INPUT-OUTPUT FUNCTION OF DPOAE IN YOUNG ADULTS

REG. NO.M9623

An Independent Project submitted as part fulfilment of First Year M.Sc., (Speech and Hearing), Mysore.

All India Institute of Speech and Hearing, Mysore

DEDICTED to

My beloved Amma, Appa,Grandpa

and

small "GANESHA"......

eternal power who gave me strength and made me what I am .

CERTIFICATE

This Is to certify that this Independent Project entitled **INPUT-OUTPUT FUNCTION OF DPOAE IN Y0UN6 ADULTS** is the bonafide work in part fulfilment for the degree of Master of science (Speech and Hearing) of the student with Register No.M9623.

Mysore
May, 1997

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CERTIFICATE

This is to certify that this **INDEPENDENT PROJECT** entitled **INPUT-OUTPUT FUNCTION OF DPOAE IN YOUNG ADULTS** has been prepared under my supervision and guidance.

Mysore
May, 1997

11/6/97

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DECLARATION

This Independent Project entitled INPUT-OUTPUT FUNCTION OF DPOAE IN YOUNG ADULTS is the result of my own study under the guidance of Mrs. Vanaja C.S., Lecturer in Audiology, 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 Reg.No.M9523
May, 1997

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INTRODUCTION

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

Since time immemorial, the ear has been recognized as the organ of hearing. However, only recently has it been demonstrated that the ear, besides receiving sounds, also produces sound (Kemp, 1978). Sound stimulation of the ear sets up mechanical vibrations of cochlear structures. In the perception of sound, the fundamental role of cochlear inner hair cells is to transduce these mechanical disturbance into neurochemical events. The neurochemical processes in turn, initiate a sequence of steps that give rise to impulses from fibres of auditory nerve. Studies have demonstrated that within the organ of corti, an active mechanical processes make use of metabolic energy to create additional microvibrations that enhance the sound induced motion of cochlear structure and increase the sensitivity and frequency selectivity of the ear (Davis, 1983; Johnstone, Patuzzi, and Yakes, 1986; Sellick, Putuzzi and Johnstone, 1982).

The cochlea activity thus produces energy as a part of the normal hearing process. Some of this added energy propagates towards the base of cochlea to the stapes footplate through the ossicles and into the external ear where it can be detected by a sensitive microphone (Kemp, 1978; Kemp, Braz, Alex, and Brown, 1986; Wilson, 1980). The sounds produced in this manner are called Otoacoustic Emissions (OAE).

The results of a considerable number of experiments and theoretical studies of OAE carried out since their discovery of (Kemp, 1978) indicated that emissions are produced as a normal by product of microchemical actions of the cochlear amplifier. The "cochlear amplifier" is thought to be situated in the outer hair cells (OHO which have been showed in vitro to be motile in response to high frequencies of electrical stimulation. The cochlear mechanical amplifier appear particularly vulnerable to physiological and physicaltrauma such as anoxia, exposure to ototoxins and loud noise (Anderson, 1980; Johnstone, et al. 1980; Sellick, et al. 1982). In actuality many forms of hearing loss are caused by a deficiency in the action of the cochlear amplifier, resulting in a corresponding reduction in the mechanical vibrations transduced by inner hair cells and thus a loss of hearing sensitivity. The results of a no.of contemporary studies indicate that reduction for loss of function of the cochlear OHC is typically reflected as a reduction (or) absent of OAE in the ear canal (Johnsen and Elberling, 1982; Kemp, 1978; 1982; 1988; Brown, 1984; Martin-Probst, Coats and Martin, 1987; Zwicker, 1983). Because hearing-impairment and OAE response are associated and because the measurement of OAE is both objective and noninvasive, OAE measurement represent a valuable techniques in diagnostic audiology.

CLASSIFICATION OF OAE : They are separated into two general categories -

1) Spontaneous otoacoustic emissions (SPOAE) : Occur in absence of any deliberate stimulation of ear and can detected in about 50% of all ears with normal hearing by sealing a sensitive miniature microphone into the external ear canal.

2) Evoked otoacoustic emissions : Occur in response to the presentation of acoustic stimulation to the ear consequently a sound source must also be sealed into the ear canal to prevent the sounds necessary for eliciting evoked emissions.

On the basis of the stimuli used to elicit evoked emissions (Lonsbury-Martin, Martin, Whitehead and Martin, 1990) have categorized OAE into 3 different subtypes.

	Notation	Stimuli	Prevalence (by ear)
a) Transient evoked otoacoustic emission	TEOAE	Click/tone burst	100%
b) Stimulus frequency otoacoustic emission	SFOAE	Continuous puretone	100%
c) Distortion product otoacoustic emission	DPOAE	a continuour pure tone	100%

Evoked otoacoustic emissions can be measured rapidly, accurately and with high resolution, permitting a very fine analysis of inner ear properties. Another important fact, is that, it is present in ears of essentially all normal hearing subjects and are reduced (or) absent in those affected by cochlear disorders. Also evoked emissions can be used to assess hearing in difficult to test patient (or) test-retest reliability in ears with normal (or) abnormal function. Another important feature of evoked emission makes them clinically useful is their specificity for testing micro mechanical activity of OHC's.

Among the evoked emission DPOAE have only recently been investigated as basis of an objective test of hearing impairment. DPOAE are evoked otoacoustic emissions evoked by the pure tone at frequencies F1 and F2 called primaries. DPOAE at frequency, 2F1-F2 is most prominent DPOAE in human ear, thus it explores the cochlear region at the frequency of geometric mean of Fl and F2 but necessarily involves a normal region at frequency of primaries.

The DPOAE as a clinical tool provides several advantages, hitherto not possible using other contemporary tools for the purpose. Martin, et al. (1990) listed the following advantages of DPOAE in addition to other advantages of evoked emissions.

1. DPOAE because of its continuous short latency nature, any frequency between 1 and 8 KHz can be tested intentionally.
2. Compared to other evoked emissions reasonably wide dynamic range of DPOAE in terms of growth response amplitude as a function of stimulus level permits a complete evaluation of cochlear function at both 'threshold' 'suprathreshold level' by stimulation, thus allowing use of it to study remaining OHC function in ear of patients demonstrating loss upto 45 to 55 dB HL.

3. Individuals with various" form of cochlear dysfunction that primarily affect OHC fine resolution of DPOAE audiogram accurately depicts boundary between ear normal and abnormal hearing with excellent frequency specificity.
4. Other application of DPOAE testing cases of Menier's disease, sudden SN hearing loss (or) acoustic neuroma have made use of proficiency of these emissions to distinguished more clearly site of primary pathology.

Acoustic distortion (distortion product otoacoustic emissions) are commonly measured using two protocols.

(1) DPOAE audiogram :

Frequency pattern of a ear's ability to generate acoustic distortion product is established by measuring emission amplitude as a function of geometric mean of two primary frequencies.

(2) Response/growth (or) input-output function :

In this protocol, a series of I/O function are determined at geometric mean frequencies that are related to the conventional audiogram by varying primary tone level in 5/10 dB steps for a range of dB SPL. Several qualitative features of emitted response can be determined from resulting curve including detection threshold, maximum amplitude, dynamic range, slope which relates the rate at which the emission grows as a function of increased primary tone level.

From clinical perspective both are useful -

(1) DPOAE audiogram appears to reflect the frequency configuration of the standard audiogram (Martin, et al. 1990).

(2) Detection threshold of I/o function apparently has a systematic relation to hearing level in many cochlear based disease (cohlms, Lonsbury-Martin and Martin, (1991)). The ADP threshold can be only determined from I/O function as the minimum intensity in which DPOAE is seen. However ADP level recorded consumer a lot of time making its clinical application limited.

Many variables including the intensity of primaries L1 and L2 have found to affect DPOAE. However, exact role of relative intensity of L1 and L2 is not clear. A few studies report that maximum DP amplitude occurs when L1 is greater than L2 (Gaskill, 1990). Others report that effect of intensity of primaries varies with geometric mean of primary frequencies. For primaries with geometric mean of 1000 Hz and 2000 Hz, the L1 should be 10 dB greater to give maximum DPOAE (Mansen, 1991). Certain studies show that L1-L2 difference to have minimal effect on DPOAE amplitude. Maximum DPOAE amplitude was found when L1=L2 except at 8000 Hz (Rasmussen, 1993).

The present study aims to measure input/output function (i.e.) growth of distortion product response across frequencies using two different protocols.

The following were the aim of the study :

1. To obtain input and output function of DPOAE for young adults. i.e. get specific information about the detection threshold, maximum output and slope of growth function.
2. To study if there is any change in I/O function with variation in relative intensity of primaries L1 and L2.
3. To Study if there is any change in maximum amplitude of DPOAE with variation in relative intensity of primaries L1 and L2.
4. To compare the detection thresholds in males and females to ascertain if there is any significant different between two groups.

REVIEW OF LITERATURE

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

A review of literature shows that though OAE was discovered by Kemp in 1978, as early as 1948, Gold had proposed that "a purely passive basilar membrane filtering action was not sharp enough for frequency selectivity". He further suggested that an active biomechanical cochlear feedback was responsible for sharp frequency selectivity. This was the first suggestion towards explaining that the ear was not merely a passive organ. However discovery of OAE is attributed to Kemp, at the Institute of Laryngology and Otology, London in 1978. He reported that on presenting brief broad spectrum sound stimuli to the ear, the ear emitted another sound of similar spectra but of very small intensity. Initially, these were thought to be echos of the stimulus and were labelled as "Kemp's Echos". However, over the years, it has been confirmed that these sounds are not echos but sounds emitted from the ear.

The source of the OAE is believed to be the OHC which were demonstrated to be electromotile (Brownell, 1983).

Later, OHC was demonstrated to be motile to pharamacologic stimulation (Scepecky, 1988) and also to acoustic stimulation (Brundiv, et al. 1989). The cause of such motility of the OHC was earlier believed to be due to the presence of action and myocin in the sterocilia (Tilney, 1980; Mac.Cartney, 1980). However, it has now been established that the mobility of the OHC is due to volume changes in the OHC by the movements of ions and not due to action and myocin fibres (wilson et al. 1980). OHCs contract and elongate at rates which no muscle fibre is capable of. This has been confirmed by studying the changes in OHC following electrical stimulation (Ashmore and Brownell, 1986). Further, OHC movement occurs as a direct conversion of electrical potential energy to mechanical energy. This was demonstrated by the presence of OHC movement even after the depeletion of cellular stores of "Adenosine Triphosphate" ATP (Brownell and Kachav, 1986). Thus it has been suggested that if the OHC length changes are rapid enough, they may be responsible for the OAE (Davis, 1983; Schloth and Zewicker, 1984).

Distortion product OAE arises due to the fact that ear is not a linear system. DP emission were first demonstrated in human ears by Kemp et al. (1979). Distortion product are produced by normal cochlea when two sinusoids slight different in frequency are simultaneously presented to the ear (Lonsbury-Martin and Martin, 1990; Lonsbury-Martin, et al. 1991). Distortion is generated by nonlinear elements in the process involved with the ear (Bekesy, 1960). The presence of a distortion product was first postulated by Hall (1974). However for a no. of years, it was not realized that the distortions could be picked up by the TM (Kemp, 1984). Gold (1967) was one who initially proposed the basilar membrane was source of the processes that generated distortion in the form of a third response frequency, not present in a two stimulus eliciting complex. DPOAE consist of acoustic energy at specific frequency that are detectable in a spectrum of ears signal. In DPOAE, frequency of two eliciting stimulus F1 and F2 are called primary frequencies or tones. In human ears, as well as in animal species, third order intermodulation distortion product at the frequency of 2F1-F2 is prominent distortion product, whether examined perceptually as so called combination tone or acoustically as an emission.

Prevalence

There is growing evidence that DPOAEs are property of all normal hearing human ears although this was not generally acknowledged in literature (ex. Furst and Lapid, 1988).

However, according to findings of several systematic studies (Harris, 1990; Harris, Lonsbury-Martin, Stagner coats and Martin, 1989; Lonsbury-Martin, Harris, Hawkins, Stagner and Martin, 1990) they appear to be property of all normal hearing individuals over a frequency range extending from about .5 to 8 KHz. Studies down by Kemp et al. (1986) and Lonsbury-Martin et al. (1990) indicate that DPOAE can be recorded in well over 90% of normal ears. There by product of normal linear cochlear function are reduced or absent in ears with hearing loss compared to ears with normal hearing. (Kinberly and Nelson, 1989; Martin et al. 1990; Gorga, et al. 1993). Indeed animals with significant amount of hearing have been shown to produce DPOAE (Norton and Rubel, 1990; Whitehead et al. 1992). DPOAE measurement perform best for moderate level of stimulation across wide range of primary frequencies (Storev et al. 1996) .

According to Moulin, Bera, Collet (1994), more than 90% of normals presented a 2F1-F2 of DPOAE at all frequencing (except 500 Hz) for primary levels 60-80 dB SPL. According to them at lower primary levels (40-50 dB SPL) percentage falls respectively to 40-50%. For 500 Hz, DPOAE presence reached only 40% at 70 dB SPL of primaries. Thus added that for DPOAE frequencies ranging .5 to 1 KHz, No DPOAE were recorded with hearing loss greater than 30 dB HL at "lower frequency. However high frequency DPOAE where recorded with hearing loss than 45 dB HL at frequency around 2F1-F2 and primary frequencies. Thus all normal hearing ears demonstrated detectable DPOAE provided that primary tone level was above a certain level. Hearing-impaired ears produce substantially reduced DPOAE compared with normal hearing subjects where primary frequencies F1 and F2 correspond to region of hearing loss (Smurzynki, etal. 1990). According to Lonsbury-Martin etal. (1990) two possibilities might account for a near's inability to generate DPOAE (1) frequency specific anomalies in the forward and/or reverse middle ear transmission of acoustic signal (2) subclinical pathological changes in cochlea or middle ear.

