REAL-EAR-TO-COUPLER-DIFFERENCE IN YOUNG CHILDREN AND ADULTS

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MAY, 2001

Dedicated
To
Lord Vighneshwara

Certificate

This is to certify that this dissertation entitled **"Real-Ear-To-Coupler-Difference in Young Children and Adults"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech & Hearing) of the student with (Register No. M 9913).

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This is to certify that this dissertation entitled **"Real-Ear-To-Coupler-Difference in Young Children and Adults"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any University for the award of any other Diploma or Degree.

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Declaration

This dissertation entitled **"Real-Ear-To-Coupler-Difference in Young Children and Adults"** is the result of my own study under the guidance of Mrs. P. Manjula, Lecturer, Department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier in any University for the award of any other Diploma or Degree.

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Chapter I

INTRODUCTION

The audiologists involved in fitting of hearing aids must constantly blend together the art and science of selection and fitting. Selection of an appropriate hearing aid for a hearing impaired individual involves an examination of electroacoustic characteristics of the hearing aid according to national and international standards. Standard test procedures have been developed and used for the measurement of each electroacoustic parameter and selection of the hearing aid.

The electroacoustic measurements are done using 2-cc coupler. Originally designed as a temporary solution, the 2-cc coupler is still in use now nearly 60 years later! The 2-cc coupler was developed by Romanow, 1942 (as cited in Hawkins, 1992) as a convenient coupler for hearing aids to readily produce standardised electroacoustic measurements. This coupler was really never intended to simulate the adult ear canal, but was designed to use for quality-control purposes by hearing aid manufacturers (Nielsen and Rasmussen. 1982).

Madsen (1986) summarised the main reasons for the differences that are found between the real-ear and coupler gain as follows:

1. In clinical use. the hearing aid is mounted on the head or the body of a patient. This changes the gain and response characteristics of the hearing aid. due to diffraction effects.

2. The actual dimensions of the sound channel in the earmold may differ from the dimensions of the channel in the earmold simulator of a 2-cc coupler.

3. During clinical use, the earmold. will not always be a tight fit in the ear canal, thereby creating "slit-leak" of acoustic energy and creating change in the amplified low frequency response.

4. The acoustic impedance of the volume between the earmold and eardrum, combined with the impedance of the middle ear, will not be equivalent to the impedance of a simple, hard walled cavity.

5. The insertion of an earmold into the ear canal changes the resonance pattern of the ear canal.

Hence, he concluded that, from a clinical point of view, real-ear gain measurements are more reliable than coupler gain measurements.

However the important advantage of coupler measurements is that they do not require the presence of the client. A dispenser can partially, or even fully optimize the setting of a hearing aid before the client has even worn the instrument. Other advantages include an easily controlled test environment, high precision and repeatability (Revit, 1994).

To obtain the maximum benefit from coupler measurements, a dispenser should be aware of all the acoustic differences between couplers and real-ears. For this reason, probe-tube microphone measurements of real-ear hearing aid performance should be obtained whenever possible. Real-ear measurements have contributed to our understanding of the role of the outer and middle ear in influencing hearing aid performance. In addition, real-ear measurements contribute in better understanding of intrasubject and intersubject variabilities that occur in fitting hearing aids (Tecca, 1994)

If such measures cannot be made, however, it is still necessary to predict by some means, how the hearing aid will perform when fitted. To account for performance difference between couplers and real-ears, one approach is to apply a set of average values from samples of adult listeners (Bentler and Pavlovic, 1989). With this approach average real-ear-to-coupler difference (RECD) values are used to predict real-ear hearing aid performance from the results of coupler based measurements. Applying a real-ear-to-coupler correction based on average data has the potential to improve the success of hearing aid fitting, but there is a potential limitation to that practice.

The frequency response of the hearing aid is inextricably tied to the ear to which it is coupled. Each individual response will differ by some degree from the average. The normal differences in length and diameter of the ear canal and middle ear impedance could create variation from the average (Killion and Revit. 1993). The average RECD data may not predict how a hearing aid would respond upon ears that exhibit pathology which are likely to van- the impedance of the middle ear and ears that have been surgically altered (Fikret-Pasa and Revit 1992; Martin. Westwood and Bamford. 1996: Martin. Munro and Langer

1997: and Liu and Lin, 2000). Hence, a prescribed 2-cc coupler response that is based on average ear correction factor would not likely give the desired real-ear response on an ear that differs substantially from the average. Therefore, an improved hearing aid prescription could result from employing a custom-tailored correction.

It is also difficult to predict how a given hearing aid with customised earmold coupling will perform when fitted to a young child, because in young children the RECD values typically exceed the average RECD values reported for adults (Feigin. Kopun, Stelmachowicz and Gorga. 1989; Westwood and Bamford, 1995).

Presently, direct measures of real-ear hearing aid performance in children are obtainable using probe tube microphone system. One particular concern was that valid and reliable probe tube microphone measurement cannot easily be obtained with many young children for several reasons. Many young children are unable or unwilling to remain sufficiently still for these measurements and some children spontaneously vocalize during the measurement process. Excessive movement and vocalization compromise the validity of the test result. Further, some young children simply will not accept the head worn instrument associated with current probe-tube microphone system for an extended period (Moodie, Seewald and Sinclair, 1994).

Hence, Fikret-Pasa and Revit (1992) and Moodie, Seewald and Sinclair (1994) developed an alternative to conventional probe tube microphone measurements for measuring "RECD"' in young children. This new procedure uses a probe microphone system to measure the frequency response of a signal delivered in to the child's ear canal. The signal is delivered through an insert earphone to which the child's custom earmold is attached. Then, the same signal is delivered into a 2-cc coupler and the levels, across frequencies, are recorded. The mathematical differences in real-ear to 2-cc coupler values across frequencies gives the RECD.

Clinical implementation of this RECD procedure offers several advantages for pediatric population. The procedure is quick and requires only minimal cooperation from the child. Because the stimulus is presented through an insert earphone than a loud speaker, head and body movements will have minimal effects on the results. Stimulus presentation is very brief so that multiple attempts to obtain the RECD can be made, if necessary. An experienced clinician can obtain RECD measures for both ears in < 10 min. Most importantly, after RECD measures are obtained, all subsequent measures of hearing aid performance can be accomplished by adding the RECD to 2cc-coupler measures of hearing aid performance, not requiring the child to be present.

Need for the study :

Although a body of literature exists detailing probe-tube microphone use with adults, there is a dearth of research data involving probe-tube microphone measures with young children that concentrate on the RECD (Nelson Barlow. Auslander and Stelmachowicz, 1988; Feigin. Kopun. Stelmachowicz and Gorga.

1989: Westwood and Bamford. 1995). This acoustic factor (RECD) has an important implication for the pre-selection and fitting of hearing aids. The advent of digital and programmable hearing aid technology and the attraction of an "objective"' measure of hearing aid performance points towards greater use of probe-tube microphone measures with the young children. Although probe-tube microphone measurements has greater face validity, little has been published about the RECD for children in the age range of 2 to 5 years. Hence the present study.

