A STUDY OF INPUT-OUTPUT FUNCTION OF DPOAE IN SUBJECTS WITH SENSORI-NEURAL HEARING LOSS

Reg. No. M9709

Independent Project submitted as a part of fulfillment for the first year M.Sc, (Speech and Hearing) to the University of Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE - 570 006
1998

To

Dr. Shompa Datta

&

Dr. Salil Datta

who introduced me
to the world of
research.....

CERTIFICATE

This is to certify that this Independent Project entitled ***A STUDY OF INPUT-OUTPUT FUNCTION OF DPOAE IN SUBJECTS WITH SENSORI-NEURAL HEARING LOSS*** *is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M9709.*

Dr.(Miss) S. NIKAM
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Mysore
May, 1998

CERTIFICATE

This is to certify that this Independent Project entitled ***A STUDY OF INPUT-OUTPUT FUNCTION OF DPOAE IN SUBJECTS WITH SENSORI-NEURAL HEARING LOSS*** *has been prepared under my supervision and guidance.*

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Mysore
May 1998

DECLARATION

This independent project entitled ***A STUDY OF INPUT-OUTPUT*** *FUNCTION OF DPOAE IN SUBJECTS WITH SENSORI-NEURAL* ***HEARING LOSS*** is the result of my own study under the guidance of **Mrs. C.S. Vanaja,** Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other diploma or degree.

Mysore
May, 1998

Reg. No. M9709

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But your memories help me pull on in life
And **those** will always be there

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TABLE OF CONTENTS

INTRODUCTION

Hearing is one of the most important sensory functions of the body. It is one of the window through which we communicate with the environment, the interaction through which one moves from the level of existence to higher living. Thus it is quite important that this sensory function be preserved with care. But, like any other biological functions, it too is prone to damage. Thus one must consult a medical or audiological personnel for its betterment, and irrespective of the type of intervention, assessment and diagnosis are the initial steps towards it.

Zeroing in on audiological assessment, it can be classified into two types; behavioural and objective, (Carhart, 1946). Behavioural assessment is one in which the subjects' behavioural output to a given auditory cue is considered for diagnosis whereas in an objective evaluation, the subjects'response is tapped at the cellular or neural level; bypassing the behavioural output. Due to the several disadvantages of subjective assessment like tester bias, and intentional response manipulation, there has been a growing need to supplement these tests with as many objective techniques as possible.

Objective evaluation includes immittance measurement introduced by Metz (1946), which opened an avenue of advantages which made the audiologists realize what was it that lacked in behvioural testing. Immittance measurements gave a clear insight of the middle ear functioning without the subject's active participation. Objective assessment probably made its debut with electrocochleography in 1930.Another important landmark in the history of diagnostic audiology was the measurement of auditory evoked potential by

Davis (1939). The most recent development amongst the objective techniques used in auditory evaluation is perhaps the measurement of otoacoustic emission (OAE)'by David Kemp (1978).

Otoacoustic emission, first hinted at by Gold (1948), are known to be microvibrations of the outer hair cells in the cochlea which propogates towards the foot plate of the stapes and is transmitted to the external auditory meatus by the ossicles where in it may be picked up by a high sensitivity microphone (Kemp, 1978; Kemp, Bray, Alexander and Brown, 1986). Otoacoustic emissions may be broadly classified into two types (Norton and Stover, 1994)

(1) Spontaneous or

(2) Evoked OAES

(1) Spontaneous OAEs (SOAEs)

These are continuous narrow band signal seens in approximately 50% of the normal human ears even in the absence of external auditory stimulation.

(2) Evoked OAES (EOAEs)

EOAEs are those emissions which are produced by acoustic stimulation of the cochlear. They are of three types :

(a) Transient evoked OAEs

(b) Distortion product OAEs and

(c) Stimulus frequency OAEs

(a) Transient Evoked OAEs (TEOAEs)

TEOAEs are frequency dispersive responses to a transient acoustic stimulation such as a click or a tone burst which provide information about cochlear integrity over wide frequency regions (Norton and Stover, 1994).

(b) Distortion Product OAEs (DPOAEs)

DPOAEs result from the interaction of two simultaneously presented pure tones which are closely separated in frequency by a prescribed difference, (Davis, 1983).

(c) Stimulus Frequency OAEs (SFOAEs)

SFOAEs reflect the response of outer hair cells to a pure tone input occurring simultaneously with,and at the same frequency of the eliciting stimulus.

Of these, DPOAEs are being delved into, to investigate the possibility of them being included as a part of diagnostic procedure in audiological assessment.

Auditory Brainstem Response (ABR) has already established itself as a proficient diagnostic tool amongst auditory assessment procedures. Thus the question which remains is, how lucrative are the investigations of DPOAE and its clinical application, with already efficient objective measures like auditory evoked potential in hand? This may be answered by the several advantages of DPOAE over ABR. ABR is not specific to cochlear physiology whereas DPOAEs give information solely on the sensory elements of cochlea, and hence to the site of pathologies such as Meniere's disease, sudden sensori-neural hearing loss, noise induced hearing loss etc. ABR does not tap outer hair cell physiology in detail which is one of the major advantages of OAEs and it can detect noise exposure through reduced emission amplitude with frequency specificity which is not possible for ABR (Smurzynski et al. 1990; Kemp et al. 1986; Leonard, et al. 1990). It takes a long time to carryout ABR testing as compared to DPOAE testing procedure. DPOAE is also more stable in comparison to ABR waveforms which may change at the slightest movement. Preparing the patient for ABR testing takes a long time, whereas it is minimal in DPOAE testing. The clause of high impedance is not there for DPOAE testing. Lastly, wave interpretation is highly subjective with respective to the tester with a high value of intra-subject variability, whereas DPOAE interpretation is much less subjective within individual ears over time and across-testers (Rhode, et al. 1993).

With the given advantages of DPOAE as a clinical tool, their application should be wide ranged in diagnostic audiometry, but the lack of a sensitive testing level is a major disadvantage in its use as it tends to enhance testing time. DPOAEs are elicited at various intensity inputs across different frequencies if used for clinical purpose. It thus becomes a long procedure, unless there is concrete data which supplies the clinical cut off value for input intensities correlated with behavioural thresholds. Probst, Harris and Hauser (1993) commented on the relatively higher utility and frequency specificity of DPOAEs compare to TEOAEs. They suggested that DPOAEs can be reliably recorded in the frequency region of 6 to 8 kHz which make it an ideal means to monitor frequency specific cochlear damages such as that induced by cochlear over stimulation.

Several studies have been carried out to correlate DPOAE amplitudes and DPOAE thresholds with pure tone thresholds to find out the presence or absence of DPOAE. Bonfils et al. (1992) reported DPOAE input output functions to be present at two separate portions with change in F2/F1 ratio from 1.8 to 1.26.

(1) Below 60 dB SPL input which shows a saturation with a DPOAE detection threshold at 36 dB SPL. and

(2) Above 66 dB SPL which shows a steep liner portion.

Hauser and Probst (1990a) studied normals and hearing-impaired subjects in terms of DP-NF amplitudes obtained. The findings showed :

(1) 0-37 dB above the noise floor in normals.

(2) 0-23 dB above the noise floor for sensori-neural hearing loss subjects.

Brown et al. (1989) reported that DPOAEs generated at intensities below 60 dB SPL probably have their origin in the outer hair cells but those generated above 60 dB SPL may be an outcome of passive properties of cochlea which implies DPOAEs will not be generated in cochlear pathology cases unless the evolving stimuli is 60 dB SPL or above. In another study Bonfils and Avans (1992) varied stimulus levels from 42 dB SPL to 72 dB SPL in steps of 10 dB from 1 to 8 kHz to record DP emissions. It was found that 72 dB SPL was not very sensitive for audiometric thresholds either below or above 30 dB hearing loss. Though 42 dB SPL was found to be a sensitive value, due to its poor specificity, it too was not the most suitable for differentiating hearing impaired from normals. Thus 52 dB SPL and 62 dB SPL were found to be the most sensitive values for the test and the best results were obtained for 52 dB SPL, stimulus intensity with both high sensitivity and specificity. DPOAEs were absent for hearing loss above 45 dB HL to 50 dB HL. Avans and Bonfils (1993) studied the frequency specificity of human DPOAEs using varying stimulus levels from 42 dB SPL to 72 dB SPL and found frequency specificely to decrease with high intensity primaries. Harris (1990) reported DPOAEs to be absent in ears with greater than 50 dB HL and Suckfull et al. (1996) said that they were absent in ears which had greater than 70 dB HL loss.

Recently, Rakhee (1997) did a study to compare TEOAEs and DPOAEs in sensorineural hearing loss subjects and found that DPOAEs were present in a few ears with severe hearing loss at an eliciting stimulus of 70 dB SPL.

Thus it is to be realized if frequency specificity of the DPOAE testing is to be exercised clinically, sensitive intensity levels for DPOAE input stimulus should be established, which is precisely what the present study is aimed at.

AIMS OF THE STUDY

(1) to find out the stimulus intensity sensitive enough to differentiate the clinical population from normals.

(2) the relationship between DPOAE output and behavioural thresholds at different input intensities.

REVIEW OF LITERATURE

Over 30 years ago Gold (1948) proposed a hypothesis regarding the sharp frequency response of the cochlea which suggested a reverse transduction in the cochlea implying presence of sound waves in the ear canal. This was followed by empirical evidence by Kemp (1978) which turned out to be the first landmark in the history of otoacoustic emissions.

The discovery of otoacoustic emissions (OAEs) turned out to be a scientific breakthrough for both theoretical and practical reasons. The potential clinical importance of OAEs lies in their ability to obtain a non-invasive and focussed examination of the mechanical working of the cochlea.

Using OAE methods, objective information concerning micromechanical activity specific to preneural or sensory elements of the cochlea can be obtained. Majority of the other objective methods available do not measure the responses of the sensory elements independently. Probst, Lonsbury-Martin and Martin (1991) predicted: "It is very likely that, in near future, OAEs will supplement the more standard clinical methods by contributing a new dimension to the audeometric measures of the status of the peripheral auditory system".

Indeed over the past few years innumerable research activities have been carried out to tap the potentials of otoacoustic emissions as an emerging clinical tool. Of the varieties of OAEs that are available, transient evoked OAEs and distortion product OAEs lead the clinical picture due to practical and clinical shortages in the other two. Since evoked OAEs are frequency dispersive responses, it is not possible to correlate them to the frequency specific behavioral thresholds of the ear, so as to improve the clinical or diagnostic value of OAEs. This correlation, on the other hand may be attempted using DPOAEs as they present more frequency specific responses (Probst, Lonsbury - Martin and Martin, 1991).