Age affects OAE measurement at least during earliest stages of life (Norton and Widen, 1990; Prieve, 1992; Bergman, et al. 1995). Effect may be result of difference in transmission characteristic of external and middle ear, different in size of cavities in which signal are delivered and response are measured or perhaps even difference in cochlea generation of DPOAE as a function of age (Gorga, Stover, Neeleg, Darielle, Montoga, 1996).

Gaskill and Brown (1990) found DPOAE were significantly large in females than male volunteers for majority of frequencies they tested. In older volunteers (31-60 years with normal hearing) Lonsbury-Martin. Cutler and Martin (1991) reported female volunteers had large DPOAE than male at frequencies 2000-8000 Hz. The factors that had lead to these results may be

1. Better auditory threshold in females than males (McFaden, 1993; Lonsbury-Martin, 1991).

2. Anatomical difference in cochlear length might also inferentially influence (Kimberley, 1991, Brown and Eggermont (1993) and Sato, Sando and Takanashi (1991).

3. According to Bilger, Mathies, Mammel and Denaret (1990); Talmadge, Long, Murphy and Tubis (1993). SOAE are more prevalent in females than male in right ear in comparision to left ear. However mere presence of SOAE in frequencies region of 2F1-F2 DPOAE cannot be taken as evidence for amplitude enhancement of response (Lonsbury-Martin, Harris, Hawkins, Stagnev and Martin, 1990). Even though some investigators (Cianforne, Mattia, Altisma and Turchetta, 1996; Weir, Pasanent and McFaden, 1988) under

certain experimental condition have provided example that the DPOAE can be enhanced when recorded within close proximity of a SOAE (typically within +/- 50 Hz). In contrast to broad band width over which gender effect on DPOAE has been reported (William et al. 1996; Gaskill and Brown, 1990; Lonsbury-Martin et al. 1991; Morgan, et al. 1993) only found significant gender effect on DPOAE at a single 2F1-F2 frequency (2000 Hz) for each of 3 primary stimulus level 50, 60, 70 dB SPL. According to them gender effect is strongly reduced when only SOAE negative subjects are considered.

DPOAE and its characteristics :

I. Frequency range :

Frequency range within which acoustic distortion product are reliably detected is between 1 KHz and 8 KHz with respect to geometric mean of F1 and F2 stimuli. DPOAEs absence at low frequency (such 500 Hz DPOAE and to lesser degree 760 Hz DPOAE) can be easily attributed to an increase in noise floor. Indeed NF is significantly greater at these low frequency than at high frequency (Avan and Bonfils, 1993). They added saying that DPOAE can explore large frequency range than TEOAE. DPOAE can be induced at any choosen frequency including 6 and 8 KHz whereas spectrum of clicks used to elicit TEOAE markedly decrease above 4.5 KHz. Study done by Gorga et al. (1993) shows at 2 KHz all OAE performed equally well but at 4 KHz DPOAE was better to distinguish between normal and impaired. At 500 Hz both TEOAE and DPOAE were unable to separate normals from impaired ears.

II Amplitude - Studies done in normal and animals.

Its dependent upon on several parametric factors including level and frequency of primaries, their frequency separation or ratio and the inmate properties unique to each ear. In humans, DPOAE response have a dynamic range of approximately 40 dB HL (Lonsbury-Martin, et al. 1990). Amplitude of distortion product depend or optimal transmission through middle ear and that measurement of DPOAE should be always preceded by determination of middle ear pressure (Osterhammel, et al. 1993). A change in DPOAE amplitude of more than 6-9 dB depending upon stimulus intensity would indicate a significant change in cochlear status if rendering condition and middle ear status are stable. DP amplitude is affected rather more by negative ear canal pressure (5 dB/100 dapa) than by positive pressure (2 dB/100 dapa). Thus many different variables influence amplitude of DPOAE in humans. The subject related factors include variability (Gaskill and Brown, 1990), integrity of middle ear (Lonsbury-Martin et al. 1990), Norton and Widen, 1990; Noeve et al. 1992; Osterhammel et al. 1992) and integrity of cochlea (Kinberleg, Nelson, 1989; Martin et al. 1990; Probst and Mausen, 1990; Sumurzynski et al. 1990). Other variables are interaction of other type of OAE (Lonsbury-Martin et al. 1991; Probst et al. 1991), overall level of primary tone (Lonsbury-Martin et al. 1990), the relative level of primary tone (Schlolk, 1982; Gaskill and Brown, 1990; Hausen and Probst, 1991; Rassmussen, etal. 1993) and variety of measurement variables such as noise floor of the measurement system and procedural factors (Whitehead et al. 1993).

a) Relation to other otoacoustic emissions ;

It has been well demonstrated that within an individual ear, SOAE, TEOAE or SFOAE influence DPOAE amplitude (Kemp, 1979; Wilson, 1980; Wite et al. 1981; Schlotn, 1982; Kemp and Brown, 1983; Burns et al. 1984; Kemp, 1986; Furst et al. 1988; Weir, et al. 1988). Generally a strong enhancing effect on DPOAE amplitude was found at or near by the frequency of other emissions. However this influence has been shown to decrease with increasing stimulus level (Kemp and Brown, 1983; Kemp, 1986; Wier et al. 1988) and with increasing F2/F1 ratio (Wilson, 1980; Kemp, 1986; Furst et al. 1988). If DPOAE lies within the frequency region of SOAE or SFOAE, then the amplitude of the DPOAE may be increased so that it lies only 10-20 dB SPL lower than the intensity of the eliciting stimuli (Wit et al. 1981; Schotn, 1982; Furt et al. 1988). The presence of SOAE and SFOAE in irregular ears indicated that emission generation and reverse cochlear transmission were operating normally within region of reduced DPOAE. Simultaneous presence of SFOAE but not SOAE appeared to reduce detection threshold and increase amplitude of low frequency DPOAEs.

(b) Post-mortem properties

Schmiedt and Adams (1981) found persistent DPOAE with nearly stable amplitude up to one hour after death. Kemp and Brown (1984) consistently measured amplitude reduction of more than 20 dB within in 5-6 minutes after death. Both sets of experiments were conducted in same species, the gerbil and on same DPOAE at 2F1-F2.

(c) Influence on efferent stimulation

The influence of efferent stimulation of crossed cochlear efferent fibre or DPOAE was reported by first

Mountain (1980) and Siegel and Kim (1982). Mountain (1980) detected a reduction in DPOAE amplitude at F2-F1 in guinea pig that reached values of about 70%, and was most pronounced in response to response to low level stimuli. Recent evidence, anasthaesia was demonstrate to have major effect by itself on DPOAE at F2-F1 (Brown, 1988) an effect that may be mediated by efferent inherent.

(d) Relation to OHC

A number of findings suggest DPOAE are intimately linked to OHC functioning. These findings include demonstration change in DPOAE amplitude with stimulation of cochlear efferent fibres and acoustic stimulation. Both manipulation are known to primarily affect OHCs. Specificity of DPOAE for assessing OHC function uniquely permits their use as assessor of the consequence of experimental manipulation or the most fragile sensory receptors.

(e) F2/F1 ratio :

Based on high level stimulation, the optimal ratio i.e. ratio of primaries yielding maximum distortion product in humans is found to be 1.22 (Harris et al, Lonsbury-Martin et al. 1989; Bonfills et al. 1991). The most optimal ratio according to Brown and Norton (990) is 1.15. Nelson et al. (1993) opine that F2/F1 ratio between 1.20 and 1.25 provide a reasonable values for clinical use in that it optimizes the magnitude of distortion product at 2F1-F2. Gaskill et al. (1990) views that frequency ratio F2/F1 where DPOAE is maximum varies only slightly across frequencies and subjects. Average optimal ratio he gave was 1.225. Wilson (1980) demonstrated that largest amplitude occurred with F2/F1 ratio between 1.1 and 1.2. A recent study (1996) done on leghon chickens indicated that at highest primary tone level (80 dB SPL) there was decrease in CDT (Cubic difference tone) i.e. 2F1-F2) with increasing F2/F1 ratio. At higher primary tone level, F2/F1 ratio which produced largest CDT was 1.05 or 1.1 while at lower primary tone level, largest CDT occurred at F2/F1 ratio of 1.2 - 1.3. This contradicated Wilson (1982) study where largest CDT amplitude in humans occurred with 5-40 dB SPL primary tone at an F2/F1 ratio of 1.1 - 1.2. This suggest that F2/F1 ratio producing largest CDT amplitude increases with increasing level which contradicts these results of the previous investigation on chickens. In cats, Kim (1980) found the optimal ratio of F2/F1 was 1.3 - 1.4 while in rabbits, largest CDT amplitude observed on F2/F1 of 1.2 - 1.4 (Lonsbury-Martin et al. 1987; Whitehead et al. 1982). As F2/F1 ratio of 1.2 -1.3 was found to be most effective in gerbil (Kemp and Brown, 1984), cat (Wiederhold et al. 1986), Mouse (Horner, et al. 1985), rabbit (Lonsbury-Martin et al. 1987) and rats (Henleg et al, 1988). The higher frequency primaries require lower ratio for the generation of DPOAEs with maximal amplitude compared to those lower frequencies.

As now, there is no clear consensus as to what is the best optimal ratio or clinical use (Norton and Storer, 1994). Beyond an optimal ratio, the amplitude of DPOAE falls at a rapid rate (Gaskill, 1990) and also small F2/F1 ratio elicits combination tone that is louder than those evoked with widely spaced primaries.

(f) L1 and L2 level :

DPOAE amplitude in human ears are usually about 60 dB less than that of primary tone level (Schoth, 1982; Kemp and Brown, 1983, Brown and Kemp, 1984; Kemp et al. 1986).

Intensity of primaries of L1 and L2 also affect DPOAE. Lower level of primaries elicit a local response and thus gives frequency specific information. At higher level, the response is more complex and nonlocal (Avan, 1993).

Investigation by Burkard, et al. (1996) shows that increasing L1 there were nonmontonic CDT growth functions for F1 frequencies of 1.6 and 2.0 KHz. These nonmontonic function were characterized by plateau region for L1 = 65-70 dB SPL. Similar results were found by Whitehead et al. (1990) for rabbits Quote Harris et al. (1991) study.

Lisa stover et al. (1996) found DPOAE amplitude in response to moderate level of primaries (L1/L2 = 60/50) had greatest predictive voice, they did not examine high level stimuli and studied for F2 frequencies 1025 to 571 Hz. Results of the study done by Norton and Rubel (1990), Whitehead et al. (1990) suggested that high level stimulation might unpredict hearing loss, roll over effect in test performance at higher stimulus were not large. The use of unequal primaries may have also reduced roll over effect seen as compared to data obtained with equal level primaries. Presence of DPOAE produced by higher level stimuli may not correspond well with hearing sensitivity. DPOAE generated with lower level pure tone may correlate with audiometric results (Harris et al. 1991).

Investigations by Widerhold et al. (1983) in animals and Schoth (1982) in human ears showed that primary tone level are most effective when L1 is 5-10 dB greater than L2.

According to Brown (1987) and Whitehead et al. (1990) level of primaries are important in that F1 amplitude of at least about 10 dB greater than F2 evoke largest DPOAE. Rossmussen et al. (1993) found reduction of DPOAE with reduction of L1 was linear at a rate that gradually increased as frequency of geometric mean increased. Gaskill et al. (1990) showed as level of one stimulus is increased relative to other DPOAEs growth saturate and in most cases show bend over.

Investigation done by Hanser et al. (1991) showed maximum amplitude of distortion product were generated when L1=L2 at all geometric centre frequency except 8 KHz and to a lesser extent, reduction of DPOAE with reduction of L1 was linear but at a rate that systematically decreased as a function of geometric mean frequency.

According to Lisa Stover et al. (1996) L1/12 = 65/55 level represent midpoint of fielding maximum performance. With exception of 500 Hz, DPOAE were able to separate normal and impaired at all frequency. Whitehead (1995) opine that even 5 dB difference in L2 can make difference in overall test performance. Whitehead et al. (1990)) and Burkard et al (1996) found CDT amplitude largest when L1 was 5-10 dB greater than L2. In cats Widerhold et al. (1986) obtained similar results. The exact role of relative intensities of L1 and L2 is not clear. A few studies report that maximum DP amplitude occurs when L1 is greater than L2 (Gaskill, 1990; Rassmussen, et al. 1993). Other report that effect of relative intensity of primaries varies with geometric mean of the primary frequencies, for primaries with geometric mean of 1000 Hz and 2000 Hz, L1 should be greater than L2 by 10 dB to give maximum DPOAE (Hanser, 1991). Certain other studies have found L1-L2 difference to have minimal effect on DPOAE amplitude. Maximum amplitude was found when L1=L2 except at 8000 Hz (Rassmussen, 1993). Thus the question of optimal stimulus level for clinical DPOAE measurement remains unanswered.

III DPOAE studies in estimation of hearing loss

DPOAE have been found to correspond well with behavioural audiometric threshold (Harris, 1990; Probst and Harris, 1993). An elevated behavioural threshold corresponds to a reduced dB amplitude if the stimulus parameters are kept constant (Harris, 1992; Lonsbury-Martin, 1997). It can thus differentiate between normal hearing and hearing loss patients (Martin 1990; Smurzyski, 1990). DPOAE may indicate hearing difficulty which may go undetacted by conventional audiometry (Gaskill and Brown, 1992). Harris (1990) systematic result of 20 patients with high frequency hearing loss DPOAE were reduced in amplitude or were absent in ears with high frequency hearing loss. Harris concluded that if hearing loss at predetermined frequency were better than 15 dB HL, DPOAE were always detected. However emission were absent/attenuated if behavioural threshold exceeded 50 dB study of both normal and patients with unspecified SN hearing loss, as excellent correlation between DPOAE amplitude, auditory threshold was obtained (Kinberles and Norton, 1989). According to Martin et al. (1990) ability of DPOAE to assess sensory component of sensori-nerual disorder may contribute to eventual understanding of the complicated pathogenesis of many cochlea disorder. Hearing-impairment produced substantially reduced DPOAE amplitude compared with normal hearing subjects when primary frequency F1 and F2 correspond to region of hearing loss. According to Roede et al. (1993) change in DPOAE amplitude of more than 6-9 dB depending upon stimulus level would indicate a significant change in cochlear status if rendering condition and middle ear status are stable.

