EFFECTS OF VARIATION IN LENGTH AND DIAMETER OF ACOUSTIC COUPLERS ON THE FREQUENCY RESPONSE CHARACTERISTICS OF HEARING AIDS

Chandra.P

A Dissertation submitted in part fulfillment for the
Degree of Master of Science (Speech and Hearing)
University of Mysore

1975

CERTIFICATE

This is to certify that the Dissertation “EFFECTS OF VATIATION IN LENGTH AND DIAMETER OF ACOUSTIC COUPLERS ON THE FREQEUNCY RESPONSE CHARACTERISTICS OF HEARING AIDS” is the bona fide work in part fulfillment for the Degree of M.Sc. (Speech & Hearing), Carrying 100 marks of the student with Register Number 21.

(Dr. N. Rathna)

Joint Director
All India Institute of
Speech and Hearing

CERTIFICATE

This is to certify that this dissertation has been prepared under my supervision and guidance.

shailaja nikam

Guide

DECLARATION

This dissertation is the result of my own study undertaken under the guidance of Dr. Shailaja Nikam, Head of the Department of Audiology, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

Mysore.

Date : June 4, 1975 Register Number 21

ACKNOWLEDGEMENT

The investigator wishes to express his sincere thanks to Dr. Shailaja Nikam, Reader and Head of the Department of Audiology, for her valuable guidance.

His thanks are due to Dr. PR Kulkarni, Director, for his permission to use the facilities available.

He would also like to thank Sri BD Jayaram, Sri D. Basavaraiah and Smt. Shankuntala Sharma of Central Institute of Indian Languages, Mysore, and Prof, Krishnaswamy Iyengar of Maharaja’s College, Mysore, for their advice.

The investigator also thanks Sri T. Keshava Murthy for neat execution in typing this dissertation.

Mysore

June 4, 1975. Reg. No. 21

CONTENTS

CHAPTER I

INTRODUCTION

The acoustic coupler is a device, made out of plastic, that links the hearing aid receiver to the ear. It serves the dual function of channelizing the sound into the ear canal and supporting the receiver to fit snugly on the ear. Thus, it is essential for all types of air conduction hearing aids.

To derive maximum benefit from a hearing aid, a custom acoustic coupler – made from the user’s ear impression – becomes a necessity. However, it is not uncommon to find stock couplers being used not only for hearing aid trail, but also for daily use. The stock coupler seldom fits the contours of the user’s ear exactly and this leads not only to poor retention of the receiver, but may also cause irritation and pain to the user. The benefit of the hearing aid would also be limited because of acoustic feedback.

Several of the disadvantages of the stock coupler can be overcome by the use of custom made acoustic coupler. Ewing & Ewing (1967) rightly say that “the amount of help that can be got from a hearing aid depends fundamentally on the design of the earnold and the precision with which it is made”. Custom acoustic couplers are usually made in heat-cure acrylic material. In recent years, cold-cure acrylic is being increasingly used, saving considerable amount of time and labour.

Modification of Acoustic Couplers

The acoustic coupler assumes critical importance in the individual fitting of a hearing aid, because of its increasing use as an acoustic modifier (Ling, 1971). Studies on modifications clearly indicate that the hearing aid response can be significantly altered by changing or modifying the structure of the coupler.

Interest in modifying acoustic couplers dates back to the early 1940’s. The major modifications that affect the hearing aid response characteristics are venting, variation in length and diameter of the sound bore of the coupler.

Venting

Vent is a hole that provides free passage of air to the sound bore of the acoustic coupler or to the ear canal. The primary purpose of venting is to attenuate low frequency. Vents create a shunting or damping action, which affects the low frequencies and enables the amplified high frequency signals to reach the ear(Dodd & Harford, 1968). Vents of very small size can bring about equalization of barometric pressure, but will not usually cause much of an effect on the performance of a hearing aid (Studebaker & Zachman 1970; Weatherton & Goetzinger, 1971; Lybarger, 1972). The results of medium sized vents are unpredictable (Weatherton & Goetzinger, 1971; Lybarger, 1972). For really significant reduction in low frequency response a short wide vent (of 3mm diameter or more) can be quite effective (Lybarger, 1972)

Open or non-occluding acoustic coupler refers to a skeleton mold designed to hold the sound tubing in place, without occluding the ear canal. The effect is similar to that of large venting. Use of open mold helps to hear the natural, unamplified sound without obstruction. Further, it reduces low frequency amplification. It also solves the problem of variability in frequency response caused by changes in vent size (Hodgson & Murdock, 1970).

Length and Diameter

According to both the American and International standards, the standard length of the sound bore in the acoustic coupler is 18mm and the diameter 3mm. The sound bore, because of its acoustic inertance and resistance ahs an appreciable effect on the frequency response (Lybarger, 1972). If the bore length is longer or the diameter smaller than the standard, the primary peak will be lower in frequency an the high frequency out-off is lowered. On the other hand, if the length is shortened or the diameter increased, the primary peak will be higher in frequency and the high frequency out-off is extended (Lybarger, 1972). No study is reported on the effect of modification of length and diameter.

Need for the study

Though the standard length and diameter of the sound bore of the acoustic coupler are 18mm and 3mm respectively, in practice, this standard may be difficult to maintain. Individual differences in the size and shape of the ear canal and the type of material used for making the couplers (whether soft or hard) are two of the factors that bring about variations in length and diameter of the sound bore of the acoustic coupler. Measuring the lengths of 22 ear molds, selected at random, showed that the length of the sound bore from the tip of the mold to the nub end of the receiver differed approximately from 17.00 mm to 24.00 mm. The diameter was not measured due to lack of facilities. It is important to know whether these variations have any effect on the response characteristics of a hearing aid and if so, to what extent. It is also essential to know how far variations in length and diameter can be made without affecting the hearing aid response. As there is no literature or study available there is a need to study the effect of variations in length and diameter of the acoustic coupler sound bore.

This study is also of importance, keeping in view, the subjects with severe hearing loss. Use of open and vented couplers by these subjects limits the hearing aid usage due to acoustic feedback. This necessitates the study of variation in length and diameter in an effort to help them use the hearing to the maximum possible extent.