By definition acoustic distortion products (Kemp, 1979) represent evoked non linear responses because they consist of new frequencies which are absent in the exciting stimuli. They result from the interaction of two simultaneously presented pure tones to produce a range of distortion products.

The presence of distortion in the ear has been known since long (Helmhotz, 1870 ; Bekesy, 1934). According to Helmohotz (1870), distortion was generated from the middle ear. Bekesy (1934) and Wever et al. (1940) explained these distortions as the products of overdriving the mechanical conduction system at excessively high levels. But Zwicker (1955), Plomp (1965), Goldstein (1967) and Wenner (1968) demonstrated the presence of distortions even at moderate levels which posed a serious doubt on the earlier hypothesis by Bekesy (1934) and finally Goldstein (1967) provided the first clear evidence of the inner ear as the source of distortions, Kemp (1979) confermed the presence of DPOAEs in human ears.

Eliation of DPOAEs is a conveniently easy procedure. The stilulies feequencies called Primaries (fl & f2 where fl < f2) are generated from 2 separate signal generator. The signals are electricaly isolated before being acoustically mixed in the ear canal. These signals (primaries) evoke distortion products or emmissions at certain frequencies which may be picked up by a microphone from the ear canal. The ear canal sound pressure is averaged to reduce the noise floor and spectrally analysed for the levels of the primaries and distortion products.

Of all the distortion products emitted the most prominent one is that at the frequency of 2fl-f2 (Norton and Stover, 1994) The amplitude of DPOAES is depended on the levels of the primaries, LI and L2. When LI is kept equilevel to L2, rodents emit DPOAEs 40dB less than the eliciting stimuli, (Brown and Kemp, 1984; Brown 1987) whereas, this difference is found to be around 60dB in humans(Lonsbury-Martin, Harris, Stagner, Hawkins and Martin, 1990).

Clinically the primaries are manipulated in one of the two available methods:

1 The intensity (LI and L2) is kept constant while the frequencies are changed.

This is called a distortion product-gram or simply DP gram, but it is to be realised that it does not have the provision to determine auditory thresholds like the conventional audiograms.

2. The second method is to keep the frequency constant and change the intensity level L1 and L2 at that frequency. This is called any input-output function and it is useful in determining distortion product threshold.

There hasn't been any conclusive studies on the choice best of parameters for clinical evaluations. Various studies have yielded various optimum values. But f 2/rfl is conventionally believed to work optimally at a ratio of 1.22 (Harris, Lonsbury-Martin, Stagner, Coats and Martin, 1989) for high levels of stimulation. But when using lower levels of stimulation the f'2/fl ratio works best at or close to 1.15 (Brown and Norton, 1990).

The relation between L1 and L2 also affects emission level and it is said to be better L1-L2 = 10 dB HL to 15 dB HL (Sun et al. 1996).

Distortion products have been measured most extensively at the 2f1 f2 frequency. This particular emission has some specific properties as put forth by Zwicker (1979, 1980, 1981), Goldstein (1967), Hall (1972), Smoorenberg (1972), Weber and Mellert, (1975), Zurek and Leshowitz (1976) and Homes (1983). These properties can be summarised as follows :

la. The amplitude of DPOAE has a variability of 10 dB HL to 20 dB HL depending on the relative levels of L1 and L2 and the frequencies fl and f2 of the primaries.

b. Small frequency ratio f2/fl elicit combination tones louder than those from a higher frequency ratio.

c. The emission strengths are larger if L1 is 5 dB SPL to 10 dB SPL greater than L2.

2. If using an equilevel stimuli (L1=L2), the DP emmission, stimuli/ growth function is linear with a slope near about to a stimulus level of 60 dB SPL to 70 dB SPL, after which saturation may be observed.

3. If f2/fl ratio is greater 1.25 non monotonous individual loudness growth may be observed.

4. Combination tones in normal hearing subjects are detected mostly in the frequency range of 500 Hz. to 5000 Hz. with heightened incidence between 1000 and 2000 Hz.

Detection thresholds for DPOAES depends almost entirely on the noise floor and the sensitivity of the measuring equipment (Probst, Lonsbuby-Martin and Martin, 1991). According to Lonsbury-Martin and Martin (1990), detection thresholds that were 3 dB SPL above the mouse floor were found at input levels of 35 dB SPL to 45 dB SPL for emissions between 1000 Hz. to 8000 Hz. Whereas much lower thresholds around 5dB SPL have been detected when measuring at near or at strong fixed place emmission frequencies. (Wilson, 1980; Schloth, 1982, Burns et al, 1984, Wier et al 1988). Probst, Martin and Lonsbury-Martin (1991) concluded that techniques which make use of temporal averaging to lower the noise floor before spectral analysis is instituted, also result in thresholds closure to the behavioural values.

FINDINGS IN NORMALS

The lowest DPOAE thresholds of 5 dB SPL, obtained in normals was given by Wilson (1980), Schloth (1982) Burns et al. (1984) and Wier et al. (1988) Wilson (1980) and Scloth (1982) each measured input-output functions for three ears. Wilson (1980) obtained a widely varied function for several f2/fl ratios but Scloth (1982) measured a slope of 1 with equilevel primaries. No clear differences could be made between otoacoustic and psycho - acoustic findings.

Lonsbury-Martin et al. (1990) averaged DPOAE input output growth functions of 44 normal ears. The functions were generally less steep for lower geometric mean frequencies (1 kHz to 2 kHz) with a slope of less than 0.8 whereas higher geometric mean frequencies showed a steeper input-output function around 0.8 to 0.95. But a linear function could not be obtained under the above conditions. This study put forth normal threshold to be 35-45dB SPL for emiissions between 1 to 8kHz.

Bonfils, Avan, Londeko, Trotoux & Narcy (1991) conducted a study to measure distortion products in a clinical setting. 51 normal ears were included in the study, an input-output function was obtained using equilevel primaries which were decreased from 84 to 30dB SPL steps of 6dB-at a 2fl-f2 of 707.5 Hz (which was constant through out th experiment). The f2/fl ratio was varied from 1.08 to 1.38 in steps of .02. Two separate portions of the input-ouput function was obtained, for the portion of f2/fl ranging from 1.8 to 1.26:

1. Below 60 dB sound pressure level a saturated portion of with a DPOAE detection threshold at 36dB SPL and
2. A linear portion above 66dB SPL input, was found. More linear behaviour was obtained at other f2/fl ratios.

FINDINGS in PATHOLOGICAL POPULATION

Abnormal findings of DPOAEs in subjects with sensory-neural hearing loss has been reported since the late 1980's. Kemp (1986) reported DPOAE measurements in three subjects with high frequency hearing loss. He found the emission amplitudes to be significantly smaller than the normal values at frequencies where hearing thresholds were better than 50 dB HL. However, emissions were present in most cases inspite of a mild hearing loss, and that the relationship between hearing loss and frequencies and DPOAE were not always straight forward.

From the beginning of this decade, there has been a surge of studies in this area, trying to find the following:

1. The pattern of DPOAE emissions in the subject with sensori neural hearing loss.
2. The sensitive primary levels at which these patterns can be tapped
3. The correlation between DPOAEs and auditory thresholds in sesori neural hearing loss.

Several investigations have been carried out from then onwards studying either distortion product grams or input/output (or growth) functions of DPOAEs.

A. Distortion Product-grams

DP-grams can be obtained using different levels of primaries. Attempts have been made to check the efficiency of DP grams at different levels in differentiating by impaired subjects from normal subjects.

Gaskil and Brown (1990) reported a close reversal correspondence between distortion products and auditory sensitivity in normals and subjects with hearing loss. 34 subjects out of which 9 had pure tone thresholds above 20 dB HL were considered for the study. They were screened at 1/3 octave intervals from 500 Hz. to 8000 Hz. to give . DP-grams. The f2/fl ratio was kept around 1.225 with stimulus levels of 40 and 65dB SPL. Results showed that when moderate levels of stimulation were used (i.e not exceeding 60 dBSPL) and L1 was 15dB higher than L2, the 2fl/f2 was 35 dB below L2 with the highest levels 20 dB below L2. This indicated low levels of distortion products with high levels of f2 stimulation. Thus with appropriate stimulus parameters, half of the subjects showed a statistically significant correlation across frequency between DPOAE and auditory sensitively at corresponding fl frequency.

Gorga, Neely, Bergman, Kaminski, ., Peters and Jesteadt (1993a) studied distortion product responses from normal hearing and hearing impaired subjects and ROC curves were constructed to estimate the extent to which normal and impaired ears would be correctly identified using these measures. 80 normal hearing subjects with thresholds within 20 dB HL and 100 subjects with sensori neural hearing loss upto 100 dB HL, were involved in the experiment. Three points were measured per octave from 500 to 8000 Hz with a f2/fl rates of 1.2. L1 was 65dB SPL and L2 was 50 dB SPL, DPOAE amplitudes and DPOAE/noise measurements were able to distinguish normal and nearly impaired subjects, at 4000 Hz. and 8000 Hz. and to a lesser extent 2000 Hz. The ability of these measurements to distinguish between groups decreased with frequency and the audiometric criteria used to separate the normal and hearing improved ears. At 500 Hz, the performance was poor, regardless of the audiometric criteria used. The results of this study indicated that under clinical conditions DPOAE measurements can distinguish normals from hearing impaired subjects for higher frequencies once the hearing loss exceeds 20 dB HL.

Gorga et al. (1993b) further compared TEOAEs and DPOAEs in normal hearing and sensori-neural hearing loss subjects which duplicated the earlier findings, in that DPOAEs were able to distinguish the two groups in higher frequencies more successfully than in the lower frequencies. A comparison between TEOAEs and DPOAEs yielded that the efficiency of either, as a clinical tool in separating normals and hearing impaired varied across frequencies.

