INPUT-OUTPUT FUNCTION AND THRESHOLD ESTIMATION USING CLICK EVOKED OTOACOUSTIC EMISSIONS IN NORMALS AND IN PATIENTS WITH SENSORI-NEURAL HEARING IMPAIRMENT

Register No.M2kl0

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

All India Institute of Speech and Hearing
Manasa Gangothri
Mysore

MAY 2001

CERTIFICATE

This is to certify that the Independent Project entitled : "INPUT-OUTPUT FUNCTION **AND THRESHOLD** ESTIMATION USING CLICK EVOKED OTOACOUSTIC EMISSIONS IN NORMALS AND IN PATIENTS WITH SENSORI-NEURAL HEARING IMPAIRMENT " is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register **No.M2kl0.**

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CERTIFICATE

This is to certify that this Independent Project entitled : "INPUT-OUTPUT FUNCTION AND THRESHOLD ESTIMATION USING CLICK EVOKED OTOACOUSTIC EMISSIONS IN NORMALS AND IN PATIENTS WITH SENSORI-NEURAL HEARING IMPAIRMENT" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

I hereby declare that this Independent Project entitled "INPUT-OUTPUT FUNCTION AND THRESHOLD ESTIMATION USING CLICK EVOKED OTOACOUSTIC EMISSIONS IN NORMALS AND IN PATIENTS WITH SENSORI-NEURAL HEARING IMPAIRMENT" is the result of my own study under the guidance of Mr Animesh Barman, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

Mysore
May 2001.

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INTRODUCTION

Otoacoustic emissions are sounds generated within the normal cochlea, either spontaneously or in response to acoustic stimulation. Since their first introduction (Kemp, 1978), otoacoustic emissions (OAEs) have gradually become a significant tool both in clinical audiology and in studies of the characteristics of fine cochlear activities.

They are potentially a valuable tool for evaluating cochlear status (Kemp, 1978; Johnsen, Bage and Elberling, 1983; Elberling, Parbo, Johnsen and Bage, 1985). OAE recording method permits repeated measures over lengthy period of time, without interfering with the cochlea's normal mode of operation and promises to make such procedures an important research tool in the auditory sciences.

The potential clinical importance of OAE lies in the ability to obtain a noninvasive and focused examination of the mechanical workings of the cochlea. The primary value of OAEs is that their presence indicates that the preneural cochlear receptor mechanism (and necessarily the middle ear mechanism as well) is able to respond to sound in a normal way. Emissions are frequency specific and frequency selective, so that it is possible to gain information about different parts of cohlea, simultaneously.

Under different conditions of stimulation, OAEs take various forms though they originate in the same hair cell mechanism (Kemp, 1986). They can be broadly classified as spontaneous and evoked emissions.

Spontaneous emissions are pure tones of about 20 dB SPL found in the quiet ear canal in 40 to 60% of healthy ears. They are not always present nor are they important for normal hearing.

When a pure tone is used to evoke an emission, it is called a stimulus frequency otoacoustic emission (SFOAE) and when 2 simultaneous, pure tone stimuli referred to as primary tones are given to the ear simultaneously, a distortion product otoacoustic emission (DPOAE) is produced in the ear.

Transient evoked otoacoustic emissions (TEOAEs) are responses which are commonly elicited by the use of brief acoustic stimulus like clicks or tone bursts. These stimuli evoke OAEs from a large part of cochlea simultaneously including all the byproducts of non-linearity and inter-modulation.

TEOAEs obtained in response to click stimuli are expected to have broad response spectra. They are most robust in the mid-frequency region, probably owing to the fact that the middle ear transfer is most favourable in the region between 1 and 3 kHz. Responses obtained from tone bursts have narrow band spectra that are predicted by stimulus properties.

TEOAEs can be processed to provide information over a wide range of frequencies simultaneously. TEOAEs are absent in approximately 5% of adult subjects with hearing thresholds better thanl5 db HL (Kemp, Bray, Alexander and Brown, 1986).

Otoacoustic emission measurement is not a substitute for pure tone audiometry. OAE findings are an almost direct measure of outer hair cell functional integrity, 'almost' because middle ear function is also a factor in OAE measurement, whereas pure tone audiometry is dependent on the status of the cochlea, eighth nerve, central auditory system and auditory perceptual factors as well as the middle ear.

Thus whereas audiometric threshold must involve afferent neuronal activity arising from inner hair cells (Evans, 1993), Pick and Evans (1983) have suggested that frequency selectivity, a function specifically of the outer hair cells, may give earlier evidence of cochlear damage, evidence that may be of more functional significance.

Clinical applications of OAEs include -

1. New born hearing screening.
2. In paediatric audiometry
3. Assessment in suspected functional hearing loss.
4. Differentiation of cochlear vs. retrocochlear dysfunction.
5. Monitoring ototoxicity.
6. Objective confirmation of cochlear dysfunction in patients with tinnitus and normal audiograms.
7. Noise/music exposure - It can provide an early and reliable 'warming signal' of cochlear dysfunction, before any problem is evident in the audiogram.

- Hall &Meueller (1997)

Thus the main interest OAEs arouse lies in their being the only non-invasive objective means of exploration of the active mechanical process assumed to be generated by the outer hair cells of the Organ of Corti. Their application in pathology seems to be all the more promising because they are found in nearly all subjects with normal hearing, although they tend to diminish with age (Bonfils, Bertrand & Uziel, 1988; Collect, Gartner, Moulin & Morgon, 1990a) and endocochlear deafness (Kemp, 1978; Probst, Lonsbury-Martin, Martin & Coats, 1987; Bonfils and Uziel, 1989; Collect et al. 1989, 1990a; Rutten, 1980). These various studies show that evoked otoacoustic emissions are never present when the subjective click sensation threshold is above 45 dB HL (Bonfils and Uziel, 1989), a hearing loss above 40 dB HL at the best frequency (Collect et al. 1990b) and in patients with a sensation threshold above 50 dB (Bonfils, 1988).

Need for the Study

1. The existence of a relationship between the audiogram and the spectrum analysis of the evoked otoacoustic emissions was suggested by Kemp Ryan & Bray (1990), but it was not demonstrated in a sizable clinical population.
2. Till date, TEOAEs are most widely used for screening purposes (Culpepper, 1995) and not much importance have been given to it as a diagnostic tool.
3. In spite of the variances in the TEOAE amplitude within the normal population itself, there should be some input intensity level which can separate the normal from the clinical population based on the presence or absence of emissions.

Hence, this study was taken up with the aim of finding out the input-output function and estimation of the behavioral threshold using TEOAEs.