Definition of length and diameter

For the purpose of this study, the length and diameter of the sound bore of the acoustic coupler are defined as follows:

“The length is the distance of the sound bore, between the tip of the acoustic coupler that goes into ear canal and the tip of the receiver nub that snaps into the ring fixed on the base of the coupler”

“The diameter is the mean diameter of the sound bore and this is calculated using mercury to find the volume of the sound bore”

Purpose of the Study

The study was undertaken to answer the following questions:

1. Does modification of the standard length of the sound bore, affect the response characteristics of the hearing aid?
2. Does modification of the standard diameter of the sound bore affect the response characteristics of the hearing aid? and
3. Does modification bring about any interaction of length and diameter of the sound bore?

CHAPTER II

REVIEW OF LITERATURE

Literature pertaining to modification of the acoustic coupler shows that most of the studies are on venting and open couplers and very few deal with modification of length and diameter. In most of these studies more than one aspect of modification at a time.

Studies of custom-made acoustic couplers

Boothroyd (1965) conducted an investigation of the influence of certain variations in the methods and materials used in earmold production. His aims were :

(a) to compare earmolds produced under the National Health Scheme in England, with molds produced under theoretically more ideal conditions;

(b) to assess the importance of impression shrinkage on the performance of the finished mold ;

(c) to obtain information on the frequency of occurrence of ears for which it is difficult to provide a satisfactory earmold and

(d) to compare soft and hard acrylic molds. For this purpose, 120 earmoulds were made, in six groups of 20 each, for children ranging from 4 to 15 years attending the Manchester School for the Deaf. Six bands of impression materials were used in the experiment. Impression shrinkage varied from ½% to 30% and linear contraction of cured hard acrylic mold was approximately 1%. About ½ reduction in size was due to polishing.

There were wide difference within the groups and small differences between the groups in the ability of the molds to reduce feedback. He found that use of soft acrylic for the finished mold was able to counteract a certain amount of shrinkage in the impression and that dimensional accuracy can further be improved by was build up around the meatgal probe. he concluded that satisfactory earmolds can be made where the impression shrinkage is less than 1%, by extending the mold behind the helix of the ear, by extending the mold approximately ½″ into the meatus and by judicious use of wax dipping.

The use of cold cure acrylic for taking the impression has been an important advance in the field of earmold making. It has resulted in saving not only time and labour but also in eliminating the use of equipment such as drilling motor, polishing lathe etc., (Bulmer, 1973).

Kunkle and Bess (1974) compared the audiometric data for custom made and stock acoustic couplers within the routine hearing aid evaluation procedure. There couplers – custom made mold, stock acrylic mold and stock inserts – were used for 17 subjects with mild to moderate sensorineural impairment. Aided Speech Reception Threshold, Speech Discrimination, Most Comfortable Level and Tolerance Levels for speech and thresholds for narrow-band noise were determined for each subject. Results showed that custom coupler Yielded lower mean thresholds at all frequencies than either of the stock couplers. SRTs were also found to be significantly lower for custom mold compared to the other two couplers. Improvement was also seen in discrimination over the other two stock couplers. The study proves that custom acoustic coupler, because of the acoustic seal it provides, serves to enhance the level of sound pressure in the ear canal, especially for low frequencies.

Several authors have included the custom acoustic couplers along with other modified couplers in their studies.

Bresson (1971) and Nielson (1972) compared the closed acoustic coupler with open mold. Subjective evaluation of nearly half of the 65 patients with, sloping and pronounced high frequency loss showed that their listening and understanding speech was better with open molds. Objective evaluation was done in three ways. First, no threshold difference between open and closed couplers was noticed, using narrow band noise audiometry on 8 patients with unilateral deafness in one ear and high frequency loss in the other ear. Second, sound pressure measurements on a human ear was made. Frequency analysis of white noise through a sound probe placed deep inside the ear canal without hearing aid amplification showed that there was leakage of sound into the ear, even when care had been taken to make the ear-mold fit tightly. The effect with open mold was 5-18 dB more. Bresson, also found that with open mold at Most Comfortable Level, 10 – 15 dB were lost in low frequencies, while something was gained in the high frequencies. Third, placing sound probe in the ear canal of a subject, he found that the subject performed better with open mold, in a critical signal to noise situation.

Nielson (1972) using subjects with high frequency loss, investigated the benefits from open versus closed acoustic couplers. In the first sub.study, group (a) had eighteen subjects with high frequency loss and in group (b) had twenty one subjects loss with sloping audiogram. The first group was more suitable for open molds than the second group. Results based on subjective preference showed that in group (a) fifteen of the eighteen persons preferred open molds while in group (b) only eight preferred the open type. In the second sub-study, two comparable groups of fifty persons in each, with a hearing very suitable for open mold were used. One group was treated with open mold and the other with closed and found that the difference was not significant. The third sub-study investigated whether introduction of fitting cases with high frequency loss with open molds affected the number of applications refused by the State Hearing Centre in Copenhagen. The steep fall in the percentage of refusals from 7.1% in 1969-70 to 2.1% in 1970-71 was ascribed to the introduction of open molds for cases with high-frequency hearing loss. But the author has not made it very clear that there were no other factors involved.

Weatherton and Goetzinger (1971) used five normal subjects aged 22-24 years to investigate the change in sensitivity using the standard coupler and five modified couplers – one standard with shortened ear canal, open mold, three couplers with vent sizes of 1.02 mm, 2.06 mm and 3.05 mm in the shortened coupler. With Bekesy audiometry they found that thresholds with the standard and small vented (1.02 mm) couplers were not significantly different, while significant differences with other modifications were noted. The use of normals is questionable , as any modification of acoustic coupler is always an attempt made to make the hearing aid more useful to the person with hearing loss. However, one significant point in this study is that responses of the standard coupler and one with very small vent do not differ significantly. Similar conclusion is made by Studebaker and Zachmann (1970) using 2 cm^3 coupler.