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

According to Gorga et al. (1990) efficiency of DPOAE in differentiating between normal hearing and hearing-impaired subject is high at frequencies above 1000 Hz and also presence of DPOAE elicited by high stimulus intensity was found to be a reliable measure of hearing loss as that of elicited by low stimulus intensity.

Research on effect of ototoxicity and aging or DPOAE is much limited as compared to TEOAE. Results of Lonsbury-Martin (1991) tend to indicate that these factors lead to a reduction of dp amplitude. The ability of DPOAE to selectivity test specific frequencies region on BM make it highly suitable for studying effect of external noise, ototoxin, aging, viral and bacterial pathogenesis etc. on the cochlea (Martin, 1980).

Other important uses for DPOAEs involve repeated measure designs in which individual are monitored for change in cochlear function from a measured baseline. Knowing if alteration in cochlear function occur after administering aminoglycoside antibiotics or chemotherapeutic drugs, during the course of acoustic tumour surgery or following occupational noise exposure, would beneficial for identifying frequency specific early warning signs of toxicity and/or cellular damage before such effects become permanent (Brown, McDowell and Forge, 1989; Hellstrom and krist, 1994; Harris and Hauser, 1993; Telischi, Widick, Lonsbury-Martin, McColy, 1995; Zorowka, Schmitt and Guttahr, 1993). Repeated measurement procedures may also be helpful in the diagnosis and management of endolymphatic hydrops (Menier's disease). Martin, Stagnar, Coats and Lonsbury-Martin, 1989) , in the management of acoustic tumors {Telischi, Roth, Stagner, Lonsbury-Martin and Balkary, 1995) and in helping to understand better the effects of acoustic tumour surgery on auditory function (Olsen, et al. 1992).

Response growth function/response slope function of DPOAE :

DPOAE detection threshold is defined as lowest intensity of primary frequency which elicits DPOAE. DPE threshold will be able to predict abnormal auditory sensitivity. I/O function is useful in helping to interpret DP gram and I/O function could be thus secondary test to be used when there are anomalous results from DP gram (Lisa stover et al. 1996). Detection threshold apparently has a systematic relation to hearing level in many cochlear based disease (Ohlms, and Lonsbury-Martin and Martin, 1991), shape slope of DPOAE I/o function and maximum CDT level are strongly influenced by F2/F1 ratio and relative L1 and L2 (Burkara Saliva and Chev, 1996). Several studies have provided evidence that DP detection threshold measures derived from DP growth function may be useful indication of status of the cochlea (Wilson 1980; Scholth 1982; Wier et al. 1988). It has been reported that detection threshold ranged fromm 30 - 70 dB SPL in normals and were typically higher in frequency region with sensori neural hearing loss. (Kimberley and Nelson 1989; Lonsbury-Martin et al. 1990; Leonard et al. 1990 and Martin et al. 1990). Detection threshold for DPOAE depends almost entirely on the noise floor and sensitivity of the measuring equipment (Lonsbury-Martin et al. 1990).

DP I/O function typically has 2 separte portions

(1) A saturating portion betwen DP detection threshold, the stimuli level around 60 dB SPL

(2) Steeper linear portion for stimulus level above 60 dB SPL (Bonfills, et al. 1984). Rate of growth of around 1 dB/dB for lower level stimuli was seen but then saturated for stimulus level greater than about 50 dB SPL.

Wit and Ritsma (1979) and Rutter (1980) found input-output function of peak-peak amplitude of response are nonlinear and saturation appear at higher intensities study done Schloth (1982) and Wilson (1980) reported the following that growth rate were often non-monotonic at intermediate level, when magtitude of dB level led off. There were sharpe notche in input function at particular primary tone frequency between 1.4 - 2.8KHz. For both 2 F1-F2, and 2F2-F1, these critical slope varied from .4 to 1.3 dB/dB averaging around 8 dB/dB in respective of primary tone frequency. At primary tone level exceeding the plateau notch region (50-60 dB SPL). Input-output function tended to grow at much faster rate. Lonsbury-Martin and Martin (1990) reported that input-output slope of DP at low level in bobtail lizards ear canal are near/below 1 dB/dB at least primary tone. In humans, the input-output slope for equal level primary tone ar 9 dB/dB (Gaskill, and Brown, 1990). But they seem to be frequency dependent ranging from 4 dB/dB at low frequency and about 1 dB/dB at high frequency (Lonsbury-Martin, and Martin, 1990).

Study done by Nelson and Kinberley (1992) showed that in mammals the growth of intput-output function varied with frequency. At 1 and 2 KHz, the growth was linear betwee 30 and 40 dB, with slope of 1.3 and 1.4 dB/dB respectively. At 4 KHz the input-output function grow linearly up to 60 dB with slope of 1.05 dB/dB. The growth in amplitude more gradual at the higher level, sometimes reaches plateau. At 8 KHz the growth in amplitude was linear across entire range of level with slope of 1.32 dB/dB, Lonsbury-Martin et al. (1990) studied input output functionin sensorineural hearing loss patients found input - output function become more linear with steeper slope. It was also found that hearing threshold above 30 dB HL, also become linear without any saturating portion.

During detection threshold estimation, one of crieteria to decide whether recorded response is emission, response should be + 3 dB above noise flow (Vandijik et al. 1987). Lonsbury-Martin et al. (1990) reported detection threshold that were 3 dB above noise floor at about 35-45 dB SPL for DPOAE between 1-8 KHz. Test was done at 2 equilevel PTS (L1=L2) threshold.

Study done by Bonfils et al. (1991) using 2 PTS of equilevel. He studied 18-28 years normal hearing individual the DPOAE input output functions presented 2 separate portion with a DPOAE detecting threshold at 30 dB SPL and above 66 dB SPL, a linear portion. With DPOAE below 512.5 Hz, no more saturating plateau could be observed.

Studies done by Moulin, Bera Collet (1994) on normal hearing adults found that mean detection threshold obtained at all frequency except at 500 Hz ranged between 45 dB and 50 dB SPL. It was 61.7 dB SPL for 500 Hz. They further reported that DPOAE detection threshold were significantly, higher in sensori-neural hearing loss for each frequency except for 500 Hz DPOAE. Detection threshold increased with hearing loss and also they found that standard deviation of mean hearing threshold increased too, at high primary levels.

I/O function for DPOAE in animals generally show 1 or 2 forms that is I/O curve are more or less linear with a slope of 1 and a saturation at stimulus level of about 70 dB SPL or they have monotonic dip at stimulus level of 60-70 dB SPL. Such reports have been reported for cat (Kim, et al. 1980) Widerhold, et al. , Chinchilla (Zurek et al. 1982), Gerbil (Kemp and Brown, 1983; Brown, 1987), Mouse (Hornar et al. 1985; Katz et al. 1989), rat (Brown, 1987; Lenon and Paul, 1987; Heneley, et al. 1989), guinea pig (Brown, 1987) and rabbit (Lonsbury-Martin et al. 1987; Whitehead et al. 1991). However exact shape of specific function depend on particular dp under study, the frequency range of primaries and F2/F1 ratio.

Rassmusen et al. (1990) opine that the sensitive thresholds appears at an F2/F1 level of about 60 dB SPL. The presence of a monmonotic input-output function may lead to seemingly paradoxical result if threshold are varied to example through acoustic over stimulation and if onlysingle level measurements are taken. Arise in threshold over TTS may lead to shift in intput output function in right (e.g. to less sensitive positions, thus a dipcould become a peak). Detection of thresholdd for DPOAE at 2F1-F2 is a function of noise flow of measuring system. Noise flow varies considerably with frequency with significant higher noise flow at lower frequency (500 and 706 Hz) than at higher frequencies (Moulin, Jean, Bera, Collet, 1994). In common laboratory animals, threshold can be expected at primary level of 20-40 dB SPL assuming a noise flow of about -10 dB SPL and DPOAE amplitude of 30-40 dB less than stimulus level. Nonmonotonic dips have been observed more often for primaries in higher frequency range and with lower F2/F1 ratios study done by (Burkard, Salvi and Chev, 1996) showed that for some F2/F1 ratio, nonmonotonic I/O function observed sometimes.

majority of these occurred at larger F2/F1 ratio and intermediate Fl frequencies. However some non-monnotonic input output function observed at small F2/F1 ratio but only at low and high Fl frequencies. Groy Monvich et al. (1991) reported monotonic DPOAE I/O function for a range of L1 frequncies when using f2/fl ratio of 1.2. Two different mechanism are thought to be responsible for generation of dips.

1. Phase cancellation between 2 or more acoustic components (Zwicker, 1980; 1986; Schniedt, 1986; Brown, 1987).

2. Suppression of the distinct level dependent distortion product components (Rosowski, et al. 1984; Brown, 1987; Lonsbury-Martin et al. 1987; Whitehead et al. 1990). Phase cancellation is more likely to appear at low F2/F1 ratio and such cancellation can occur between waveform of the primaries or between depend primary tones with regards to superimposition of the level dependent components several lines of evidence suggest that DPOAE consist of low level component associated with linear growth at low stimulus level to a saturation at about 60 dB SPL along with high level component with a steeper scope that is characteristic of power series. Theoretically the

superposition of the components could create dips at stimulus level of about 60 dB SPL. The presence of a nonmonotonic I/O function may lead seemingly paradoxical result if threshold are varied tor example through acoustic overstimulation, if only single level measurements are taken. Arise in threshold due to TTS may lead to shift in I/O function to the right or to less sensitive position a dip could become thus a peak.

All the experiments conducted to find out DPOAE detection thresholds have used primaries L1 and L2 to be equal.

However, there is evidence in literature that variations in relative intensity of primaries might affect DPOAE amplitude. A few studies have reported that maximum DP amplitude occurred when L1 is greater than L2 (Gaskill, 1990; Rasmussen, et al. 1993).

It is essential that I/O function of DPOAE be measured under optimal conditions. Hence, it is necessary to determine which stimulus conditions provide the best DPOAE response.

METHODOLOGY

This study was taken up with an aim of finding the input and output function of distortion product otoacoustic emissions (DPOAE) in young adults using two different protocols.

a) at L1=L2 level where L1 and L2 refers to the intensities of stimulus frequencies.
b) at L1 greater than L2 level, L1 > L2 by 10 dB.

I SUBJECTS

Fourteen volunteers in the age range of 17-24 years with a mean age of (19.9) were as subjects for the study. Equal number of males and females were tested.

Other criteria for subject selection were -

a) Pure tone hearing threshold less than 25 dB HL in frequency range of 250 to 8000 Hz.

b) Normal middle ear functioning, as ascertained by using the immittance audiometer.

c) No history of any otological or neurological problems.

II EQUIPMENT

The following equipment were used in the study.

a) Pure tone audiometer

A two channel clinical audiometer (Orbiter 922) was used to assess the behavioral thresholds. The audiometer was calibrated prior to the study. The earphone used was TDH-39 housed in MX/4'/ear cushion.

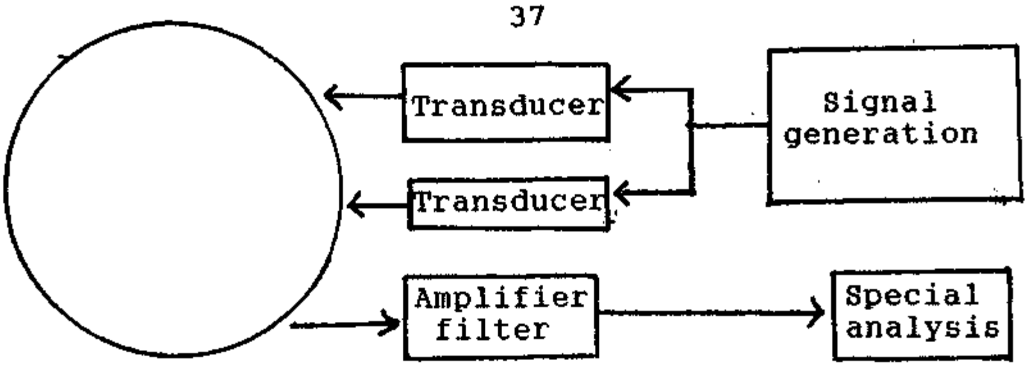
b) Immittance audiometer

A screening immittance Siemens Hand Tympan Z3002 was used to assess the middle ear function of the subjects.

c) DPOAE measuring system

Madsen Celesta 503 Cochlear Emission Analyzer was used for the study. This instruments allows user specification for stimuli and response measurement to be used in testing for a number of parameter.

Fig. 3.1



Schematic Diagram of Instrumentation of Measure DPOAE

For the present study, the following parameters were set-up and used.

1. Display type

The 'display type' controls the pattern of measurement. Since the basic purpose of the study was to get a input and output function curve of DPOAE, display was set to "input/output display". This setting plots growth of distortion products response at a single frequency for a variety of input levels of the two primary tones.

2. F2/F1 Ratio

Celestra 503 has a default ratio of 1.22.

3. L1 and L2 level

This refers to the intensities of the stimulus frequencies. Two different intensity levels were used.

(1) L1 is equal to L2 level i.e. L1=L2
(2) L1 is 10 dB greater than L2 level (i.e. L1 > L2

4. S/N ratio : It is one of the criteria for determining when to stop averaging a frequency at different intensity levels. Measurement was stopped at a level where S/N ratio was less than +3 dB.