Aims of the study

1. To find out the input intensity level which would separate the normal from the clinical population based on the presence or absence of emissions.
2. To find out if there is any significant difference in OAE amplitude between subjects with normal hearing and subjects with sensori-neural hearing-impairment at 80 dB SPL.
3. To find out the correlation between pure tone threshold and amplitude (SNR) of TEOAEs.
4. To find out the correlation between pure tone threshold and TEOAE threshold.
5. To find out the overall magnitude of hearing loss using TEOAEs.
6. To find out the sensitivity and specificity of TEOAEs.

REVIEW OF LITERATURE

Transient evoked otoacoustic emissions are frequency dispersive responses arising in the cochlea that can be measured in the external ear canal after the presentation of a brief acoustic stimulus such as a click or tone burst (Kemp, 1978; Norton and Neely, 1987). After Kemp's (1978) initial reports of TEOAEs there has been considerable interest in their clinical application.

The results of a number of survey studies of TEOAEs have been reported in the literature (Kemp, 1978; Rutten, 1980; Johnsen and Elberling, 1982; Grandori, 1985; Zwicker, 1983; Elberling et al., 1985; Kemp et al., 1986; Probst, Coats, Martin & Lonsbury-Martin, 1986; Dijk and Wit, 1987; Bonfils et al, 1988; Stevens, 1988). Overall, in these studies, despite the use of varying types of stimulation ranging from briefly lasting clicks to short tone burst limited to half or full cycles, TEOAEs were detected in nearly all of the human ears that have been tested with normal hearing, regardless of age or gender.

Several investigations have been carried out using TEOAEs to study its various applications in normals as well as the clinical population. They are reviewed under the following headings :

1. Relation between TEOAE reproducibility, signal-to-noise (S/N) ratio and hearing status.
2. Correlation between pure tone audiogram and TEOAE responses.
3. Magnitude of hearing loss.

RELATION BETWEEN TEOAE REPRODUCIBILITY, SIGNAL-TO-NOISE (S/N) RATIO AND HEARING STATUS

There are two distinct situations in which the association of TEOAEs and hearing is straight forward. The case in which TEOAEs are present in 99% of individuals with normal hearing and TEOAEs absent in ears with different pathologies. This basic dichotomy provides the basis for using TEOAEs in the identification of hearing loss in screening programs. For such purposes, overall parameters such as percentage of reproducibility, response level or a combination of measures is calculated from the TEOAE and used to determine the presence or absence of hearing loss. The response is present only when the whole reproducibility score is 50% or greater, and values less than 50% is associated with hearing loss (Kemp, et al. 1986).

In another study by Dijk and Wit (1987), wave reproducibility and response power to the noise power were used as criteria to decide whether a click evoked response is actually an emission. The measured emission was called an OAE, if the emission power was 3 dB above noise power and the waveform correlation was better than 70%. Eighty-five out of two hundred and ten normal hearing ears had cochlear emissions, when 3 dB SNR was used as a criteria. Also, 97% of adults and 95% of neonates had EOAE, when the criterion applied was 70% reproducibility studied by Dolhen, Hennaux, Chantry & Hennebert (1991) in seventy one and thirty nine normal hearing adult and neonate ears respectively.

Whitehead, McCoy, Martin & Lonsbury-Martin (1993) reported results from one hundred and forty nine normal hearing ears and one hundred and forty two ears with high frequency sensory neural hearing loss with at least a portion of the pure tone threshold better than 25 dB HL. 50% reproducibility was able to differentiate ears with hearing loss from those without hearing loss.

Study by Welz-Muller and Stephen (1994), in five hundred and twenty five ears (aged 3-11 years) indicated that in most of their absent TEOAEs the response level was about 7 dB and in most of the present TEOAEs it was above this level. Reproducibility of more than 60% was mainly observed in present TEOAEs.

Herer, Glattke, Pafitis & Cummiskey (1996), studied two hundred and sixty children and adults and found very high efficiency scores for response reproducibility in the region of 2000 Hz (using 50% reproducibility criterion) and suggested that the clinicians can have greater confidence in their ability to identify presence of hearing loss between 250 Hz to 4000 Hz using this measure.

CORRELATION BETWEEN PURE TONE AUDIOGRAM AND TEOAE RESPONSES

One application that has been emphasized is the determination of the relation of OAE test results to audiometric findings. Results have been evaluated in terms of their potential for screening or for predicting hearing levels by frequency.

Avan, Bonfils, Loth, Narcy & Trotoux (1991) investigated the relationship between the amplitude and threshold of TEOAE and the audiogram and found that these parameters (threshold and amplitude) do not show frequency specificity.

In 1991, Collect, Veuillet, Chanai & Morgon calculated correlations between spectrum analysis of evoked OAEs and hearing loss in one hundred and fifty patients with pure sensory neural hearing loss. Significant correlations were found and they concluded that greater the high frequency spectral components of the EOAE, the better the high frequency hearing and was difficult to establish audiogram knowing only the spectrum analysis of EOAEs.

Similarly, Fuse, Aoyage, Suzuki & Koike (1994) studied the amplitude power spectrum of TEOAE and the audiogram of one hundred and fifty four patients with sensori-neural hearing loss and forty-two normal hearing adults. There was no significant correlation between the audiogram and response spectrum of the TEOAE observed However, it may be difficult to derive an audiogram based on the response spectrum of TEOAE transversely.

One goal of recent studies by Prieve et al. (1993) and Gorga et al. (1993) was to determine which TEOAE parameter best predicted hearing levels when worst threshold at .5, 1, 2, or 4 kHz was used as the audiometric parameter. They found that the measures of percentage reproducibility, TEOAE level or TEOAE level above noise were highly inter-related, and that they predicted audiometric outcome approximately equally well. The parameter or percentage reproducibility performed slightly better than did the other two. When hearing threshold levels were less (i.e. poorer) than 20 dB HL, TEOAE responses decreased sharply, and there was no direct correspondence between the degree of change in any TEOAE parameter and the magnitude of hearing loss. Therefore, using any of the TEOAE parameters, a hearing level of 20 dB HL could be used as the cut off point for predicting the amount of impairment.

Attias, Bresloff & Furman (1995) examined the association between audiometric hearing thresholds and click evoked OAE spectral properties in one hundred and twenty nine adult subjects with and without a noise induced hearing loss. They suggested that the presence of CEOAEs necessarily suggests hearing thresholds of 20 dB HL or less at the corresponding frequency though a lack of emissions does not necessarily indicate hearing thresholds beyond 20 dB HL.