Testing the hypothesis that persons with primarily high, frequency hearing loss can discriminate better in noise when wearing a hearing aid with a vented coupler than when wearing an unvented acoustic coupler was the aim of the study by McClellan (1967). Five subjects with near normal hearing upto 1000 Hz and a loss of 35 dB or more at 2000 Hz listened to spondee words at 60 dB SPL in sound field against a background of “Speech Noise” (+ 10 dB S/N). He observed no gain in discrimination when the standard coupler was worn, but a significant gain (70.8 to 86%) was observed when wearing vented couplers, over the unaided performance.

Dodds and Harford (1968) selected 35 cases with high frequency hearing loss, for analysis of test results using standard, vented and open couplers. Using the ‘t’ test for matched pairs, it was found that there was no significant difference between vented and standard couplers. Using an open coupler produced greater improvement in discrimination ability than did the standard coupler. There was significant improvement in discrimination with either coupler over the group’s unaided sound field results and this was attributed to increased sensitivity provided by the hearing aid. Two significant drawbacks seem to be the use of hearing aids from sixteen manufacturers, and use of two types of couplers for each subject, and not all the three types of couplers used in the study.

A CROS hearing aid was utilized with four different acoustic couplers – conventional, vented, open and crimped polythene tubing to obtain spondee thresholds and speech discrimination scores from three groups of hearing impaired subjects by Jetty and Rintelmann (1970). Results showed that the first group of ten subjects with conductive hearing loss obtained better mean Speech Reception Thresholds with conventional coupler than with the modified couplers. In the second group of ten subjects having sensorineural loss with gradual slope, lower Speech Reception Thresholds were obtained with conventional coupler, whereas speech discrimination was improved with the modified couplers. In the sensorineural group of ten subjects with steep high frequency loss, mean Speech Reception Thresholds were essentially the same for all couplers and there was improved speech discrimination with modified couplers.

Northern and Hattler (1970) compared four types of couplers with behavioral speech audiometric tasks in five normal-hearing and seven subjects with sensorineural loss. The four types of couplers used were:

(i) Solid coupler with a canal approximately 9.5mm length and diameter 3 mm;

(ii) Cavity coupler having a essentially hollow body with a similar length, but the mean diameter was about 5.6 mm;

(iii) The Solid vented coupler had a 1.9 mm vent; and

(iv) Vented coupler with a 2.2 mm vent but with a canal length of 1.5 mm and a mean 7.7 mm bore diameter. Results, in general, showed that solid couplers yielded slightly lower thresholds than vented couplers ;

Aided speech intelligibility scores were obtained in quiet and in noise from eighteen subjects with high-frequency SN loss using standard, vented and open acoustic couplers in the study by Hodgson and Murdock (1970). They found better aided speech intelligibility with open coupler than with a standard coupler.

Studies on vented acoustic couplers

Vents are employed for providing barometric equalization of the ear cavity with outside atmosphere and to attenuate low frequency amplification.

Vents of different sizes change the low frequency output differently. Very small sized vents, apart from bringing about barometric qualization will not cause much of an effect on the performance of a hearing aid (Studebaker and Zachman, 1970;) Weatherton and Goetzinger, 1971; Lybarger, 1972).

Medium vents bring about attenuation of low frequencies. According to Lybarger (1972) they cut very low frequencies and may show an increase in the response for the middle lows. Weatherton and Goetzinger (1971) caution that the use of medium vented coupler without specific threshold data would be a dubious procedure.

For a significant reduction in low frequency response, a wide short vent can be quite effective (Lybarger, 1972). The larger the diameter of the vent, the greater the reduction of low frequencies and higher the frequency where the reduction begins

(Curran, 1973; Cooper et al, 1975). Keeping in view the above studies, Hoffman’s statement not ton be afraid of drilling holes in the coupler may be discounted.

in studies related to venting, vent sizes differ from study to study and as such comparison becomes difficult. For example, Studebaker and Zachman (1970) have used vents having diameters 0.75 mm, 1.5 mm and 3.00 mm. While Northern and Hattler (1970) have used vents with 1.9 mm, 2.2 mm and 7.7 mm diameters. Weatherton and Goetzinger (1971) have used 1.02 mm, 2.06 mm and 3.05 mm diameter vents. Some studies have made use of commercially available vented couplers called ‘Acoustic Modifier’ patented by Zenith Radio Corporation (McClellan, 1967; Dodds and Harford, 1968; Jetty and Rintelmann, 1971). In Some studies along with venting, the canal portion of the coupler has been reduced (Weatherton and Goetzinger, 1971). Thus while studying differences in vent size introducing variables such as shortening the canal length makes interpretation of test results difficult.

Venting of acoustic coupler can be done in two ways – side branch or diagonal venting and parallel venting. In side-branch venting, the vent enters the sound bore before the end of the ear canal, whild in parallel venting, the vent runs parallel to the sound bore and terminates at the end of the earmold canal. the study by Cooper et al (1975) showed that side-branch venting is more effective and results in a greater reduction of intensity at both the high and low ends of the frequency range. In addition, the reduction extends over a broader portion of the frequency range. Moreover, side branch venting is possible in all cases, while lateral venting is possible only if the canal is large.

Studebaker and Zachman (1970) investigated the effects of vents on the frequency response of a hearing aid, using 2 cm^3 coupler and four normal subjects. They used on unvented and three vented couplers having diameters of 0.75 mm, 1.5 mm and 3mm. Each acoustic coupler had the standard length and diameter; the vent length was 11 ± 1 mm. Using a specially made 2 cm^3 coupler and drilling a second canal in the coupler to use probe-tube microphone, responses from each coupler were recorded. Results showed that the effects of the smallest vent (0.75 mm) varied little from the unvented acoustic coupler. The coupler with a vent of 1.5 mm affected low frequencies and showed a sharp resonance in the region of 400 – 500 Hz. The effect of the largest vent, was similar except that low frequency filtering wa greater and there was a sharp resonance at about 3500 Hz. They also found that probe tube microphone had very little influence on sound level. Damping was the principal acoustical difference noticed between the real ears and 2 cm coupler. The response curves obtained on human ears were smooth.