Aims of the study :

The aims of the present investigation were:

1) to estimate the test-retest reliability of the real-ear response for children and adults,
2) to measure the changes in RECDs for children and compare it with that of adults and.
3) to evaluate the inter-subject variability in RECDs for children and adults.

Chapter II

REVIEW OF LITERATURE

The goal of custom hearing instrument prescription is to specify a set of amplification characteristics that will be compatible with the auditory characteristics and everyday listening needs of the patient. Once the extent and configuration of hearing loss is known, and when amplification is to be a part of the habilitative intervention, choice of appropriate amplification characteristics (particularly gain and maximum output) involves matching manufacturers hearing aid specifications with real-ear requirements. As manufacturer's specifications are expressed in terms of 2-cc coupler values, which do not perfectly reflect the hearing aid performance on real-ear, particularly in the smaller ear of children, it is important and clinically efficient to take account of "real-ear to coupler differences (RECDs)".

"The RECD can be defined as the difference in decibels, as a function of frequency, between the output of a hearing aid measured in a real-ear and a 2-cc coupler" (Mueller, Hawkins and Northern, 1992). Questions concerning the accuracy with which the 2-cc coupler represented real-ear values were considered as early as the 1940s (Romanov. 1942. as cited in Hawkins. 1992). However, systematic study of this issue was not conducted until the 1970s (Sachs and Burkhard. 1972).

There are several reasons for the absolute output SPL in a real ear to be greater than that measured in a 2-cc coupler. First, the volume of the 2-cc coupler is more than the volume found in the typical ear canal (Bratt, 1980. as cited in Hawkins. 1992). The smaller the volumes of real-ear canals greater is the SPL enclosed compared to that of the 2-cc coupler. The second factor is that the impedance of the 2-cc coupler is not representative of that of the average human ear. When these two factors are combined, a significant increase in SPL is evident in the ear canal relative to that in a 2-cc coupler, especially at the higher frequencies.

The sound pressure generated by a hearing aid receiver is affected by the acoustic properties of the air space to which the receiver is connected. For example, consider two identical receivers, one coupled to a small closed volume (e.g., a 2-cc coupler) and the other coupled to a larger volume (e.g. a 6-cc coupler). When the same oscillating voltage is applied to both the receivers, although sound is present in both couplers, the peak pressure are not the same. Vibration of the diaphragm creates a greater sound pressure in the smaller cavity because it produces a larger fractional change in volume and thus larger change in air density. As identical motion produces a greater sound pressure, we say that the smaller volume is "stiffer" (i.e.. has a larger acoustic impedance). Just as the size (or impedance) of a closed cavity affects the sound pressure generated by an attached receiver, the impedance or size of an external ear also affects the sound pressure enclosed in the ear canal. (Voss, Rosowski. Merchant, Thornton. Shera and Peake. 2000).

RECD in Children and Adults

Sachs and Burkhard (1972) measured the sound pressure developed in five adult ears, the standard 2-cc coupler and Zwislocki coupler. Their results have shown that:

1. Sound pressure in Zwislocki coupler essentially was identical to pressure in real-ears (with no ear mold leaks) below 500 Hz implying an equivalent real-ear volume of about 1.2 cc. Sound pressure in the 2-cc coupler was about 4 dB lower.
2. Between 500 and 5000 Hz. the RECD increased with frequency about 2.5 dB/octave to 12 dB upto 5000 Hz.
3. Above 5000 Hz. the pressure in real ears decreased with frequency relative to both the couplers.

Hawkins, Cooper and Thompson, 1990 (as cited in Jonge. 1996) obtained RECDs for thirty normal adults, aged 23 to 56 years. The results ranged from about -6 dB at 250 Hz. 0 dB at 500 Hz to 12 dB at 6000 Hz. indicating greater SPL in real-ear than in the 2-cc coupler, except for the lowest frequencies. They opined that leakage around the foam earmolds may have reduced the real-ear output at low-frequencies.

Children tend to have RECDs that are greater than adults. Presumably, this is due to the smaller size of their ear canals. Bratt. 1980 (as cited in Hawkins. 1992) reported the average residual volume to be 0.66 cc in children and

1.26 cc in adults. This reduction in volume, along with potential middle ear impedance differences, can cause large differences in the output of a hearing aid as measured in a 2-cc coupler and in the ear canal.

Nelson Barlow. Auslander. Rines and Stelmachowicz (1988) measured real-ear to coupler difference in fifteen hearing impaired children, (aged 3 to 15 years) and fifteen hearing impaired adults, (aged 19 to 87 years). They observed no systematic variation in RECD between the values obtained for adults and those obtained for children. However, the RECD was smaller for children than adults at 700 Hz and 1600 Hz and was even larger at 3000 Hz. The}' also examined the test-retest reliability, by the same examiner having to repeat the real-ear measures three times within the same session. Mean intrasubject standard deviation was roughly 1 dB at the low- frequencies, and increased to no more than 2.5 dB at the high- frequencies. They reported that the mean and SD across frequencies never exceeded 2.8 dB for the children and 2.2 dB for the adults, atleast up to 4000 Hz.

Feigin. Kopun, Stelmachowicz, and Gorga (1989). estimated the RECDs for thirty-one children (ranging in age from 4 weeks to 5 years) and for twenty-one adult subjects (age 17 through 48 years). They used ER-3A insert phone coupled to impedance probe tips or small plastic sleeves to seal the sound delivery tube into the ear canal for both children and adults. However, their results showed that RECDs were larger for children than adults, and that infants below twelve months of age showed the greatest RECD. For 1000 Hz to 3000 Hz. a systematic decrease in RECD was noted with increasing subject age. This trend is illustrated in Figure 2.1. where RECDs are plotted as a function of age groups. A different frequency is represented in each panel. The open circle at right side of each panel depicts the adult mean for that frequency.

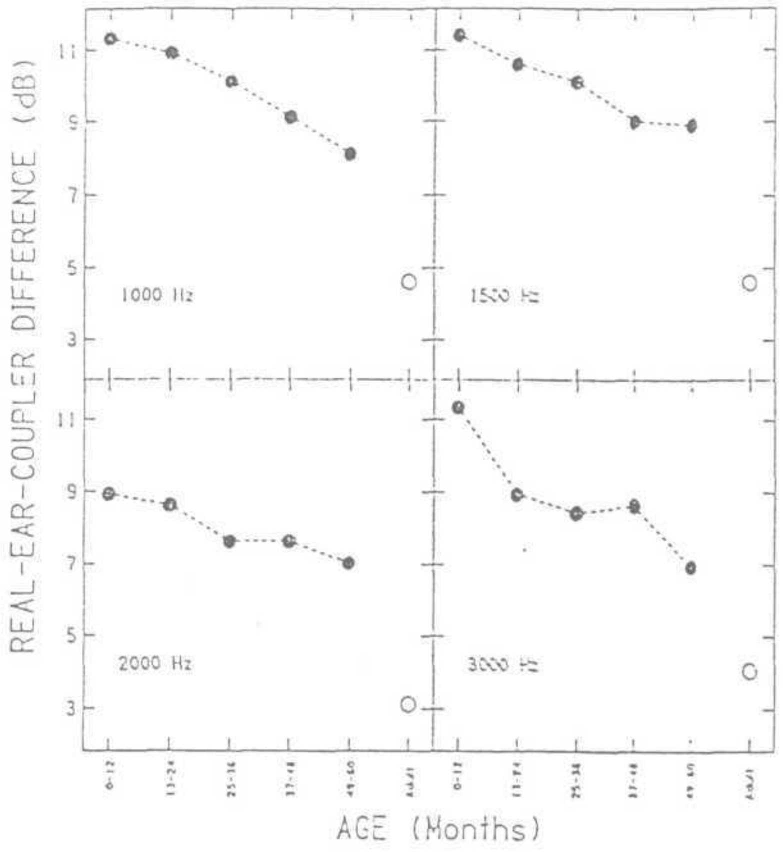

Fig. 2.1: Real-ear-to-coupler difference (in dB) as a function of age(in months) for four frequencies. Open circles are corresponding adult means at each frequency

