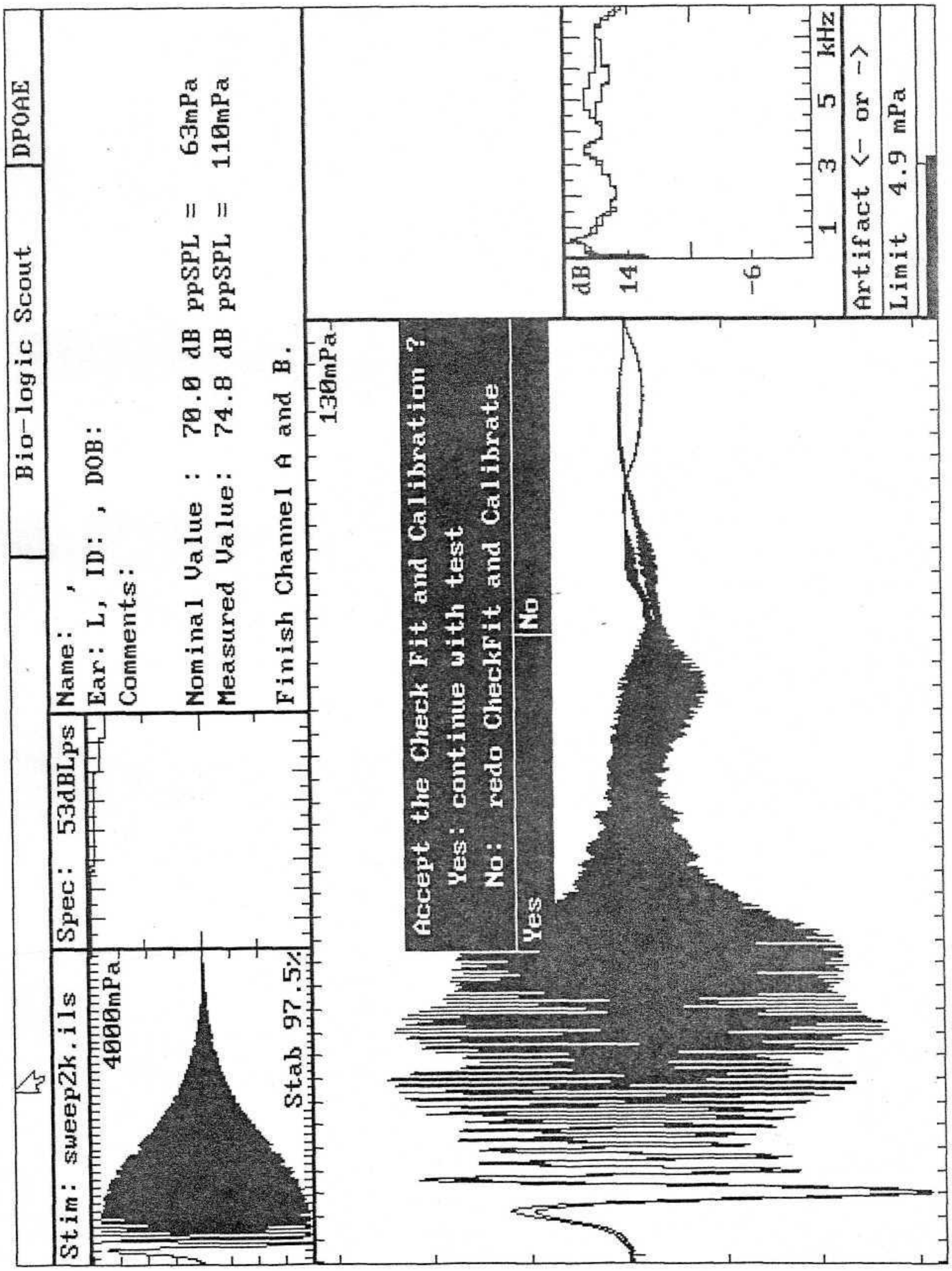

Bio-logic Scout
DPOAE
Stim: sweep2k.ils
Spec: 53dBLps
4000mPa
Stab 97.5%
Name: ,
Ear: L, ID: , DOB:
Comments:
Nominal Value : 70.0 dB ppSPL = 63mPa
Measured Value: 74.8 dB ppSPL = 110mPa
Finish Channel A and B.
130mPa
Accept the Check Fit and Calibration ?
Yes: continue with test
No: redo CheckFit and Calibrate
Yes
No
dB
14
-6
1
3
5
kHz
Artifact <- or ->
Limit 4.9 mPa

Figure 3

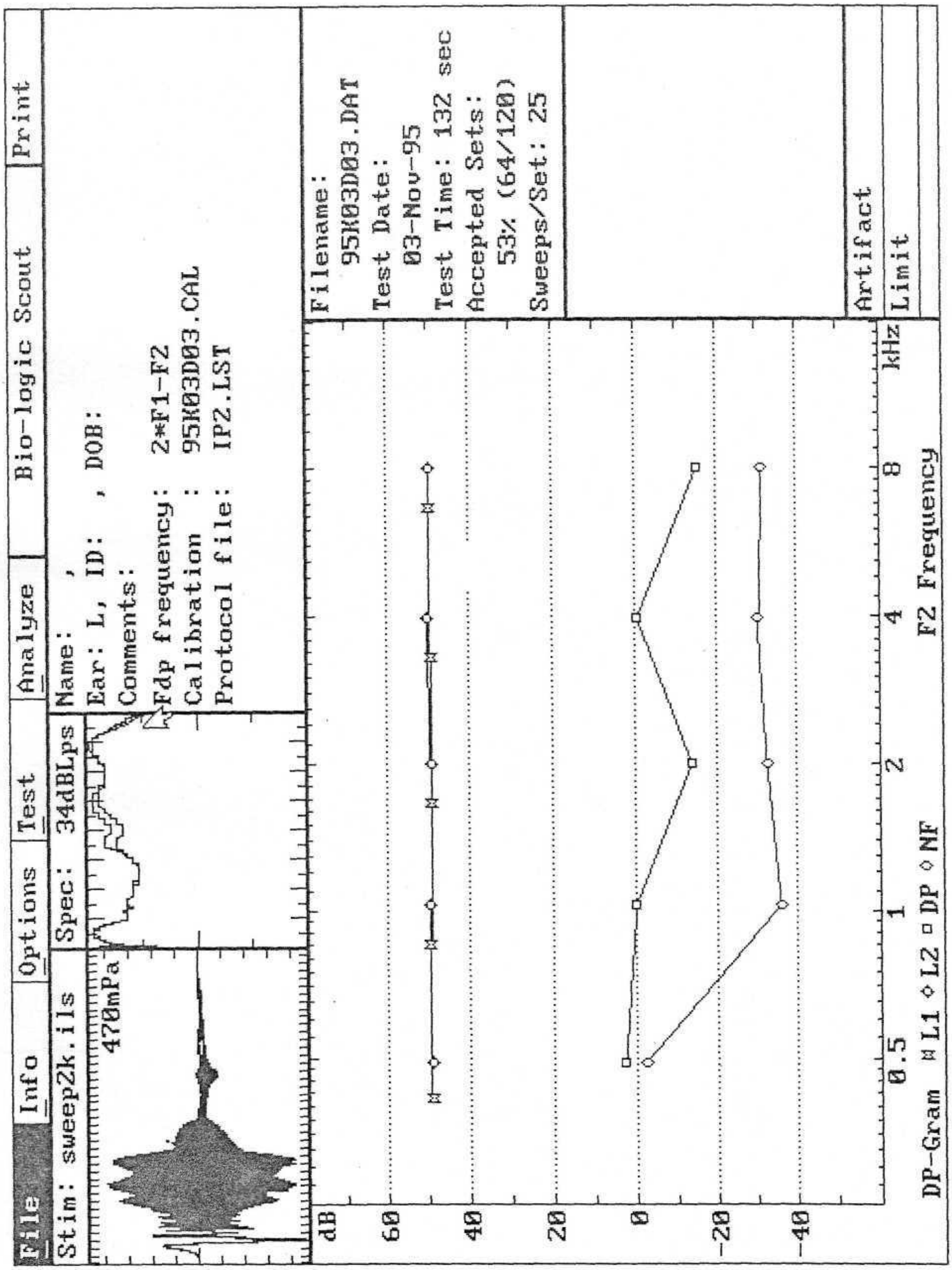
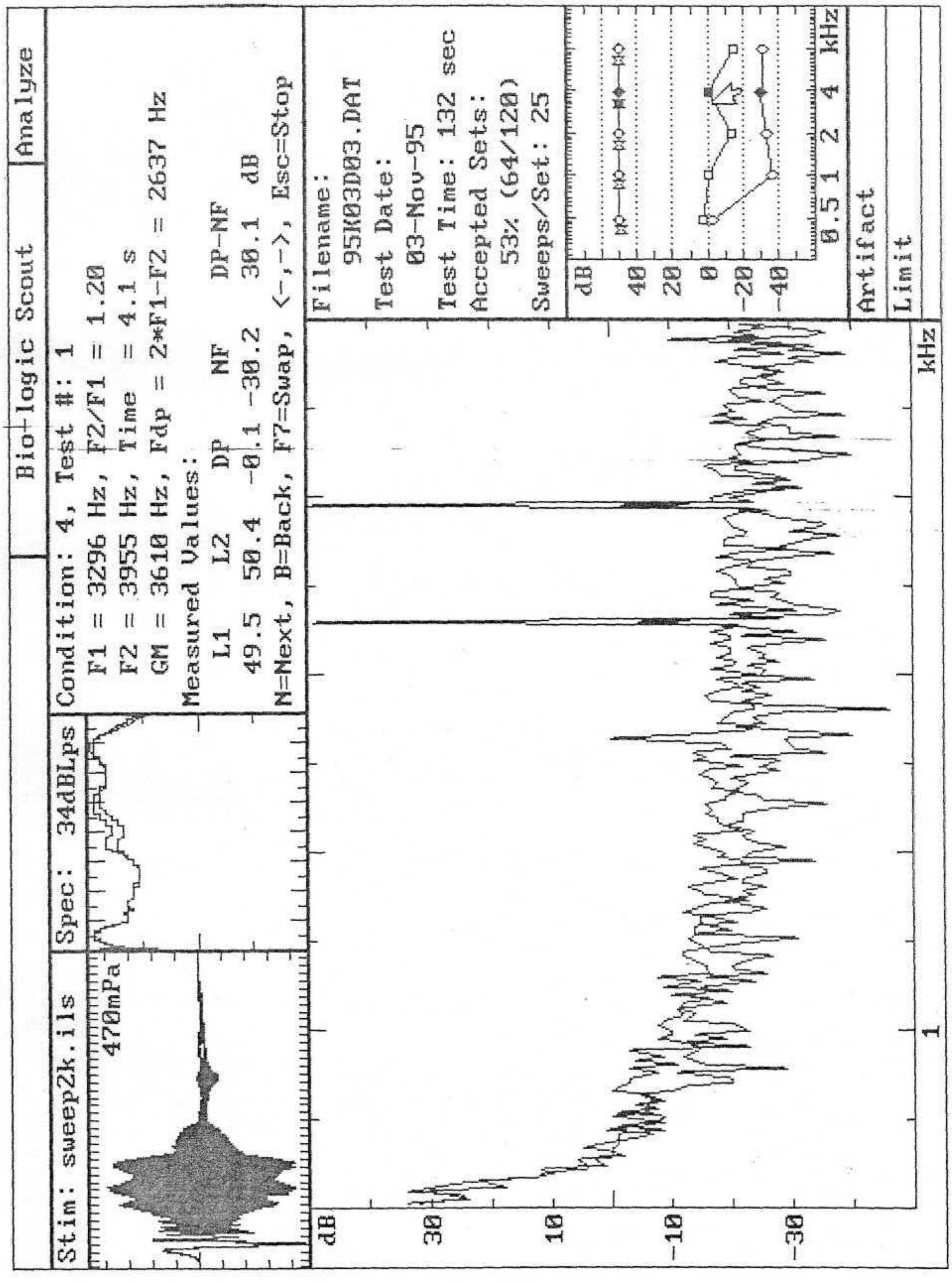