Sensitivity reduction for the frequencies below 1000 Hz was related to the size of the vent and enhancement of sensitivity was observed in the high frequencies, in the study by Weatherton and Goetsinger (1971). They concluded that the coupler with large vent (3.05 mm) would be the best choice for subjects with high frequency hearing loss, because of significant reduction of sensitivity in low frequencies, with minimal effects in upper frequencies and little variability among subjects. They cautioned that couplers with medium vent (2.06 mm) should be used only after testing it on the individual and the small vent (1.016 mm) coupler should not be used for reducing low frequency sensitivity.

Five subjects with high frequency loss showed a mean gain of 70.8% to 86% in discrimination in noise when wearing vented coupler relative to their mean unaided discrimination (McClellan, 1967).

Northern and Hattler (1970) used five normal – hearing subjects whose hearing levels were better than 10 dB (Ref: ISO 1964) from 250 to 8000 Hz and 6 hearing-impaired subjects with mild to severe sloping audiometric configurations bilaterally. The purpose was to discover if difference among earmold structures could influence hearing aid performance as measured with clinical speech tests. Four types of acoustic couplers – solid, hollow cavity, solid vented and vented large bore – were used. Speech Bekesy thresholds were obtained under each earmold condition for detectability, intelligibility, most comfortable loudness and tolerance. It was found difficult to demonstrate differences in speech test scores which could be attributed to earmold variation, in spite of the fact that variation existed in earmold structure and electro-acoustic analyses. The authors suggest that parameters exist by which subjective judgements can differentiate among earmold types and that consistant differences are not distinguished with our present speech identification taks.

In summary, studies show that venting of acoustic coupler brings about attenuation of low frequency amplification and this attenuation varies with the size of vents. Large vents of the size 3mm or more are proved to be effective in bringing about effect attenuation of low frequency amplification and are proved used for subjects with high frequency loss. However, for those subjects who need high amplification, even small vents can cause acoustic feedback (Lybarger, 1972).

Studies on open or non-occluding acoustic couplers

Open acoustic couplers are an extension of vented couplers. Open couplers, in addition to reducing the low freqeuency amplification, enable the listener with good low frequency sensitivity to hear that portion of the signal unaided. It is primarily employed with a CROS hearing aid since acoustic feedback is avoided (Lybarger, 1972). However, it is also used with the hearing aid on the same side of the head for cases requiring limited gain (Green, 1969; Lybarger, 1972). Open couplers are recommended for subjects with sloping audiograms and mild overall hearing loss (Ling, 1971). They are also used by subjects having suuppurative otitis media (Green, 1969).

While Green’s study (1969) was concerned with non-occluding couplers with B_1 CROS and IROS hearing aids, Green and Ross (1968).

Bresson (1971) and Nielson (1972) compared the performance of standard and open couplers, Studies by Dodds and Harford (1968, 1970), Weatherton and Goetzinger (1971) and Hodgson and Murdock (1970) have used standard, vented and open acoustic couplers for comparison. Jetty and Rintelmann (1970) in addition to the above three types of couplers included crimped polyethylene tubing for comparison.

Green (1969), employing IROS and BICROS mode of hearing aid amplification, used non-occluding couplers with four subjects with Bekesy Audiometry. Both aided and unaided sound field measurements were made. For subject 1, open coupler was used for medical reasons; the right wear had mixed loss and chronic external titis. A plug was made to occlude the open coupler whent it was necessary to enhance low-frequency amplification. Subject 2 had servers SN loss in right ear and mild sensorineural loss in left ear with good hearing at 2000 Hz, was fitted with a “low frequency emphasis” spectable BICROS hearing aid with a open mold in left ear. Substraital improvement wasa reported in the threshold of speech, with good speech discrimination. Subject 3 had bilateral SN loss with saucer curve in both ears, loss being greater in the right ear. Hearing aid was placed on the right ear with a plastic tubing leading the sound to the left ear. An open coupler was used in the left ear and this was found to be satisfactory. Subject 4 had bilateral high frequency loss and each ear was fitted with a aid in IROS mode, using non-occluding couplers. There was improvement in aided thresholds and speech discrimination was better compared to unaided score, for all four subjects.

Re-examination by Bresson (1971) of nearly half of the sixty five cases with presbyacusis or noise-induced hearing loss revealed that with open coupler, their hearing and understanding of speech improved. Objective evaluation of the performance of open and closed couplers also showed that the patient could understand speech with background noise better with open coupler. However, the author did not find any difference in threshold between open and closed couplers, when narrow band noise audiometry was done on eight pateients with high frequency loss.

The three sub-studies by Neilson (1972) shows that subjects with high frequency hearing loss preferred open coupler, compared to the closed coupler. He ascribed that the fall in the percentage of refusals of applications for hearing aid at the State Hearing Center in Copenhagen was mainly due to the introduction of open couplers in that centre. But, it should also be noted that when two comparable groups with hearing loss suitable for open couplers were evaluated after treating one group with open and the other with closed couplers, thre was no significant difference.

Green and Ross (1968) obtained sound-field audiograms, from one experienced hearing impaired subjects wearing an ear level hearing aid with a standard and a non-occluding CROS type acoustic coupler. The findings indicated that a non-occluding CROS type coupler alters the frequency response characteristics of a hearing aid markedly,, reducing the amplification for low frequencies. Using only one subject in this study, limits the generalization of the findings.

Hodgson and Murdock (1970) obtained aided speech intelligibility scores in quiet and in noise, from eighteen subjects with high frequency SN loss, using standard, vented (3 mm) and open acoustic couplers. A comparison of performance in the earmold conditions show that the subjects obtained better aided speech intelligibility with open coupler than with standard coupler, both in quiet and in noise. They opined that using an open rather than vented coupler solves the problem of variability in frequency response caused by changes in vent size.

Dodds and Harford (1968) obtained speech discrimination scores in sound field, using average conversational level (70 dB SPL) on thirty five subjects with high frequency, sensorineural hearing loss with standard, vented and open couplers. Enhanced PB scores were obtained using any one of the three couplers and this is attributed to the increased sensitivity provided by the hearing aid. Only the open acoustic coupler used with a CROS hearing aid resulted in a significant improvement in discrimination when compared with the group’s unaided PB scores under earphones or when comparing inter-coupler scores.

In a follow-up study done through questionnaire, Dodds and Harford (1970) concluded that there was a tendency for those using an open acoustic coupler to obtain more beneficial results from amplification in everyday communication than those using standard or vented couplers.