Ricci et al. (1996) assessed distortion product otoacoustic emissions in cochlear hearing loss where 19 patients (30 ears) with sensori - neural hearing loss (diagnosed through audiometric tonal threshold testing) was selected for study. DPOAEs for seven discrete geometric mean frequencies of 750, 1000, 15000, 2000, 3000, 4000 and 6000 Hz. were examined. The resulting DP-gram indicated the following.

a. At certain frequencies, the overlap between the hearing loss and the reduction in DPOAE amplitude was virtually total.

b. There was a modest correlation between the degree of hearing loss and the decrease in or absence of DPOAEs, although there was a spectrum of inter mediate hearing losses where DPOAEs varied widely from one individual to another.

c. The absence of DPOAE g at 750 Hz restricted them to predict hearing loss for this frequency, as at this frequency there many have been a lack of DP em ission even at normal audiometric threshold.

A recently a study was done by Suckfull, Schneeweis, Dreker and Schorn (1996) correlating auditory thresholds with DP emmissions both TEOAE and DPOAE were measured in 53 subjects (86 ears) with sensori ne-irat hearing loss and 8 subjects (16 ears) with normal hearing. DPOAE measurements were carried out using DP-grams with primaries of intensity level 70dBSPL where L1=L2 and f2/fl = 1.22 from 0.46 to 4kHz. The DP amplitudies generated were correlated with the patients audiometric threshods at 500, 1000, 2000, 3000, 4000 and 6000 Hz. Results of the Pearson's correlation shown a range of r = 0.5 to 0.89 through out the frequencies, which was higher than what was obtained for TEOAEs. The authors concluded that both TEOAE and DPOAE could be used for detecting frequencies with smaller hearing loss when other methods are not applicable.

Kim, Paparello, Jung, Smurzynski and Sun (1996) carried out a study similar to that done by Stover et al., (1996). They took 71 normal ears and 71 ears with sensori-neural hearing loss (auditory thresholds equal to or above 23 dB HL) for this study. The DPOAEs were measured with stimulus levels of two tones equal to 65 dB SPL and a constant f2/fl ratio of 1.2 across geometric mean frequencies ranging from 500 Hz. to 8000 Hz. The main findings from the DP-grams obtained showed that the test of sensori-neural hearing loss by DPOAE at stimulus level L1=L2=65 dB SPL yielded relatively high measures of test performances i.e sensitivity, specificity and predictive efficiencies all were greater than 85% for 4000 and 6000 Hz and 72% and 82% for 1000 and 2000 Hz respectively. The correlation coefficient between pure tone thresholds with DP amplitude ranged from 0.55 to 0.83 across the test programme. The ROC area was 0.90 to 0.94 which indicated a good performance of DPOAE test. They concluded that the conditions of DPOAE test were strongly dependent upon frequency, not only regarding the test performance but also an optimum DPOAE amplitude used for differentiating hearing impaired from normals.

A study comparing the effects of equal and unequal primary levels on DP emissions of sensori-neural hearing loss was carried out by Sun, Kim, Jung and Randolph (1996). They studied the DPOAEs of 44 ears with normal nearly and 45 ears with sensori neural hearing loss on a DP level versus frequency paradigm DP emmissions for input levels L1=L2 = 65 dB SPL and Ll=65/L2=50 dB SPL, was elicited across frequencies ranging from 500 Hz to 8000 Hz with an approximately f2/fl ratio of 1.2. The DP amplitudies obtained correlated with pure tone thresholds revealed coefficients of r=0.49 and 0.87 and r = 0.43 to 0.80 for Ll=65/L2=50 dB SPL and L1=L2=65 dB SPL input levels respectively. The results thus indicated a better correlation with unequal levels of prumaries.

Kim, Jong & Leonard (1997) attempted to increase the speed of DPOAE testing of cochlear function by employing a new multiple tone pair method. A total of 192 normals and hearing impaired (sensori-neural hearing loss) subjects were included in the study DPOAEs, were measured using a multiple pair method. They compared the 2fl-f2 DPOAE obtained using a three pair method with the conventional one pair, in these ears fl and f2 represented two frequencies of each tone pair, where fl was less than f2 and f2/fl was 1.2. Two sets of three pair stimuli was used, fl at 1.5 kHz., 3 kHz. and 6 KHz and f2 at 2 kHz., 4 kHz. and 8kHz.

The one pair stimuli had f2 at each of the six frequencies. The primary tone levels were unequal L1 = 65 dB SPL and L2 - 50 dB SPL. The three pair method correlated strongly with one pair method and were successfully able to distinguish hearing impaired from the normal ears.

A study of both DP-grams and input-output functions was done by Ohlms, Franklin, Harris and Lonsbury-Martin (1990). They studied the influence of sensori neural hearing loss on distortion product otoacoustic emissions. Subjects with sensori-neural hearing loss from various cochlear pathologies were considered for this study. DPOAEs were elicited from 1 to

8kHz at 100 Hz intervals in the form of DP grams where, L1 was kept equal to L2. In addition an input-ouput function was also obtained in 5dB steps at 11 discrete frequencies at one-fourth octave intervals from 1 kHz. to 8 kHz. High correlation coefficients (r=0.52 to 0.87 and r = 0.46 to 0.89 for DP gram and input-ouput function respectively) were obtained for 15 noise induced hearing loss patients. The results thus indicated DPOAEs to be a sensitiive tool for the detection of sensori-neural hearing loss. The investigators concluded.

1. DPOAEs could detect mild hearing loss
2. They were sensitive to dynamic changes in the cochlea
3. They could monitor progressive impairment
4. They could be related systematically to the magnitude of sensori-neural hearing loss.

Another study using both the paradigms was done by Speckter, Leonard, Kim, Jung and Smurzynski (1991), who compared the DPOAE and TEOAES of between normal and hearing impaired children and normal adults. 13 normal children, 11 children with sensori-neural hearing loss and 7 normal adults were included in the study. The f2/fl ratio was approximately 1.2. The primary level was kept . constant,. 65dB SPL for the DP-gram, whereas it was varied from 80dB SPL to 35 dB SPL in 5dB steps for the input output paradigm. Testing was carried out from frequencies 500 Hz. to 8000 Hz. Results showed a close correlation between DPOAEs and pure tone audiograms of the children, especially in the high frequency region. Minimal frequency hearing loss was successfully detected in 7 out of the 11 hearing impaired children. 4 of the which showed normal DPOAE at high frequency region may have had retrocochlear pathology. The normal DP emissions from input-output functions of the adult ears were 5 dB SPL less than the childrens DP emission across all stimulation levels.

B. Input-output / growth functions.

Investigations have compared the amplitude of DPOAE, slope of input output functions and DPOAE detection threshold in subject with sensori-neural hearing loss and normal hearing.

Kimberly and Nelson (1989) correlated DPOAE emission with auditory thresholds. They took 21 subjects. 11 with thresholds below 25 dB SPL and the remaining 2 with pure sensori-neural hearing loss, in seven frequency regions from 700 Hz. to 6000 Hz. They carried out an input-output function of DPOAE over a stimulus range of 30 dB SPL to dB SPL in 6 dB steps for all seven frequency regions (at geometric means of 707, 1000, 1414, 2000, 2828, 40000 and 5656 Hz respectively). The results showed a correlation coefficient of 0.86 from a linear relation between auditory sensitivity and distortion product emission which suggested that distortion product emission measurement can predict frequency specific auditory thresholds within 10 dB over a range of sensory thresholds from 0 to 60 dB SPL. This study has been claimed to be a pi oneer in such precise correlation of auditory sensitivity and distortion product emissions.

This was followed by another study by Lonsbury - Martin and Martin (1990) and Ohms et al (1990) who tested several patients with SN hearing loss having various pathological conditions like noise induced hearing loss, sudden hearing loss, Meniere's disease etc. and found out their input-output functions. They showed that acoustic distortion products objectively detected a 20 dB noise induced hearing loss in an individual and a 10 dB improvement in the hearing of another subject with Meniere's disease who had undergone a glycerol testing. The usefulnes of DPOAEs in tracking the boundary between normal and abnormal hearing in more severe cases of noise induced hearing loss and those of hereditary hearing loss were also investigated by (Lonsbury-Martin and Martin, 1990 and Ohlms et al. 1990).

Similar results were reported by Harris (1990) in 20 subjects with high frequency hearing loss. The results of the input-output functions carried out showed reduced emissions in frequencies which had hearing loss. DPOAEs were stimulated with two pure tones whose geometric means approximated the frequencies tested for the behavioral thresholds from 750 Hz. to 8000 Hz. -f 2/f 1 was constant at 1.21.

Amongst other studies in the same year, Smurzynski et al. (1990) studied a possible correlation between DPOAE characteristics and hearing impairment. Both normal and sensori-neural loss subjects were considered and the input-output functions obtained showed that all normal ears produced detectable emissions with primary tones, whereas hearing impaired ears produced substantially reduced DPOAEs as compared with normals. These regions of low emissions corresponded to the frequency regions of hearing loss.

A study similar to Gorga et al. (1993b) was done by Harris and Probst (1991) who compared TEOAE and DPOAE with pure tone audiograms. Normative data was established in 40 normal ears. 31 ears with Meniere's disease were taken up for this study. L1 was 6 dB higher than L2. The primaries ranged from 750 Hz. to 6000 Hz. at seven geometric mean frequencies. An input-output function was generated for each frequency wherein the stimuli level of L1 was decreased from 70 dB SPL to 25 dB SPL or until the 2fl-f2 was less than 3 dB SPL above the noise floor. (The result showed consistent correspondence with audiometric contour. For example, in one subject,who had a 6 kHz dip, showed a corresponding reduction in 6 kHz. emission.They concluded that the threshold of DPOAE may be more useful diagnostically in predicting hearing levels by frequency than absolute amplitude of responses at specific levels of stimulations.

Bonfils and Avan (1992) made an attempt to establish clinically useful values of stimulus levels in DPOAE testing. They took 2 groups, 25 normal subjects in the age range of 7 years to 42 years and 50 subjects with sensori-neural hearing loss between the ages of 23 years to 70 years. Equilevel stimuli were used from 707 Hz. to 5575 Hz. with a fixed f2/fl ratio of 1.23. An input-output function was obtained by decreasing the stimuli level from 72 dB SPL to 42 dB SPL in steps of 10 dB SPL across all the geometric mean frequencies. Results showed, 72 dB SPL stimulus levels did not prove to be a sensitive value to separate subjects with hearing level above and below 30 dB HL. 42 dB SPL served as a sensitive value but the specificity of the test decreased on using this as the clinical value. Thus, 52 dB SPL and 62 dB SPL were the optimum values of stimuli levels in differentiating normal and subject with hearing loss (with threshold above 30 dB HL) with a sensitivity of 93-100% and a specificity of 63-95%.