File
Info
Options
Test
Analyze
Bio-logic Scout
Print
Stim: sweep2k.ils
470mPa
Spec: 34dBLps
Name: ,
Ear: L, ID: , DOB:
Comments:
Fdp frequency: 2*F1-F2
Calibration : 95K03D03.CAL
Protocol file: IP2.LST
Filename:
95K03D03.DAT
Test Date:
03-Nov-95
Test Time: 132 sec
Accepted Sets:
53% (64/120)
Sweeps/Set: 25
Artifact
Limit
dB
60
40
20
0
-20
-40
0.5
1
2
4
8
kHz
DP-Gram ⊠ L1 ◇ L2 □ DP ◇ NF
F2 Frequency

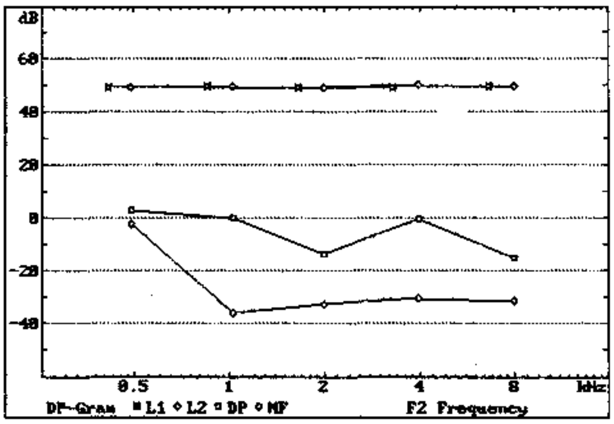
Figure 4


Stim: sweep2k.ils
470mPa
Spec: 34dBLps
Bio-logic Scout
Analyze
Condition: 4, Test #: 1
F1 = 3296 Hz, F2/F1 = 1.20
F2 = 3955 Hz, Time = 4.1 s
GM = 3610 Hz, Fdp = 2*F1-F2 = 2637 Hz
Measured Values:
L1 L2 DP NF DP-NF
49.5 50.4 -0.1 -30.2 30.1 dB
N=Next, B=Back, F7=Swap, <-,->, Esc=Stop
Filename:
95K03D03.DAT
Test Date:
03-Nov-95
Test Time: 132 sec
Accepted Sets:
53% (64/120)
Sweeps/Set: 25
dB
40
20
0
-20
-40
0.5 1 2 4 kHz
Artifact
Limit
dB
30
10
-10
-30
1
kHz

BIO-LOGIC OTOACOUSTIC EMISSIONS (OAE) REPORT

BIO-LOGIC SYSTEMS CORP.
ONE BIO-LOGIC PLAZA
MUNDELEIN, IL 60060
(800)323-8326

Patient: Ear: Left
Birthdate: ID:
Comment:



Testdate: 03-Nov-95 Filename: 95K03D03.PAT

LI (dB)	L2(dB)	Fl(Hz)	F2(Hz)	GM(Hz)	DP (dB)	NJT(4B)	DP-NF(dB)
49 .3	49.4	415	488	450	3 .3	-2.1	' '5.4
49 .6	49.8	855	1025	936	0 .1	-36.1	36.2
49 .4	49.5	1660	2002	1823	-13 .4	-32.7	19.3
49 .5	50.4	3296	3955	3610	-0 .1	-30.2	30.1
49 .6	49.6	6665	8008	7306	-15 .1	-31.2	16.1

Figure 5

RESDLTS AND DISCUSSION

The collected samples were analysed through appropriate statistical techniques, to obtain the normative values, as well as to compare the adults' and the children's DPOAE levels. The results are as follows.

I. Left vs. Right ear DPOAE in adults with a stimulus **of 70 dB** HL

The normative levels of DPOAE in adults with the stimulus level 70 dB HL ($L_1 = L_2 = 70$ dB HL) are -

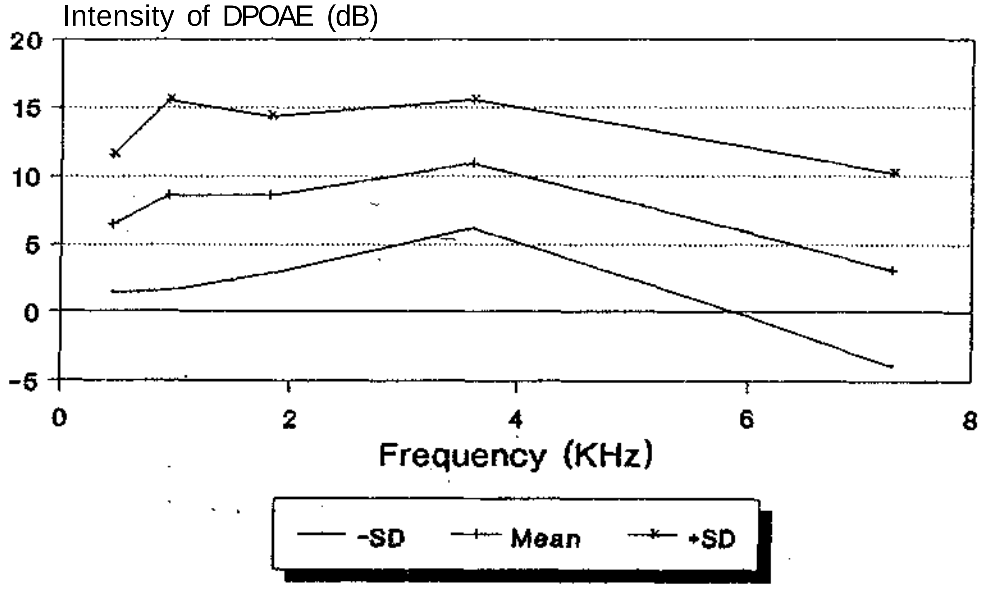
Table 1: Normative levels **of DPOAE in adults with stimulus level at 70 dB HL ($L_1 = L_2 = 70$ dB HL)**