5. Accepted sweeps : Celestra 503 has a default value of 1000. When averaging at a particular frequency reached 1000, instrument automatically plots down the level of signal and noise at that particular intensity level.

6. DP frequency : It refers to the frequency of emission. Measurement was done at 2F1-F2 relating.

Table 3.1 Showing frequency (in Hz) (Fo, Fl, F2, 2F1-F2)

F1	F2	F0	2F1-F2
452	553	500	351
910	1112	1006	708
1819	2223	2011	1415
2651	4462	4036	2840
7312	8937	8084	5687

III TEST ENVIRONMENT

The test was carried out in a sound treated room. The test room had adequate lighting and was at a comfortable temperature. The subjects were provided with a comfortable chair to sit on during the test. Since this is an objective test, the subjects were not required to do any task.

IV TEST PROCEDURE

All volunteers were first screened for their pure tone thresholds in both ears using a 2 channel clinical audiometer (Orbiter 922) . The AC frequencies were tested from 500 Hz to 8000 Hz. Any volunteers with thresholds greater than 25 dB HL at any frequency were not takenup for the study.

Subjects who had thresholds within 25 dB HL were then tested for tympanograms and acoustic reflex in both ears using an immittance audiometer (Siemens Hand Tympan Z3002). Only subjects who had 'A' type tympanogram with acoustic reflex were tested further.

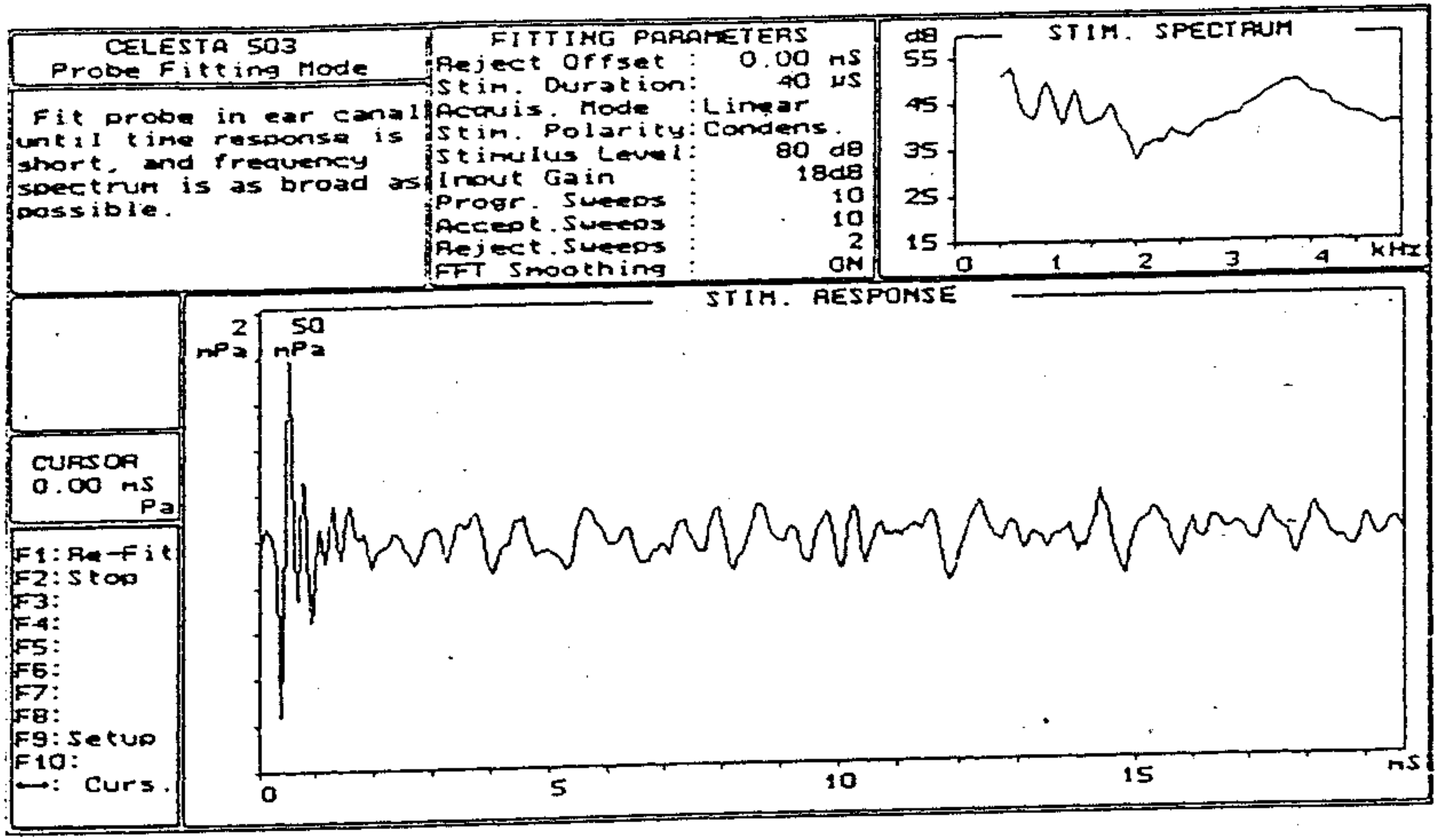
Subjects who fulfilled both of these criteria were studied for their distortion product otoacoustic emissions. In the 14 subjects, right or left ear of the subjects were selected randomly and tested under two different intensity conditions described earlier. Thus 2 test were done on each subjects were. Each test consist of 2 phases which was done in following order.

1. Checkfit :

In this phase, a transient stimulus (frequency sweep) was presented to the ear and the measured response was displayed as a spectrum and a waveform. A correct probe fit would give a waveform (Fig.32. It such a waveform was not obtained the probe was taken out, checked for debris and refitted. The check fit phase was redone to obtain correct fit.

2. Measurement :

This was the main phase of the test. Here amplitude of DPOAE was measured at different intensity for each frequency in accordance with the parameters described earlier. The instrument automatically reduced the intensity of the stimuli in steps of 10 dB from 70 dB. Emissions at each level was also plotted automatically by the instrument. The testing was continued to obtain the lowest level where dp emissions were +3 dB above the noise floor. This gives the detection threshold at that particular frequency. The frequencies tested were 8 KHz, 4 KHz, 2 KHz, 1 KHz and 500 Hz. The measures were then displayed as "input/output displacy" where growth of distortion product response at a single frequency for a variety of input levels of primary tone.



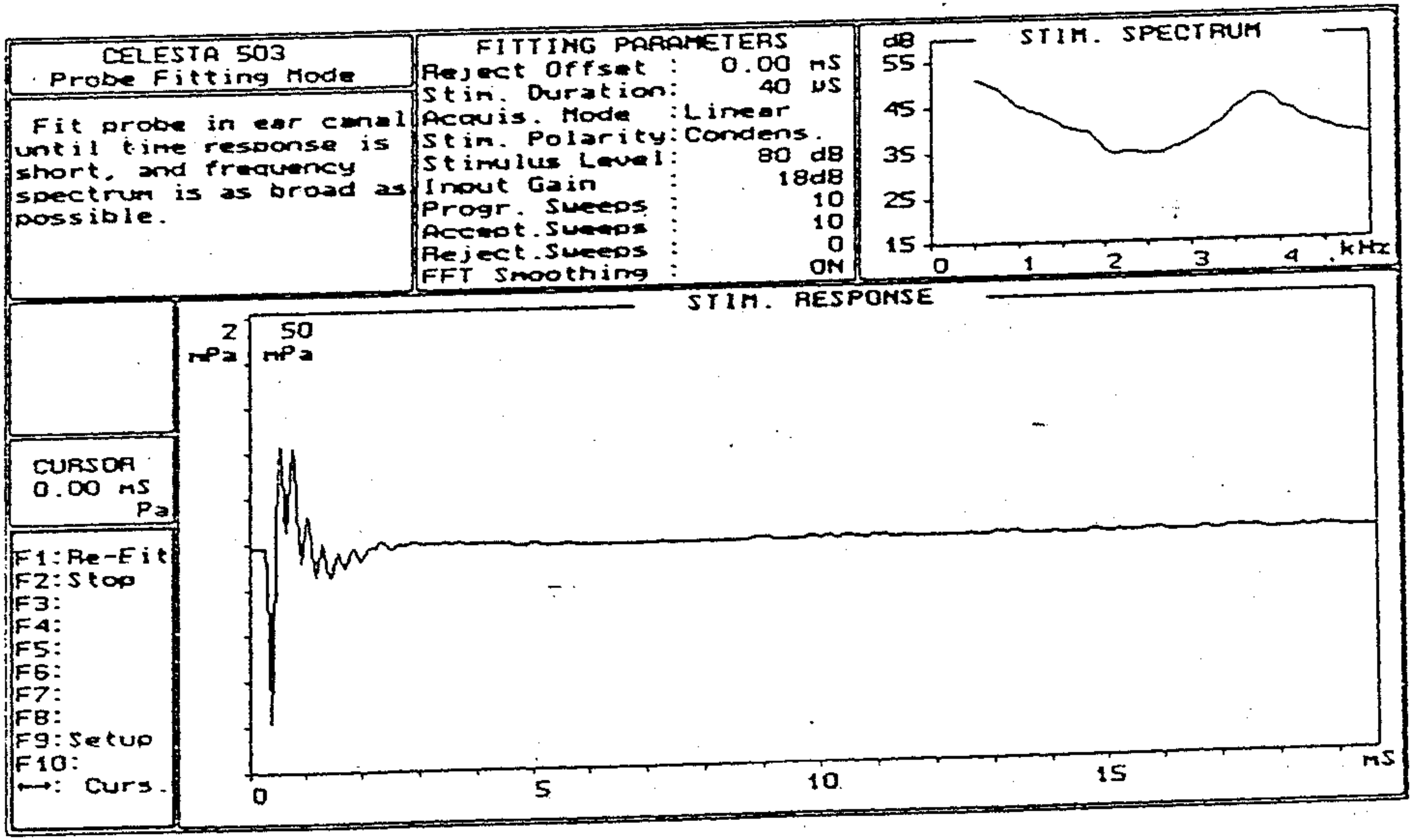
CELESTA 503
Probe Fitting Mode

Fit probe in ear canal until time response is short, and frequency spectrum is as broad as possible.

FITTING PARAMETERS
Reject Offset : 0.00 mS
Stim. Duration: 40 µS
Acquis. Mode : Linear
Stim. Polarity: Condens.
Stimulus Level: 80 dB
Input Gain : 18dB
Progr. Sweeps : 10
Accept.Sweeps : 10
Reject.Sweeps : 2
FFT Smoothing : ON

CURSOR
0.00 mS
Pa

FIGURE 3.1 - AN 1U *FITTINF PROBE*



CELESTA 503
Probe Fitting Mode

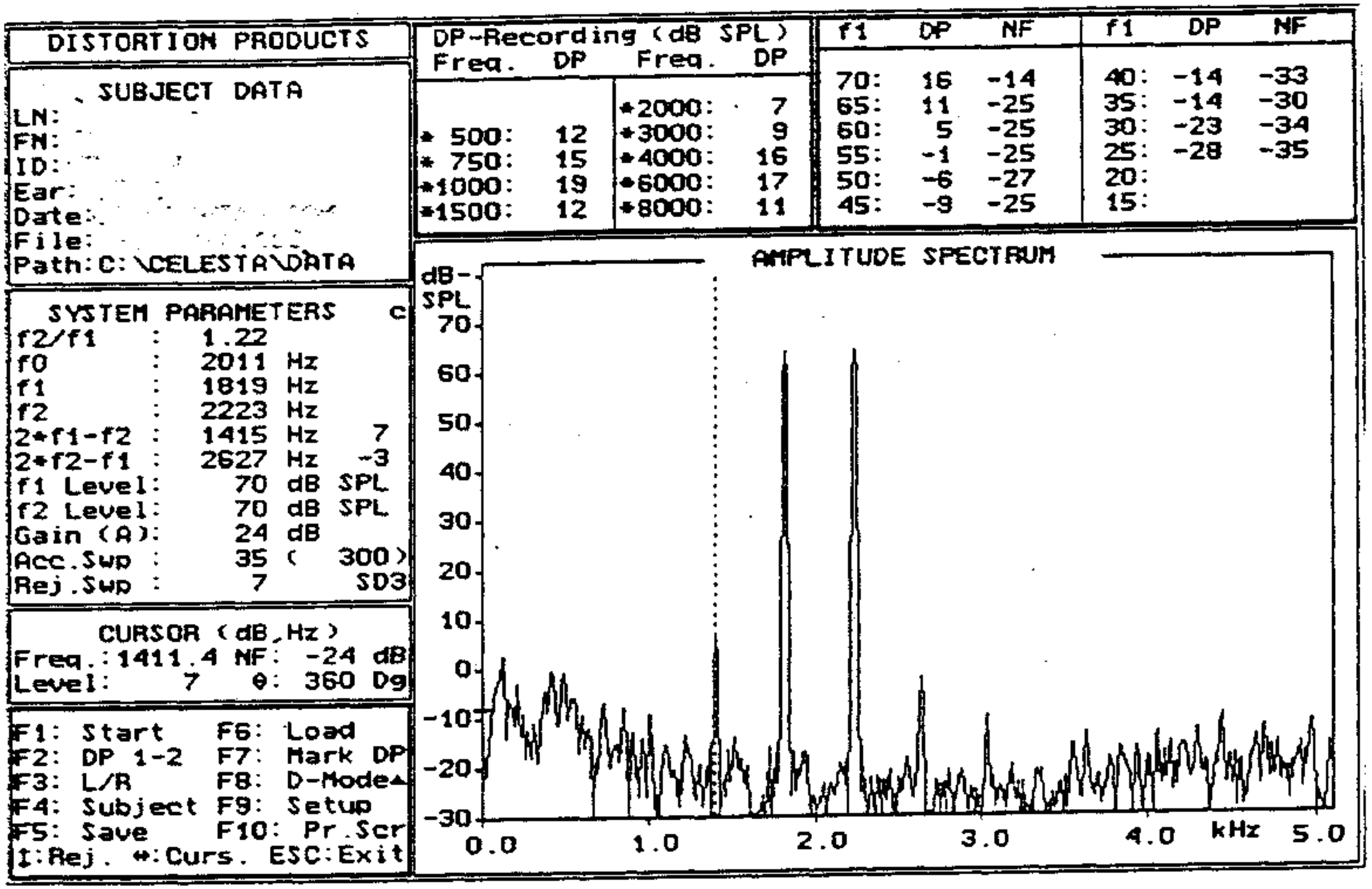
Fit probe in ear canal until time response is short, and frequency spectrum is as broad as possible.