Avan and Bonfils (1993) did another study on the same lines to find out the frequency specificity of human DPOAES. 25 normal ears and 50 ears with cochlear damage were taken up in the experiment. Equilevel stimulus intensities were used at geometric means of 1, 1.5, 2, 4, 6 and 8kHz with a fixed f2/fl ratio of 1.22. The stimuli levels were decreased from 72 dB SPL to 42 dB SPL in steps of 10 dB SPL. Results showed partial correlation between DPOAE amplitude and auditory thresholds (which were assessed from 0.25 kHz. to 8 kHz. in mid octaves). The amplitude of DPOAES evoked by low intensity primary tones less than equal to 62 dB SPL were strongly correlated with auditory threshold at their mean frequencies and DPOAEs disappeared for local hearing losses larger than than 30 dB HL. When elicited by higher intensities of primary tones, (72 dB SPL) DPOAEs exhibited a more complex behaviour and their sensitivity to detect hearing loss was decreased.

Nelson and Kimberly (1992) who related DPOAE with auditory sensitivity in both normal hearing and cochlear hearing loss subjects 32 normal ears and 21 ears with cochlear hearing loss were considered for this study seven frequency regions from 707 to 5656 Hz were tested, results showed single segment monotonic input-output functions with low and moderate level stumuli. There was a moderate positive correlation (i.e r = 0.5 to 0.81) between DP growth functions and auditory thresholds. (DPOAE thresholds proved to have 79% sensitivity in predicting auditory sensitivity

Probst and Harris (1993) carried out another study where they compared TEOAEs and DPOAEs obtained from normal and hearing impaired human ears. They took 21 normals and 62 subjects with sensori-neural hearing loss.

The DPOAEs were tested at seven discrete frequencies (geometric means of 0.75, 1, 1.5, 2, 3, 4 and 6 kHz respectively) with L1 = 6 dBs greater than L1. The f2/fl ratio was fixed at 1.22. The input-output functions were plotted varying L1 from 70 dB SPL to 20 dB SPL for each of the seven frequencies tested. DPOAE emissions (amplitudes) showed a high correlation with audiometric thresholds (Spearman's r = -0.84) and were found to be present more often than TEOAEs when hearing loss across frequencies were greater than 30 dB HL, but only with stimulus levels above 60 dB SPL.

A similar study was carried out by Kimberly, Hernardi, Lee and Brown (1994) who assessed the predictaility of pure tone thresholds using DPOAEs. 181 subjects with normal hearing and 133 subjects with sensori-neural hearing loss in the age range of 15 years to 89 years were taken up for the study. Half of the data set (115 ears) was used by a discriminant analysis routine to classify DPOAE into either the normal or hearing impaired (above 30 dB HL auditory threshold) group. Frequency specific accuracy valued from 71% (correct classification of hearing impaired) to 92% (correct classification of normals) at 705 Hz. The DPOAE amplitude obtained from the input-output function associated with for primary of moderate level (50 dB 5PL) and a geometric mean frequency of 1025 Hz. was most predictive.

Stover, Gorga, Neely and Montoya (1996) attempted optimizing the clinical utility of distrotion product otoacoustic emission measurement. It examined the effect of primary stimulus level on the ability of distortion product emission measurement. A total of 210 subjects were included in the age range of 7 years to 86 years where 103 were normal and 107 were suffering from sensori-neural hearing loss. Nine f2 frequencies were listed in half octave steps from 500 Hz. to 8000 Hz. with f2/fl ratio of 1.2. L1 was 10 dB greater than L2, wherein, L1 was varied from 65 dB SPL to 10 dB SPL in steps of 5 dB SPL to obtain an input-output function. The results confirmed that high level stimulation might underpredict hearing loss. The moderate level stimuli L2 = 60 dB SPL or L2 = 50 dB SPL were recommended to be optimal in sensitivity of detecting hearing loss.

A study specifically on ototoxic hearing loss was done by Mochekan & Dellg (1997) who compared distortion product emission generation between a patient group receiving frequent gentamycin therapy and control subjects. 15 young cystic fibrosis patients (9 years to 18 years) had their audiometric thresholds and distortion product emissions measured along with 36 age matched normals. Distortion product OAEs were obtained for f2 = 2, 4 and 6kHz, f2/fl was kept constant, at 1.22 while the stimulates range increased from 35-70 dB SPL in 1.5dB increaments. The resulting input-output function showed that though 4 out of 15 patients showed normal (< 10 dB HL) a significantly elevated stimuli level was required to generate their DP emission at 4 kHz. This indicated the sensitivity of DPOAE over pure tone audiometry as a clinical tool in predicting the earliest form of cochlear damage.

On the basis of all the studies reported above, it may be inferred that distortion product emissions are sensitive in distinguishing normals from the sensori-neural hearing impaired. The following conclusions may be drawn from the results of the above studies:

1. DPOAE testing is more sensitive in higher frequencies (i.e 2000 Hz., 4000 Hz., 6000 Hz., 8000 Hz)

2. DPOAE testing is more reliable for moderate stumulus levels (i.e 50 dB SPL to 60 dB SPL)
3. DPOAE amplitudes correlate moderately well with behavioural thresholds especially in higher geometric mean frequencies.

The present study was carried out to compare the efficiency of DPOAE amplitude and DP-NF amplitude at various intensities and DP detection threshold in predicting hearing loss.

METHODOLOGY

This study was aimed at comparing the Distortion Product Otoacoustic Emissions in subjects with normal hearing and those with sensori-neural hearing loss. The emission strengths were taken as a function of decreasing intensities of input stimuli. Finally, an attempt was made to correlate the obtained emissions of subjects with sensori-neural hearing loss to their behavioural output.

A. SUBJECTS

Two groups of subjects were taken up -

1. Normal hearing
2. Sensori-neural hearing loss

Criteria considered for each group were as follows :

1. Normal hearing

Subjects in the age range of eighteen years to fifty years were taken up for the study. The total number of ears tested was 20.

All the subjects were required to have

(1) Auditory thresholds within 15 dB HL at all octave frequencies (Goodman, 1965) from 250 to 8000 Hz.

(2) No history of neurological or otological problems.

2. Sensori-neural hearing loss

Subjects in the age range of eighteen years to fifty years considered for the study. Number of subjects taken was 7 and number of ears tested was 11.

All the subjects were required to have -

(1) a sensori-neural hearing loss with a pure tone average of 16 dB HL to 55 dB HL at octave frequencies of 500 Hz., 1000 Hz. and 2000 Hz.

(2) No history of neurological problems

B. INSTRUMENTATION

(a) Pure tone audiometer

A double channeled diagnostic audiometer OB-822 with a TDH-39 earphone housed in MX-41/AR cushions and radio ear B-71 bone vibrator was used to carry out all the pure tone testing required for differential diagnosis. The instruments were calibrated prior to this study.

(b) Immittance Meter

A calibrated middle ear analyser GSI-33 version-2 was used to test the middle ear condition of all the subjects.

(c) Otoacoustic Emission Analyser

An Otoacoustic Emission Analyser, Biologic Scoutplus Otoacoustic Averager, Version 1.21 was used to measure the DPOAEs obtained. The various parameters used were as follows:

Intensity Level (L1 and L2)

A decreasing sweep starting from 70 dB SPL was used, wherein the intensity dropped in steps of 10 dB SPL till no emission could be obtained for 2 consecutive intensities. L1 was kept equal to L2.

Frequency (Fl and F2)

Testing was carried out using tones of 4 sets of frequencies, Fl and F2 such that the ratio between Fl and F2 remained constant at 1.22. The geometric means of the frequencies were around 1000 Hz., 2000 Hz., 4000 Hz., and 8000 Hz.

The frequencies chosen for testing were as shown in the table IIIa :

TABLE IIIa : TEST FREQUENCIES

Fl (H) Primary	F2 (Hz) Primary	Fo (Hz) Geo-metrical mean	2F1-F2 (Hz) DP frequency
6665	8008	7306	5322
3345	4004	3660	2686
1660	2002	1823	1318
830	1001	659	912

Signal-to-Noise-Ratio

A S/N ratio >/+3 dB was chosen to be the criteria for an emission. If the S/N ratio fell below +3 dB for two consecutive levels, the averaging was stopped at that intensity.

Acceptance Sweep

The limit for acceptance sweep was 64 stimuli. If the S/N ratio was not fulfilled, the testing continued till 64 stimuli were accepted.

C. TEST ENVIRONMENT

All testing was carried out in a sound treated room with optimum lighting and temperature. The ambient noise level was kept low. The subjects were made comfortable in a chair during the testing session.

D. TEST PROCEDURE

(a) Case History

A case history was obtained for every subject. It was made sure that no subject with history revealing neurological problems were accepted under either group and none with the history of otological problem was accepted in the group with normal hearing.

(b) Pure Tone Testing

This was done for every subject and thresholds were obtained at all the octave frequencies from 250 Hz. to 8000 Hz. for both air-conduction and bone-conduction, using modified Hughson-Westlake procedure (Carhart and Jerger, 1959).

(c) Immittance Testing

Tympanometry and acoustic reflexometry was carried out for subjects with hearing loss to assess middle ear condition.

(d) Special Testing

This was carried out when required to differentially diagnose between cochlear and retrocochlear pathology. Tests such as Suprathreshold Adaptation Test. Tone Decay Test, Reflex Decay Tests and/or Brainstem Response were done as and when necessary.

(e) Distortion Product Otoacoustic Emission Measurement

1. Preparation of the Subject

A suitable probe tip was selected and fitted on to the probe. This was inserted into the subjects ear canal of the test ear. He was instructed to sit back and relax and minimize his body movements as much as possible.

2. Check fit

This is a procedure to check adequate fitting of the probe into the ear canal. This was carried out, automatically by the instrument. A transient stimulus was presented whereupon successive waveforms appeared on the screen. If the waveforms overlapped, it ensured a good probe fit.

3. Stimulus Calibration

On obtaining a good probe fit, the primaries were calibrated. Two transient stimuli were presented consecutively and if then the corresponding waveforms (red and blue respectively) overlapped adequately, the stimuli were considered calibrated.

4. Emission Measurement

The subject was presented with two pure tone stimuli at 70 dB SPL at the outset. Their intensities L1 and L2 respectively were swept from 70 dB SPL in steps of 10 dB till the intensity where no emission was obtained.