Lichtenstein and Stapells (1996) measured the TEOAEs in 72 normal hearing and hearing-impaired subjects (eighty-six ears) to determine which stimuli best separated normal from sensori-neural-impaired ears in a frequency specific manner. These results show that separation of normal and hearing-impaired ears at 1000, 2000 and 4000 Hz was best achieved by TEOAEs evoked by clicks.

MAGNITUDE OF HEARING LOSS

There is growing evidence in the literature showing that TEOAEs are closely related to hearing levels at the mid octave frequencies of 1 kHz to 2 kHz (Collect et al., 1991; Johnsen, Parbo & Elberling, 1993; Hurlay and Musiek, 1994; Hatzopoulous et al., in press). Such a relationship for predicting threshold levels at the mid-frequencies, have a clinical potential complementing the TEOAE screening programs.

The concept of threshold prediction by TEOAE is not new, and several studies (Gorga et al., 1993; Prieve et al., 1993; Suckfull, Schneeweih, Dreher & Schorn, 1996) have reported an estimation of hearing levels in the 1 kHz to 4 kHz octaves.

A spectral discrimination methodology (Hatzpopulous, Mazzoli & Martini, 1995) has recently been reported that can efficiently classify various sensory neural hearing loss (SNHL) groups from the corresponding TEOAE recordings.

Hatzopoulous, Martini & Stephens (1999) used the same statistical algorithm to determine an estimate of the auditory threshold in the mid-frequencies. The purpose of the study was to estimate the hearing levels, at the mid-frequencies, of 233 ears with sensory neural hearing loss by classifying the corresponding transiently evoked otoacoustic emissions recordings into three threshold groups. The most accurate prediction estimates were obtained when TEOAE data were assigned into10-29 dB HL, 30-39 dB HL or > 40 dB HL groups with a

90.9% accuracy in the 10-29 dB HL group, 82% in the 30-39 dB HL group and 71.4% in the > 40dB HL group.

In a previous paper (Hatzopoulous, Prosser, Martini, Mazzoli & Rosignoli, 1998) data were presented on the low correlation between the TEOAE spectrum and the threshold at 4 kHz octave. Particularly low correlation values were observed in cases presenting threshold levels at 4 kHz, > 50 dB HL.

Rutten (1980) studied twenty nine ears of eighteen subjects with no conductive pathology and found that emissions will be observed if the hearing loss at the frequency of emissions is less than 15 dB HL. The ears with losses up to 20 dB HL can produce cochlear emissions whereas no emissions could be measured when greater losses were present (Johnsen and Elberling, 1982; Johnsen, Bage & Elberling, 1983; Ruggero, Rich & Freyman, 1983).

About 80-90% of normally hearing ears produce OAEs but these emissions can seldom be recorded from persons with hearing loss in excess of 20-30 dB HL (Cope and Lutman, 1988).

Otoacoustic emissions can be measured in almost all normally hearing individuals of all ages and OAEs are absent or reduced in the presence of hearing-impairment (Kemp, Ryan and Bray, 1990).

TEOAEs are frequently reduced in ears with minor sensory neural hearing-impairment and generally absent in ears with SNHL exceeding 30 dB HL (Kemp, 1978).

Contrasting to this, Kemp et al. (1986) recorded click evoked OAEs in eighty eight ears with SNHL and reported that only five ears with a mean hearing loss exceeding 15 dB HL generated an emission above the mean noise level obtained. About 5% of the subjects with a mean hearing threshold better than 15 dB HL failed to produce a CEOAE above the mean noise level obtained.

Bertoli and Probst (1997) studied two hundred and one subjects aged 60 years, with sensory neural hearing loss, and found a prevalence of TEOAEs in a typical clinical population of elderly subjects of 60%, when PTA was within 30 dB HL. No emission could be detected if PTA exceeded 30 dB HL. If TEOAEs were present, response levels decreased as hearing threshold levels increased but there was no influence of age alone. They concluded that evaluation of TEOAE is of little clinical value in the routine evaluation of elderly persons with mild to moderate hearing loss.

CEOAEs were detected in thirty four out of thirty-five SNHL ears with a subjective click threshold less than 55 dB SPL (25 dB nHL) by Probst, Lonsbury-Martin, Martin & Coats (1987). None of nine ears with SNHL and a subjective click threshold above this level demonstrated CEOAE.

Study by Stevens (1988) in thirty-one ears with hearing-impairment and thirty-six ears with normal hearing showed that no subject with a hearing threshold at or above 18 dB nHL for the click stimuli produced emissions. 97.4% of the ears produced emissions if the threshold was at 13 dB nHL or lower. If the mean of the pure tone audiogram was used, the division was at 20 dB HL, although two ears produced emissions with a mean threshold of 23.8 and 33.8 dB HL and they said that the test will only differentiate between normal and hearing-impairment and that cannot be used to estimate psycho-acoustical thresholds.

Collect et al. (1989) recorded CEOAE in one hundred and forty eight ears of seventy-six subjects with SNHL and found statistically, a highly significant correlation between CEOAE threshold and hearing loss at 1000 Hz. CEOAEs were never found when hearing loss at 1000 Hz exceeded 40 dB HL and when the mean hearing loss at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz exceeded 45 dB HL.

No CEOAEs were obtained from ears with significant high frequency losses with preservation of hearing at 1000 Hz (Bonfils and Uziel, 1989). Another study by Johnsen, Parbo and Elberling (1993) on mild to moderate, flat, steeply sloping hearing showed that no emission could be obtained from ears with a flat cochlear hearing-impairment exceeding 40 dB HL in the mid-frequency region, but that emission could be recorded in ears with significant high frequency loss. Even a severe cochlear hearing loss at 4000 Hz and 8000 Hz seems to be of no significance for the presence of CEOAE.

However, in the case of high frequency hearing loss, the threshold at 1000 Hz and 2000 Hz appears to be crucial. No CEOAEs could be obtained from ears with a threshold exceeding 25 dB HL at 1000 Hz and 60 dB HL at 2000 Hz. The audiometric limits for the generation of CEOAE in flat sensory neural losses were 30-40 dB HL in the 1000-2000 Hz region (Robinette, 1992).

Not much information is got from the literature regarding the relationship between the spectrum analysis of TEOAE and audiogram.

Also the input intensity level which can demarcate the normal and abnormal populations is not much discussed about. Hence this study was taken up.