FITTING PARAMETERS
Reject Offset : 0.00 mS
Stim. Duration: 40 µS
Acquis. Mode :Linear
Stim. Polarity:Condens.
Stimulus Level: 80 dB
Input Gain : 18dB
Progr. Sweeps : 10
Accept.Sweeps : 10
Reject.Sweeps : 0
FFT Smoothing : ON

CURSOR
0.00 mS
Pa

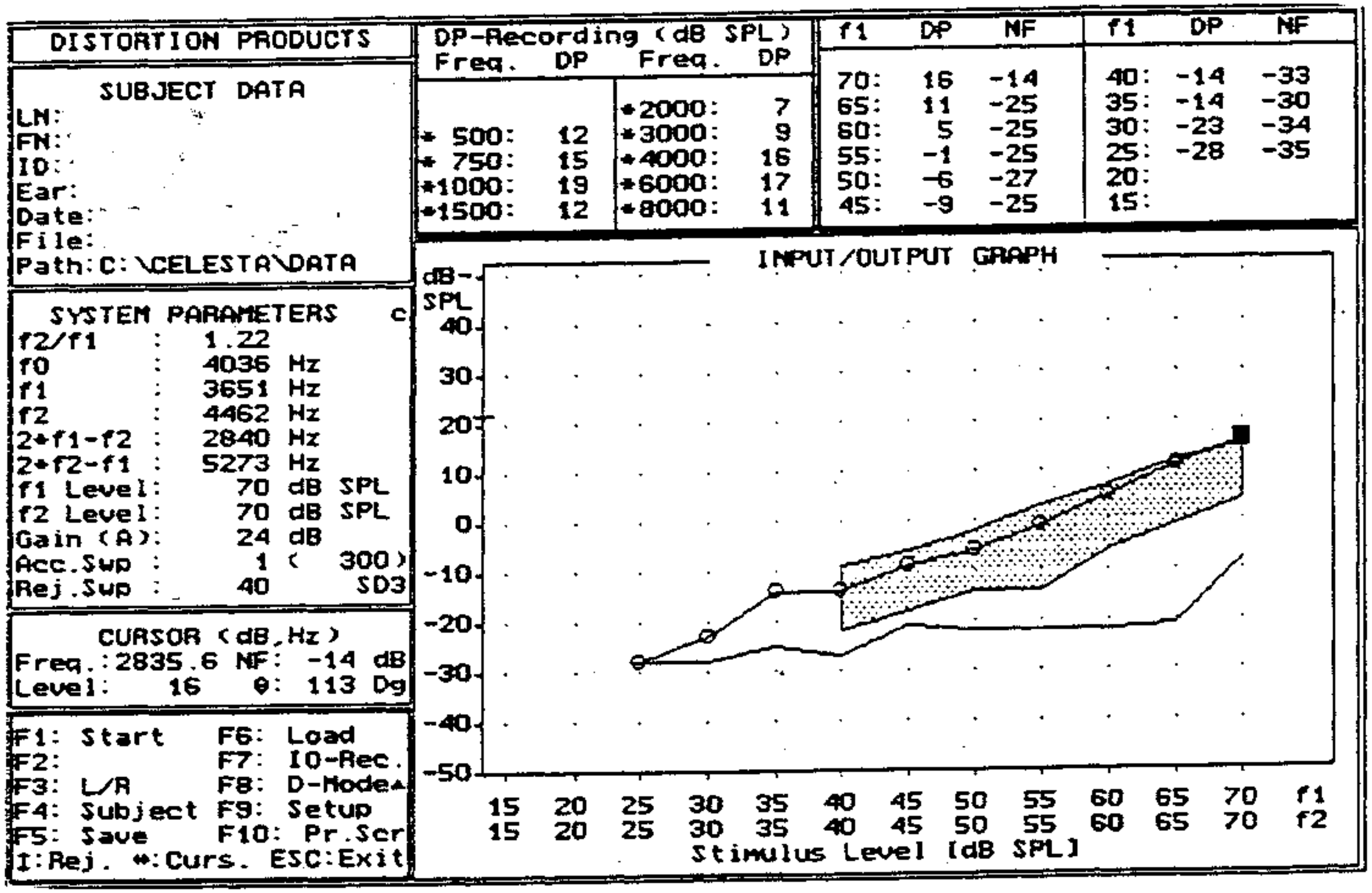
F1:Re-Fit
F2:Stop
F3:
F4:
F5:
F6:
F7:
F8:
F9:Setup
F10:
⟷: Curs.

FIGURE 3.2 A GooD *PROBE FIT*



```
DISTORTION PRODUCTS

  SUBJECT DATA
LN:
FN:
ID:
Ear:
Date:
File:
Path:C:\CELESTA\DATA

SYSTEM PARAMETERS        c
f2/f1      :  1.22
f0         :  2011 Hz
f1         :  1819 Hz
f2         :  2223 Hz
2*f1-f2    :  1415 Hz    7
2*f2-f1    :  2627 Hz   -3
f1 Level:       70 dB SPL
f2 Level:       70 dB SPL
Gain (A):       24 dB
Acc.Swp  :      35 (   300)
Rej.Swp  :       7      SD3

   CURSOR (dB,Hz)
Freq.:1411.4 NF:  -24 dB
Level:     7   θ:  360 Dg

F1: Start    F6: Load
F2: DP 1-2   F7: Mark DP
F3: L/R      F8: D-Mode▲
F4: Subject  F9: Setup
F5: Save     F10: Pr.Scr
↕:Rej.  ↔:Curs.  ESC:Exit

DP-Recording (dB SPL)
Freq.   DP    Freq.   DP

* 500:  12   *2000:    7
* 750:  15   *3000:    9
*1000:  19   *4000:   16
*1500:  12   *6000:   17
             *8000:   11

f1    DP    NF     f1    DP    NF

70:   16   -14     40:  -14   -33
65:   11   -25     35:  -14   -30
60:    5   -25     30:  -23   -34
55:   -1   -25     25:  -28   -35
50:   -6   -27     20:
45:   -9   -25     15:
```

FIGURE 3.3 - AMPLITUDE SPECTRUM OF DPOAE.



```
DISTORTION PRODUCTS        DP-Recording (dB SPL)     f1   DP   NF     f1   DP   NF
                           Freq.   DP   Freq.   DP
SUBJECT DATA                                         70:  16  -14     40: -14  -33
LN:                                  *2000:   7      65:  11  -25     35: -14  -30
FN:                        * 500: 12 *3000:   9      60:   5  -25     30: -23  -34
ID:                        * 750: 15 *4000:  16      55:  -1  -25     25: -28  -35
Ear:                       *1000: 19 *6000:  17      50:  -6  -27     20:
Date:                      *1500: 12 *8000:  11      45:  -9  -25     15:
File:
Path:C:\CELESTA\DATA

SYSTEM PARAMETERS     c
f2/f1      :   1.22
f0         :   4036 Hz
f1         :   3651 Hz
f2         :   4462 Hz
2*f1-f2    :   2840 Hz
2*f2-f1    :   5273 Hz
f1 Level:        70 dB SPL
f2 Level:        70 dB SPL
Gain (A):        24 dB
Acc.Swp :         1 (  300)
Rej.Swp :        40     SD3

CURSOR (dB,Hz)
Freq.:2835.6 NF:  -14 dB
Level:    16   θ:  113 Dg

F1: Start    F6: Load
F2:          F7: IO-Rec.
F3: L/R      F8: D-Mode▲
F4: Subject  F9: Setup
F5: Save     F10: Pr.Scr
I:Rej. ↔:Curs. ESC:Exit
```

FIGURE 3.4 - INPUT/OUTPUT GRAPH OF DPOAE

RESULTS AND DISCUSSION

In the present study, intput/output function was studied in young adults when primary levels (i.e. L1 + L2) were

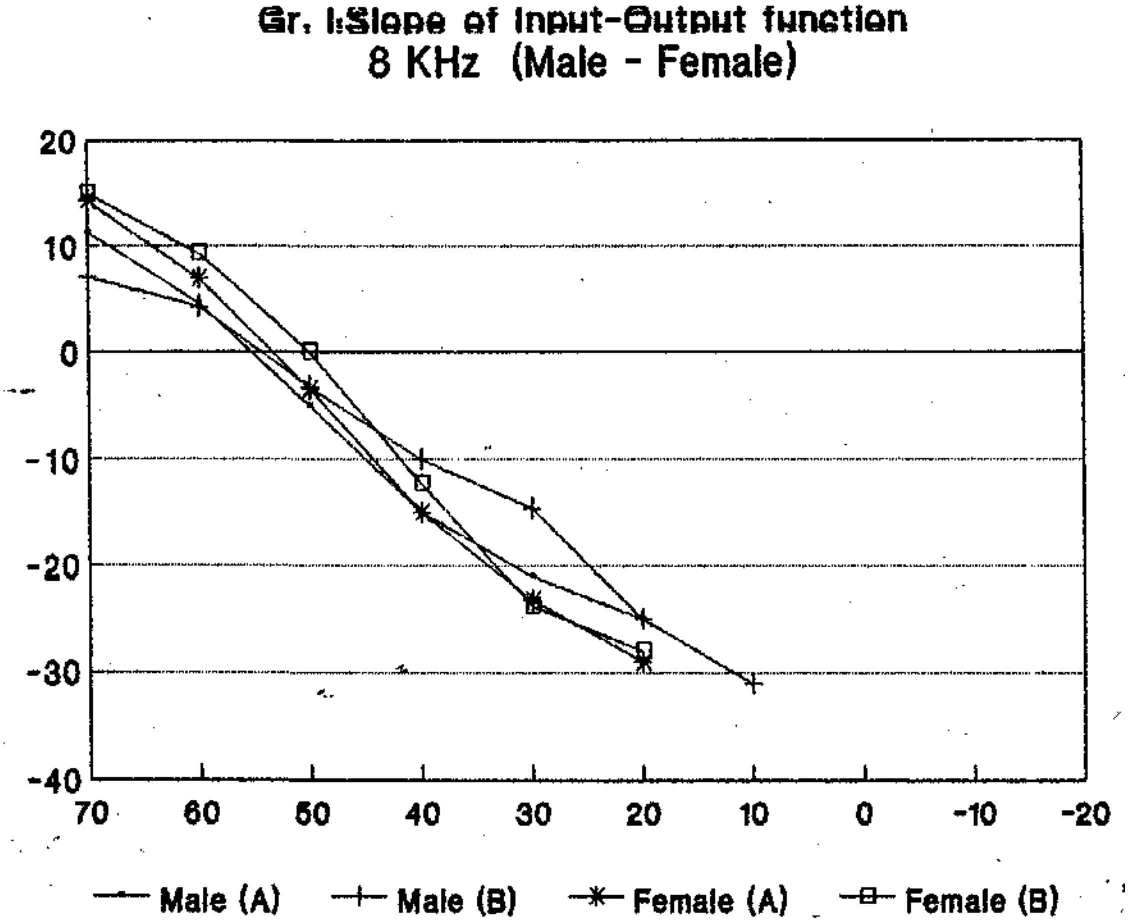
(1) Same intensity (condition A(i.e.Ll=L2)
(2) When intensity of L1 was higher than that of L2 by 10 dB (condition B (i.e.L1 - L2)

The collected samples were analyzed and descriptive statistics and results of 't' test were obtained.

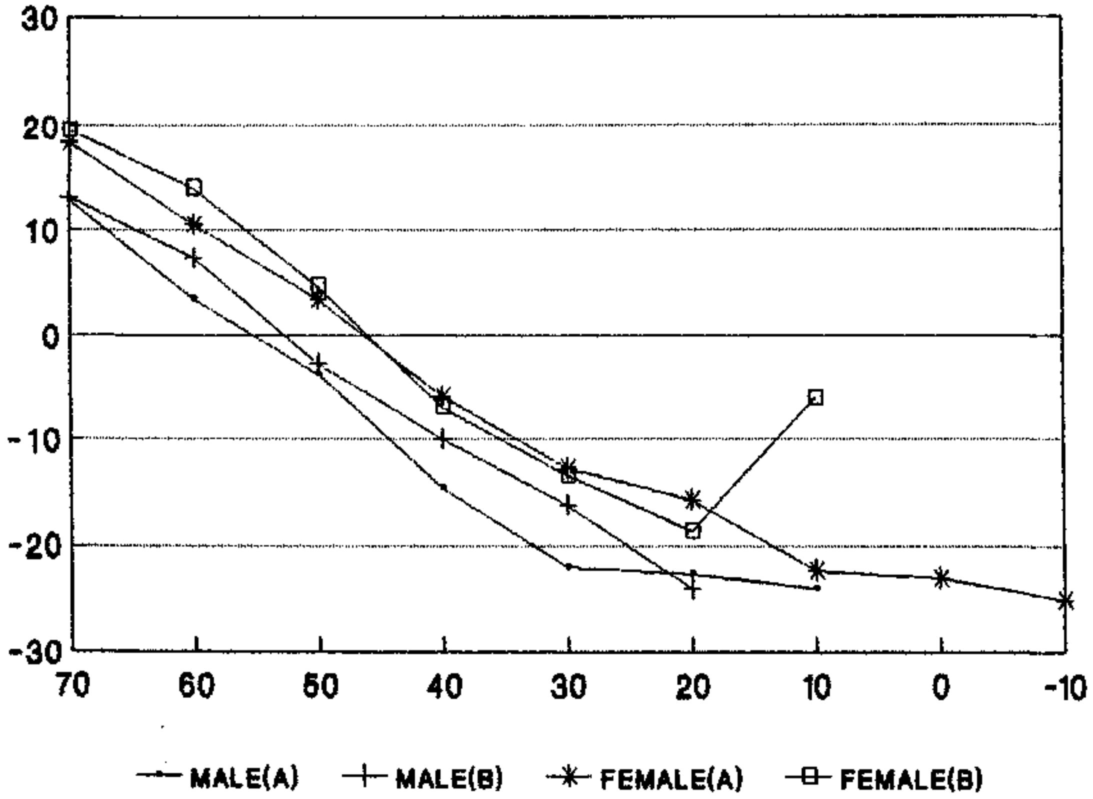
4.1 Input-Output growth function

As expected it was observed that in both conditions, the amplitude of DPOAE decreased as the intensity of stimulus was decreased. This was true for all frequencies for both males and females subjects.