Frequency (Hz)	Left ear Mean (dB)	Left ear SD (dB)	Left ear Range	Right ear Mean (dB)	Right ear SD (dB)	Right ear Range
450	4.25	5.58	-8.3 to 14.6	6.49	5.86	-8.8 to 12.9
936	7.52	6.89	-8.4 to 19.0	8.53	6.96	-5.6 to 19.7
1823	7.00	5.82	-2.5 to 16.4	8.55	5.76	-5.9 to 16.5
3610	9.11	6.47	-9.2 to 20.3	10.56	4.66	-1.2 to 18.8
7306	0.82	9.68	-22.1 to 14.7	3.15	7.00	-11.1 to 13.1

These values have been shown in Figure 6 and 7, for left and right ears respectively.

On comparing the two ears, left and right, using the 't' test, the following results were obtained.

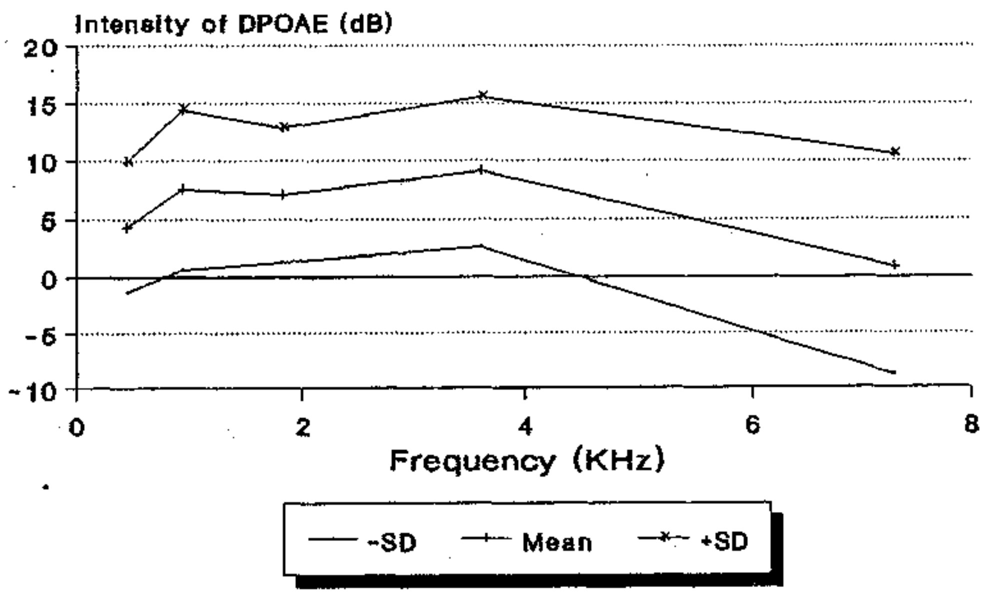
Normatjve data for DPOAE



Right ear, Adults, stimulus at 70 dB

Figure 6

Normative data for DPOAE



Left ear, Adults, stimulus at 70 dB

Figure 7

Table 2:: Comparison of left and right ears DPOAE in adults with stimulus at 70 dB HL ($L_1 = L_2 = 70$ dB HL)

Frequency	t-value
450 Hz	2.58**
936 Hz	1.48ns
1823 Hz	1.42ns
3610 Hz	2.42**
7306 Hz	1.20ns

** - Significant difference at 0.01 level;
ns - Not significant

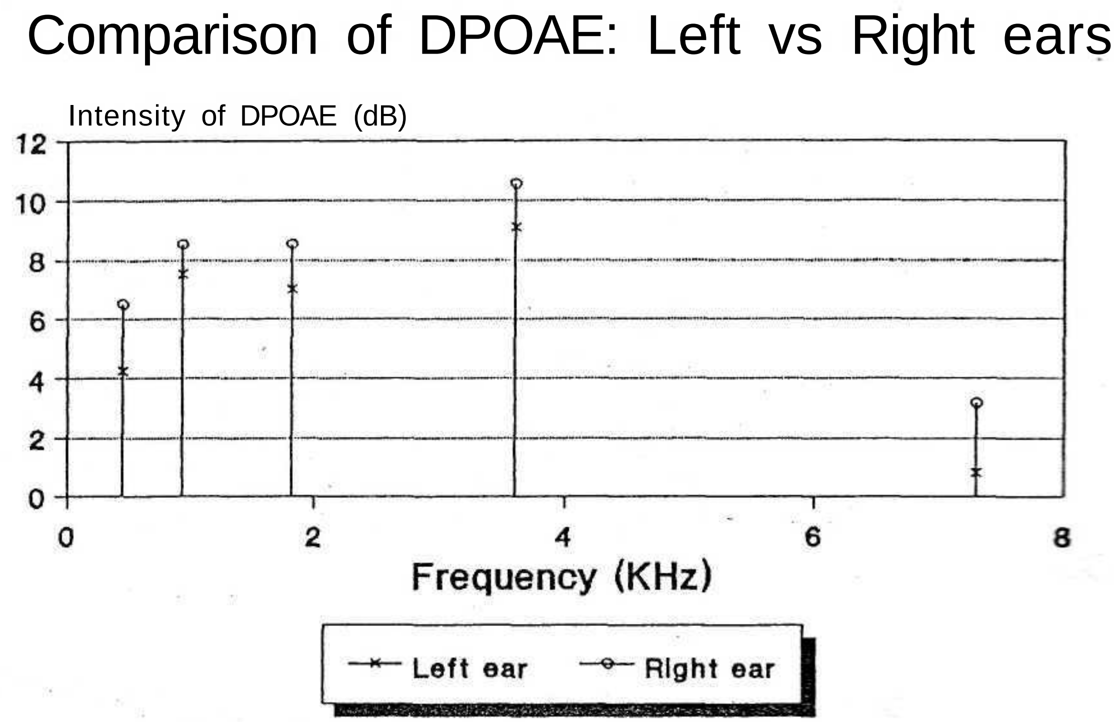
These findings have been shown in Figure 8.

It is seen that the mean level of DPOAE is consistently greater in the right ear, than the left ear. However, the difference was found to be statistically significant only at two frequencies, 450 Hz and 3610 Hz. The left ear has a greater variability than the right in the high frequencies as shown by a greater SD.

II. Left vs. Right ear DPOAE in children with a stimulus of 70 dB HL

The normal values of DPOAE levels in children with the stimulus at 70 dB HL (L1 = L2 = 70 dB HL) were found to be as follows.

Figure_8



Adults, with stimulus at 70 dB

Table 3: Normative values for DPOAE levels in children with stimulus level at 70 dB HL ($L1 = L_2 = 70$ dB HL)

Frequency (Hz)	Left ear Mean (dB)	SD (dB)	Range	Right ear Mean (dB)	SD (dB)	Range
450	5.72	5.54	-3.2 to 16.9	6.37	6.36	-9.9 to 16.4
936	6.99	7.10	-9.6 to 16.9	9.36	5.85	-2.0 to 19.2
1823	6.43	7.10	-13.1 to 16.4	11.45	4.68	-5.0 to 18.0
3610	6.15	7.71	-8.5 to 19.5	10.67	5.49	-0.4 to 18.4
7306	2.65	8.82	-15.6 to 16.6	9.88	5.61	-2.3 to 19.5

These results have been shown in Figures 9 and 10.

On comparing the two ears, left and right, for the DPOAE levels in children the following results were obtained.