METHODOLOGY

The present study was taken up with the aim of comparing the behavioral thresholds with the click evoked otoacoustic emission threshold or amplitude (SNR) in both normals and subjects with sensory neural hearing-impairment

SUBJECTS

Two groups of subjects were taken; control group consisting of people with normal hearing and experimental group consisting of people with minimal to moderate sensori-neural hearing-impairment.

CRITERIA FOR THE SELECTION OF SUBJECTS

***Control** Group*

The subjects were in the age range of 18 to 50 years. A total if twenty-two ears were tested to match with the experimental group. All the subjects had auditory threshold within 15 dB HL at all octave frequencies from 250 Hz to 8000 Hz (Clark, 1981). None of the subjects had any history of otological or neurological symptoms. The external and middle ear were normal in function which was assessed using immittance measurement. Immittance measurement showed 'A' type tympanogram with normal reflexes.

Experimental Group

The subjects were in the age range of 18 to 50 years. A total of twenty-two ears with sensori-neural hearing loss were considered for the study. All the subjects had an auditory threshold between 16 dB HL and 55 dB HL at all octave frequencies from 250 to 8000 Hz. with no history of external ear or middle ear problems. The tympanogram showed 'A'; type with normal or elevated reflexes. In order to rule out any retrocochlear pathology, a special test, either tone decay test or reflex decay test, was administered. Only those individuals who showed negative results in the special tests were considered for the study.

INSTRUMENTATION

1. Pure tone audiometer

A two channel clinical audiometer (Grason Stadler 61/Orbiter 822 with TDH 50/TDH 39 earphones respectively and radio ear B 71 bone conduction vibrator) was used to find out the pure tone thresholds. The audiometer was calibrated prior to the study according to the standards specified.

2. Immittance audiometer

A calibrated middle ear analyzer, Grason Stadler-33 was used to assess the middle ear functions of the subjects.

3. Otoacoustic emission analyzer

An OAE analyzer, ILO 292 (Software Version 5) in standard default operational mode was used to measure the click evoked otoacoustic emissions. The filter setting of the stimuli was from 500 Hz to 6000 Hz.

80 umsc rectangular pulses (clicks) presented at 20 msec, intervals in the ear canal was used as stimuli. Repetitions about every 20 msec, and synchronous averaging allow the signal to noise ratio of the complex OAE waveform to be enhanced as required.

A total of 260 averages, above the automatic noise rejection level of the instrument was stored for analysis.

The presentation mode included a series of 4 stimuli, three stimuli at the same level and polarity and a stimulus three times greater in level and inverted in polarity. This was done so as to minimize the artifacts.

The parameter measured was input-output function. The signal was presented at first at 80 dB SPL and the intensity was dropped in steps of 10 dB SPL initially and 5 dB SPL near the threshold, till no emission was obtained at an intensity two times consecutively. A waveform was considered an emission depending on its reproducibility and signal to noise ratio.

The wave had to be reproducible at least 50% of the time (Kemp, 1990) and have an S/N ratio of > + 3 dB (Dijk and Wit, 1987) for it to be considered an echo or emission.

TEST ENVIRONMENT

All the tests were carried out in a sound treated room where the ambient noise level was minimum. The test room had adequate lighting and comfortable temperature. The subjects were provided with a comfortable chair to sit on during the test.

TEST PROCEDURE

a. Case History

A case history was obtained for all the subjects. It was made sure that no subject with a history revealing otological or neurological symptoms were accepted under the control group. In the experimental group, no individual with symptoms related to the external or middle ear pathologies or neurological involvement was included.

b. Pure Tone Testing

The subjects were asked to respond on hearing a tone by raising their hand. The thresholds were obtained at all octave frequencies from 250 Hz to 8000 Hz for both AC and BC, using Modified Hughson-Westlake Procedure (Carhart and Jerger, 1959).

c. **Immittance Testing**

It was carried out under the standard testing conditions and the standard instructions were given. Both tympanometry and reflexometry were carried out to assess the middle ear condition. This was done because any middle ear abnormality can affect the recording of an emission.

d. Special Tests

Either reflex decay test or tone decay test was carried out in order to rule out retrocochlear pathology. Only those individuals who showed negative results in either TDT or RDT were included in the study under the experimental group.

TEOAE

Instructions

The testing was carried out in the standard test environment. The subjects were not required to do any task.

Fitting of the Probe into the External Ear Canal

The probe was tried to be placed such that it fit tightly to exclude as much ambient noise as possible. The placing was so that the tubing protruding from the tip was not crushed or pinched against the ear canal wall and the probe tip was facing the tympanic membrane (Kemp, Bray and Ryan, 1990).

The same procedure was followed for the probe placement during immittance testing also.

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 where upon successive waveforms appeared on the screen. The overlapping of the waveforms ensured a good probe fit as shown in Fig.2.

Stimulus Calibration

On obtaining a good probe fit, the stimulus was calibrated. Both the spectrum of the presented stimulus and the measured SPL appeared on the screen. The system was considered calibrated if the measured SPL was the same as the spectrum of the given stimulus.

Then the signal was presented first at 80 dB SPL and later was decreased in 10 dB steps initially and in 5 dB steps near the threshold till an emission was not got at an intensity two times consecutively. The intensity 5 dB above this level was considered as the threshold of emission.

ANALYSIS

Data obtained by the above mentioned procedure were tabulated and were subjected to statistical analysis to find out how behavioral thresholds and the TEOAEs thresholds or amplitudes are related.