For the youngest group (0-12 months), the maximum mean RECD was 11.3 dB. occurring at 3000 Hz. This corresponded to a 7.3 dB difference from the adult mean at that frequency. For the oldest group (49 - 60 months), the maximum mean RECD decreased to 8.8 dB at 1500 Hz. This value is only 4.2 dB greater than the mean for adults. For all four frequencies, the decrease in RECD appears to be relatively linear from 0 to 5 years. They predicted that RECD of children would fall within 1 SD of the adults by 7.7 years of age.

There was slightly more variability across the children (SD of 2.6 dB) than the adults (1.9 dB). Variability was less in the mid frequencies and greatest for the low- and high- frequencies (SD of about 4.5 to 6 dB). The mean SD for test-retest reliability ranged from a low of about 0.5 dB to high of 2 dB. Variability was greater for higher frequencies.

Westwood and Bamford (1995) investigated the gain of hearing aid developed in a 2-cc coupler and compared this with real-ear gain for thirty three normally developing infants under twelve months of age. using soft acrylic full shell mold. RECDs were calculated for six frequencies and are shown in comparison with the study by Feigin et al. (1989) in the Table 2.1.

Table 2.1: Mean RECD for Westwood and Bamford's (1995) study compared with Feigin et al. (1989).

	500 Hz	1000 Hz	2000 Hz	3000 **Hz**	4000 Hz	5000 **Hz**	6000 Hz
Feigin et al.(1989) Mean : infants under 12 mo(n = 7)	5.8	11.3	8.9	11.3	17.5	-	23.2
Westwood and Bamford (1995) Mean:infants under 12 mo(n = 29)	4.9	6.4	10.9	11.5	8.2	15.9	-

(Data are in dB indicating greater SPLs in the real-ear).

The data studied by Feigin et al.. show a small notch at 2000Hz. Beyond the notch, the RECD steadily increased with increasing frequency. At 500. 2000 and 3000 Hz, the data sets are very similar, but the average RECDs given by Westwood and Bamford are 4.9 dB less at 1000 Hz and 9.3 dB less at 4000 Hz. The reason for these differences could be the procedural differences between the two studies. Common to both studies was the use of the HA-2 coupler and a 10 mm insertion depth. However, Feigin et al.. used insert earphone signal delivery with impedance tips or plastic sleeves for the real-ear measures. In Westwood and Bamford's study, loudspeaker delivery was chosen with aided gain referred to the head surface. So possible pinna/concha (rather than purely ear canal) effects are included. Further more, the signal passed through typical hearing aid components and a soft acrylic earmold modifying the final output, giving rise to a marked difference in acoustic coupling seen between the two studies.

Westwood and Bamford (1995) found acceptable test-retest reliability in a group of seventeen infants with test-retest differences less than 3.4 dB from 500 to 5000 Hz. They also have reported a high intersubject variability and indicated the need for RECD measures to be carried out individually rather than using average figure for the hearing aid fitting.

Zelisko. Seewald and Gague, 1992 (as cited in Jonge. 1996) measured RECD for nine adolescents. Intersubject variability ranged to almost 12 dB where as intrasubject SD of only 1.5 dB was obtained by testing each subject on three separate occasions. They suggested that when measurements are carefully performed, measurement errors can be much less than inter subject variability.

Munro and Hatton (2000) evaluated the validity of predicting the real-ear aided response (REAR) by adding customized RECD to the performance of a hearing aid in a 2-cc coupler. The RECD was measured in both ears of twenty-four normally hearing subjects, age ranging from 22 to 30 years, using probe-tube microphone equipment. The RECD transform function was obtained using two procedures. The first of these involved delivering the stimulus to the ear using an ER-3A insert earphone. This method was originally described by Moodie, Seewald and Sinclair (1994). The second procedure involved presenting the stimulus via a loudspeaker with the subject wearing the hearing aid. This method was described by Westwood and Bamford (1995). An RECD transfer function was also obtained with a customized earmold, and temporary earmolds (ER -

3A foam tip and an otoadmittance tip). Results clearly indicated that the two methods of signal delivery result in essentially equivalent mean RECD. The derived real-ear aided response was generally within 5 dB of the measured real-ear response when it incorporated an RECD transform function obtained with a customized earmold for the specific ear. However, there was significance difference between the RECD obtained with customized and temporary earmolds.

The differences in SPL between RECD with custom earmold and temporary earmolds are probably due to differences in the volume of air within the ear canal and the degree of acoustic seal. The least satisfactory match between derived and measured REAR occurred when the RECD transform function was obtained using temporary earmold. particularly the oto-admittance tip. Discrepancies between derived and measured real-ear response also increased when the RECD was obtained from the same subject but the opposite ear. This finding suggested that derived REAR based on a RECD transform function using temporary earmolds should only be used to guide initial hearing aid selection until the RECD can be measured with a customized earmold.

RECD in Pathologic Ears

Fikret-Pasa and Revit (1992) performed RECD measurements on eighteen ears of fifteen subjects aged 43 to 80 years. Although most diagnosis indicated presbycusis. there were middle ear anomalies such as a neomembrane of the eardrum, otosclerosis, perforated eardrum, large canal volume, and both increased and decreased middle ear admittance. As might be expected, larger intersubject standard deviations were obtained, roughly 5 to 8 dB across frequency. One subject with a perforation had an RECD about 20 dB lower than the average value for low frequencies. The most prominent feature of RECDs for the perforation is the approximate 15 dB reduction in low frequency response.

Martin, Westwood and Bamford (1996) investigated the effect of otitis media with effusion (OME) on the RECD in children, aged between 4.6 and 7.6 years. The mean RECD in the frequency range 200 to 3000 Hz was found to be 0.8 to 3.5 dB greater for children having OME than for those without OME. The OME groups RECDs were higher in the low-and mid-frequency range, which could be explained by the increased mass and stiffness of a fluid filled ear, increasing the impedance of the middle ear, which particularly affect the low- and mid-frequency SPLs. In the higher frequencies, the RECDs of the control group exceeded those of OME group. A possible explanation is that in the higher frequencies there is a natural drop in the pressure gain achieved by the middle ear, due to less effective movement of the tympanic membrane and increased ossicular chain fixation. The fluid in the middle ear could counter act this increased fixation and thus, the natural drop in pressure gain could not be so marked, as more sound is transmitted into the inner ear than when middle ear is free from fluid. All real-ear and coupler measures revealed good test-retest reliability at 4000 Hz and below. Large intersubject variability was found with a maximum standard deviation of 5.6 dB at 2000 Hz.