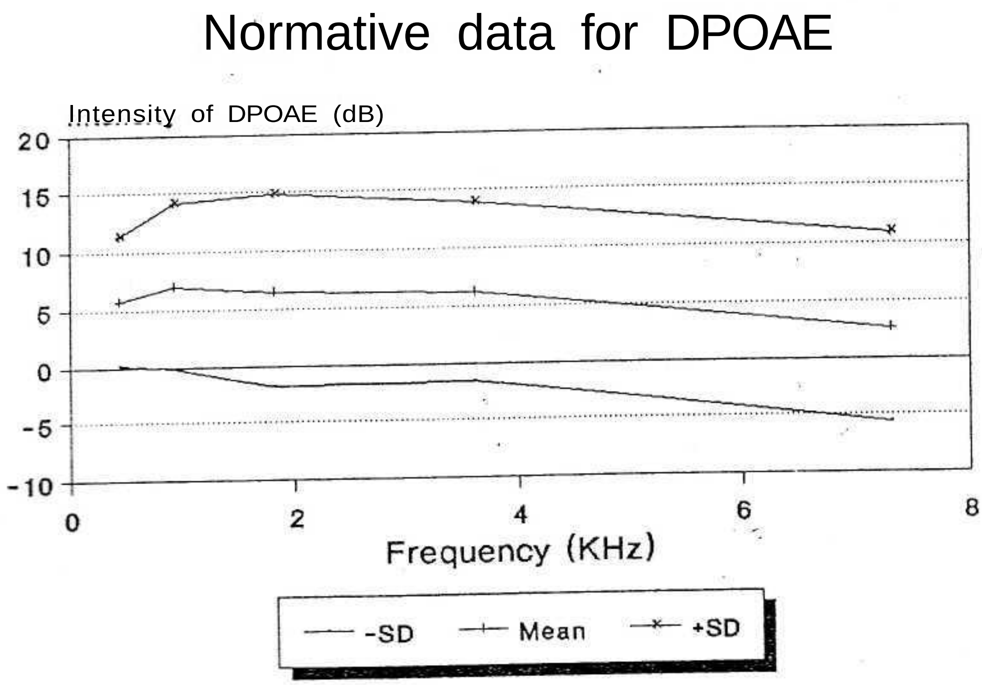
Table 4: Comparison of DPOAE levels in left and right ears in children with stimulus at 70 dB HL ($L_1 = L_2 =$ 70 dB HL)

Frequency	t-value
450 Hz	1.53 ns
936 Hz	2.38**
1823 Hz	1.87*
3610 Hz	2.45**
7306 Hz	2.24**

* - Significant difference at 0.05 level; ** Significant difference at 0.01 level; ns - Not significant

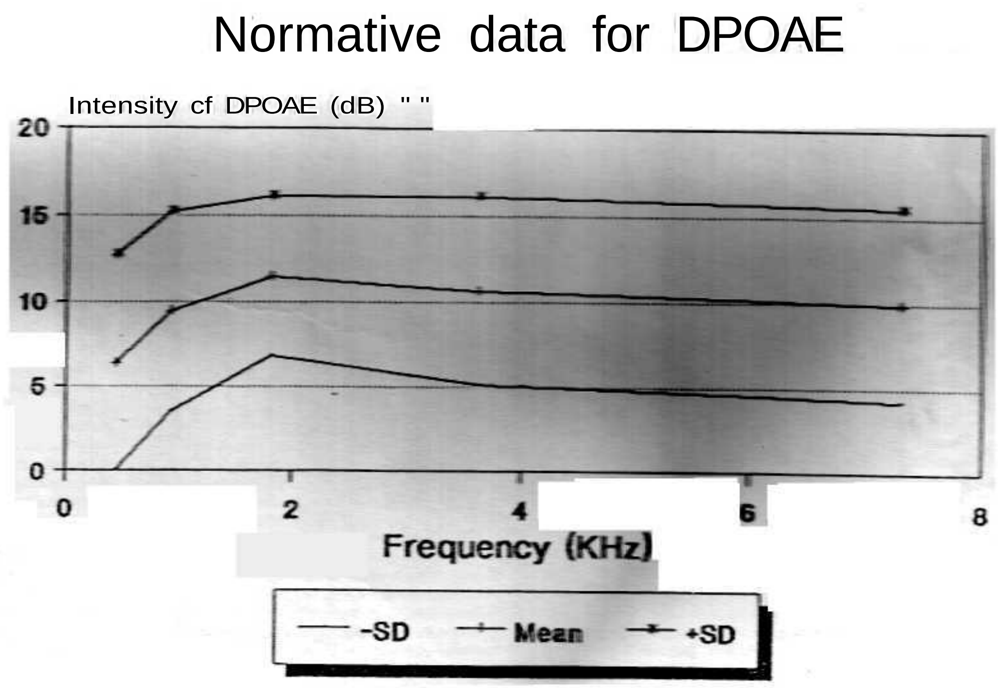
These results are shown in Figure 11.

Figure 9



Celt ear.Children, stimulus at 70 dB

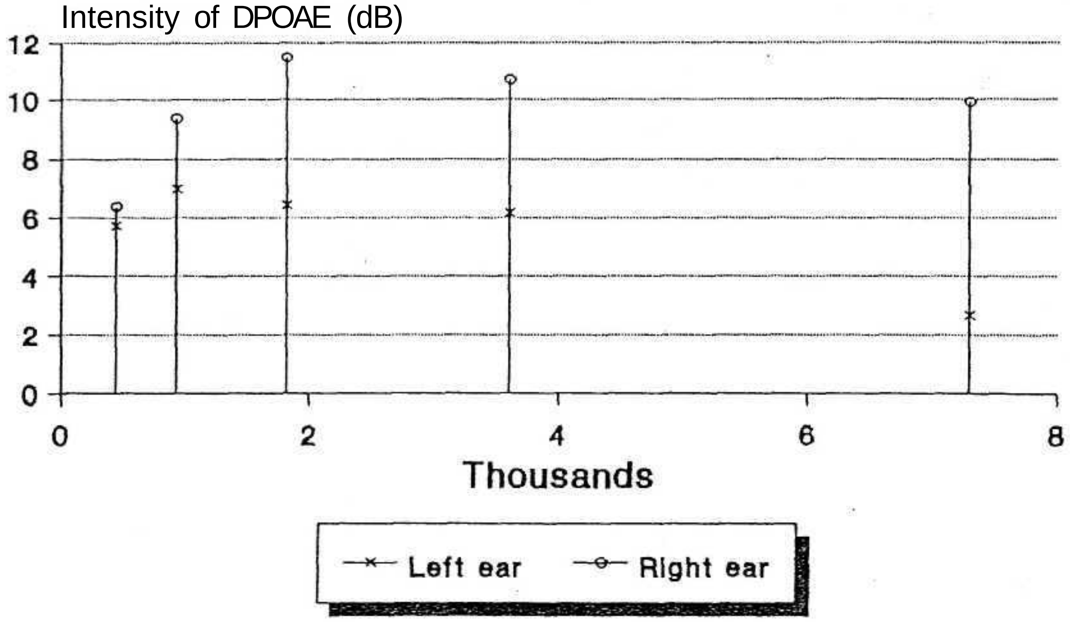
Figure 10



Right ear,Children, stimulus at 70 dB

Figure 11

Comparison of DPOAE: Left vs Right ears



Children, with stimulus at 70 dB

Thus in children too the mean level of DPOAE is greater in the right ear than in the left ear. This difference is statistically significant at all frequencies except at 450 Hz. However, the left ear has a greater variability of DPOAE emissions than the right ear, as indicated by a greater standard deviation except at 450 Hz.

III. Left vs. Right ear DPOAE in adults; stimulus 50 dB HL

The normative range for this stimulus condition was found to be as follows.

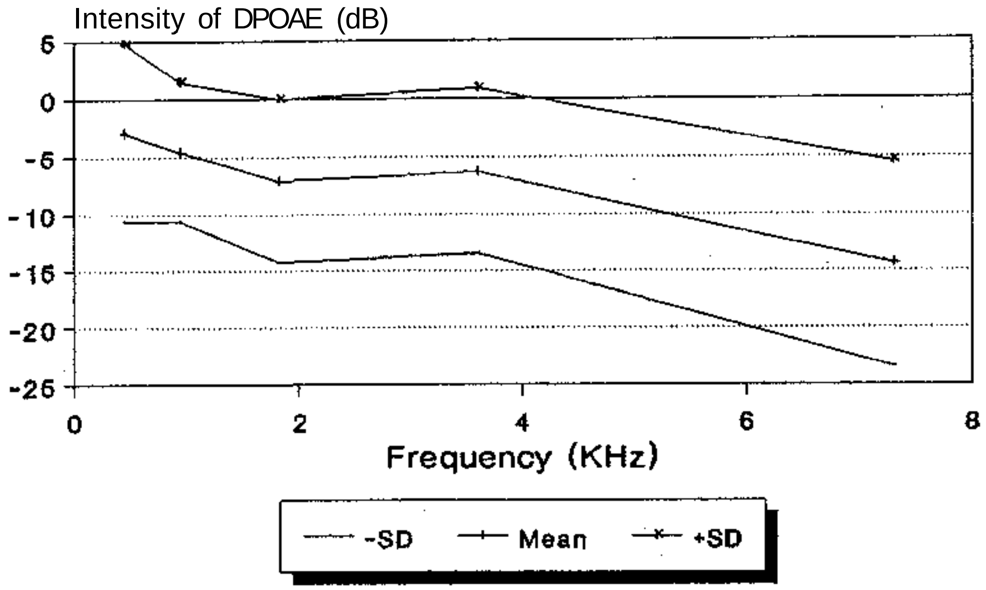
Table 5: Normative values for DPOAE levels in adults with stimulus level at 50 dB HL (L = L = 50 dB HL)

	Left ear			Right ear		
Frequency (Hz)	Mean (dB)	SD (dB)	Range	Mean (dB)	SD (dB)	Range
450	-2.88	7.69	-23.5 to 15.0	-3.67	5.10	-10.4 to 6.3
936	-4.60	5.99	-13.7 to 8.0	-2.95	5.07	-10.0 to 6.9
1823	-7.12	7.13	-21.6 to 7.7	-4.43	6.48	-14.2 to 5.6
3610	-6.36	7.18	-23.9 to 3.9	-4.70	5.33	-13.6 to 4.8
7306	-14.44	9.19	-29.7 to 5.8	-12.57	9.54	-25.4 to 6.6

These results are shown in Figures 12 and 13.