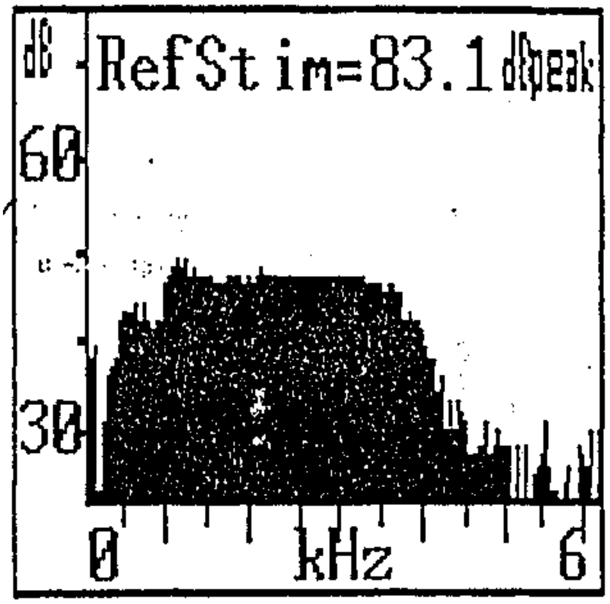

Fig 1: Checkfit panel

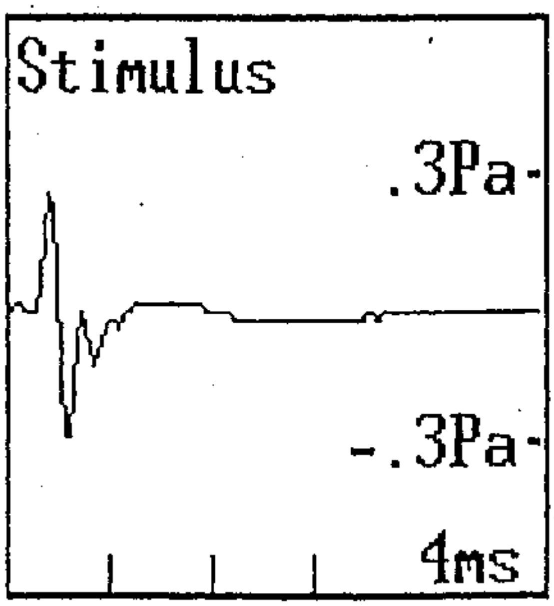

Fig 2: Shows a good probe fitting.

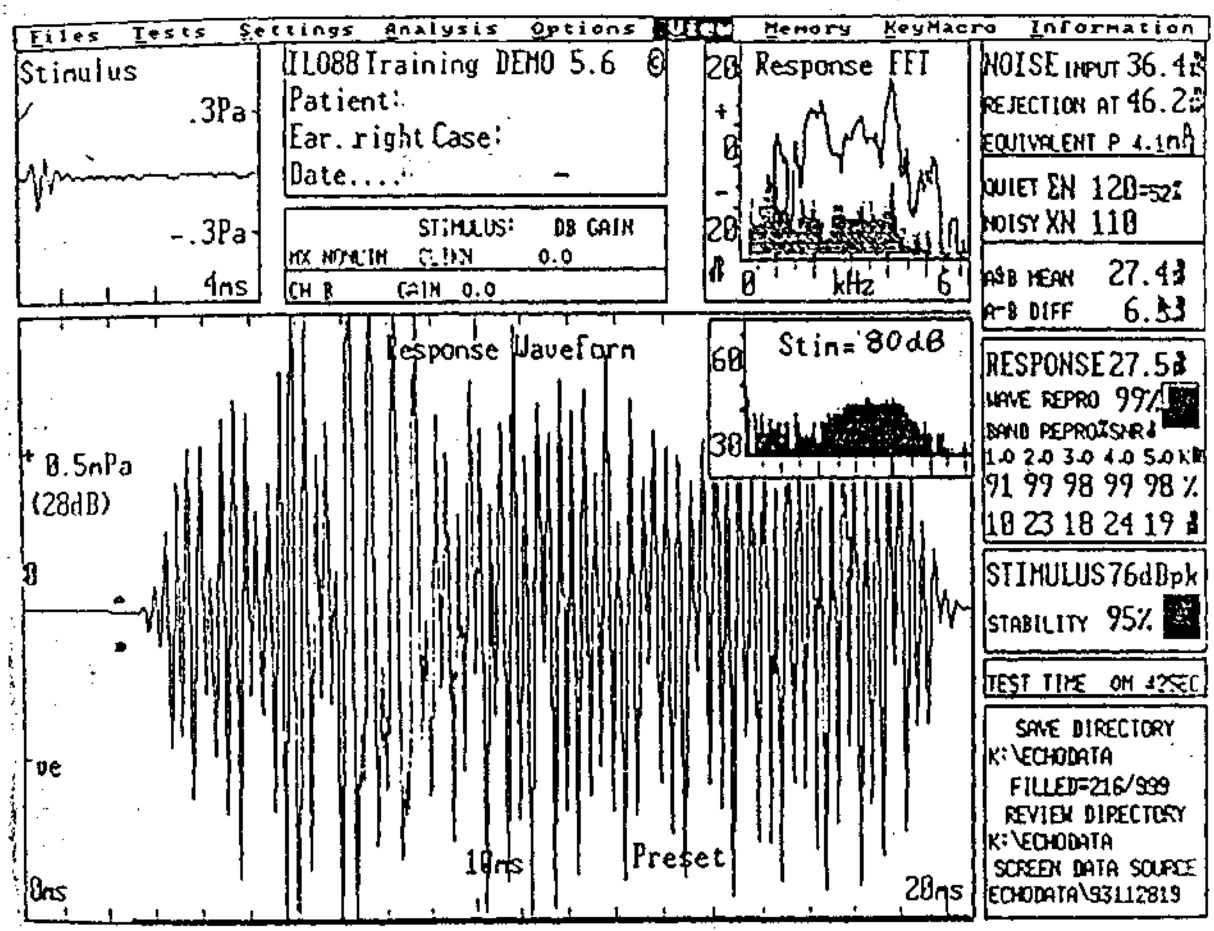

Fig 3: TEOAEs in an individual with normal hearing.