Weatherton and Goetzinger (1971) had five normal subjects trace Bekesy thresholds with a commercial hearing aid receiver coupled to each of the six types of couplers used. The coupler used were, standard, standard coupler with shortened canal, three types of vented couplers having vent sizes of 1.02 mm, 2.06 mm and 3.05 mm with shortened canal and an open coupler. They found that open acoustic coupler induced greater reduction in sensitivity than any of the other couplers at all test frequencies. They also noticed individual differences for the open coupler than for the large vented coupler. Another observation was that the shortened or vented couplers do not affect sensitivity in upper frequencies as much as the standard or open couplers.

The use of normal subjects to trace aided hearing thresholds does not seem to be correct. Choice of subjects with hearing loss would have been much more valid to come to the conclusion which types acoustic coupler modification suit which type of loss. so, the choice of normals in the comparison of different modified couplers is a drawback of this study. Their finding that open acoustic couplers are more variable across subjects when compared to large vented coupler is contradictory to some other studies. The study by Dodds and Harford (1968) and Hodgson and Murdock (1970) obtained PB scores using standard, vented and open couplers, showed that subjects obtained better speech discrimination with open couplers when compared to others both in quiet and noise. Though we cannot compare to others both in quiet and noise. Though we cannot compare sensitivity threshold with discriminative scores, there seems to be some contradiction. Hodgson and Murdock (1970) further say that use of open coupler solves the problem of variability in frequency response caused by changes in vent size. Their finding that open couplers affect upper frequencies needs verification.

In the study by Jetty and Rintelmann (1970) a CROS hearing aid was utilized with four different acoustic couplers – standard, vented, open and crimped plythylene tubing – to obtain spondee thresholds and speech discrimination scores from three groups of hearing impaired subjects.

In the SN group with a gradual slope, open coupler resulted in a lower mean threshold than vented coupler and tubing. In the SN group with a precipitons drop, a slightly lower mean threshold was obtained with the open earpiece than with any of the other coupling devices.

CHAPTER III

EXPERIMENTAL PROCEDURE

Twenty five acrylic substitute earmolds, with varying diameter and length, were used in the experiment and the response with each mold was recorded in SPL values, at each frequency employed. Data was manually recorded and analysed using the analysis of variance.

For this study, the following instruments were used :

Hearing Aid Test Box (Bruel and Kjaer 4217)

Frequency Analyser (Bruel and Kjaer 2107)

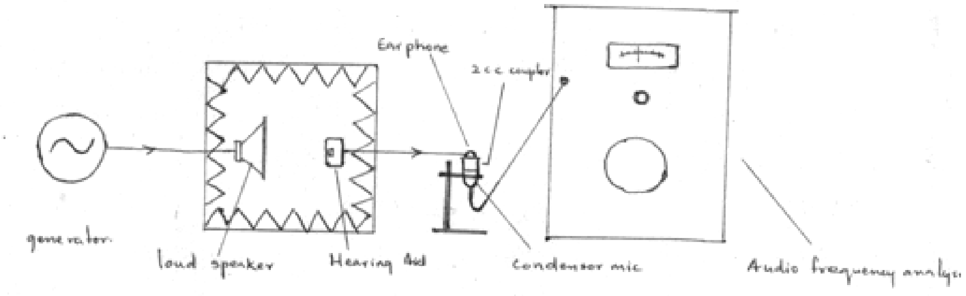
Condenser Microphone (Bruel and Kjaer 4144)

2 cm^3 coupler (DB 0138) and

Danaid I hearing aid with one Danavox Sub Minor Receiver.

Given below is the block diagram of the experimental set up:

Figure 1



Test Enviroment

The test was carried out in a quiet room. Ambient noise, measured using Sound Pressure Level Meter (Bruel and Kjaer 2203) with condenser microphone (Bruel & Kjaer 4144) on ‘C’ scale was around 45 dB SPL.

Preparation of Substitute acrylic acoustic couplers

Five variations in length and five in diameter of the sound bore in the acoustic couplers were chosen. The dimensions were both below and above the standard length and diameter. Specifically, five variations in length were – 14 mm, 16 mm, 18 mm, 20mm and 22 mm. Five variations in diameter were – 1.50 mm, 2.25 mm, 3.00 mm, 3.75 mm and 4.5 mm. Thus for each length, there were five variations in diameter and for each diameter, five variations in length. A total of twenty five acrylic substitute acoustic couplers were required, including the one with standard length and diameter.

The substitute acoustic couplers were made similar in shape and size to the metal substitute acoustic coupler used with the 2 cm^3 couplers. These were made in transparent heat-cure acrylic material, and were cylindrical in shape with a diameter of approximately 15 mm. No attempt was made to keep the diameter of the acrylic substitute to be exactly same as the diameter of the metal substitute, as it has no functional value.

The lengths of the acrylic substitute were made 1 mm shorter than the required length. The remaining length of 1 mm had to be made to suit the hole of the wall between the two cavities in the 2 cm^3 coupler. To achieve this, each acrylic substitute was held in the upper chamber of the 2 cm^3 coupler. To achieve this, each acrylic substitute was held in the upper chamber of the 2 cm^3 coupler. Inverting the coupler, the hold area in the separating wall was filled with the cold cure acrylic. The acrylic substitute was removed when the cold cure acrylic was set and the exact impression of the hole was got on the acrylic substitute in the form of nub having a length of 1 mm. This way, the nub fitted snugly into the hole in the separating wall of the 2 cm^3 coupler and there was no leakage of sound. a slide calipers was used to measure the length of the acrylic substitute.

To keep the diameter of the required dimensions, five steel rods, having diameters a little more than the required diameters were chosen. Using a dental lathe and sand paper, the diameter of the rods were reduced to the desired values. Five rods of the diameters 1.5 mm, 2.25 mm, 3.00 mm, 3.75 mm and 4.5 mm were thus prepared. The exactness of the diameter was maintained atleast upto a length of 25 mm in each red. A screw guage was used to measure the diameter of the rods.