On comparing the two ears, left and right, the following results were obtained.

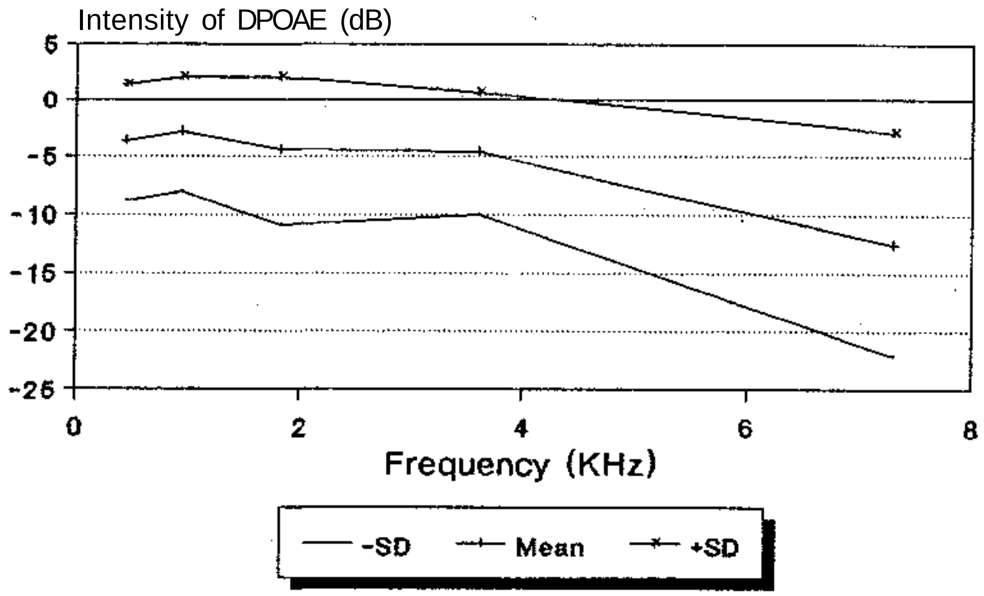
Normative data for DPOAE



Left ear. Adults, stimulus at 50 dB

Figure 12

Normative data for DPOAE



Right ear. Adults, stimulus at SO dB

Figure 13

Table 6: Comparison of DPOAE levels in left and right ears in adults with stimulus at 50 dB HL (L_1 = L_2 = 50 dB HL)

Frequency	t-value
450 Hz	2.99^{**}
936 Hz	0.58^{ns}
1823 Hz	1.50^{ns}
3610 Hz	1.62^{ns}
7306 Hz	0.72^{ns}

** - Significant difference at 0.01 level;
ns - Not significant

These results are shown in Figure 14.

Thus at 50 dB HL stimulus condition also, the right ear has a greater mean DPOAE level in adults, it being significant statistically only at 450 Hz. The left ear has a greater variability than the right, at all frequencies.

IV. Left vs. Right ear DPOAE in children within stimulus of 50 dB HL

The normative values for DPOAE levels in children when the stimulus was at 50 dB HL (L_1 = L_2 = 50 dB HL) are as follows.

Figure 14

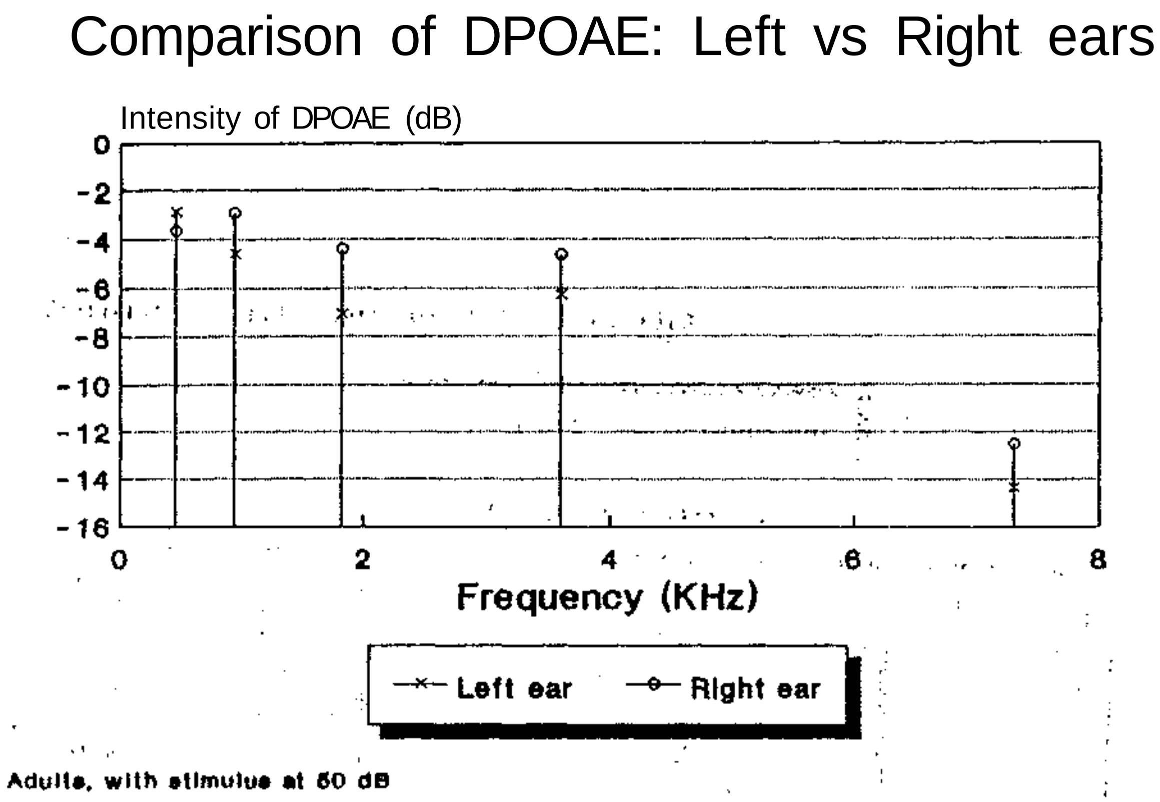

Comparison of DPOAE: Left vs Right ears
Intensity of DPOAE (dB)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
2
4
6
8
Frequency (KHz)
Left ear
Right ear
Adults, with stimulus at 60 dB

Table 7: Mean DPOAE levels in children with stimulus level at 50 dB HL (L1 = L_2 = 50 dB HL)

Frequency (Hz)	Left ear Mean (dB)	Left ear SD (dB)	Left ear Range	Right ear Mean (dB)	Right ear SD (dB)	Right ear Range
450	3.53	6.61	-5.5 to 16.4	-0.51	8.00	-10.7 to 13.8
936	-1.33	5.39	-14.6 to 6.6	-1.03	5.82	-15.5 to 6.5
1823	-3.53	9.71	-29.3 to 17.4	-2.69	6.07	-14.7 to 6.6
3610	-8.58	9.76	-26.9 to 8.7	-6.01	6.33	-17.3 to 5.6
7306	-13.84	10.90	-28.9 to 12.3	-6.40	9.26	-23.3 to 12.3

These results have been shown in Figures 15 and 16.