The following year, Martin. Munro and Langer (1997) investigated the effects of patent grommets on RECDs in children aged between 4 and 7 years. The mean RECD of the experimental group in the frequency range 125 to 750 Hz was 15 dB lesser than control group, while the response at high frequencies are similar for both groups. The mean RECDs are shown in Fig. 2.2

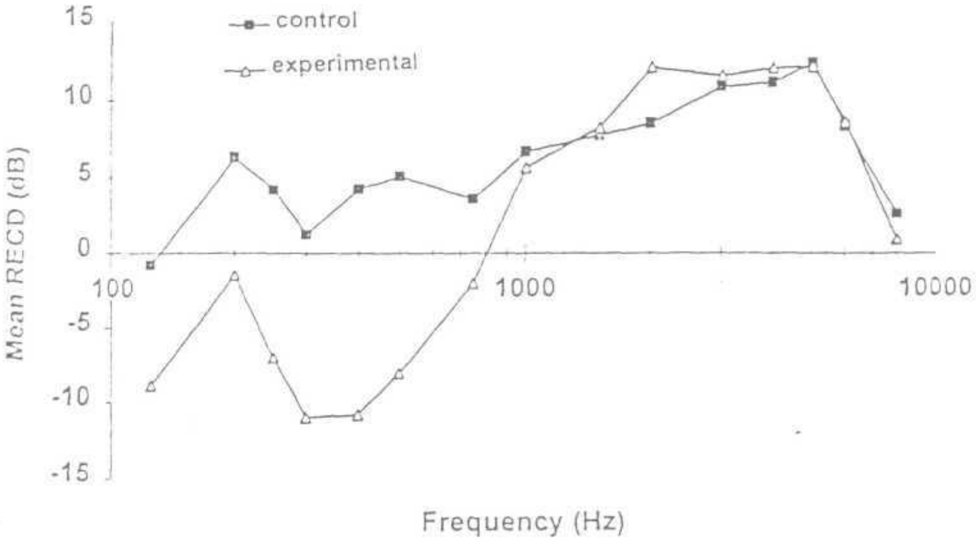

Fig. 2.2 : Mean RECDs for the experimental and control groups

Martin. Munro and Langer (1997) proposed a few theories to explain the reduced RECD at low frequencies for the experimental subjects. The first is that low frequency sounds have "escaped" in to the middle ear cavity through the grommet, in the same way that low frequency sound levels are reduced for hearing aid wearers by using a vented ear mould. The second explanation is that the admittance of the tympanic membrane has increased for the low frequency sound. This is because air in the middle ear cavity is no longer compressed and expanded when the tympanic membrane moves in and out. The elastic stiffness of the middle ear inversely affects the transmission of low frequency sound through the cavity, and thus if the stiffness is reduced, more low frequency sounds will be transmitted.

Liu and Lin (2000) measured RECD in fifteen patients who underwent open mastoid surgery. Their ages ranged from 16 to 59 years. The results showed that, in ears with mastoidectomy. mean RECDs appear to be smaller than normal at all tested frequencies. Possible explanation for the reduction of RECD includes increased ear canal volume, increased ear canal length and change in middle ear impedance resulting from open-mastoid surgery. Furthermore, their results showed that the intersubject variation in the operated group is much larger than that in normal control group.

Chapter III

METHODOLOGY

Subjects:

Subjects were divided into two groups. Group one comprised of thirty one children aged between 2 and 5 years, with a mean age of 3.9 years. All the subjects had sensorineural hearing loss in both ears, ranging in degree from moderate to profound. Group two consisted of thirty otologically normal adults, age ranging from 18 to 28 years with a mean age of 22 years. The distribution of subjects by age is shown in Table 3.1

Table 3.1: Distribution, by age. of subjects.

Subjects	Age in years	No. of ears
Children (Group I)		
A	2-3	24
B	3.1-4	18
C	4.1-5	20
Adults (Group II)	18-28	60

All subjects had ear canals that were free from cerumen, debries or foreign body on otoscopic examination and had normal middle ear function as indicated by screening acoustic immittance measurement (Middle ear pressure +50 to -100 daPa. middle ear compliance +0.5 to 1.75 ml with a probe tone frequency of 226 Hz).

Test environment:

Testing was carried out in a relatively quiet environment

Instrumentation:

The Fonix 6500-C hearing aid test system with computer controlled real time analyser, Version 3.09, was used in combination with an EAR-Tone 3A insert earphone instead of loud speaker for signal delivery.

To measure the RECD transform function using Fonix 6500-C system, the following protocol was configured from the quick-probe II menu

Stimulus	Composite noise (test tone consisting of 80 pure tones presented simultaneously)
Signal level	60 dBSPL
Smoothing	Log (removing minor peaks and valleys, to create a more readable curve)
Output limiting	120 dBSPL
Data Conversion	Insertion gain
Reference microphone	Off
Noise reduction	16 X (way of producing a more stable reading by averaging many samples)

For the RECD measurement, the Fonix 6500-C system remained in an unleveled condition. This is because the probe-tube microphone system was being used to measure the relative difference between the levels measured in the real-ear and the 2-cc coupler with the voltage that drives the earphone held constant. Once the instrument had been appropriately configured instead of loudspeaker, the EAR-Tone 3 A insert earphone was connected to the loudspeaker output terminal using a 1⁄4 to 1⁄8 inch adaptor. Thus the stimulus was presented through EAR-Tone 3 A insert earphone

Procedure:

The procedure used in the study for measuring the RECD transform function was originally described by Fikret-Pasa and Revit (1992) and Moodie, Seewald, and Sinclair (1994)

It consisted of three steps:

Step 1 : *Real-Ear SPL Measurement:* This step involved delivering the signal into the ear through an EAR-Tone 3A insert earphone to which individuals custom earmold was attached. The SPLs in the ear across frequencies from 200 to 8000 Hz were recorded.

Step 2 : *2-cc Coupler SPL Measurement:* The same signal was delivered into a 2-cc coupler through an EAR-Tone 3A insert earphone and the SPLs across frequencies were recorded.

Step 3 : *RECD Transform Function :* The mathematical difference between the SPLs in the real-ear and the 2-CC Coupler, across frequency gave the RECD transform function.

Step 1 : *Real-Ear SPL Measurement*

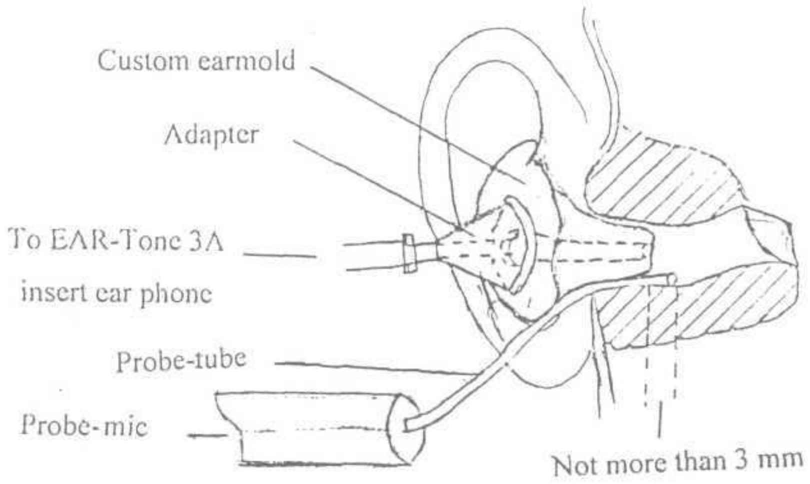

Fig 3.1: Apparatus for measuring the response of an insert earphone in the real-ear

The real-ear SPL measurement was carried out on both ears of the subject using the customized acrylic hard mold. The adult sat upright for testing and the children either sat upright or were held by mother in a comfortable position.