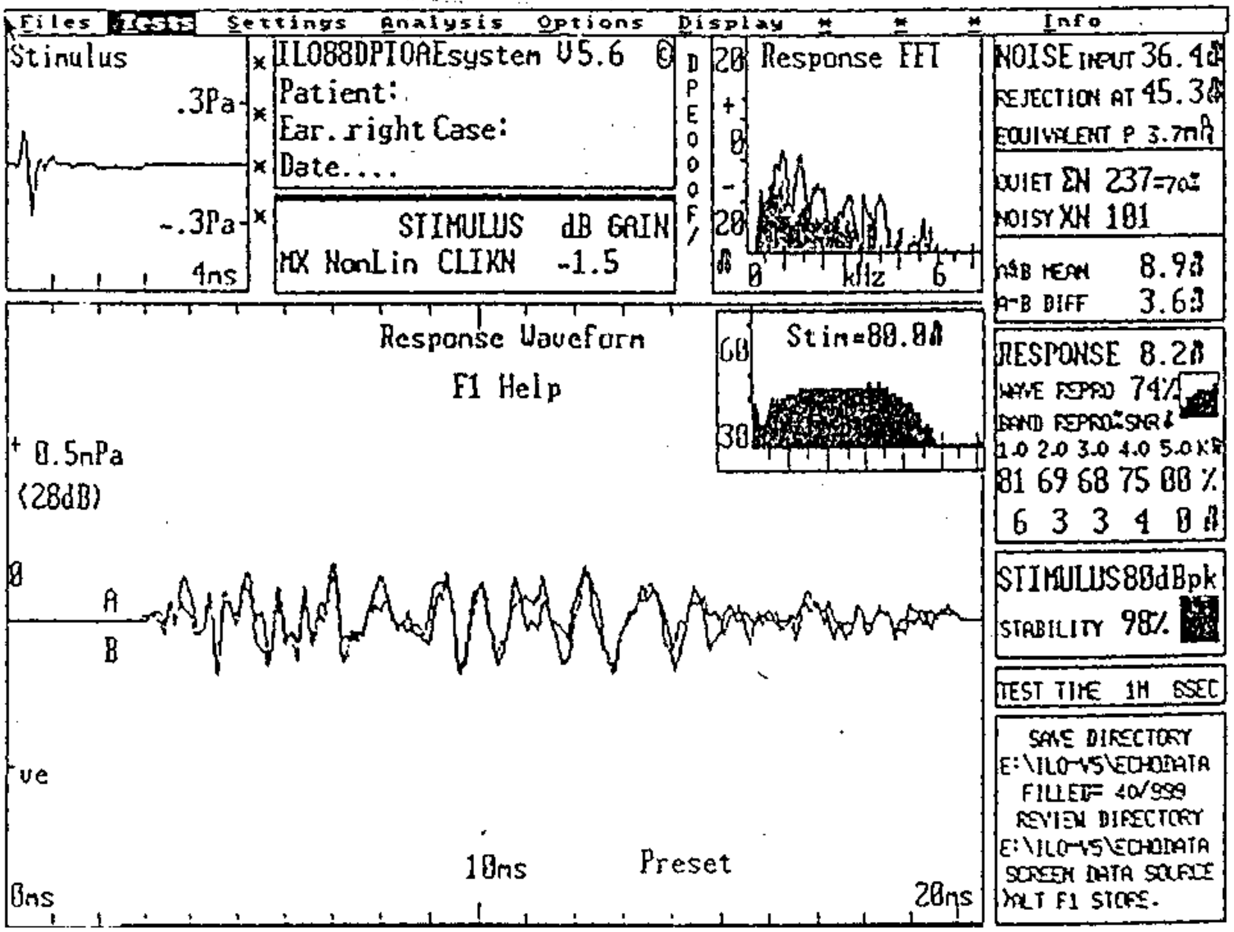

Fig 4: TEOAEs in an individual with
SN impairment.

RESULTS AND DISCUSSION

The data obtained from both the experimental and control group were tabulated. The observed data were analyzed both statistically and subjectively under the following headings:

1. To find out the input intensity level which would separate the normal from the clinical population, based on the presence or absence of emissions.
2. To find out if there is any significant difference in OAE amplitude between subjects with normal hearing and subjects with SN hearing impairment, at 80 dB SPL.
3. To find out the correlation between pure tone threshold and amplitude (SNR) of TEOAE.
4. To find out the correlation between pure tone threshold and TEOAE threshold.
5. To find out the overall magnitude of hearing loss using TEOAEs.
6. To find out the sensitivity and specificity of TEOAEs.

The table summarises the mean, standard deviation and the range values of the TEOAE thresholds, pure tone thresholds and TEOAE amplitudes (SNR) at 80dB SPL input intensity level in normals, in the abnormal population.

Table-1: Indicates the mean, standard deviation and range of pure tone thresholds, TEOAE thresholds and TEOA amplitude (SNR at 80 dB SPL input intensity) for normals and clinical population.

		Mean	SD	Minimum	Maximum
PTT	Normal	09.09	04.26	00	15
	SN loss	33.00	10.52	20	55
TEOAE T	Normal	57.04	06.10	45	65
	SN loss	79.31	01.75	75	80
SNR (80dB)	Normal	17.04	04.98	5	27
	SN loss	04.68	03.72	00	09

Key: PTT : Pure tone threshold. TEOAE T: TEOAE threshold

The graph (Fig.5) shows the sample of an input-output function curve in both subjects with normal hearing as well as subjects with SN impairment.

As shown in Table-1, while in normals, the TEOAE thresholds were present in the range of 45-65 dB SPL, in the abnormal population the TEOAE thresholds were present in the range of 75-80 dB SPL. Thus, at 65 dB SPL to 70 dB SPL TEOAE was present in 100% of the normal hearing subjects whereas none of the subjects with SN impairment got emissions at this level. This suggests a 100% sensitivity and specificity in separating normals, from the abnormal population if 65-70 dB SPL is used as the input intensity level.