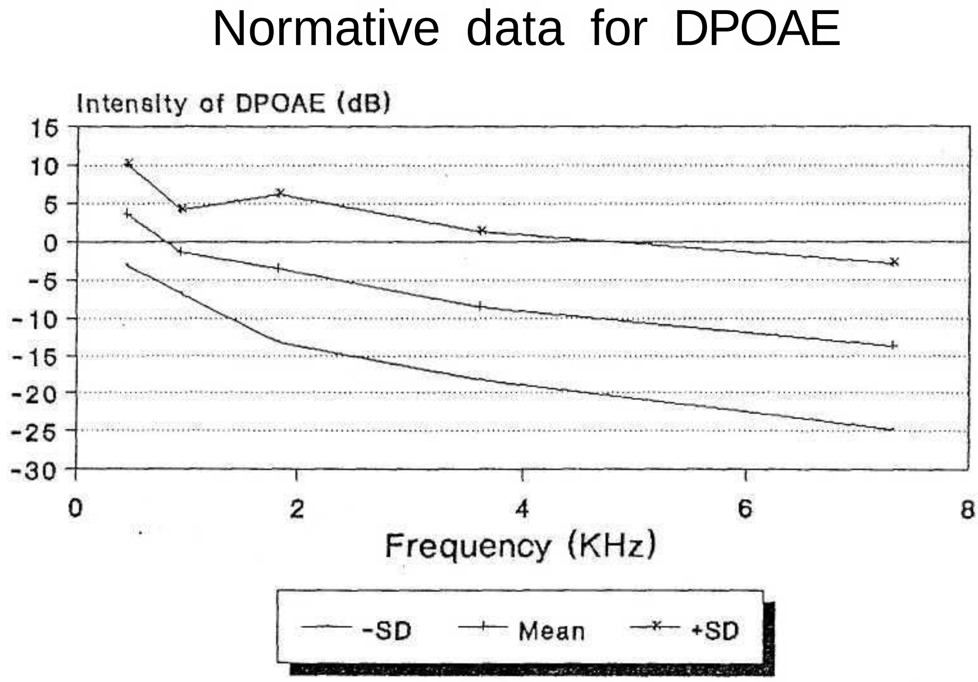
Comparing of mean DPOAE values levels in left and right ears in children with stimulus at 50 dB, the following results were obtained.

Table 8: Comparison of DPOAE levels in left and right ears in children with stimulus at 50 dB HL (L1 = L2 = 50 dB HL)

Frequency	t-value
450 Hz	3.62^{**}
936 Hz	1.46^{ns}
1823 Hz	1.48^{ns}
3610 Hz	0.99^{ns}
7306 Hz	0.76^{ns}

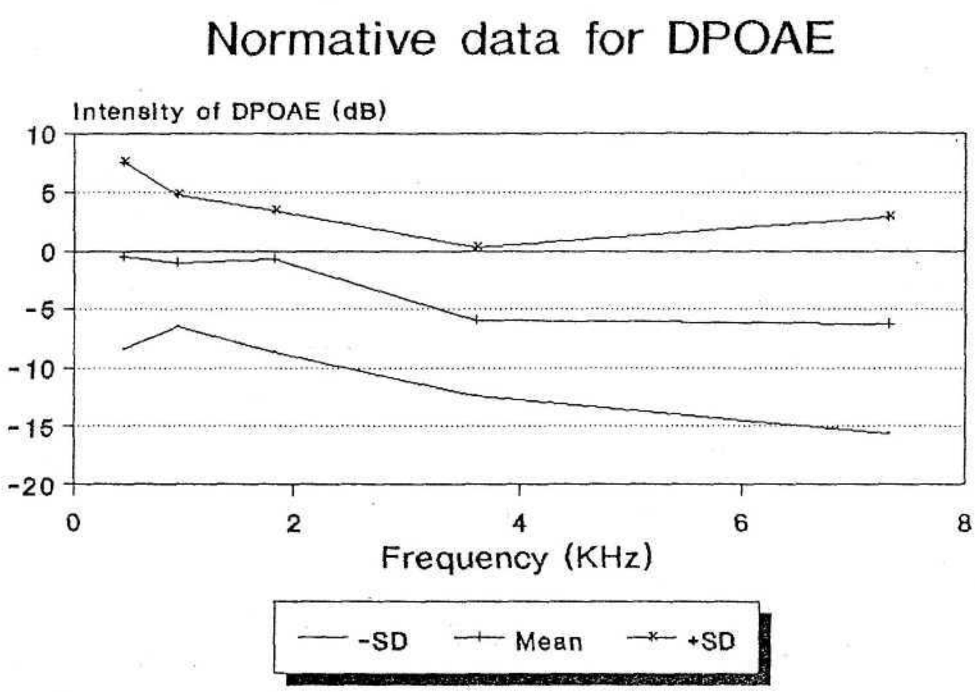
** - Significant difference at 0.01 level;
ns - Not significant

These results are shown in Figure 17.



Left ear,Children, stimulus at 50 dB

Figure 15

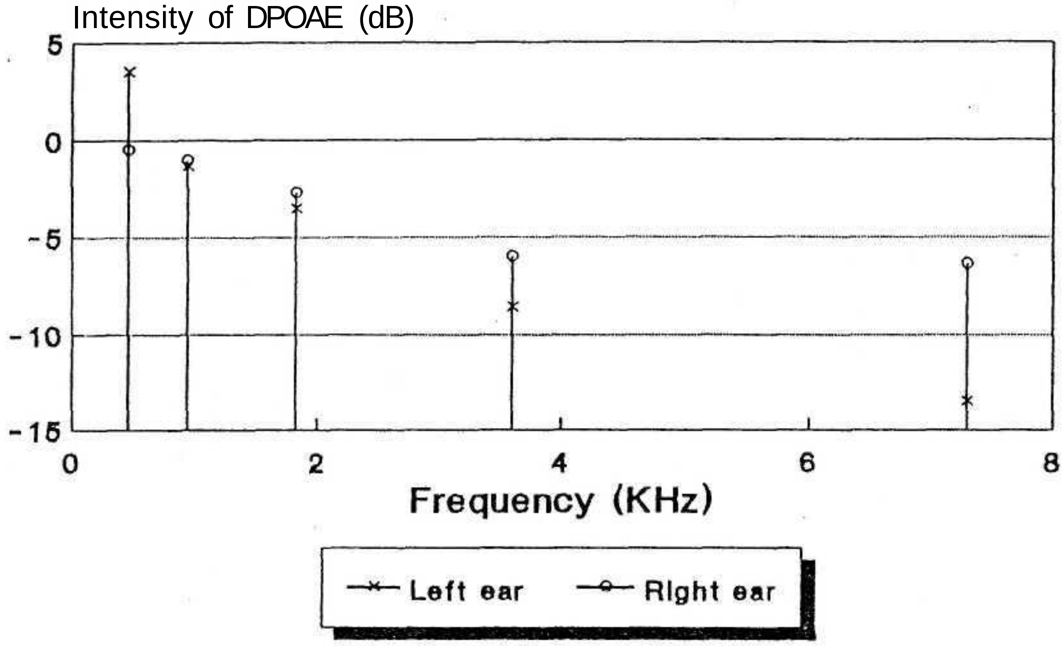


Right ear,Children, stimulus at 50 dB

Figure 16

Figure 17

Comparison of DPOAE: Left vs Right ears



Children, with stimulus at 50 dB

In this stimulus condition in children it is seen that the mean DPOAE level is greater in the right ear, at three frequencies, viz., 1823 Hz, 3610 Hz, 7306 Hz. At 450 Hz and 936 Hz, the emission level is greater in the left ear. However, these differences are not statistically significant, except at 450 Hz. The variability, as indicated by the standard deviation (SD) is greater in left ear for high frequencies (1823 Hz, 3610 Hz, 7306 Hz) and greater in the right ear for low frequencies (450 Hz, 936 Hz).

Thus, it is evident that, in both children and adults, the mean DPOAE levels are greater for the right ear than for the left ears. However, these differences are significant only at 450 Hz in all stimulus conditions (70 dB HL or 50 dB HL). In children, when the stimulus is at 70 dB HL, the difference is significant at all frequencies. It was also observed that a majority of the subjects had a greater DP emission levels in their right ear as compared to their left ear. Also the left ears tend to have a greater variability in the emission levels.

Ear differences for DPOAE have so far not been reported in literature. These need to be further investigated. These may be arising due to either the differences in the middle ear/external ear canal volume between the left and right ears or due to some differences in the contralateral suppression pathway between the left and right ears. However, more research is needed to explain these differences.

The DPOAE at low frequencies especially at 450 Hz were often at intensities equal to or less than the noise levels. Thus, not only does it take a longer time to be measured, its reliability is questionable. This finding is consistant with other such studies (Harris, 1993).

The mean DPOAE levels were found to be higher when the stimulus intensity was 70 dB HL than when it was 50 dB HL. This is true for both children and adults, for left ear as well as for the right ears. Thus, this finding supports the fact that the DPOAE levels increase with stimulus intensity before reaching saturation (Lonsbury Martin, 1990) .

V. Comparison of DPOAE in left ears of adults and children, with stimulus 70 dB HL (L1 = L2 = 70 dB)

The comparison of mean DPOAE levels in children and adults was done using the t-test and the results obtained are shown in Table 18.

in the contralateral suppression pathway between the left and right ears. However, more research is needed to explain these differences.