To obtain the real-ear SPL measurement, the probe-tube and the custom earmold were positioned in the ear so that the tip of the probe tube extended no more than 3 mm from the tip of the earmold. The insert earphone was then connected to the custom earmold through an adaptor as shown in Figure.3.1. A 60 dBSPL composite noise was delivered through the insert earphone/custom earmold coupling into the subject's ear canal. The resulting real-ear SPL for each subject was noted across the sixteen different frequencies (200, 300, 400, 500, 600, 800, 1000, 1300, 1600, 2000, 2500, 3000, 4000, 5000, 6000 and 8000 Hz). To obtain an estimate of test-retest reliability, the probe-tube and custom earmold were removed after each trial and re-inserted by the same examiner. Two measures were made for each ear.

Step 2 : *Coupler SPL Measurement*

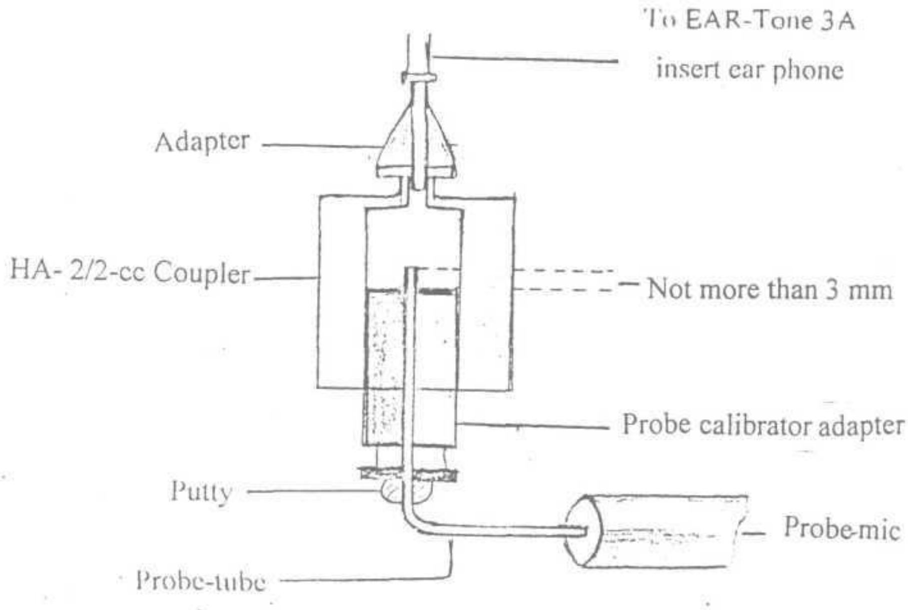

Fig.3.2: Apparatus for measuring the response of an insert earphone in the HA-2/2-cc coupler.

The HA-2/2-cc coupler was used and not the HA-l/2-cc coupler because HA-2/2-cc coupler allows the acoustic effects of the earmold coupling to be reflected in the measurement.

To obtain 2-cc coupler SPL measurement, the probe-tube was threaded through the probe microphone calibrator adaptor plug so that the tip of the probe tube extended no more than 3 mm above the surface of the plug. With the probe tube in position the distal end of the calibration adaptor entrance port was sealed with putty to hold the probe-tube in place and to avoid acoustic leakage. The calibrator adapter plug was then be placed into the microphone port of the HA-2/2-cc coupler and the insert earphone (minus the earmold coupling) is attached to the 2-cc coupler through an adaptor as shown in Figure. 3.2.

With the Fonix 6500-C system operational parameters unchanged, the 60 dBSPL composite noise was delivered through the insert earphone into the HA-2/2-cc coupler. The SPL in the 2-cc coupler was noted across the frequency range from 200 to 8000 Hz.

The coupler response was measured on a total of twenty occasions during the period of data collection. These values were averaged and the mean coupler response was used for the calculation involving the insert earphone RECD.

Step 3 : *RECD Transform Function*

The RECD transform functions were calculated at the end of the data collection by subtracting each subject individual real-ear response from the averaged coupler response. The RECD for each ear was tabulated and statistical analysis was done for the following frequencies : 200, 300, 400, 500, 600, 800, 1000, 1300, 1600, 2000, 2500, 3000, 4000, 5000, 6000 and 8000 Hz., using the paired t-test, ANOVA and post hoc Duncan's multiple range test.

Chapter IV

RESULTS

Test-retest reliability :

The mean intrasubject standard deviation of the two real-ear measurements as a function of frequency for both the children and adults are depicted in Figure 4.1. In general test-retest variability is lower in low- and mid-frequency range than at higher frequencies.

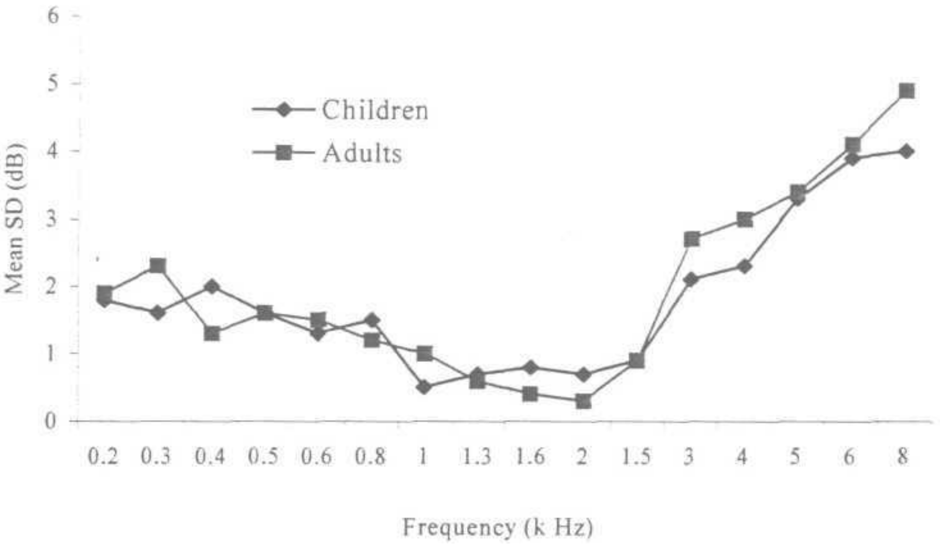

Fig 4.1 : Mean intrasubject standard deviation (in dB) as a function of frequency (in kHz) for thirty-one children and thirty adults from whom repeated measures were obtained.