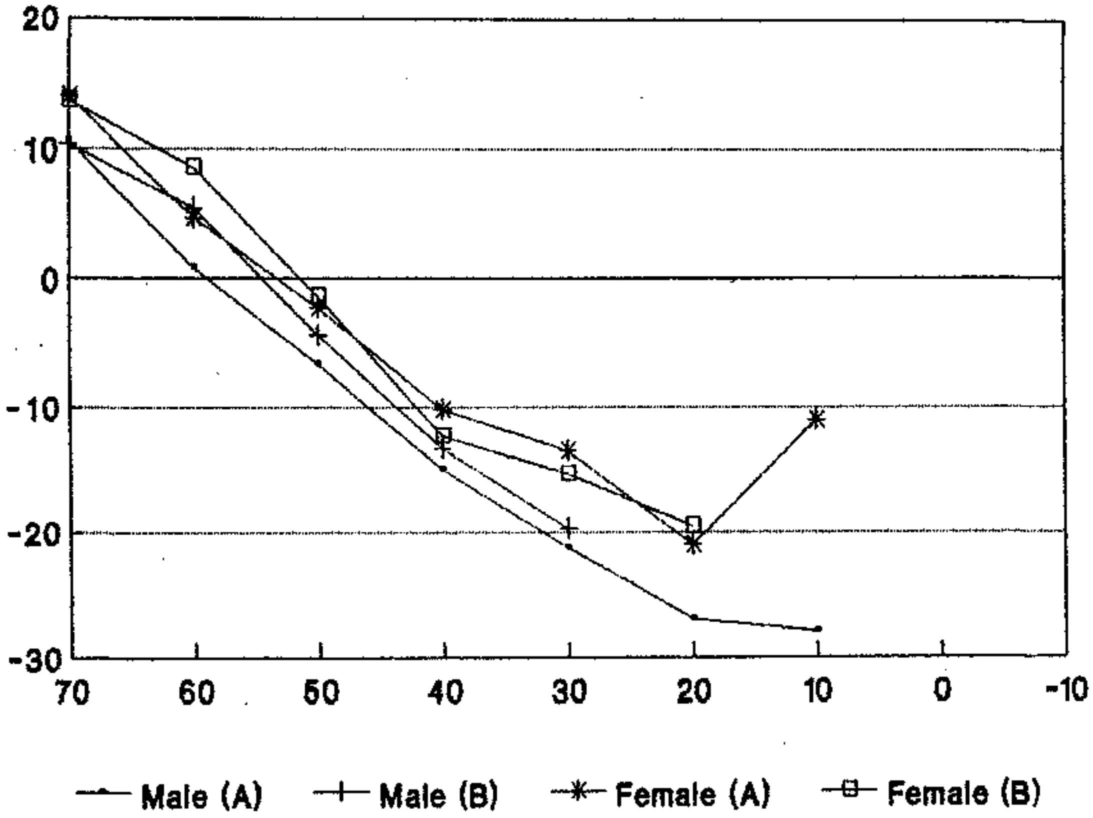
Graph 1, 2, 3, 4, 5 illustrates the input/output function of DPOAE for 8 KHz, 4 KHz, 2 KHz, 1 KHz and 500 Hz respectively. The decrease in amplitude was greater at lower Intensity. Similar results have been reported in literature. Rutter (1980) showed input/output function of peak-peak amplitude of response are nonlinear and saturation appears at higher intensities study done by Schlpth (1982) and Wilson (1980) found growth rate to be often non-monotonic at intermediate level, where magnitude of DP leveled off.



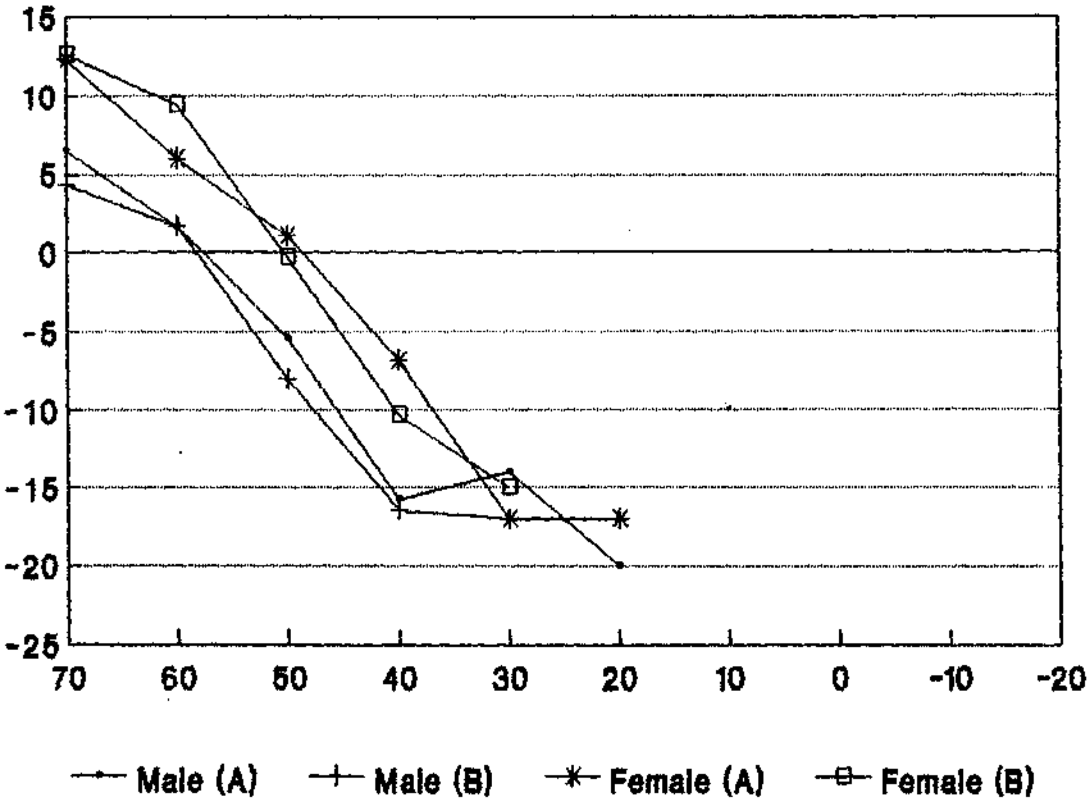
Gr2: slope of input output function.
4Khz (Male - Female)



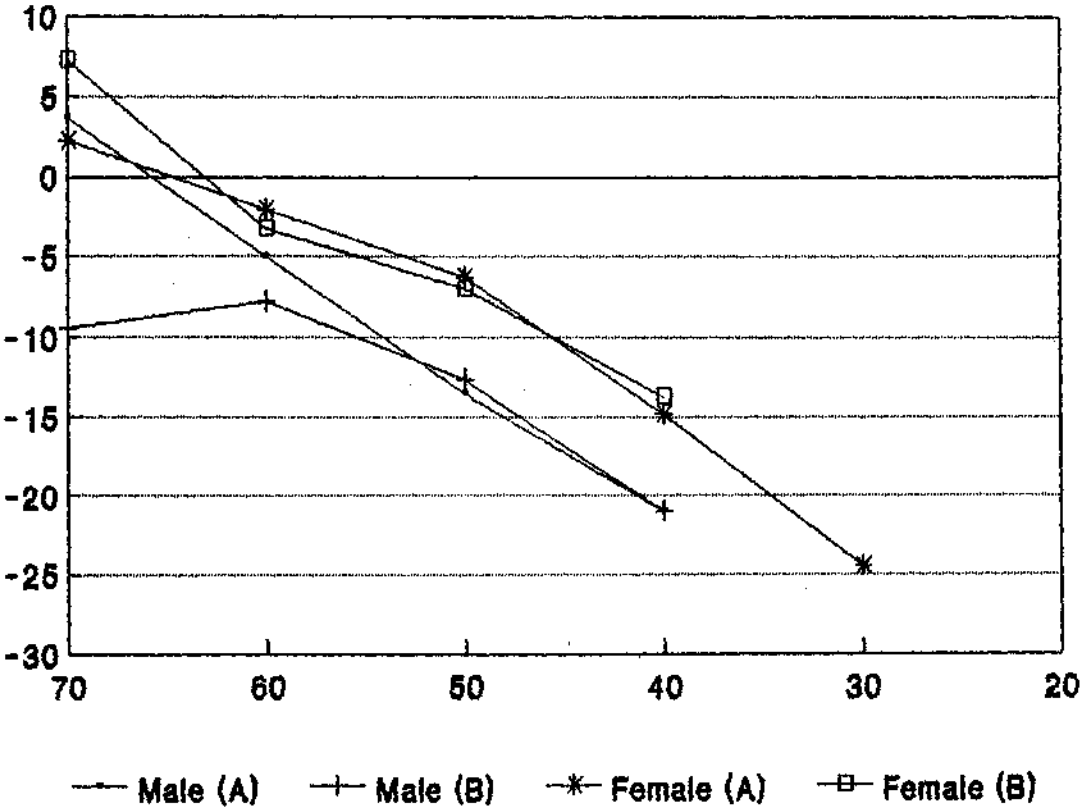
Gr3: SLOPE OF INPUT OUTPUT FUNCTION.
2KHz (Male -Female)



Gr.4: Slope of input-output function
1 KHz (Male - Female)



Gr.5:Slope of input-output function
500 Hz (Male and Female)



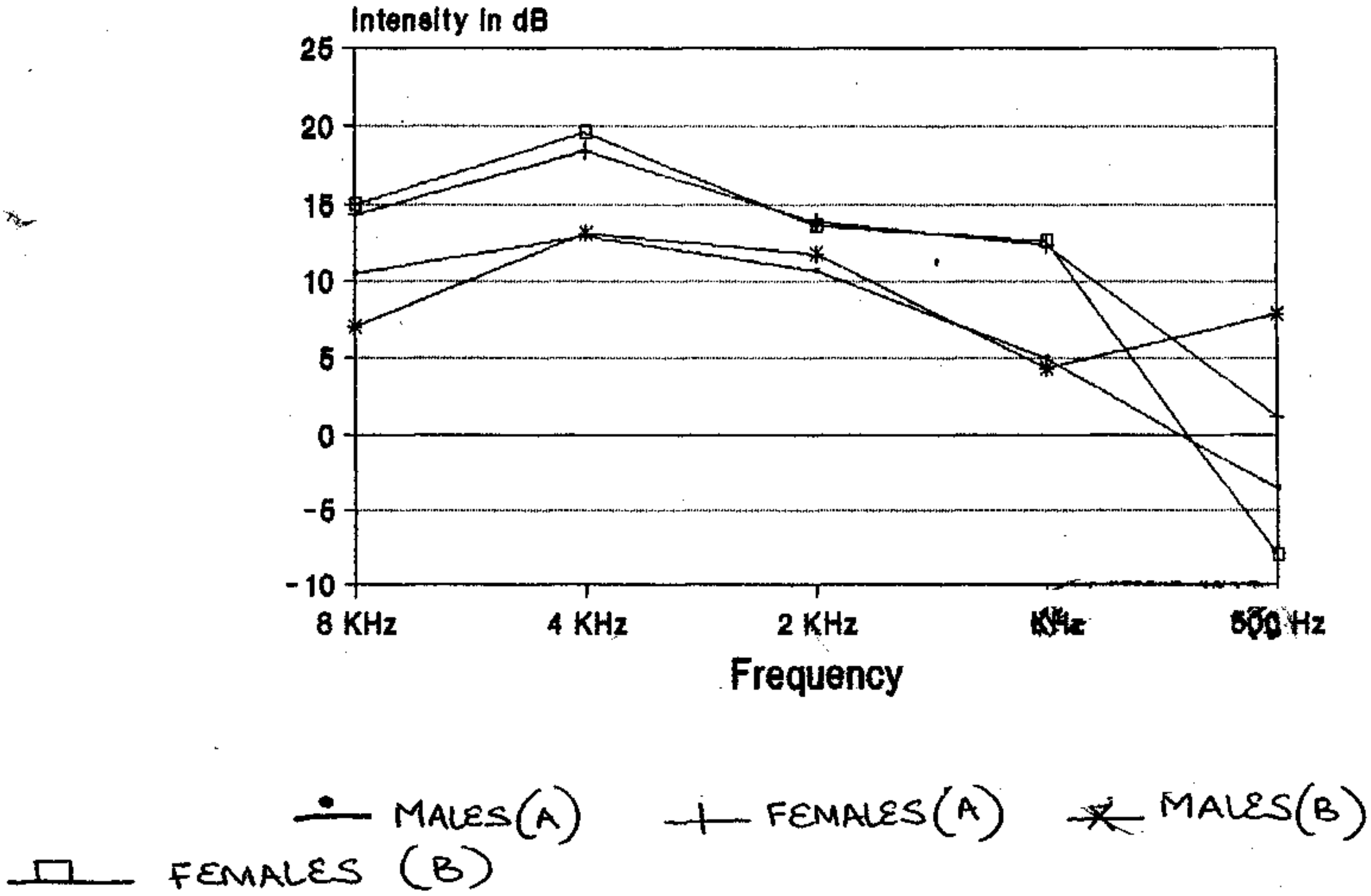
II Maximum amplitude of DPOAE

Table 4.2.1: Maximum amplitude of DPOAE

Frequency	A		Intensity (dB SPL)	B		
Males	Mean	SD	Range	Mean	SD	Range
8 KHz N=7	10.4	7.82	(-)3-21	7	5.18	0-17
4 KHz N=7	12.9	7.64	1-22	13.1	5.46	5-21
2 KHz N=7	10.6	2.99	6-13	11.7	3.25	9-18
1 KHz N=7	5	6.25	(-)2-11	4.3	5.82	(-)7-9
500 Hz N=5	-3.6	6.7	(-)14-6	7.8	4.37	<-)14-(-)2
Females						
8 KHz N=7	14.3	5.96	4-22	15	6.37	4-21
4 KHz N=7	18.4	2.50	16-23	19.6	3.10	16-26
2 KHz N=7	13.9	6.89	2-23	13.6	6.39	4-24
1 KHz N=7	12.3	5.76	7-20	12.6	4.40	5-17
500 Hz N=5	1.2	5.89	(-)6-7	-8	4.89	(-)13-(-)1