The instrument plotted an input-output function for each set of primaries (Fl and F2). The test was aborted at each intensity if -

(1) the S/N ratio met/exceeded +3 dB SPL during average, or

(2) 64 stimuli were accepted.

If the S/N ratio for an input level fell below + 3 dB SPL; the test was terminated at that frequency.

RESULTS AND DISCUSSION

This study was taken up to investigate the following:

1. The input intensity level which would separate the normal from the clinical population.
2. The correlation between behavioural audiometry and distortion product otoacoustic measurements.

The values obtained from the input output functions of normal and sensori-neural hearing loss subjects (Fig. IVa and IVb) were analysed using various statistical procedures.

A. Distortion product detection thresholds

1. Normals

The DPOAE detection thresholds for 20 normal ears were elicited for geometric mean frequencies of approximately 1000 Hz., 2000 Hz., 4000 Hz. and 8000 Hz. The mean values, standard deviations and ranges for the detection thresholds obtained were as given in Table IVa.

TABLE IVa: DP DETECTION THRESHOLDS IN NORMALS :

FREQENCY(Hz)	MEAN(dBSPL)	SD(dBSPL)	RANGE(dBSPL)
1000	23.00	11.74	10-50
2000	20.50	11.46	10-50
4000	22.50	14.46	10-50
8000	30.00	13.76	10-50

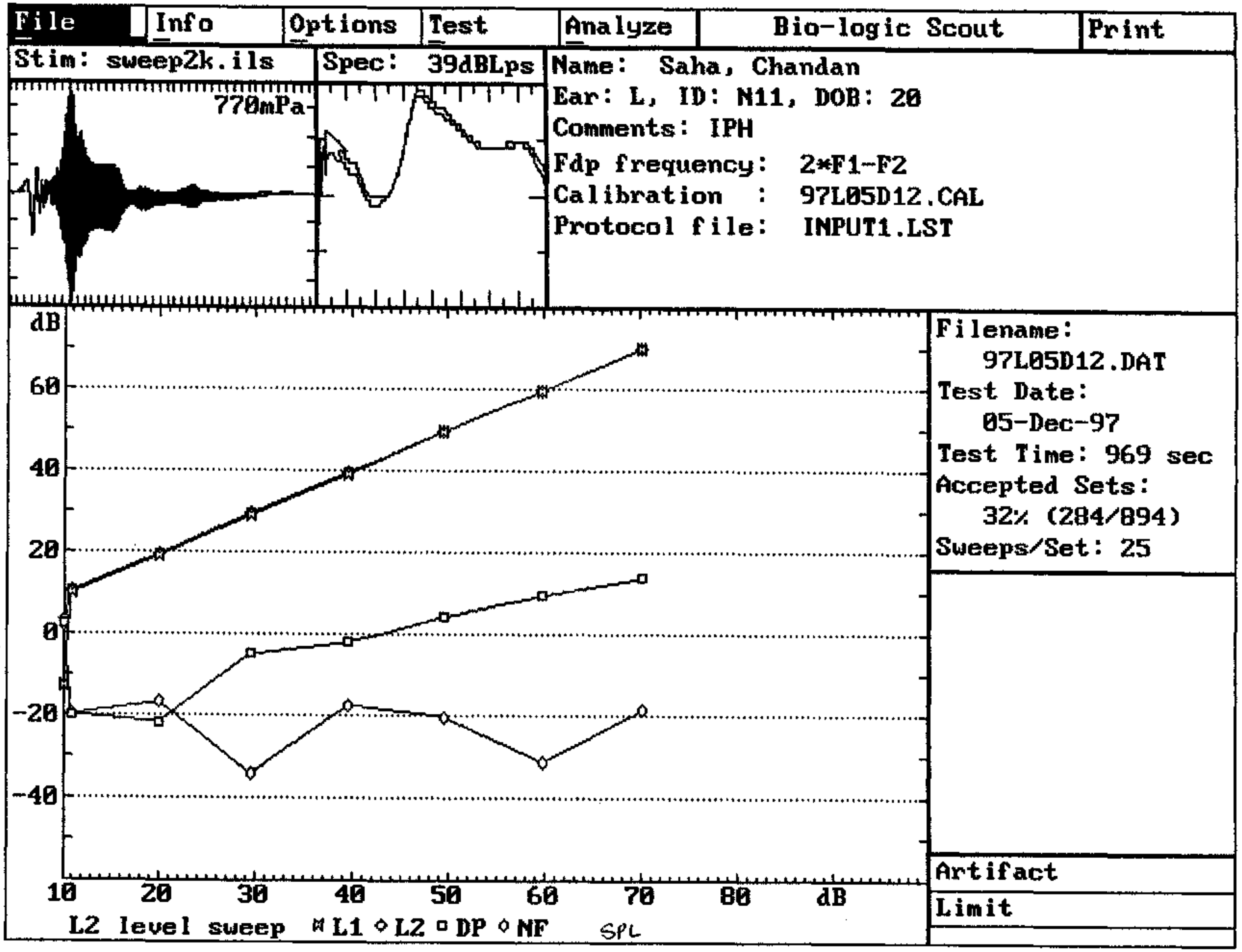

FIG. IV a. AN INPUT-OUTPUT FUNCTION OF DPOAE IN NORMAL.

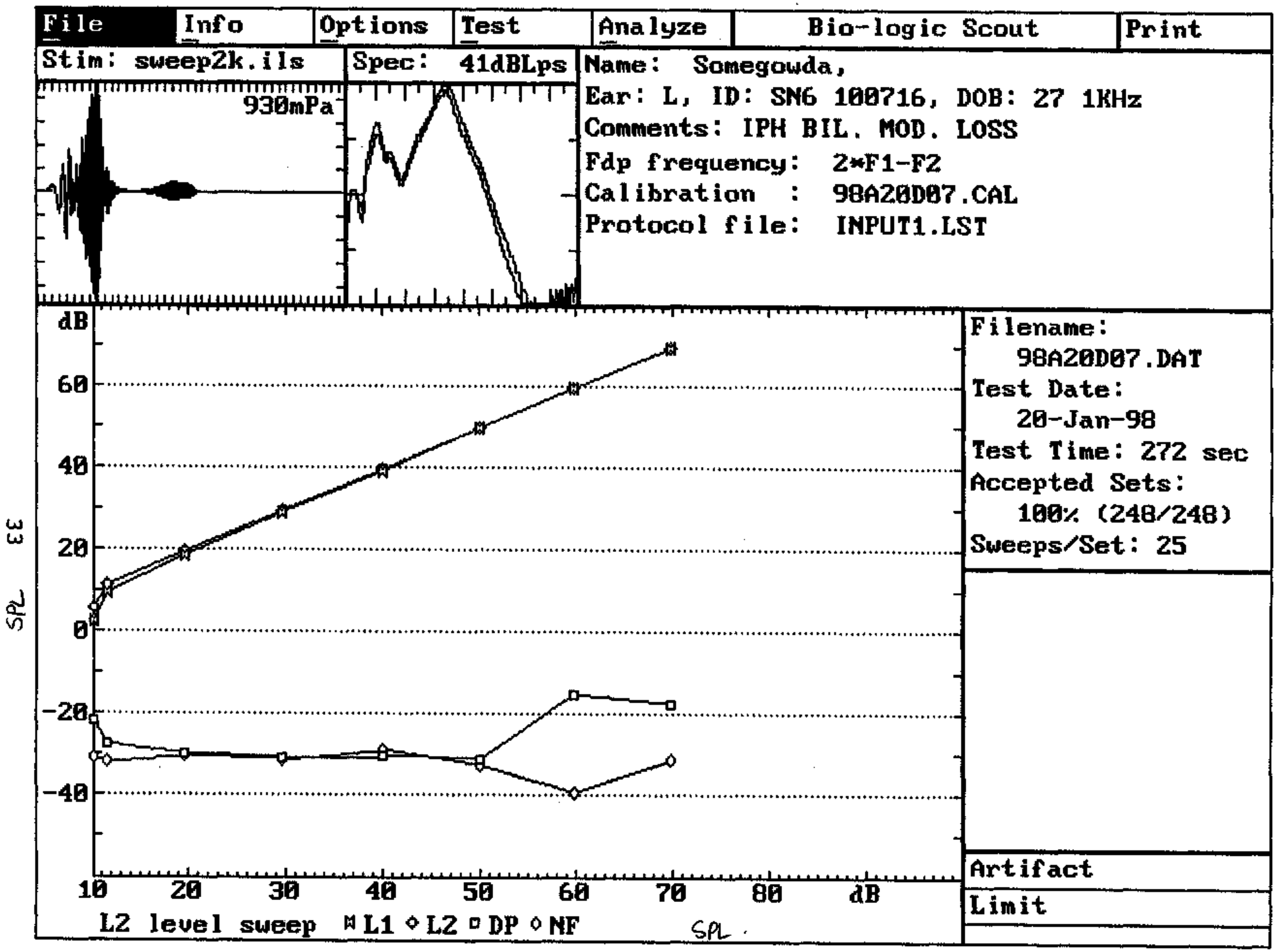

FIG. IV b AN INPUT OUTPUT FUNCTION OF DPOAE IN NORMALS.

Extensive studies on the measurement of 2fl-f2 distortion product OAE of normals have been carried out over the past two decades and a majority of them report that DP detection thersholds which were 3 dB SPL above the noise floor corresponded to 35 dB SPL to 45 dB SPL input stimulus levels between 1000 Hz. to 8000 Hz. (Lonsbury-Martin et al. 1990; Bonfils, Avan, Londeko, Trotoux, & Narcy, 1991) The lowest "DP thresholds" (ie. the input stimulus levels at which DP detection thresholds were elicited) were reported by Wilson (1980), Schloth (1982), Burns et al. 1984; Wier et al. (1988) as 5 dB SPL.

Thus according to these investigations, the sensitive input levels to separate normals from the clinical population would be anywhere between the range of 5 dB SPL to 35 dB to 45 dB SPL. These results may be supported by the findings of the present study which show mean DP detection threshold of normal to be 20 dB SPL to 30 dB SPL and their range as 10 dB SPL to 50 dB SPL. Thus 20 dB to 30 dB SPL could be taken as the sensitive values to distinguish normals from subjects with hearing loss but specificity of the test would be reduced as 21.25% of the normals were found to have thresholds as high as 40 dB SPL to 50 dB SPL.