After the preparations of the five metal rods of desired diameters. straight vertical holes were drilled in the acrylic substitutes such that the holes were a little wider than the desired diameter. After drilling the hole in the acrylic substitute, the hole was filled with cold-cure acrylic and the rod with the required diameter inserted into the whole length of the acrylic substitute, allowing the excess acrylic to flow out. The rod was removed, when the acrylic was set. Required diameters for all the 25 acrylic substitutes were similarly made.

Comparison of metal and acrylic substitutes

A pilot study was carried out to compare the accuracy achieved in the preparation of acrylic substitutes. The response curves of the standard metal earmold substitute and the standard acrylic substitute were plotted (Figure 2). The response curves were essentially the same. This pilot study proved that the method adopted in making acrylic substitutes were satisfactory and also that the performance of the metal substitute and the acrylic substitute are identical, though they were made of different materials.

The metal cap in the 2 cm^3 coupler could not be used because of variations in length of the acrylic substitutes. So a rubber sheet similar in thickness to rubber washer used in the 2 cm^3 coupler was chosen. Circular rubber washers were out from the rubber sheet and holes were made in the washers so that the receiver nub could fit snugly without any sound leakage. The rubber washers were then glued to the top of each of the acrylic substitute. Care was taken to see that the bore of the acrylic and the hole in the rubber washer were centred.

Procedure

The procedure followed in this study is the same as the one used in the evaluation of response characteristics of hearing aids.

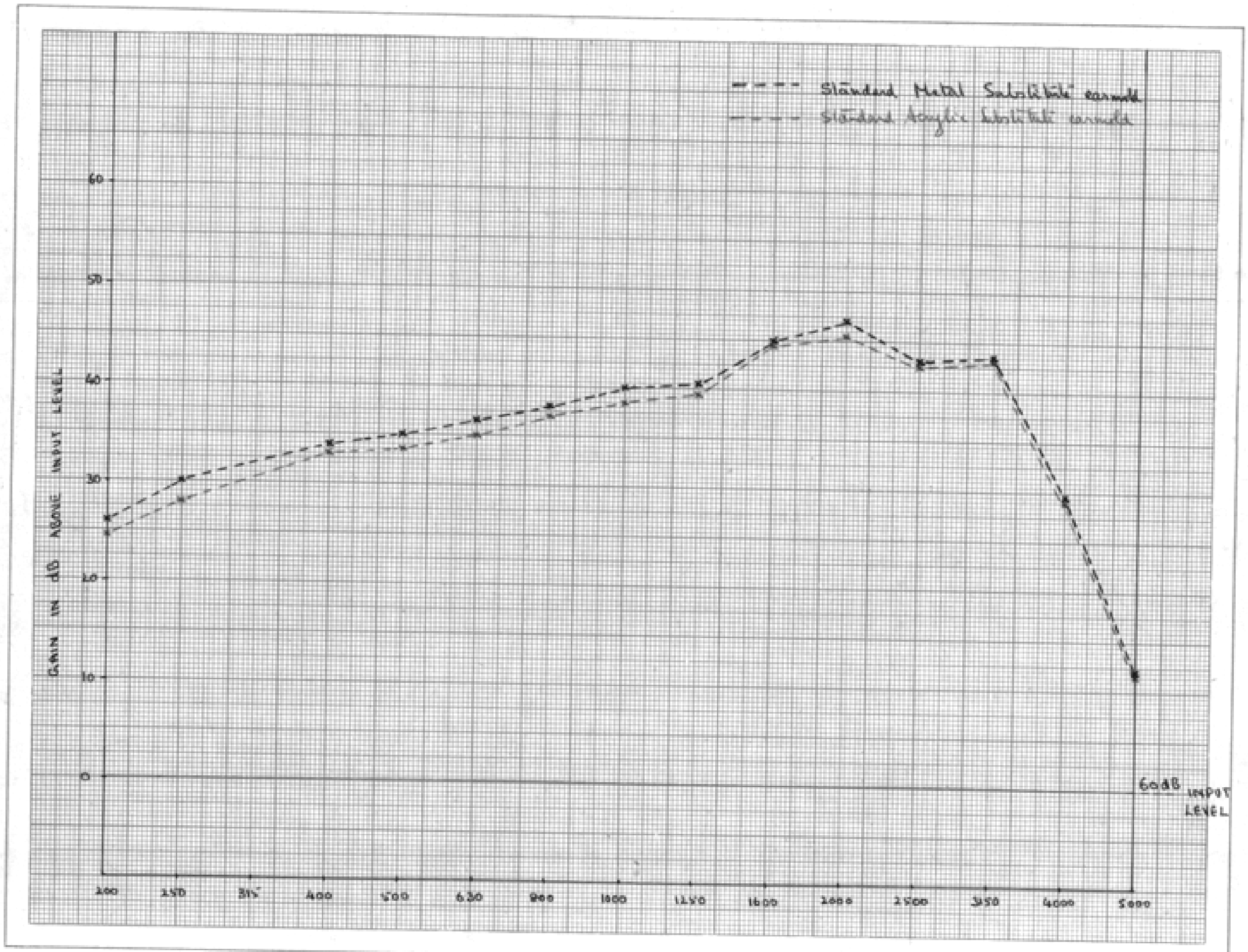


Figure 2 : Comparison of the Response curve plotted using the Standard Metal earmold substitute and the Standard Acrylic earmold Substitute.

The input level in the Hearing Aid Test Box (Bruel and Kjaer 4217) was 60 dB for all the test frequencies. When the hearing aid was kept in the Test Box, using the metal earmold substitute, the volume control of the aid was adjusted until the output at 1000 Hz was 100 dB. Following this, other substitute acrylic were used in the place of standard metal substitute keeping the volume control at the same position and the output recorded.

The condenser Microphone (Bruel and Kjaer 4144) was kept on the frame meant for that purpose, inside the Test Box (Bruel and Kjaer 4217). After connecting the condenser microphone to the Frequency Analyser (Bruel and Kjaer 2107) both the instruments were switched on and sufficient time was allowed for warm up.

Sensitivity of the amplifier input and that of condenser microphone, in the Frequency Analyser were adjusted and ‘K’ factor of the microphone was added. The weighting net work, of the Analyser was set to ‘Linear, 20-40000’ and the Meter Switch to ‘RMS-Slow’. Then, the attenuator knob on the front panel.