There was no significant difference between the test-retest RECD measurement carried out on the same day in Group I and II i.e., in children and adults ('t' test P>0.05). At and below 4000 Hz, the mean standard deviation never exceeded 3 dB for children and 2.3 dB for adults. Since the intrasubject variability was minimal, the mean value across the two trials for each subject was used for calculating real-ear-to-coupler difference (RECD).

Similarly, the coupler measures carried out on separate days as well as on the same day were highly repeatable up to 4000 Hz, with less than 2 dB variation. More variation was seen at 5000 Hz and above. However, the overall coupler measures were very stable, repeatable and reliable as expected.

Real-Ear-to-Coupler Difference (RECD):

The mean RECD were calculated for both children and adults at sixteen different frequencies (200, 300, 400, 500, 600, 800, 1000, 1300, 1600, 2000, 2500, 3000, 4000, 5000, 6000, and 8000 Hz). The RECDs were obtained by subtracting coupler response from the average real-ear response of each subject. The mean RECDs for children and adults are shown in Figure 4.2.

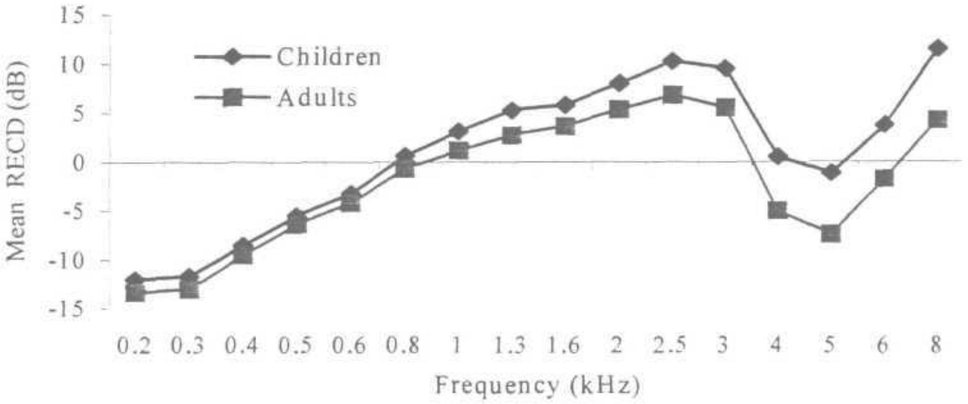

Fig 4.2 : RECD (in dB) as a function of frequency (in kHz) for thirty one children and thirty adults

To determine whether the mean RECD values obtained by children at each frequencies were significantly different from those obtained by adults, a paired t-test was used. The mean RECD, standard deviation and 't' values are shown in Table 4.1.

Table 4.1 : Shows the mean and SD of RECD for children (C) and adults (A), and t-values at different frequencies.

Frequency (Hz)	Subjects	n	Mean (dB)	SD (dB)	Mean Difference (dB)	t-Value
200	C	62	-12.03	8.25	1.38	0.963
	A	60	-13.41	7.58		
300	C	62	-11.77	8.20	1.26	0.908
	A	60	-13.04	7.17		
400	C	62	-8.60	8.26	0.95	0.688
	A	60	-9.55	6.91		
500	C	62	-5.53	8.10	0.89	0.669
	A	60	-6.43	6.64		
600	C	62	-3.29	7.83	0.89	0.692
	A	60	-4.19	6.41		
800	C	62	0.56	7.39	1.31	1.082
	A	60	-0.74	5.94		
1000	C	62	3.10	6.67	1.97	1.821
	A	60	1.12	5.21		
1300	C	62	5.24	5.76	2.54	2.695*
	A	60	2.70	4.57		
1600	C	62	5.77	5.29	2.12	2.457*
	A	60	3.64	4.16		
2000	C	62	7.91	4.88	2.56	3.096*
	A	60	5.34	4.24		
2500	C	62	10.23	5.44	3.41	3.868*
	A	60	6.82	4.20		
3000	C	62	9.52	5.91	3.94	3.943*
	A	60	5.58	5.08		
4000	C	62	0.47	8.40	5.56	4.013*
	A	60	-5.09	6.81		
5000	C	62	-1.19	10.48	6.31	3.935*
	A	60	-7.51	6.80		
6000	C	62	3.68	9.35	5.49	3.745*
	A	60	-1.81	6.57		
8000	C	62	11.48	8.29	7.25	50.93*
	A	60	4.23	7.38		

* - Significant difference at 0.05 probability level.

SD - Standard Deviation

n - Number of ears

C - Children

A - Adults

In general, the mean RECDs for children exceeded those for adults at all frequencies except 200, 300, 400, 500, 600, 800 and 1000 Hz.

To further evaluate RECDs in children as a function of age, the mean RECD for children were divided into the three groups as listed in Table 2.1 and compared with that of adults. These data are shown in Figure 4.3 and tabulated in Table 4.2.

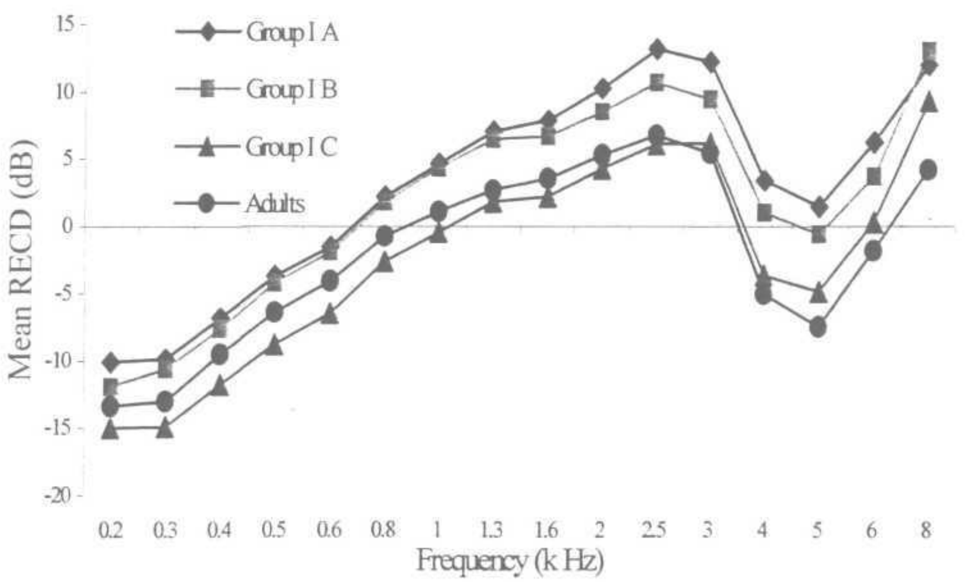

Fig 4.3. RECD (in dB) as a function of frequency (in kHz) for the three groups of children and adults.

Table 4.2 : Shows Mean and SD of RECD for three groups of children and adults at different frequencies.