2. Sensori - Neural Hearing Loss.

The distortion product detection threshold of 11 pathological ears were obtained for the same geometric means of 1000, 2000, 4000 and 8000 Hz respectively. The mean values, standard deviations and ranges for the group may be summarized as shown in Table IVb.

TABLE IVb : PURE TONE THRESHOLDS AND DP DETECTION THRESHOLDS IN SENSORI-NEURAL HEARING LOSS

FREQUENCY **(Hz.)**	MEAN PURE TONE THRESHOLDS (dB HL)	MEAN DP DETECTION THRESHOLDS (dB SPL)	SD (dB SPL)	RANGE (dB SPL)
1000	44.9	52.73	19.02	10-70
2000	42.7	37.27	18.49	10-70
4000	42.7	39.09	19.21	10-70
8000	54.5	49.09	13.75	30-70

The mean values of the normal and pathological groups were tested for significant difference at 0.01 levels wherein significant differences were present at all geometric frequencies. This implies that pathological ears as a group has a significantly higher threshold than the normal ears and all frequencies tested.

The sensitivity and specificity of the DPOAE test using thresholds obtained from the normal and pathological data were tested, the result of which is given in table IVc and IVd respectively.

TABLE IVc : SENSITIVITY AND SPECIFICITY OF DPOAE TEST USING DP DETECTION THRESHOLDS FROM NORMALS

F(Hz)	% sensitivity	% speicificity
1000	90.9	65
2000	81.8'	70
4000	72.7	70
8000	63.6	60

TABLE IVd : SENSITIVITY AND SPECIFICITY OF DPOAE TEST USING DP DETECTION THRESHOLDS FROM SENSORI-NEURAL HEARING LOSS

F(Hz)	% sensitivity	% speicificity
1000	63.6	100
2000	72.7	93
4000	63.6	75
8000	54.5	85

It was seen that is the specificity increased sensitivity of the value decreased and viceversa. Values from normative data tended to have high sensitivity and low specificity while values obtained from pathologcal data had high specificity but low sensitivity. This could probably be explained by the large standard deviations obtained in the data comparing the values obtained from the 2 groups of data, the values from the normative data has a more balanced distribution of sensitivity and specificity than those from the clinical population, andhence would be comparatively more successful in clinical practice.

3. Correlation between DP detection threshold and behavourial audiometry:

TABLE IV e : CORRELATION OF DP THRESHOLD Vs PURE TONE THRESHOLD

Frequency (Hz)	Correlation co-efficient	Significance
8000	0.01407	0.9673
4000	0.18640	0.7274
2000	0.48210	0.1332
1000	0.44530	0.3114

None of the frequencies tested showed a high correlation between distortion product detection thresholds and pure tone thresholds. The highest correlation amongst the four octave frequencies was obtained for 2000 Hz. (r=0.48210), whereas others showed a poorer correlation.

Most of the investigations carried out to relate behavioural threshold and DP emissions were limited to correlating DP amplitudes to audiometric thresholds rather than DP detection thresholds due to the added advantages of less measurements and reduced test time in the former. Though good correlations between DP detection thresholds and pure tone thresholds, r =

0.61 (Nelson and Kimberly, 1992) r = 0.52 to 0.87 (Ohlms, Martin and Harris, Franklin, Lonsbury-Martin, 1990) ; r = 0.52 to 0.85 (Lonsbury-Martin and Martin, 1990), has been reported extensively in literature, according to Stover, Gorga and Neely (1996), inspite of its slightly improved test performance over DP amplitudes, the difficulty in threshold determination against the noise floor reduces efficiency of the DPOAE threshold as a clinical tool in identifying hearing loss. This difficulty in threshold detection from the variable noise floor may be contributing majorly to the poor correlations obtained in this study. According to Nelson and Kimberly (1992), high correlation coefficients may be attributed to homogeneity of the cochlear pathologies amongst the subjects of their study. The same reasons could hold good for the study as well.

B. DISTORTION PRODUCT AMPLITUDE :

The amplitudes of DP and DP-NF obtained for both the normal and the pathological group were subjected under statistical analysis.

1. Normals :

The mean values, standard deviations and ranges calculated for the amplitudes of DP and DP-NF for geometric mean frequencies of approximately 1000 Hz., 2000 Hz., 4000 Hz. and 8000 Hz respectively at their detection thresholds are as tabulated in Table IVf and IVg.

TABLE IVf : DP AMPLITUDES IN NORMALS

FREQUENCY **(Hz.)**	MEAN (dB SPL)	STANDARD DEVIATION (dB SPL)	RANGE (dB SPL)
1000	-19.12	8.88	-41.4 to - 0.1
2000	-21.48	4.10	-26.9 to - 9.9
4000	-21.13	4.92	-27.7 to -11.5
8000	-23.03	5.03	-30.6 to - 9.9

TABLE IVg : DP-NF AMPLITUDES IN NORMALS

FREQUENCY (Hz.)	MEAN (dB SPL)	STANDARD DEVIATION (dB SPL)	RANGE (dB SPL)
1000	12.68	8.10	3.3 to 29.7
2000	10.36	5.45	1.9 to 26.5
4000	12.03	6.63	3.0 to 27.7
8000	10.87	5.20	3.3 to 21.4

2. Sensori Neural Hearing Loss :

The same statistical procedure had been carried out for the pathological group as well. Thus the mean values, standard deviations and ranges of this group, for the same geometric mean frequencies, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz was obtained as shown in table IVh and IVi.

TABLE IVh : DP AMPLITUDES IN SENSORI-NEURAL HEARING LOSS

FREQUENCY (Hz.)	MEAN (dB SPL)	STANDARD DEVIATION (dB SPL)	RANGE (dB SPL)
1000	-11.36	5.00	-18.8 to - 3.8
2000	-20.15	6.01	-29.3 to - 7.2
4000	-19.27	9.07	-33.86 to - 8.6
8000	-22.48	3.80	-28.5 to -17.1

TABLE IVi : DP-NF AMPLITUDE IN SENSORI-NEURAL HEARING LOSS

FREQUENCY (Hz.)	MEAN (dB SPL)	STANDARD DEVIATION (dB SPL)	RANGE (dB SPL)
1000	16.55	8.62	5.0 to 15.8
2000	11.96	8.30	4.2 to 32.2
4OOO	12.24	8.1O	3.1 to 25.2
8OOO	10.12	3.87	3.O to 28.3

Ilso to be noted that the standard deviations for emission amplitudes are not DP-NF) is seen at 1000 Hz. in both normal and pathological groups. It is also to be noted that the standard deviations for emission amplitudes are not as high as for their detection theresholds. This may be attributed to the slightly better correlation obtained between emissin amplitudes and pure tone audiometric results as discussed in the following paragraphs.

3. CORRELATION BETWEEN EMISSION AMPLITUDE (DP and DP-NF) AND BEHAVIOURAL AUDIOMETRY :

Karl Pearson's product moment correlation coefficient was calculated for behavioral thresholds and DP and DP-NF amplitudes for each of the test frequencies, the results of which has been summarized in table IVj and IVk.

The negative values of the correlation coefficient imply reduced DP or DP-NF amplitudes for corresponding high pure tone thresholds is similar to the finding of Smurzynski et. al., (1990) and Harris and Probst (1991).

In general, the correlation coefficients ranged from poor to moderate.

Correlation between the pure tone thresholds and DP and DP-NF amplitudes at 8000 Hz. was poor overall for all the intensities (Refer to tables IVj and IVk). Among the r values obtained 70 dB SPL and 50 dB SPL had comparitively higher correlation coefficients (r=-0.41167 and r=-0.4070 respectively) for DP amplitude, as compared rest of the stimulus intensity levels. Thus on the whole, 8000 Hz. did not show a good correlation betweent he behavioural thresholds and emission amplitudes.

The correlation at 4000 Hz. was slightly better at 70 dB SPL and 60 dB SPL, the rest of the intensities having poorer values. Therefore, an overview of the results obtained at 4000 Hz. show a poor to moderate correlations at this frequency.

The correlation results obtained for 2000 Hz. at various intensities were the best, as compared to the other frequencies. Moderate correlation coefficients were obtained for 70 dB SPL, 60 dB SPL and 50 dB SPL respectively. 50 dB SPL and 60 dB SPL having higher r values (-0.65631 and -0.61608) than 70 dB SPL (r = -0.54517) for DP amplitudes.

TABLE IV i : CORRELATION OF DP AMPLITUDE Vs PURE TONE THRESHOLDS

Intensity (dB SPL)	Frequency (Hz.) 1000		2000		4000		8000	
	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance
70	-0.17302	0.6109	-0.54517	0.0828	-0.53984	0.0865	-0.41167	0.2084
60	-0.37182	0.2602	-0.61608	0.0436	-0.51027	0.1088	-0.29616	0.3765
50	-0.09391	0.7836	-0.65631	0.0283	-0.22859	0.4990	-0.40720	0.2139
40	0.04428	0.9099	-0.36287	0.3372	-0.35205	0.3185	-0.21248	0.5556
30	-0.18238	0.6955	-0.14062	0.7182	-0.37265	0.3233	-0.03102	0.9419

TABLE IV k : CORRELATION OF DP - NF AMPLITUDE Vs PURE TONE THRESHOLDS

Intensity (dB SPL)	Frequency (Hz.) 1000		2000		4000		8000	
	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance	Correlation Co-efficient	Significance
70	0.36648	0.2676	-0.31092	0.3520	-0.33634	0.3119	-0.20800	0.5394
60	-0.43741	0.1785	-0.54666	0.0818	-0.39751	0.2260	-0.27030	0.4215
50	-0.20419	0.5470	-0.65155	0.0299	-0.32896	0.3170	-0.31377	0.3314
40	0.07741	0.8431	-0.32490	0.2936	-0.43026	0.5697	0.28611	0.4229
30	-0.25348	0.5834	-0.08012	0.8377	-0.19301	0.5932	-0.04776	0.8199

The results of correlations carried out at 1000 Hz. showed poor values for all the intensities, the highest being r = -0.37182 for DP amplitude at 60 dB SPL.