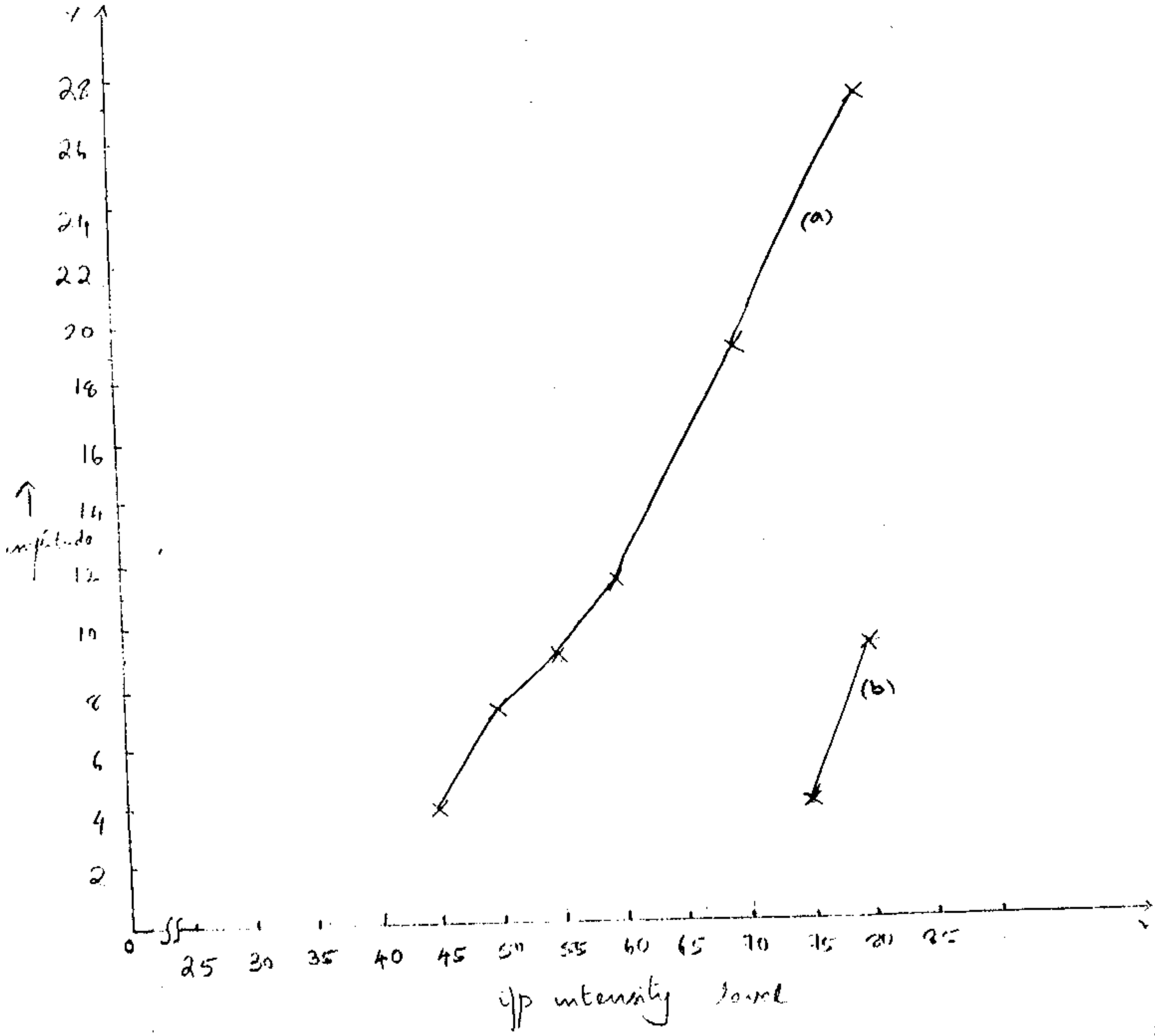

Fig 5: gra[h depicting i/p - o/p function of TEOAEs in normal(a) and chimical population(b)

If the input intensity level is increased to 75 dB SPL, many of the abnormal population will be identified as normals when the presence of emissions is the criteria for pass, thereby decreasing the sensitivity of the test. On the other hand, if the input intensity level is lowered to55 or 60dB SPL many of the normals will fall under the abnormal population thereby decreasing the specificity.

Hence, an input intensity level of 65 to 70 dB SPL will best separate the subjects with normal hearing from those with SN impairment.

Datta (1998) had done a similar study using DPOAEs. Her results indicated that 23 dB SPL, 20.5 dB SPL, 22.5 dB SPL and 30 dB SPL are the input intensity levels which can differentiate the hearing impaired from subjects with normal hearing at 1000 Hz,2000 Hz, 4000 Hz and 8000 Hz respectively.

2. The mean, SD and range of the OAE amplitudes (S/N ratio) at 80 dB SPL are shown in table 1. The Wilcoxon signed rank test (which is a matched pair test) was used to find out the significant difference in the signal to noise ratio of the CEOAEs between subjects with normal hearing and subjects with SN impairment at an input intensity level of 80 dB SPL. A 'Z' value of 4.107 was obtained which indicates a

significant difference in the S/N ratio between subjects with normal hearing and those with hearing impairment at .001 level.

This shows that OAE amplitude can be used to distinctly distinguish normal hearing subjects from hearing impaired subjects.

Prieve et al. (1993) and Gorga et al. (1993) determined which TEOAE parameter best predicted hearing levels. They found that the measure of percentage reproducibility, TEOAE level or TEOAE level above noise were highly interrelated, and that they predicted audiometric outcome approximately equally well.

3. Pearson's rank correlation was used to find out how the pure tone thresholds are related to the TEOAE amplitude (SNR) in subjects with normal hearing and those with SN impairment.

Table-2 Shows the correlation values obtained in both subjects with normal hearing and those with SN hearing impairment.

Subjects	Person's Rank correlation coefficient
Normals	.237
SN impairment	-.331
Overall	-.721

As shown in the table a negative correlation between pure tone threshold and TEOAE amplitude was found in subjects with SN impairment as well as when the overall correlation was calculated. But when the group of normals was taken alone, a low positive correlation of .237 was found between pure tone threshold and TEOAE amplitude.

The positive correlation seen in normals between the two variables can be explained as follows:

As shown in the table-1, the range of pure tone thresholds in normals is very narrow, having a range of just 0 to 15 dB HL. Moreover, behavioral thresholds are not absolute, that is, they do not remain constant but tend to fluctuate somewhat as a function of the subject's physical, emotional and mental state by about $\pm$ 5-10 dB. (Carhart and Jerger, 1959; Chaiklin & Ventry, 1961). Even though hearing threshold maybe within a range of what is considered to be audiometrically normal, the TEOAE amplitude vary from individual to individual having the same pure tone threshold. This is because the amplitude of TEOAEs are influenced by various factors such as age, presence of spontaneous emissions, and the gender of the subject, TEOAE being more robust in women (Robinette, 1992; Stover and Norton, 1993; Glattke, et al. 1994). Hence there need not be a one to one correlation between the TEOAE amplitude and pure tone threshold.

Similarly, a study done by Fuse et al. (1994) revealed no significant correlation between the audiogram and the response spectrum of TEOAEs in normal hearing adults.

An overall negative correlation seen for subjects win SN hearing impairment and for the entire population, i.e. when the abnormal and the normal population are put together, suggests that whenever there is an increase in the pure tone threshold, there will be a decrease in the TEOAE amplitude given as S/N ratio.

In subjects with SN hearing loss due to cochlear pathology, the cochlear dysfunction increases with increase in pure tone thresholds. Hence the S/N ratio of TEOAE decreases because the origin of OAEs are said to be the outer hair cells in cochlea.

Similar results were obtained in a study by Bertoli and Probst (1997). They reported that the response levels (SNR) decreased as hearing levels increased. The study done by Collect et al., (1991) also showed significant correlations between spectrum analysis of evoked OAEs and hearing loss but they concluded that greater the high frequency spectral components of the EOAE, the better the high frequency hearing and it was difficult to establish the audiograms knowing only the spectrum analysis of EOAEs.

4. Pearson's rank correlation was used to find out the correlation between pure tone threshold and TEOAE threshold. The results obtained as summarized in the following table.

Table-3: Shows the correlation between pure tone thresholds and TEOAE thresholds

Subjects	Pearson's rank correlation efficient
Normals	-.428
SN loss	-.145
Overall	.739

No direct positive correlation was found between the pure tone thresholds and TEOAEs thresholds in either normals or in subjects with hearing impairment. But overall when the entire population was taken together, a high positive correlation of .739 was got between the 2 variables.