Graph 6

Gr.6: Maximum Amplitude of DPOAE
(A) and (B) condition



DPOAE was maximum with input of 70 dB SPL for both the conditions. Table 4.2.1 shows the maximum amplitude of DPOAE for males and females. In males, at all frequency except at 4 KHz, 2 KHz (A) condition of highest amplitude than (B). In females except at 8 KHz, 4 KHz in all other frequencies, similar results were obtained. The difference however were not statistically significant. Study done by Hanser et al. (1991) showed maximum amplitude of distortion product to be generated when L1-L2 at all geometric centre frequency except at 8 KHz. Similarly Rassmussen etal.(1992) reported maximum amplitude when Ll=L2 except at 8000 Hz.

Females had greater amplitude than male at all frequencies. The results were not statistically significant. These results support the findings of study done by Gaskill and Brown (1990) who reported that DPOAE were significantly larger in female than male volunteers for majority of frequencies tested. Also study by Lonsbury-Martin and Cutler and Martin (1991) in older volunteer (31-60 Years), showed that female volunteers had largest DPOAE than males at frequencies 2000-8000 Hz.

As the frequency increased, maximum amplitude of DPOAE was also found to increase. Least amplitude at 500 Hz. This could be probably due to increased noise flow at lower frequencies. These results support the findings of Avan and Bonfils (1993) who reported that noise flow was significnatly greater at lower frequency than at higher frequency. In both males and females amplitude at 4 KHz was higher in comparistlon to other frequencies.

III Detection threshold

For the purpose of the study, DPOAE detection threshold was defined as the lowest intensity of primary frequencies which elicits DPOAE 3 dB above the noise flow.

(i) Detection threshold for males

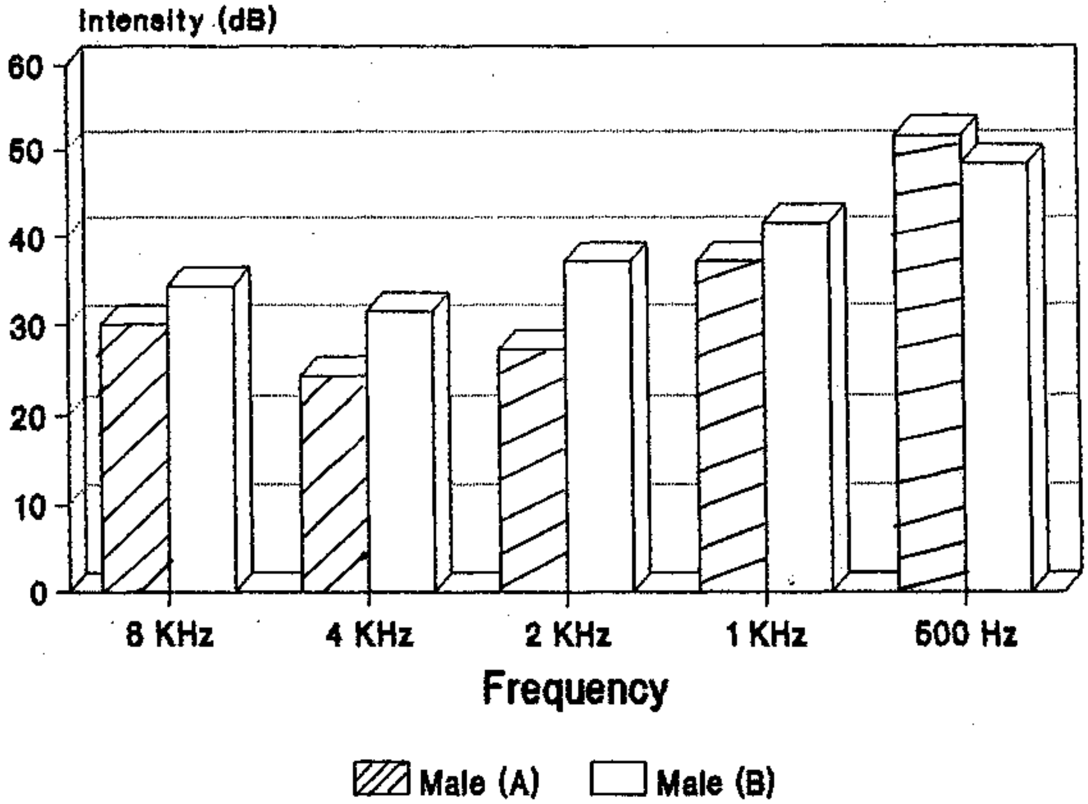
Table 4.3.1 : Detection threshold for males

Frequency	A		Intensity dB SPL		B	
	Mean	SD	Range	Mean	SD	Range
Males						
8 KHz N=7	30	10	20-40	34.3	15.1	20-50
4 KHz N=7	24.2	7.86	10-30	31.4	13.45	10-50
2 KHz N=7	27.1*	4.87	20-30	37.1*	11.12	30-60
1 KHz N»7	37.1	11.12	20-50	41.4	8.99	30-50
500 Hz N=5	51.6	11.68	40-70	48.3	11.69	40-70

* Statistically significant difference at 0.05 level

Gr.7: Detection threshold (Male)

Graph 7



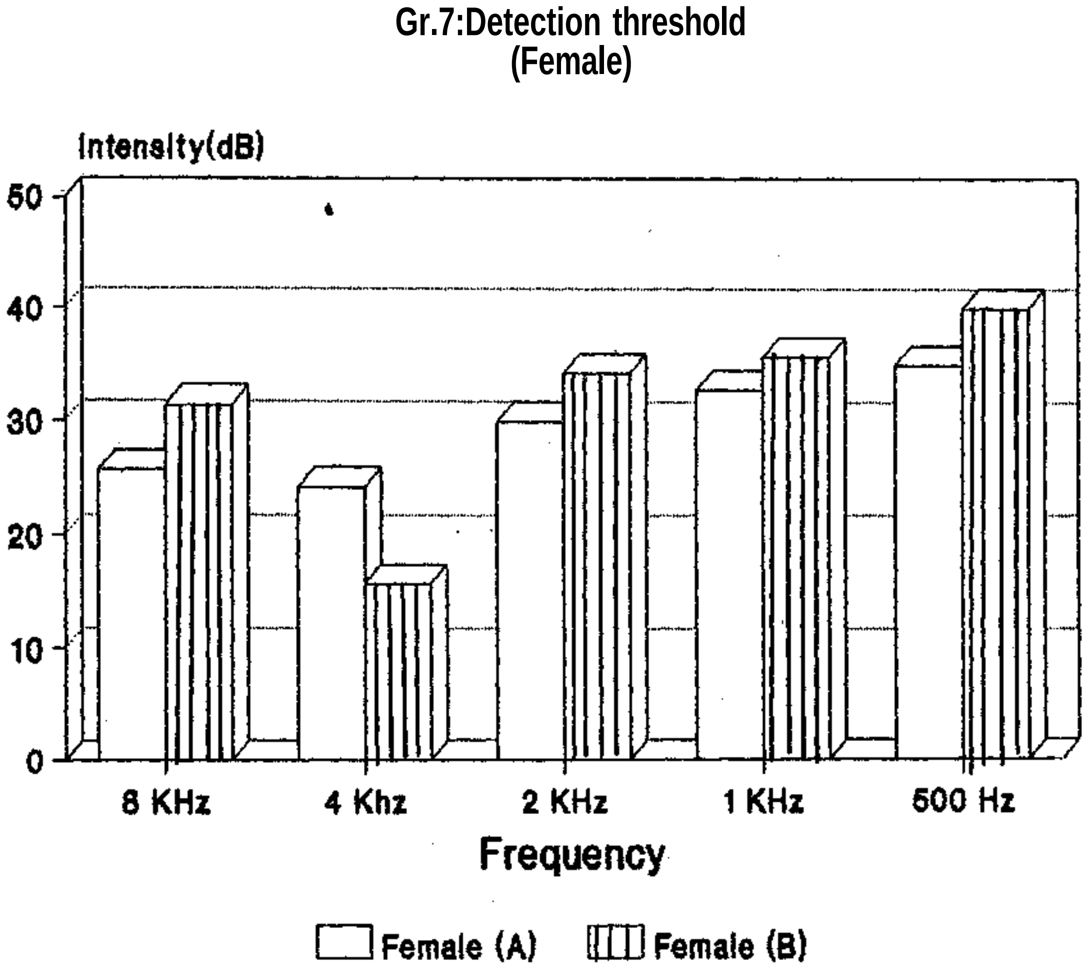
As shown in Table 4.3.1 and Graph 7 at all frequencies except 500 Hz (A) condition (i.e. L1-L2) yielded a lower detection threshold when compared with (B) (i.e.) L1 >L2 condition. However, the difference were statistically significant (0.05 level) only at 2 Khz.

(ii) Detection threshold for females

Table 4.3.2: Dection threshold for females

Frequency	A		Intensity dB SPL		B	
	Mean	SD	Range	Mean	SD	Range
Females						
8 KHz N=7	25.7	8.45	10-40	31.4	6.9	20-40
4 KHz N=7	24.2	13.97	10-50	15.7	7.35	10-30
2 KHZ N=7	30.0	16.32	10-50	34.2	14.85	10-50
1 KHz N=7	32.8	12.77	20-60	35.7	7.86	30-50
500 Hz N=5	35	5.77	30-40	40	8.16	30-50

Graph 8

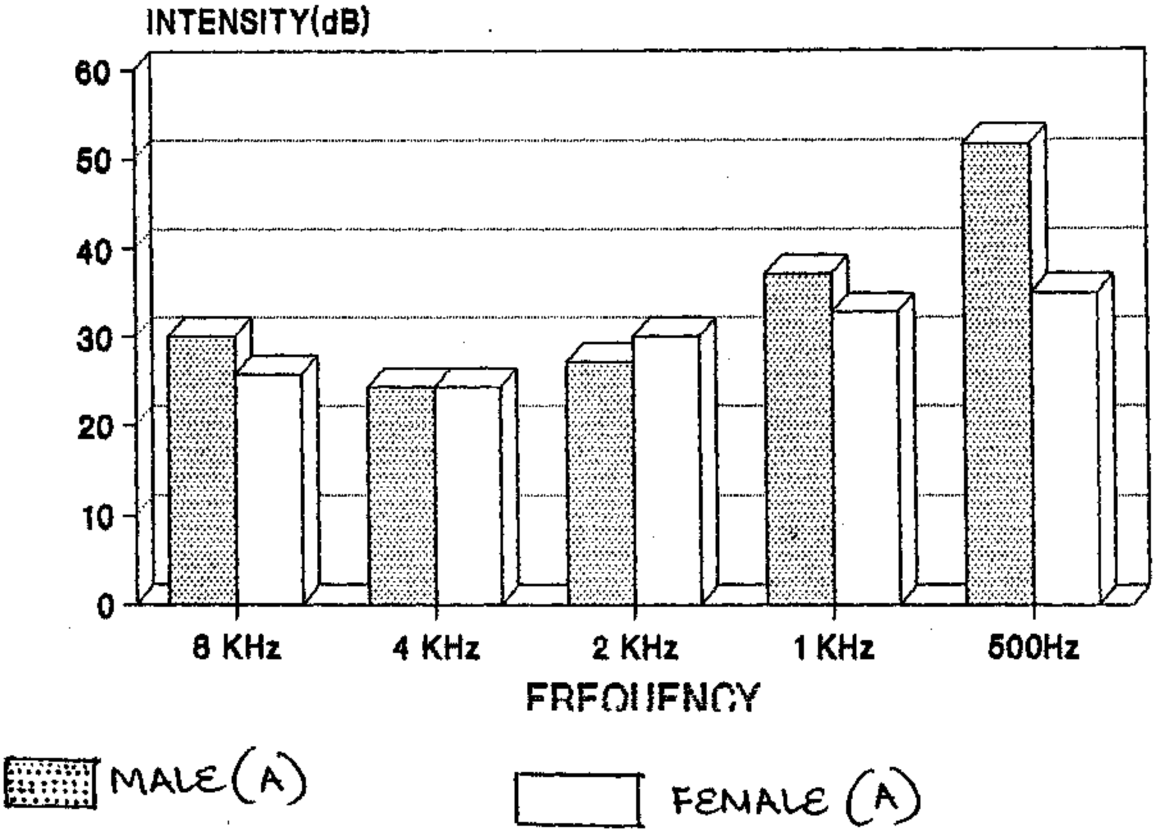


Results obtained for females (Table 4.3.2 and Graph 8) were similar to all male subjects. At all frequencies, except 4 KHz, L1=L2 (A) condition was better than L1>L2 (B) condition. However, these results were not statistically significant. For one subject, DPOAE was absent at 500 Hz, even with an input of 70 dB SPL. DPOAE absence at lower frequency can be attributed to an increase in noise flow.