Input-output studies correlating behavioural thresholds to DP-amplitudes over the past few years have agreed on a moderate to high correlation between the two entities (Kimberly and Nelson, 1989 ; Harris and Probst, 1991 ; Bonfils and Avan, 1993 ; Probst and Hauser, 1993; Kimberly, Hernardi, Lee and Brown, 1994 ; Gaskil and Brown, 1990 ; Ricci et al. 1997). Kimberly and Nelson (1989) reported a high correlation coefficient of -0.86 on an average throughout the frequencies tested. Hauser and Probst (1990b) obtained a moderate coefficient of 0.52, supported by Probst and Harris (1993) who reported a Spearman's correlation coefficient of -0.84 Kim et. al., (1996) carried out a study on similar lines and found r to be ranging from -0.55 to -0.83. Sun et al. (1996) conducted a study to find out the effect of equivalence of primary levels (L1 and L2) on distortion product emission in sensori neural hearing loss results showed a higher correlation between auditory thresholds and DP amplitudes (r=0.78 to 0.87) for unequal levels of primaries (L1 = 65/ L2 = 50) as compared to (r = 0.66 to 0.79). equal level primaries (L1 = L2 = 65).

Higher co-relations may have been obtained in this study as well, if unequal stimulus levels were used. Another reason for the poor correlation between auditory threshold and DP amplitude in the present study may be the variations in instrumentation, since at present there are no standards for otoacoustic emission analyzers.

The general trend in the studies done on correlation of auditory thresholds and DP emissions (whether detection thresholds or amplitudes) have shown better correlation in the higher frequencies than the lower frequencies (Martin et al. 1994; Probst and Hauser, 1990; Gorga et al. (1993b), Kim et al. (1993) reported the following correlations between auditory thresholds and DP amplitudes : 0.55 for 1000 Hz, 0.76 for 2000 Hz, 0.77 for 4000 Hz, and 0.83 for 6000 Hz. According to Martin et al (1990), correlation coefficients were found to be 0.76, 0.84, 0.89 for DP amplitudes at 4000 Hz., 6000 Hz., 8000 Hz. respectively, and 0.52, 0.84, 0.84, 0.87 for DP detection threshods at 1000 Hz., 2000 Hz., 4000 Hz., 8000 Hz., respectively, detecter threshold. The above studies were supported by Sun et al. (1996) who found correlation coefficients to be as follows: 0.43 for 1000 Hz., 0.66 for 2000 Hz., 0.79 for 4000 Hz. and 0.8 for 6000 Hz. as well as Nelson and Kimberly (1992) who reported r = 0.68 for 1000 Hz and 0.77 for 2000 Hz respectively.

Gorga et al (1993a) has reported poorer correlation for 8000 Hz. (r = 0.71) as compared to 4000 Hz. (r = 0.85) ; *as* well as, Lonsbury - Martin and Martin (1990) who reported 0.85, 0.70, 0.69 and 0.77 for 3000 Hz., 4000 Hz., 6000 Hz. and 80000 Hz. respectively. A majority of the studies carried out on the lines of comparing DP emission and pure tone thresholds generally have had homogeneous population. For example*'. Ohlms* et al (1990) took 15 ears with noise induced hearing loss for their study whereas Gorga et al (1993a) had a heterogenous population. The present study did not control the etiology of cochlear hearing loss amongst the subjects which may have been a factor in contributing to the discrepancy between this study and majority of that in literature.

Comparing the correlations for various input levels across frequencies, it was found that though the overall correlation coefficients were poor. The best correlation were obtained at 70 dB SPL, 60 dB SPL and 50 dB SPL as reported in literature. But since 70 dB SPL would have low sensitivity, 50 dB SPL and 60 dB SPL may be taken as more appropiate values for clinical testing. Scanning through the frequencies individually DP amplitudes at 50 dB SPL and 60 dB SPL correlated best with the pure tone thresholds at 2000 Hz., which was also the frequency with highest overall correlation values. The other frequencies did not show this trend very consistently though scattered results on the same lines were present.

These results thus support the findings of studies conducted by Avan and Bonfils, (1992, 1993) Nelson and Kimberly (1992); Kimberly, Hernard, Brown and Lee (1994), Stover, Gorga, Neely and Montoya (1996) Kim et al (1996) and Stova Gorga and Neely (1996). According to Avans and Bonfils (1992), 1993), 52 dB SPL and 62 dB SPL were the most sensitive and specific stimulus levels. This was supported by Kimberly et al (1994) who found 50 dB SPL input level corresponding best with auditory threshold. Stover, Gorga, Neely and Montoya (1996) suggested 50 dB SPL or 60 dB SPL stimulus levels to be optimal for detecting hearing loss.

SUMMARY AND CONCLUSION

Otoacoustic emissions have been a developing clinical tool in the recent past amongst which the distortion product otoacoustic emissions look promising as a diagnostic test.

Several attempts at correlating DPOAEs with behavioural audiometry in the last decade has met with positive results.

The present study was taken up on similar lines to (1) Find a sensitive input level for DPOAE which could seggragate the normals from the clinical population and

(2) Correlate the DP detection threshold, DP amplitude and DP-NF amplitude with the pure tone threshold.

20 normal ears from 20 subjects and 11 ears with sensori-neural hearing loss from 7 subjects were included in the study. Behavioural audiometry and DPOAE testing were carried out for both the groups.

DPOAE testing was done using Biologic Scoutplus Otoacoustic Analyser version 1.21 using an input-output paradigm. Geometric mean frequencies of approximately 1000 Hz., 2000 Hz., 4000 Hz. and 8000 Hz. were tested across intensities from 70 dB SPL to 10 dB SPL reduced in steps of 10 dB SPL.

The results showed the following

1) Normals

Normals had mean DP detection thresholds of 23 dB SPL, 20.5 dB SPL, 22.5 dB SPL and 30 dB SPL for geometric mean frequencies of approximately 1000 Hz., 2000 Hz., 4000 Hz. and 8000 Hz. respectively.

2) Sensori-Neural Hearing Loss

The mean DP detection thresholds for this group of subjects were 52.73 dB SPL 37.27 dB SPL, 39.09 dB SPL and 49.09 dB SPL for frequencies lOOOHz, 2000Hz, 4000Hz and 8000Hz respectively.

There was significant differences between the mean detection thresholds of the normal and pathological group indicating an elevated DP detection threshold for the pathological group. The mean detection threshold of normals at various frequencies may be taken as the cutoff values to differentiate hearing impaired from subjects with normal hearing.

The correlation between DP detection thresholds and audiometric thresholds were poor, indicating the requirement for a better control in the etiology of the cochlear pathologies of the subjects included in the study, as well as a larger group before drawing any inferences.

The DP and DP-NF amplitudes showed a low to moderate correlation with behavioural thresholds; the value of coefficient correlation r=-0.0312 to -0.65631 and r = -0.04776 to -0.65155 respectively, again the best correlation obtained at 2000 Hz. for intensities 50 dB SPL and 60 dB SPL.

Though 1000 Hz. had poor correlation as per literature, 8000 Hz. too showed poor correlation which was deviant from previous findings.

The moderate correlation observed between DP amplitude and pure tone thresholds for 50 dB SPL and 60 dB SP1 at 2000 Hz. was also in agreement with the most sensitive values which is recommended for testing in literature.

Thus it could be concluded that distortion product otoacoustic emissions are in the direction of being established as a diagnostic tool, but it requires extensive experimentation and investigations on its correlation with behavioural testing in all groups of cochlear pathologies to determine clinical values of high sensitivity and specificity.

LIMITATIONS :

(1) This study had a very small group subjects for both normative and pathological investigations.

(2) The study had not controlled the etiologies of the cochlear pathologies included in it.

(3) It did not deal with the various degrees and configurations of the cochlear hearing loss.

REFERENCES

Avan, P., and Bonfils, P. (1993). Frequency specificity of human distortion product otoacoustic emession. **Audiology,** 32, 12-26.

Bekesy, Von G. (1934), cited in Probst R., Lonsbury-Martin B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-2067.

Bonfils, P., and Avan, P. (1992). Distortion product Otoacoustic emissions: Values for clinical use. **Archieves of Otolaryngology : Head and Neck surgery,** 118, 1069-1076.

Bonfils, P., Avan, P., Londero, A., Troutoux, J., and Narcy, P. (1991). Objective low frequency audiometry by distortion product otoacoustic emissions. **Archieves of Otolaryngology : Head and Neck surgery,** 117, 1167-1171.

Brown, A.M. (1987). Acoustic distortion products for rodent ear : A comparsion of responses from rats, guinea pys and gerbils. **Hearing Research,** 31, 25-38.

Brown, A.M., and Kemp, D.T., (1984). Suppressibily of the 2fl-f2 stimulated acoustic emissions in gerbil and man. **Hearing Research,** 13, 29-37.

Brown, S.J., and Norton, S.J. (1990), cited in Norton, S.J., and Stover, L.J, (1994). Otoacoustic emissions: An emerging clinical tool. In J.Katz (Eds). Handbook of clinical audiology (448-462). Baltimore : Wilkins and Williams.

Burns, E.M., Struckland, E.A., Tubis, A., and Jones, K. (1984). Interactions among spontaneous otoacoustic emissions. **Hearing Research,** 16, 271-278.

Carhart, R. (1946), cited in Millian, J.P. (1980). Practical and philosophical considerations. In M.C. Pollack (Ed.) Amplification for the hearing impaired (143-176). New York : Grune and Stratton, INC.

Carhart, R. and Jerger, J.F. (1959). Preferred method for clinical determination of pure tone thresholds. **Journal of Speech and Hearing Disorders,** 24, 330-345.

Davis, A. (1983). An active process in cochleas mechanics. **Hearing Research.** 9, 79-90.

Davis, P.A. (1939), Cited in Ferraro, J.A., and Durrant, D.D. (1994). Auditory evoked potential. In J.Katz (Ed.) Handbook of clinical audiology Baltimore : Wilkins and Williams.

Gaskil, S.A., and Brown, A.M. (1990). The behaviour of the acoustic distortion product : 2fl-f2 from the human ear and its relation to auditory sensitivity. **Journal of Acoustic Society of America,** 88, 821-839.

Gold T. (1948), cited in Norton, S.J., and Stover, S.J. (1994). Otoacoiistic Emissions. An emerging clinical tool. In J.Katz (Ed.) Handbook of clinical audiology (448-462). Baltimore : Wilkins and William.

Goldstein, J.C. (1967). Auditory non linearity. **Journal of Acoustical Society of America,** 41, 676-689.

Goodman, A. (1965). Reference zero level for pure tone audiometer. **American Speech and Hearing Association,** 7, 262-263.