The Condenser Microphone (Bruel and Kjaer 4144) after the above adjustments, was taken out and was fixed vertically to a wooden stand. The 2 cm^3 coupler with metal earmold substitute was screwed on to the Condenser Microphone. The hearing aid (Danaid I) was kept inside the Test Box in such a way that the hearing aid microphone was in the same position where the condenser microphone had been kept. The hearing aid was, then switched on and its volume control was adjusted such that the meter in the Analyser showed a reading of 100 dB with the Frequency Selector in the Box was set at 1000 Hz, when the Test Box lid was closed. Then the Frequency

Selector in the Test Box was set at ‘200 Hz’ and the output as shown on the Frequency Analyser (Bruel and Kjaer 2107) was recorded. This procedure was followed for the other frequencies – from 200 Hz to 5000 Hz – except at 315, which was not used for this study.

After plotting the response curve, the standard earmold substitute was removed and each of the acrylic substitutes were used and their response curves were plotted.

Reliablity Check

Response curve with the standard metal earmold substitute was recorded thrice on the days the experiments were conducted – in the beginning before using the acrylic substitutes were used, in the middle and in the end, after using the acrylic substitute. So, comparison of these three readings formed the basis for calibration check of the instruments used and the reliability of the data collected. The data were rejected if there was significant variations in the three response curves of the standard metal substitute earmold.

Analysis of Data

For purposes of statistical analysis, the entire frequency range was arbitrarily divided into low, middle and high frequency ranges. Frequency from 200 Hz to 400 Hz formed the low frequency range, 500 Hz to 2000 Hz as middle frequency range and the range between 2500 Hz to 5000 Hz formed the high frequency range. Actual

SPL output at each frequency with each of the acrylic substitute couplers was noted. The difference in the SPL values from those of the input level were treated as gain in dB. The mean of the sound pressure levels for the frequencies within the range were used in the two-way analysis of variance with multiple Observations in each cell, to find out the statistical significance of the differences observed.

CHAPTER IV

RESULTS AND DISCUSSIONS

Results

The data obtained, using twenty five acrylic substitute earmolds of varied lengths and diameters are presented in Appendix I and II. The results, in terms of Mean and Standard Deviation are given in Tables 1 and 2. The tables include values for low, middle and high frequency ranges. The frequencies from 200 to 5000 Hz were divided into three ranges; frequencies from 500 to 2000 Hz were considered as middle frequency range, frequencies below 500 Hz were considered as low frequency range and those above 2000 Hz as high frequency range.

The data was analysed using the technique of ANOVA.

<u>Table 1</u> showing the Mean output values in dB spl and their Standard Deviation at different frequencies for each diameter used.

		Frequency in Hz.																	
Diameter		200	250	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	L.F. Range	M.F. Range	H.F. Range	Total Range
1.5 mm	$\bar{x}$	87.10	89.3	93.4	93.3	97	99	101.3	102.2	103.8	96	93.3	92	79.6	74.6	89.93	98.93	84.87	91.24
	SD	1.14	0.56	0.91	1.22	1.62	1.69	2.71	2.39	2.56	2.35	1.52	2.42	1.49	1.71	0.8	1.56	1.19	
2.25 mm	$\bar{x}$	88.40	89.5	93.1	94.6	97.1	91	100.5	101.8	106.6	102.9	99.4	97.9	83.9	75.2	89.66	100.36	89.09	93.04
	SD	0.41	0.36	0.34	2.04	0.55	0.55	1.0	0.96	1.29	0.89	0.65	0.96	0.65	1.48	0.24	0.68	0.65	
3.00 mm	$\bar{x}$	86.3	88.6	92.5	92.5	97	98.7	100	100.6	104.1	103.5	102.2	100.3	91.2	77.1	89.13	99.48	92.69	93.76
	SD	0.72	0.74	0.79	2.27	1.11	0.57	1.11	0.82	1.85	0.82	1.68	1.79	4.95	1.88	0.58	0.3	2.46	
3.75 mm	$\bar{x}$	86.8	89.5	93.41	93.8	97.5	99.6	101.2	101.4	105.1	103.9	104.6	101.6	93.5	78.3	89.89	100.35	94.5	94.91
	SD	1.79	1.5	2.83	2.25	2.57	1.91	2.84	2.58	3.31	2.88	2.58	3.4	3.85	1.67	1.95	2.51	2.61	
4.5 mm	$\bar{x}$	85.8	88.7	92.7	93.2	96.7	98.4	99.7	100.4	103.5	102.6	103.4	100.5	93.9	77	89.06	99.21	93.69	93.98
	SD	1.94	0.92	1.28	1.99	1.02	0.66	0.92	0.13	1.41	1.09	105	2.37	2.56	3.43	1.17	0.72	2.2	

TABLE 2 showing the Mean output values in dB SPL and their Standard Deviation at different frequencies for each diameter used.

Length		Frequency in Hz.														L.F. Range	M.F. Range	H.F. Range	Total Range
		200	250	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000				
14 mm	$\overline{X}$	85.7	89	92.9	94.8	96.4	98.7	99.5	100.9	103.9	101.8	100.5	97.2	86.5	75.6	89.19	99.42	89.94	92.85
	SD	1.26	0.87	0.42	0.57	0.42	0.57	0.79	1.25	1.75	1.61	3.53	2.17	4.45	1.78	0.8	0.54	2.24	
16 mm	$\overline{X}$	85.8	89.3	92.6	94.6	96.3	98.1	99.3	100.3	103.6	101.6	100.3	97.5	86.6	74.2	89.23	99.11	89.64	92.66
	SD	0.28	0.28	0.28	0.55	1.02	1.25	1.3	1.16	2.36	3.41	4.67	3.76	6.23	1.76	0.22	1.84	3.97	
18 mm	$\overline{X}$	86.8	89.2	93.4	94	97.6	99.2	100.6	101.7	104.1	102	101.1	98.6	90.8	77.1	89.79	99.89	91.89	93.85
	SD	1.24	0.57	1.02	1.14	1.3	0.57	1.64	2.04	2.75	3.16	4.47	4.46	8.58	2.51	0.87	1.32	4.94	
20 mm	$\overline{X}$	86.5	88.5	92.1	90.6	96.6	98.7	100.7	100.8	104.9	101.1	99.8	98.6	86.3	77.7	89.03	99.05	91.07	93.05
	SD	0.5	1.12	0.66	0.66	0.42	0.57	0.84	1.3	1.39	3.21	4.28	2.98	6.5	1.67	0.54	0.44	3.97	
22 mm	$\overline{X}$	87.6	89.6	94.1	93.3	98.4	100.1	102.6	102.7	106.6	102.4	101.2	100.4	89.9	77.6	90.43	100.86	92.27	94.52
	SD	1.64	1.71	2.44	2.62	1.88	1.96	2.07	2.33	3.25	5.8	6.56	6.33	7.94	1.71	1.96	2.43	5.61	