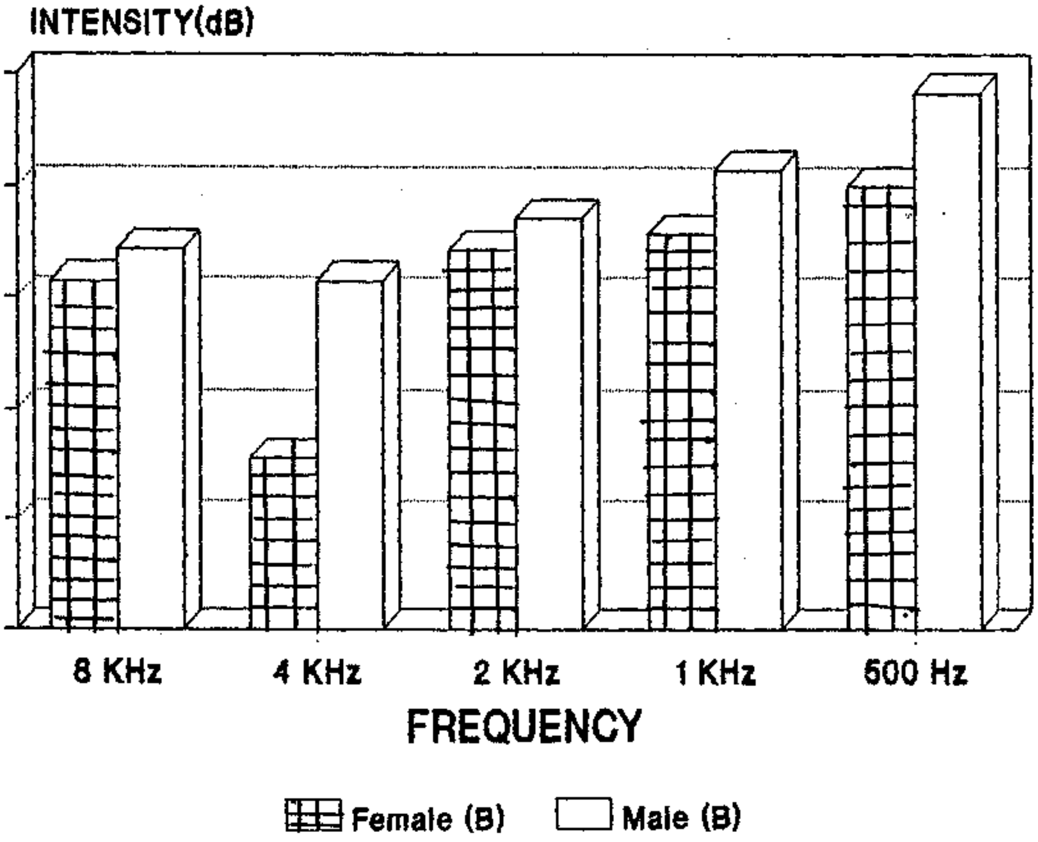
In both males and females, time taken to test higher frequencies was less than that of lower frequencies. Approximately one hour was required to test lower frequencies. This finding is consistent with findings of Harris (1990). This could be attributed to the increased noise flow at lower frequencies. Paul Avan, Pierre, Bonfills (1993) reported that noise flow was significantly greater at lower frequencies than at higher frequencies. Total time taken to complete the test at each frequency varid from 60 minutes to 90 minutes. Thus it may be recommended that the test protocol for DPOAE should start from higher frequiencies and end at lower frequencies. This would ensure that more number of frequencies are tested in initial few minutes.

III Comparison of detection threshold in males and females

Gr9:Comparision of male and female detection threshold.(A)



Gr10:COMPARISION OF FEMALE AND MALE DETECTION THRESHOLD (B)



in general female subjects had better detection threshold than males except at 2 KHz (A) condition.

The results of the present study (Table 4.3.1 and 4.3.2) and other studies by Gaskill and Brown (1990), Lonsbury-Martin, Cutler and Martin (1991) reveal that female volunteer have larger DPOAE in comparision to male. The higher amplitude in females may lead to lower detection threshold. Martin et al. (1990) has reported that as amplitude increased detection threshold decreased.

The possible reason for larger amplitude and hence better detection threshold in females would be

(a) Better auditory thresholds in female than males (McFadew, 1993; Lonsbury-Martin, 1991) .

(b) Anatomical differences in cochlea length (Kimberley, Brown, Eggermont, 1993; Sato, Sands, and Takanashi (1991) .

(c) SOAE are more prevalent in females than males (Martin, et al. 1990; Murphy et al. 1993). Presence of SOAE increases the amplitude of DOPOAE, Cianfore, Mattia, Altisma and Turchelta (1996);Weir, Pasaent, and McFaden (1988).

(iii) Combined mean value for detection threshold in adults.

Table 4.3.3 Combined mean value for detection threshold in adults.

Frequency	Intensity - combined A L1=L2	mean dB SPL B L1>L2
8 KHz	27.95	32.9
4 KHz	24.2	23.55
2 KHz	28.6	35.7
1 KHz	34.95	38.55
500 Hz	43.3	44.5

Lonsbury-Martin et al. (1990) reported detection threshold that were 3 dB above noise flow at about 35-45 dB SPL for DPOAE between 1-8 KHz. Test was done using primaries at equal intensity (L1=L2). Studies done by Moulin, Bera, Collet (1994) on normal hearing adults revealed that mean detection threshold ranged between 45 dB and 50 dB SPL for 1000 Hz to 8000 Hz. It was 61.7 dB SPL for 500 Hz. Majority of the experiment conducted in literature have used primaies L1 and L2 tobe equal (i.e., A condition hoever there is evidence in literature that variations in relative intensity of primaries might affect DPOAE amplitude, thus affecting detection threshold in turn. A few studies ahve reported that maximumdp amplitude occured with L, > L2 (Gaskill, 1992; Rassmussen et al. 1993). The present study shows that though there is difference in both conditions (i.e., L1 = L2) is better fthan L1 > L2, it is not statistically significant. Hence both conditions canbe used to obtain DPOAE detection threshold.

(iv) Comparision of DPOAE detection threshold for right vs left ears.

Table 4.3.4: Detection threshold for left ear vs. right ear Condition A.

Frequency	Intensity - dB SPL					
	Right ear (A)			Left ear (A)		
	Mean	SD	Range	Mean	SD	Range
8000 Hz	26.6	8.16	20-40	32.9	12.10	10-40
4000 Hz	25	5.47	20-30	27.1	11.71	10-30
2000 Hz	30	10.95	20-50	31.4	12.39	10-40
1000 Hz	40	12.6	30-60	35.7	12.2	20-50
500 Hz	43.3	10.4	30-60	47.5	17.07	30-70

* Significant difference level at 0.05 and 0.01

Table 4.3.5: Detection threshold for left ear vs. right ear Condition B.

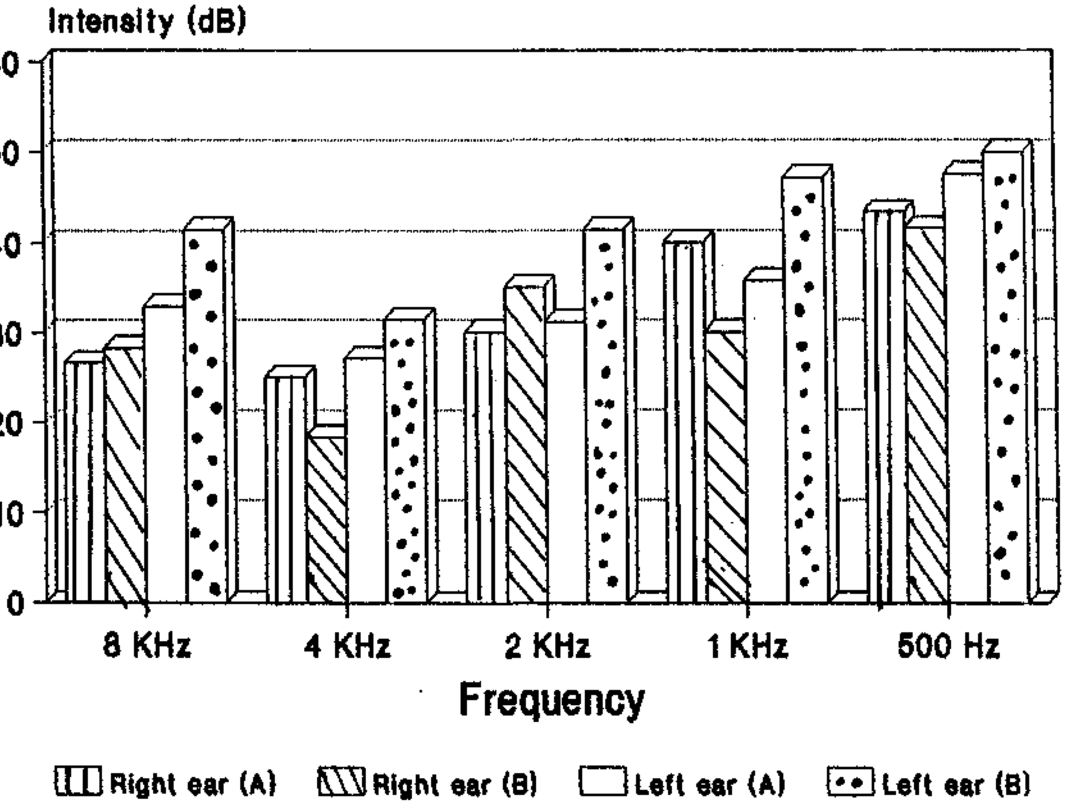
Frequency	Intensity - dB SPL					
	Right ear (B)			Left ear (B)		
	Mean	SD	Range	Mean	SD	Range
8000 Hz	28.3	11.69	10-40	41.4	11.95	20-50
4000 Hz	25	12.23	0-40	31.4	13.12	10-40
2000 Hz	35	8.36	30-50	41.4	14.14	20-60
1000 Hz	30*	10	30-50	47.1*	10.4	30-50
500 Hz	41.6	4.10	40-50	50	16.3	30-70

As shown in Table 4.3.4 and Table 4.3.5 mean detection threshold of right ear was better than left ear, for all frequencies except at1 KHz (A) condition. The differnce however was not statistically significant except at 1 KHz (B) condition. The variaibility was also greater in leftear than right ear.

Ear difference for DPOAE have sofar not been widly studied in literature. Rahul (1996) studied normal adults and children, and found that right ear effect was found in both adults and children. He found that right ear effect more in children. However, the results obtained was statistically significant at 75 dB SPL but not significant at 50 dB SPL.

These may be arising due to either the difference in the middle ear or external ear canal volume difference between left and right ears or due to some different in the contralateral suppression pathway between the left and right ears. Studies done byBilger, Mathies, Mannel and Denovest, (1990); Talmadge, Long Murphyu and Tubis (1993) shows SOAE are more prevalent in right ear in comparaiison toleft ear. Conclusive results cannot be drawn without further research.

Gr.1O: Comparision of DPOAE thresholds Left vs.Right ears



SUMMARY AND CONCLUSION

Distortion Product Otoacoustic Emissions are evoked otoacoustic emissions produced when two sinusoids slightly different in frequency are simultaneously presented to the ear. Distortion is generated by nonlinear elements by the process involved within the ear. DPOAE consist of acoustic energy at specific frequency that are detectable in a spectrum of ears signal. Acoustic distortion are commonly measured using two protocols 1. DPOAE audiogram. 2. Response growth or input-output function. DPOAE detection threshold is defined as lowest intensity of primary frequency which elicits DPOAE. Detection threshold may be able to predict abnormal auditory sensitivity.

THe present study was taken up to study

1. Input- Output function (I/O function) of DPOAE in young adults (ie) to study the detection threshold, maximum amplitude of DPOAE and growth function of DPOAE.

2. If there is any change in I/O function with variation in relative intensity of primaries L1 and L2.

3. If there is any change in maximum amplitude of DPOAE with

variation in relative intensity of primaries L1 and L2

4. Compare the detection threshold in males and females to ascertain between the two groups.

Fourteen volunteers in the age range of 17-24 years with mean age of 19.9 years served as subjects for the study . DPOAE was recorde using two sets of stimulus condition:-
Condition A L1=L2 ; Condition B L1>L2.

The results of the study can be summarised as follows.

1. In general at all frequencies detection threshold was better in L1=L2 condition than L1>L2 condition.Results however was not statistically significant at all frequencies.

2. As frequency decreased, maximum amplitude of DPOAE tended to decrease. This was true for all subjects ib both stimulus condition . However at 4KHZ, detection threshold and maximum amplitude at 70dB SPL was better in comparision to other frequencies tested for both stimulus condition.

3. Amplitude of DPOAE decreased as stimulus level decreased in all subjects in both A and B condition.

4. Females had better detection threshold and maximum amplitude at 70dB SpL in comparision to males.However the results were not stastically significant at all frequencies.

5. Mean detection threshold of right ears was better at all frequencies, results were not significant statistically.

Direction for future research in DPOAE are as follows

1. To study I/O function of DPOAE with varying degree of hearing loss.
2. Effects of different pathology on the I/O function of DPOAE.
3. To study I/O function of DPOAE with different F2/F1 ratios.
4. To study the ear effect on large population.

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