Frequency(Hz)	Group IA (2-3.1 yrs) (n = 24)		Group IB (3.1-4 yrs) (n = 18)		Group IC (4.1-5 yrs) (n = 20)		Group II (Adults) (18-28 yrs) (n = 60)	
	M	SD	M	SD	M	SD	M	SD
200	-10.12	8.43	-11.20	6.58	-15.07	8.88	-13.41	7.58
300	-9.98	8.43	-10.67	5.94	-14.92	9.08	-13.04	7.17
400	-6.84	8.51	-7.37	5.95	-11.83	9.15	-9.55	6.91
500	-3.75	8.40	-4.23	5.78	-8.86	8.84	-6.43	6.64
600	-1.54	7.92	-1.96	5.90	-6.59	8.54	-4.19	6.41
800	2.25	7.36	1.85	5.85	-2.61	7.95	-0.74	5.94
1000	4.72	6.68	4.43	5.23	1.4	7.0	1.12	5.21
1300	7.14	5.45	6.52	4.52	1.82	5.83	2.70	4.57
1600	7.96	4.49	6.73	4.39	2.27	5.32	3.64	4.16
2000	10.36	4.03	8.56	3.93	4.38	4.68	5.34	4.24
2500	13.24	4.50	10.75	4.30	6.16	4.97	6.82	4.20
3000	12.29	5.52	9.53	4.82	6.19	5.77	5.58	5.08
4000	3.48	8.83	1.01	6.71	-3.63	7.89	-5.09	6.81
5000	1.52	10.9	-0.67	10.09	-4.91	9.59	-7.51	6.80
6000	6.37	9.18	3.97	9.60	0.35	8.68	-1.81	6.57
8000	12.07	8.17	13.05	9.30	9.38	7.43	4.23	7.38

M - Mean (in dB), SD - Standard Deviation (in dB), n - No. of ears

Analysis of variance was carried out and no significant main effect between groups [Group IA, Group IB, Group IC and Group II (adults)] was found at 200, 300. 400, 500, and 600 Hz. However significant main effect between the groups were found at certain frequencies such as 800, 1000, 1300, 1600, 2000, 2500, 3000, 4000, 5000, and 6000 Hz. Therefore, post hoc Duncans multiple range test was considered at these frequencies. A significant difference of RECDs between the group IA vs. group IC and group IA vs. group II. as well as. group IB vs. group IC and group IB vs. group II were found at frequencies across 800 to 6000 Hz. There was no significant difference of RECD between group IA vs. group IB and group IC vs. group II in all the frequencies. In general, at mid - and high-frequencies the RECDs are smaller for group IC and group II compared to group IA and group IB. At mid - and high - frequencies the RECDs are 4 to 6 dB larger in group IA and IB.

The 500 to 4000 Hz region was used to determine the RECD as a function of age, because that range represents the frequency region where the measurements remained quite stable and were not affected by slit leaks or ¼ - wave antiresonances (Dirks and Kincaid, 1987; Fikret-Pasa and Revit, 1992).

A systematic decrease in RECD was noticed with increasing subject age. This trend can be seen more clearly in Figure 4.4 where RECDs are plotted as a function of age group. For the youngest group (2 to 3.1 years), the maximum mean RECD was 13.2 dB occurring at 2500 Hz. This corresponded to a 6.4 dB difference from the adult mean RECD at that frequency. For the oldest group (4.1 to 5 years), the maximum mean RECD decreased to 6.19 at 2500 Hz. This value is 0.7 dB lesser than the adult mean RECD.

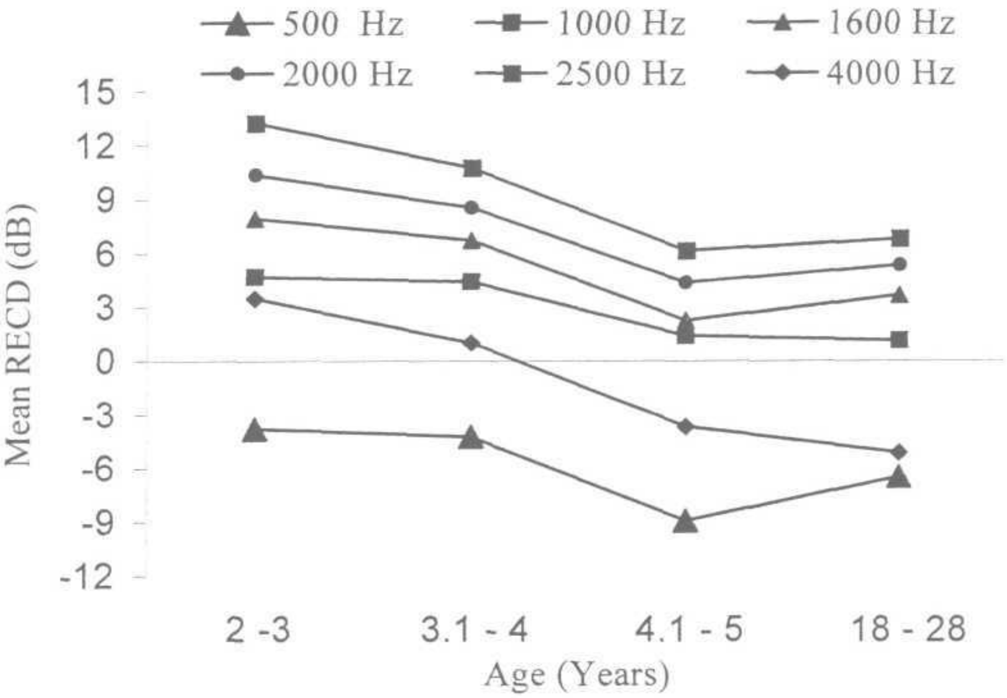

Fig 4.4 : RECD (in dB) as a function of age (years) for frequencies at 500, 1000, 1600, 2000, 2500 and 4000 Hz.

Intersubject Variability :

The mean standard deviation of the RECDs for both groups (children and adults) is a measure of intersubject variability. Figure 4.5 shows the SD for children and adults across the different frequencies. At 4000 Hz and below the standard deviations are very similar for both groups differing by a maximum of 2 dB. Variability across subjects was low at mid-frequencies (SD's of about 4 to 6 dB), and increased to SD's of 6 to 8 dB at low-frequencies. At higher frequencies, variability across subjects were higher for children compared to adults (SD = 8.1 to 10.9 dB for children and 6.8 to 7.3 dB for adults).

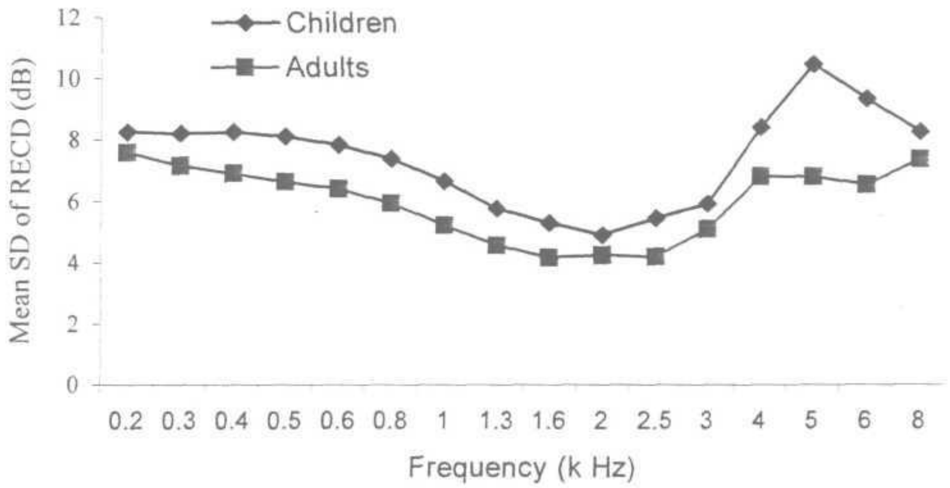

Fig 4.5 : Mean intersubject standard deviation (in dB) as a function of frequency (in kHz) for children and adults.