Gorga, M.P., Neely, S.T., Bergman, B., Beauchaine, K.L., Kaminski, J.K., Peters, J., and Jeasteadt, W. (1993a). Otoacoustic emissions from normal hearing and hearing impaired subjects: Distortion product responses. **Journal of Acoustical Society of America,** 93, 2050-2060.

Gorga, M.P., Neely, S.T., Bergman, B.M., Beauchaine, K.L., Kanuski, J.R., Peters, J., Schulte, L., and Jeasteadt, W. (1993b). A comparison of transient evoked and distortion product otoacousitc emission in normal hearing and hearing inparied subjects. **Journal of Acoustical Society of America,** 94, 2639-2648.

Hall, J.L. (1972). Auditory distortion products f2-fl and 2fl-f2. **Journal of Acoustical Society of America,** 51, 1863-1871.

Harris, F.P., (1990).Distrotion product otoacoustic emissions in humans with high frequency sensori neural hearing loss. **Journal of Speech and Hearing Research,** 85, 220-229.

Harris, F.P., Lonsbury - Martin B.L., Stagner B.B., Coats, A.C, and Martin, G.K. (1989). Acoustic distortion products in humans: Systematic changes in amplitude as a function of f2/fl ratio. **Journal of Acoustical Society of America,** 85, 220-229.

Harris, F.P., and Probst, M.D. (1991). Reporting click - evoked and distortion product otoacoustic emission results with respect to the pure tone audiogram. **Ear and Hearing,** 12, 399-405.

Hauser, R., and Probst. R., (1990a), cited in Bonfils, P., and Avan, P., (1992). Distortion product otoacoustic emissions: Values for clinical use. **Archieves of Otolaryngology : Head and Neck Surgery,** 118, 1069-1097.

Hauser, R., and Probst, R., (1990b), cited in Kim, D.O., Paparello, M.D., Jung, J., Smurzynski, J., and Sun, X.M. (1996). Distortion product otoacoustic emission test of sensori-neural hearing loss: Performance regarding sensitivity, specificity and receiver operating characteristics. **Acta Otolaryngologica.** 116, 3-11.

Helmhotz, H. (1870), cited in Probst, R., Lonsbury - Martin, B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-2067.

Humes, L.E. (1983). Psychophysical measures of two tone suppression and distortion products (2fl-f2) and (f2-fl). **Journal of Acoustical Society of America,** 73, 930-950.

Kemp, D.T. (1978). Stimulated acoustic emissions from within the human auditory system. **Journal of Acoustical Society of America,** 64, 1386-1391.

Kemp, D.T. (1979). Evidence of mechanical nonlinearity and frequency selective wave amplification in the cochlia, **Archives of Otolaryngology : Head and Neck Surgery,** 224, 37-45.

Kemp. D.T., Bray, P., Alexander, L., and Brown, A.M. (1986). Acoustic emission cochleography : Practical aspects. **Scandanavian Audiology,** Supplementary, 25, 71-82.

Kemp, D.T. (1986). Otoacoustic emission, travelling wave and cochlear mechianics. **Hearing Research,** 22, 95-104.

Kim, D.O., Sun, X.M., Jung, M.D., and Leonard, G. (1997). A new method of measuring distortion product otoacoustic emissions using multiple tone pairs: Study of human adults. **Ear and Hearing,** 18, 277-285.

Kimberly, B.P., Hernardi, I., Lee, A.M., and Brown, D.K. (1994). Predicting pure tone thresholds in normal and hearing impaired ears with distortion product emission and age. **Ear and Hearing,** 15, 199-209.

Kimberly, B.P., and Nelson, D.A. (1989). Distortion product emissions and sensori-neural hearing loss. **Journal of Otolaryngology,** 18, 365-369.

Kim, D.O., Paparello, J., Jung, M.D., Smurzynski, J., Sun, X.M. (1996). Distortion product otoacoustic emission test of sensori-neural hearing loss: Performance regarding sensitivity, specificity, and receiver operating characterstics. **Acta Otolaryngologica,** 116, 3-11.

Leonard, G., Smurzynski, J., Jung, M.D., and Kim, D.O. (1990), cited in Avan, P., and Bonfils P. (1993). Frequency specificity of human distortion product of otoacoustic emissions. **Audiology,** 32, 12-26.

Lonsbury-Martin, B.L., Harris, F.P., Stagner, B.B., Hawkins, M.D., and Martin, G.K. (1990). Distortion product emissions in humans : I. Basic properties in normally hearing subjects. **Annals of Otology,Rhinology and Laryngology,** 99, 3-42.

Lousbury-Martin, B.L., and Martin, G.K. (1990). The clinical utility of distortion product emission in humans. **Ear and Hearing,** 11, 144-154.

Martin, G.K. (1990). Distortion product emission in humans : Basic property in normal hearing subjects. **Annals of Otology, Rhinology and Laryngology,** supplementary 147, 3-14.

Metz, D. (1946), cited in Silman, S., and Silverman, C.A. (1991). Auditory diagnosis : Principles and applications (107). NewYork : Academic press.

Mulheran, M.L., and Degg, C. (1997). Comparison of distortion product OAE generation between a patient group referring frequent gentamycin therapy and control subjects. **British Journal of Audiology,** 31, 5-9.

Nelson, D.A., and Kimberly, B.P. (1992). Distortion product emission and audiory sensitivity in human ears with normal hearing and cochlear hearing loss. **Journal of Speech and Hearing Research,** 35, 1142-1159.

Norton, S.J., and Stover, S.J. (1994). Otoacoustic emissions: An emerging clinical tool. In J. Katz (Ed.), Handbook of clinical and Audiology (448-462). Baltimore : Williams and Wilkins.

Ohlms, L.A., Harris, F.P., Franklin, D.J., and Lonsbury Martin, B.L. (1990). Distortion product otoacoustic emissions in humans : III. Influence of sensori neural hearing loss. **Annals of Otology, Rhinology and Laryngology,** 99, 30-42.

Plomp, R. (1965), cited in Probst, R., Lonsbury Martin, B.L., and Martin G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Soceity of America,** 89, 2027-2067.

Probst, R., and Harris, F.P., (1993). Transiently evoked and distortion product otoacoustic emissions: Comparison of results from normally hearing and hearing impaired human ears. **Archieves of Otolaryngology : Head and Neck Surgery,** 119, 858-860,

Probst, R., Harris, F.P., and Hauser, R. (1993). Clinical monitoring using otoacoustic emissions. **British Journal of Audiology,** 27, 85-90.

Probst, R., Lousbury-Martin, B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acousitical Society of America,** 89, 2027-2067.

Rakhee (1996). Comparison of DPOAE and TEOAE in the subjects with sensori-neural hearing loss. An unpublished Dissertation submitted to University of Mysore.

Rhode, J., Harris, F.P., Probst, R. (1992). Repeatability of DPOAE in normally hearing humans. **Audiology,** 32, 273-281.

Ricci, G., Molini E., Fantera, A., Manna, V., Simoncelli. C. (1996). Distortion product otoacoustic emissions in cochlear neurosensorial hearing loss. **Acta Otorhinolarygol. Ital.,** 16, 492-500, abstract from Internet.

Schloth, E. (1982), cited in Probst R., Lonsbury-Martin, B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-2067.

Sharma, M. (1994). Otoacoustic emissions : Review of studies from 1975-1994 which can be done on celesta 503. An Independent project submitted to University of Mysore.

Smoorenburg, G.F. (1972). Combination tones and their origin. **Journal of Acoustical Society of America,** 52, 303-328.

Smurzynski, J., Leonard, G., Kim, D.O., Lafreniere, D.C., and Jung, M.D. (1990). Distortion product otoacoustic emissions in normal and impaired adults ears. **Archieves of Otolaryngology: Head and Neck Surgery,** 116, 1309-1316.

Speckter, Z., Leonard, G., Kim, D.O., Jung, M.D., Smurzynski, J. (1991). Otoacoustic emission in normal and hearing impaired children and adults. **Laryngoscope,** 101, 965-976.

Stover, L., Gorga, M.P., Neely, S.T., and Montoya, D. (1996). Towards optimizing the clinical utility of distortion product otoacoustic emission measurements. **Journal of Aconstical Society of America,** 100, 965-977.

Suckfull, M., Schneeweiss, S., Dreher, A., and Schorn, K. (1996). Evaluation of TEOAE and DPOAE measurements for the assessment of auditory thresholds in sensori neural hearing loss. Acta otolaryngologica, 116, 528-533.

Sun, X.M., Kim, D.O., Jung, M.D., and Randolph, K.J. (1996). Distortion product otoacoustic emission test of sensori neural hearing loss in humans: Comparison of unequal and equal level stimuli. **Annals of Otology, Rhinology and Laryngology,** 105, 982-990.

Visalakshi., E. (1997). An study of input output function. in normals. An unpublished Independent Project submitted to University of Mysore.

Weber, R., and Mellert, V., (1975). On the non monotonic behaviour of the cubic distortion products in the human ear. **Journal of Acoustical Society of America,** 57, 207-214.

Wenner, C.H. (1968). Intensities of aural difference tones. **Journal Acoustical Society of America,** 43, 77-80.

Wever, R., Bray, C.W., and Lawrence, M. (1940), cited in Probst, R., Lonsbury-Martin, B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-207.

Wier, *C.C.*, Pasanen, E.G., and McJadden, D. (1988). Partial dissociation of spontaneous otoacoustic emissions and distortion products during aspirin use in humans. **Journal of Acoustical Society of America** 84, 230-237.

Wilson, J.P. (1980), cited in Probst R., Lonsbury-Martin B.L., and Martin, G.K. (1991). A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-2067.

Zurek, P.M., and Leshowitz, B.H., (1976). Measurement of combination tones fl-fl, and 2fl-f2. **Journal of Acoustical Society of America,** 61, 155-168.

Zwicker, E. (1955). cited in Probst, R., Lonsbrury-Martin, B.L., and Martin G.K. (1991).A review of otoacoustic emissions. **Journal of Acoustical Society of America,** 89, 2027-2067.

Zwicker, E. (1980). Nonmonotonic behaviour (2fl-f2) explained by a saturation feedback nodel. **Hearing Research,** 2, 513-518.

Zwicker, E. (1979). Different behaviour of quadratic and cubic difference tones. **Hearing Research,** 1, 283-292.

Zwicker, E. (1981). Dependence of level and phase of the (2fl-f2) cancellation tone on frequency range, frequency difference, level of primaries and subject. **Journal of Acoustical Society of America,** 70, 1277-1288.