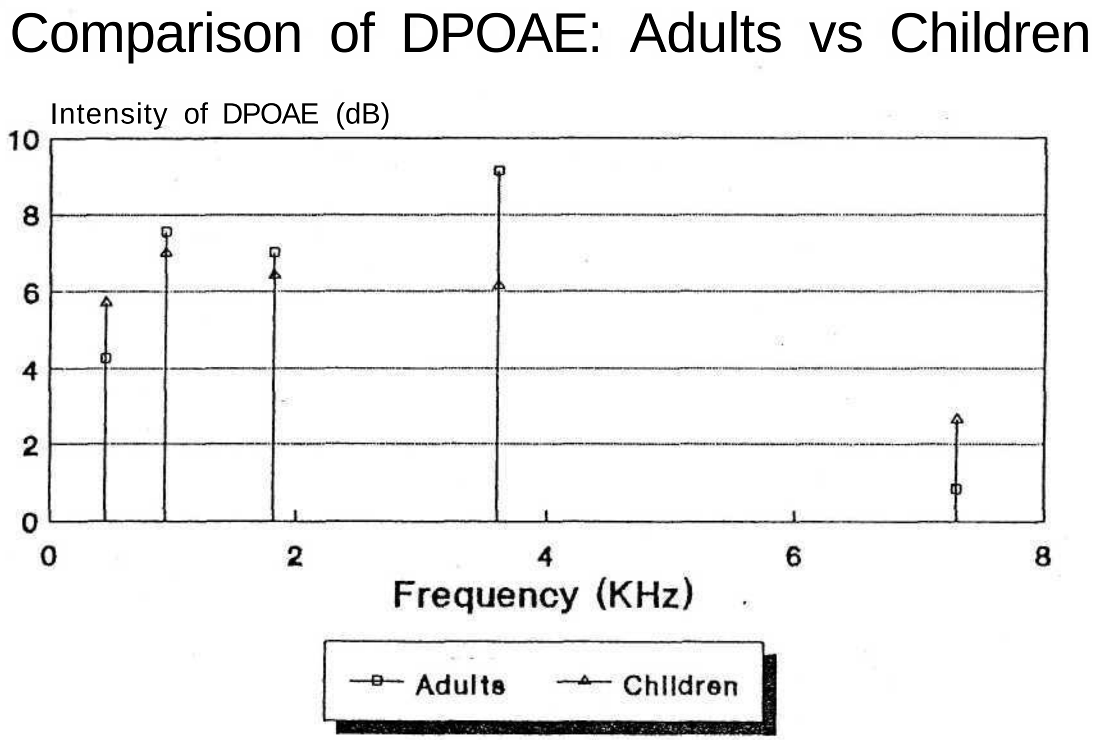
The DPOAE at low frequencies especially at 450 Hz were often at intensities equal to or less than the noise levels. Thus, not only does it take a longer time to be measured, its reliability is questionable. This finding is consistant with other such studies (Harris, 1993).

The mean DPOAE levels were found to be higher when the stimulus intensity was 70 dB HL than when it was 50 dB HL. This is true for both children and adults, for left ear as well as for the right ears. Thus, this finding supports the fact that the DPOAE levels increase with stimulus intensity before reaching saturation (Lonsbury Martin, 1990).

V. Comparison of DPOAE in left ears of adults and children, with stimulus 70 dB HL (L1 = L_2 = 70 dB)

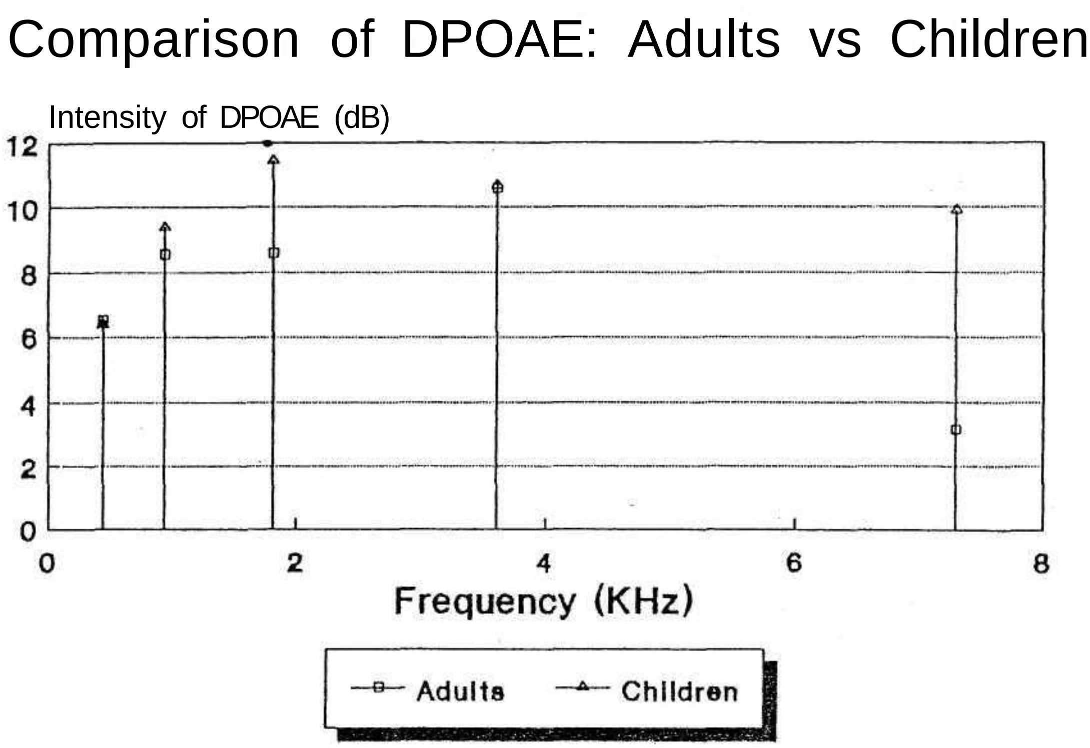
The comparison of mean DPOAE levels in children and adults was done using the t-test and the results obtained are shown in Table 18.

Figure 18



Left ears,with stimulus at 70 dB

Figure 19



Right ears,with stimulus at 70 dB

Thus a significant difference is obtained for the right ear at all the frequencies tested with stimulus at 7 0 dB HL.

VII. Comparison of mean DPOAE levels in left ears of adults and children, with stimulus 50 dB L (L1 = L2 = 50 dB)

The results of the t-test are as follows.

Table 11: Comparison of mean DPOAE levels in left ears of adults and children with stimulus at 50 dB HL ($L1 = L_2 = 50$ dB HL)

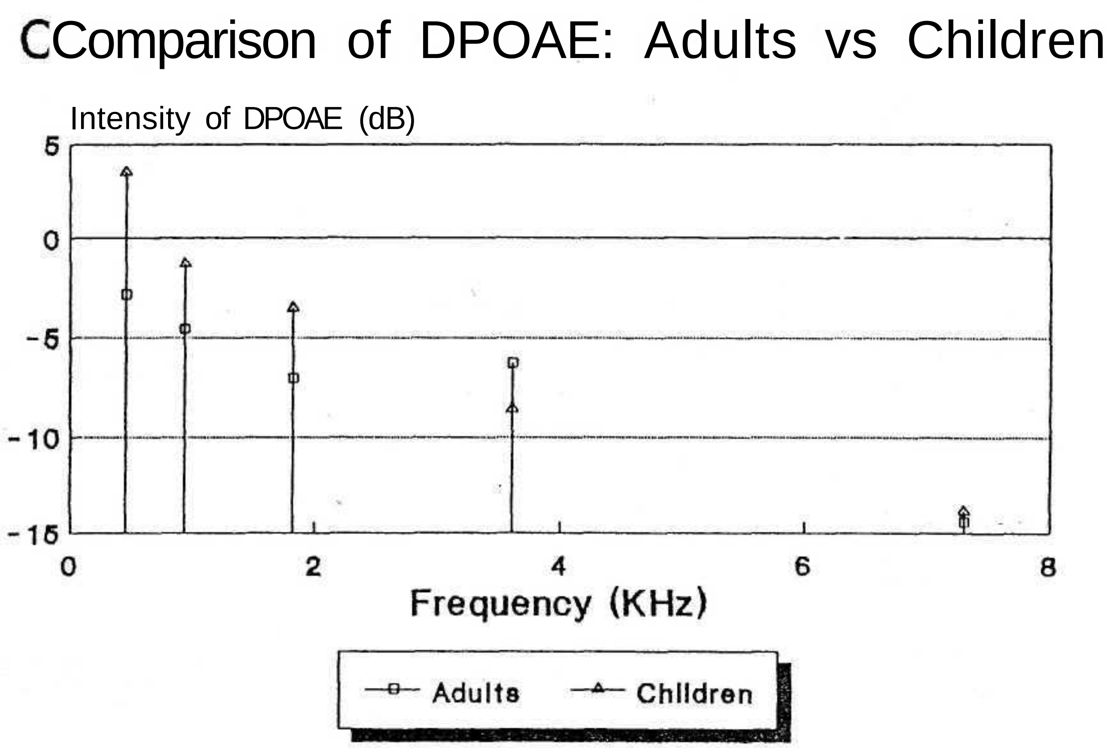
Frequency	t-value
450 Hz	2.44**
936 Hz	2.19**
1823 Hz	1.21^ns
3610 Hz	0^ns
7306 Hz	0.34^DS

** - Significant difference at 0.01 level;
ns - Not significant

These results have been shown in Figure 20.