Chapter V

DISCUSSION

Test-retest reliability :

The high intrasubject test-retest reliability in the present study confirms that measurement of RECD provides relatively stable and reliable estimates of real-ear sound pressure levels. For both the groups (adults and children) the variability is lowest in the low and mid-frequency range. The increase in variability in the high frequencies is consistent with other reports (Nelson Barlow, Auslander, Rines and Stelmachowicz, 1988; Feigin, Kopun, Stelmachowicz, and Gorga 1989;Fikret-Pasa and Revit. 1992). This variability can be accounted for by the decrease in the wavelength of sound with increasing frequency, resulting in greater influence of standing waves on probe-tube measures, made at a point remote from the eardrum (Dirks and Kincaid, 1987).

However, as hearing aids amplify very little above 5000 Hz, this increased variation in this frequency range is not of major clinical significance .

Real-Ear-to-Coupler Difference (RECD) :

Real ear to coupler differences increased as a function of frequency for both groups, reflecting the limitations of a 2-cc coupler in predicting real ear sound pressure level at higher frequencies. The same general pattern of RECDs increasing with increased frequency below 6000 Hz was also found in Feigin, Kopun, Stelmachowicz and Gorga (1989) and Fikret-Pasa and Revit (1992).

However, in the present study, a notch in the 4000 to 6000 Hz region is consistently seen in all the groups (refer Figure 4.3). A similar notch in the 4000 to 6000 Hz region is also reported by Fikret-Pasa and Revit (1992) for their RECD data using adult subjects. Two explanations can be offered for this finding:

1) Possible probe-tube placement in a standing wave pressure minima for the 4000 to 6000 Hz range and

2) Probe-tube tip too close to insert earphones sound outlet causing invalid estimates of eardrum SPL due to spreading inertance

However, in the present study the probe-tube was not placed near the eardrum and also the probe-tube tip was located 3 mm beyond the medial tip of the earmold. Hence, both explanations may have relevance to mean RECD data in the 4000 to 6000 Hz range.

The maximum real-ear-to-coupler deviation occurred at 2500 Hz for both children and adults. This could be attributed to the reduced volume between the tip of the earmold and the tympanic membrane causing resonance at that frequency. This has also been reported by Nelson Barlow, Auslander, Rines and Stelmachowicz (1988). It was found that at 600 Hz and below, the SPLs in the real ear were lesser than coupler SPLs. The reduced RECDs at low-frequencies, for children as well as adults, is probably due to sound leakage around the custom earmold occurring during the real-ear measurement.

Although RECDs were measured over the frequency range from 250 to 8000 Hz, most hearing aids provide greatest output in the mid frequencies (for 1000, 1600, 2000, 2500, and 3000 Hz). The mean RECDs for group IA, group IB, group IC over this frequency range was 9.6. 7.9 and 3.8 dB with a standard deviation of 5, 4.5 and 5.5 dB respectively. In contrast, the mean RECD for adults was 4.4 dB (SD = 4.5 dB). These data suggested a greater risk of over amplification for children less than four years when the maximum output of hearing aids is determined using 2-cc coupler measures of SPL. Implies cautious decisions for children during selection, to avoid hearing damage due to over amplification.

RECD as a function of age indicate a systematic decrease with increasing subject age (Figure 4.4). For all four frequencies, the decrease in RECD appears to be relatively linear from 2 to 5 years. When compared to adults, the group IA (2 to 3 years) showed the maximum RECD followed by group IB (3.1 to 4 years). It is apparent that the higher RECDs in children compared to adults may correspond more closely to the fact that ear canal volume is smaller in children as suggested by Bratt (1980) as cited in Hawkins (1992) and Feigin. Kopun, Stelmachowicz and Gorga (1989).

It is also important to note that the children's mean RECDs reach the adult mean by approximately 4 to 5 years of age. Feigin. Kopun, Stelmachowicz and Gorga (1989) also reported that by 4 to 5 years, the children's mean RECDs were within 4 dB of the mean adult value.

Intel-subject Variability :

The present study, in line with others (Westwood and Bamford, 1995; Fikret-Pasa and Revit, 1992), has shown relatively large intersubject variability in RECDs . In addition, the mean SD for children is around 1 dB higher than adults. Variation in the canal size and diameter could have accounted for. at least, part of intersubject variability. The variation in the actual dimension of the sound channel in the earmold and slit leaks around the earmold may have accounted for further individual variability in RECD.

Chapter VI

SUMMARY AND CONCLUSIONS

It has been well established that 2-cc coupler measures of hearing aid output do not adequately reflect individual differences in a number of factors that are known to affect hearing aid performance (Bratt, 1980, as Cited in Hawkins. 1992; Madsen. 1986; Seewald. Cornelisse. Richert. and Block. 1997). These factors include the acoustic impedance of the ear, earmold acoustics, impedance of the ear, earmold acoustics, ear canal size, acoustic leakage of sound from the ear canal, head diffraction effects, etc. Discrepancies between real-ear and coupler measures may be particularly large for infants and young children primarily resulting from smaller ear canal volumes in this population (Feigin, Kopun, Stelmachowicz and Gorga, 1989; Nelson Barlow. Auslander, Rines, and Stelmachowicz, 1988; Westwood and Bamford. 1995). However, there is a dearth of literature on the RECDs for young children .

Hence, the present study aimed at investigating

1) the test-retest reliability of the real-ear response for children and adults.

2) the changes in RECDs for children and comparing it with that of adults and.

3) the intersubject variability in RECDs for children and adults.

Sixty-two ears of children with sensorineural hearing loss, ranging in age from 2 to 5 years and sixty ears of otologically normal adults, ranging in age from 18 to

28 years were included in the study. The real-ear-to-coupler difference transfer function was obtained for all the subjects using the procedure originally described by Moodie, Seewald and Sinclair (1994).

The results from this study suggest that:

1) Real-ear measures can provide reliable estimates of ear canal sound pressure levels for young children and adults, i.e.. the test-retest variability' was minimal for both children and adults suggesting that probe-test measurements are stable across trials.

2) The mean RECDs for children under four years of age exceeded those for adults at mid- and high- frequencies, but systematically decreased with increasing age. The children's mean RECD fell within the adult mean by approximately 4.1 to 5 years of age.

3) The intersubject variability was quite large for both children and adults.

In general, the present study supported the premise that RECDs in young children typically are greater than in adults, especially in the frequency range where most hearing aids provide their maximum output. Also the high degree of intersubject variability in this study indicates the need for RECD measures to be carried out individually rather than using average values.

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