This indicates that though TEOAE separates normals from subjects with SN impairment as indicated by the overall high positive correlation, TEOAE does not vary linearly with pure tone thresholds within normal population or within hearing impaired population. The poor correlation again indicates the requirement for a larger group of subjects before drawing any inferences.

On the other hand, the high positive correlation seen when the entire population is considered together, can due to the fact that the range of both the pure tone thresholds and TEOAE thresholds are much more wider.

5. It was found that if the hearing loss was greater than45 dB HL, TEOAEs were always absent and when the average hearing was better than 25 dB HL, TEOAEs were always present at 80 dB SPL input level.

When the hearing level was in the range of 25 to 45 dB HL, TEOAEs were sometimes present but were reduced drastically in amplitude and in frequency content in comparison to findings from ears with thresholds falling within 15 dB HL.

Studies done by Bonfils et al. (1988a, 1988b), Kemp et al. (1986), and Probst et al. (1991) showed that TEOAEs are present in 99% of the ears when the overall hearing was better than 25 dB HL. When the SNHL was greater than 40 dB HL with no complicating etiological factors, TEOAEs were always absent (Bonfils et al., 1988a, 1988b; Collect et al., 1991, 1993; Stevens and Ip, 1998; Prieve et al. 1993). It is not certain that a linear relationship exists between decreases in pure tone threshold and the level and reproducibility of TEOAEs.

Spectral analyses of TEOAEs can assist in their interpretation because a fragmented response is often associated with partial hearing loss.

It was also noticed that when the hearing threshold level at 1 kHz or 2 kHz exceeded 40 dB HL, the TEOAEs were always absent though the pure tone average of 1 kHz, 2 kHz and 4 kHz in these individuals were either better or poorer whereas when the hearing threshold levels at 1 kHz or 2 kHz was 25 dB HL and below TEOAEs were always present at an input intensity level of 80 dB SPL. These findings are similar to the results obtain by Collect et al. (1989) in their study. They reported that CEOAEs were never found when the hearing loss at 1000 Hz succeeded 40 dB HL.

6. Sensitivity is the proportion of true cases who would be correctly identified by an instrument and specificity is the proportion of population who truely are not cases and who are correctly identified as non-cases by the instrument.

In the present study the sensitivity and specificity were found as 33% and 100% respectively when the input intensity level used for the calculation was 80 dB SPL. The reduced sensitivity in the present study when compared to information got from literature can be due to the following reasons:

a) In the present study, 80 dB SPL was used as the input intensity level at which a subject was marked as pass or fail based on the presence or absence of emissions.

b) In most of the other studies a hearing level till 25 dB HL was considered as normal whereas in the present study an average hearing level of 15 dB HL was considered as the cutoff point separating normals from SN hearing impaired population.

But when an input intensity level of 70 dB SPL was used as the criteria for marking a subject pass or fail, both sensitivity and specificity in the order of approximately 100% was obtained.

SUMMARY AND CONCLUSION

The TEOAEs and behavioral hearing threshold levels are both derived following stimulation to the cochlea. However, they do not sample the cochlear response in the same way.

For measuring TEOAEs, the ear is stimulated by either clicks, tone bursts, or noise bursts that are usually presented at suprathreshold levels. This results in a generalized response from the cochlea that is composed of contributions from sources that are distributed along the cochlear partition (Avan and Bonfils, 1993). The TEOAE has no "true" threshold because its measurement is always constrained by the noise floor of the measuring system.

By contrast, a 'hearing threshold' is the point where a listener can just detect the presence of a signal at some predefined criterion rate (such as 50% or 75%). A "true" threshold is obtained for the stimulating signal.

Despite these methodological differences, TEOAEs and subjective detection thresholds do relate to one another because they share features of a common mechanism. If this mechanism is functioning normally, then the parameters derived from both measures are generally within some grossly normal range. An abnormal mechanism affects both measures. This points to some sort of relationship existing between the TEOAEs and subjective detection thresholds. The aim of the present study was to compare the subjective detection threshold with the TEOAE amplitude/threshold in subjects with normal hearing as well as in subjects with pure sensori-neural hearing impairment

Twenty-two ears each were tested in both the experimental and control group. The age range was from 18 to 50 years. Both the pure tone thresholds and the TEOAE amplitude/thresholds were obtained in all the subjects. The results obtained from the study were as follows:

1. When TEOAEs are used, an input intensity level of 65 dB SPL - 70 dB SPL can effectively separate the normal from the clinical population.
2. There is a significant difference in the OAE amplitude between subjects with normal hearing and subjects with SN hearing impairments at 80 dB SPL input intensity level having a mean of 17.04 dB and 4.68 dB in normals and SN loss cases respectively.
3. Generally, there is a negative correlation between pure tone threshold and amplitude of TEOAE threshold, i.e., as the pure tone threshold increases the amplitude of TEOAE threshold decreases as expected.

4. No direct positive correlation was found between the pure tone thresholds and TEOAE thresholds in both normals and subjects with SN hearing impairment.
5. If the hearing loss was greater than 45 dB HL, TEOAEs were always seen to be absent and when the average hearing was better than 25 dB HL, TEOAEs were always present. When the hearing level was in the range of 25 to 45 dB HL, TEOAEs were sometimes present but were reduced drastically in amplitude and in frequency content in comparison to findings from ears with thresholds falling within 15 dB HL.
6. An overall specificity and sensitivity in the order of 100% and 33% was obtained for TOAE at an input intensity level of 80 dB SPL whereas at 65-70 dB SPL a sensitivity and specificity of approximately 100% was obtained.

Thus when an overall impression of cochlear functioning is desired in a short period of time, such as for screening purposes, a click evoked otoacoustic emission can be elicited at an input intensity level of 65-70 dB SPL. Also, an absent TEOAE is a definite indication of a hearing threshold level poorer than 40 dB HL at either 1 kHz or 2 kHz and a present TEOAE points to hearing thresholds better than or equal to 25 dB HL at 1 kHz or 2 kHz thereby indicating a good correlation between TEOAE and behavioral thresholds at 1 kHz and 2 kHz.

Researchers' understanding of the best methods for using TEOAEs clinically is still in developmental stages. However, it is clear that OAE testing can be used effectively as part of a clinical test battery.

Suggestions for future research

1. A larger group of subjects should be included in both the normal and pathological group.
2. The variables should be restricted in terms of degree and configuration of cochlear hearing loss.
3. Age range should be strictly restricted as OAE amplitude varies across various age groups.

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