While the results at the lower frequenceis, viz., 450 Hz and 936 Hz show a significant difference between adults and children, there is no statistically significant difference at the higher frequencies in the left ear with stimulus at 50 dB HL.

Figure 20



Left ears,with stimulus at 50 dB

VIII- Comparison of mean DPOAE levels in right ears of adults and children, with stimulus 50 dB L (L1 = L2 = 50 dB)

The results of the t-test are as follows.

Table 12: Comparison of mean DPOAE levels in right ears of adults and children with stimulus at 50 dB HL (L1 = L2 = 50 dB HL)

Frequency	t-value
450 Hz	1.49^{ns}
936 Hz	2.79**
1823 Hz	1.99*
3610 Hz	0.56^{ns}
7306 Hz	0.68^{ns}

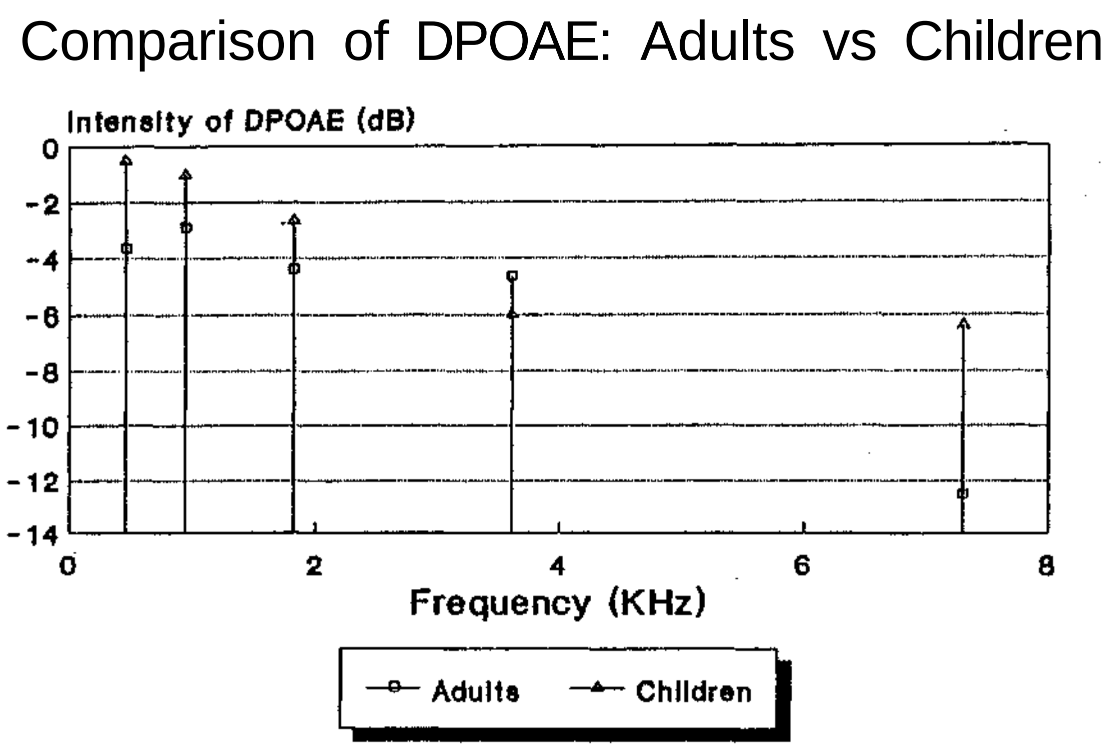
* - Significant difference at 0.05 level; ** - Significant difference at 0.01 level; ns - Not significant

These results are shown in Figure 21.

A statistically significant difference was found only for DPOAE frequencies of 936 Hz and 1823 Hz at 50 dB HL between adults and children in the right ears.

Thus as revealed by the normative values, the children have a greater mean level of DPOAE in all stimulus conditions. However, these differences are statistically significant only for low frequencies in all stimulus conditions. The right ear DPOAE levels however, differ significantly at all frequencies when the stimulus is at 70 dB HL. This further suggests that there may be variables other than the stimulus parameters and age which may affect. the DP emission levels.

Figure 21



Right ears,with stimulus at 50 dB

SUMMARY AND CONCLUSIONS

The study was taken up with an aim of

a. comparing DPOAE levels for fixed stimulus parameters in adults and children.

b. to generate normative data for DPOAE for adults and children using the same parameters.

For this purpose, 30 young adults (age range 17 to 28 years, mean age 20.5 years) and 30 children (age range 2 to 12 years, mean age 7.7 years) were studied for their Distortion Product Otoactoustic Emissions. These emissions were recorded in both, left and right ears, for two sets of stimulus conditions. The obtained results were then used to generate the normative values for DPOAE for different stimulus conditions used. These were also used for the comparison between adults and children using appropriate statistical techniques.

The results of the study indicate that while the children do have a higher mean level of DPOAE, it is significant only for higher intensities. The difference is most in the right ear. The results also indicate an "ear effeet", as the right ear has a greater mean level of DPOAE as compared to the left ear in children as well as in adults. This difference is more for the high intensity

(70 dB HL) stimulus. This finding has not been reported before and needs to be investigated further.

The time taken to complete this test varies from about 90 seconds to 5 minutes. In general, the higher frequencies take a shorter time than the lower frequencies. Thus, it may be recommended that the test protocol be slightly varied so as to start from high frequencies and end at the low frequency. This would enable to get better results, especially in case of infants and young children, who may not be cooperative for testing for longer durations. The reversing of test direction from high frequencies to low frequencies, will ensure that more number of frequencies are tested in the initial few minutes.

The measured values may then be compared to the normative data for the ear and stimulus condition tested, and it may be determined whether the patient has normal cochlear function.

The study also makes possible further research on the DPOAE, since the expected normal values have now been determined. It also gives a few directions for future research on the DPOAE. A few topics for further research in the DPOAE are as follows:

1. Ear effect - a. to look into causes of the ear effect

   b. to determine input-output functin of-the left and right ears for DPOAE .

2. Use of DPOAE for retrocochlear lesion detection, using the principle of contralateral suppression (Collet et al.)
3. Effects of middle ear pathology on the DPOAE

DPOAE measurement is the latest, state of the art technology for clinical audiology. It is the current hot topic for research in audiology around the world. This study, the first one on DPOAE in India, was thus a most important one, since it opens the doors to further research on the topic.

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APPENDIX I

STANDARDS FOR CALIBRATION OF PORE TONE AUDIOMETER

The following standards were used for the caliberation of the audiometer.

Air conduction (ear phones) - ANSI S3-6 1989

Bone conduction (BC vibrator) - ANSI S3-26 1981

The procedure used was as prescribed by the instruction manual of the audiometer, using a Sound Level Meter with Octave filter set, 1 inch condenser microphone, artificial ear (for headphone calibration) and artificial mastoid (for bone conduction vibrator calibration).

APPENDIX II

STANDARDS FOR CALIBRATION OF IMMITTANCE AUDIOMETER

The immitance audiometer used for the study was calibrated using the following standards:

ANSI	S3-7	1973
ANSI	S3-39	1987
ANSI	S3-6	1969
IEC	645	1979
IEC	126	1973

APPENDIX III

AMBIENT NOISE LEVELS IN TEST ROOM

The noise levels in the test room were measured using a Type 1 sound level meter with an octave filter. The measurements were made on the 'C-scale' in the 'slow' mode. The obtained measures were as follows.

Frequency (Hz)	Intensity (dB SPL)			
	0°	90°	180°	270°
125 HZ	24	26	26	24
250 Hz	18	20	20	18
500 Hz	15	14	15	14
1000 Hz	**14**	14	10	10
2000 Hz	**8**	10	10	10
4000 Hz	10	10	10	10
8000 Hz	8	8	8	8
16000 Hz	10	10	10	10
31500 Hz	12	12	12	12

These confirm to the ISO 91 standards.