Effect of Diameter Variation

Table 1 shows the mean effect of diameter variation. Considering the entire range, the mean maximum gain is found at 3.75 mm diameter. Compared to the standard diameter, an overall mean gain of 0.94 dB is obtained for 4.5 mm. In low frequency range, the mean gain is maximum 1.5 mm. However, significant difference was not found, the range between the minimum and maximum being only 0.87 dB. In the middle frequency range, the Max mean gain was obtained at 2.25 mm as well as at 3.75 mm. The amount of gain is 1.43 dB for 2.25 mm and 1.42 dB for 3.75 mm, over the mean minimum.

On the whole, compared to other diameters, 1.5 mm seems to bring about an increase in gain at low frequency range, though not to a significant degree and 3.75 mm is effective for middle and high frequency ranges in terms of gain. Another significant point is that, while the amount of gain for low frequency range is 0.87 dB for the diameters used, it is 9.63 dB for high frequency range Table 1). However, statistical analysis shows that F Ratio for the main effect of diameter is not significant (Table 3).

Figures 3, 4 and 5 graphically illustrate the effect of diameter variations on different lengths, at low, middle and high frequency ranges. At all the three ranges, the effect of diameter variation seem to be consistant for 22 mm length when compared to other lengths used. The increase in gain for 22 mm length (L5)

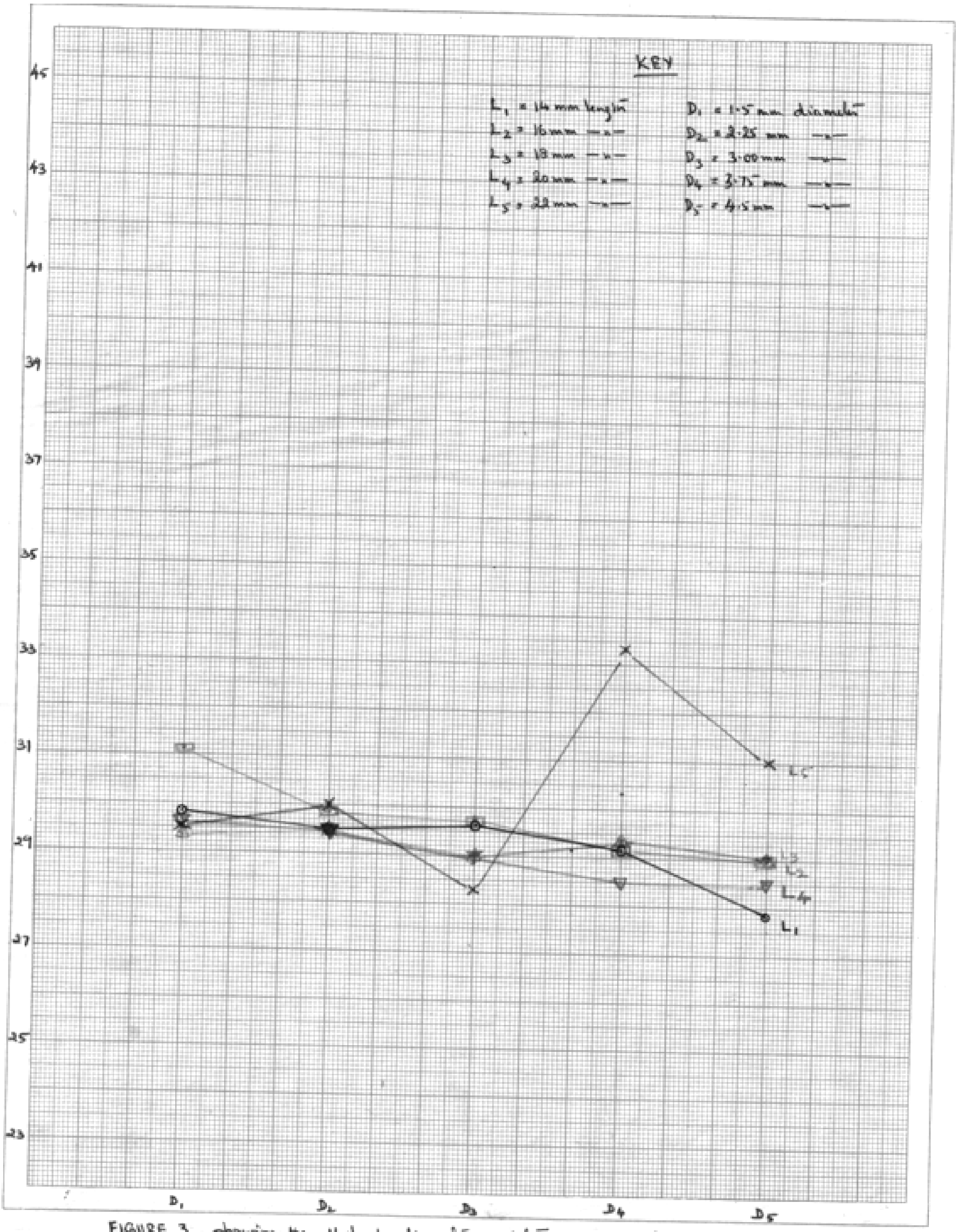


FIGURE 3 showing the effect of diameter variation on gain at different lengths for Low Frequency Range

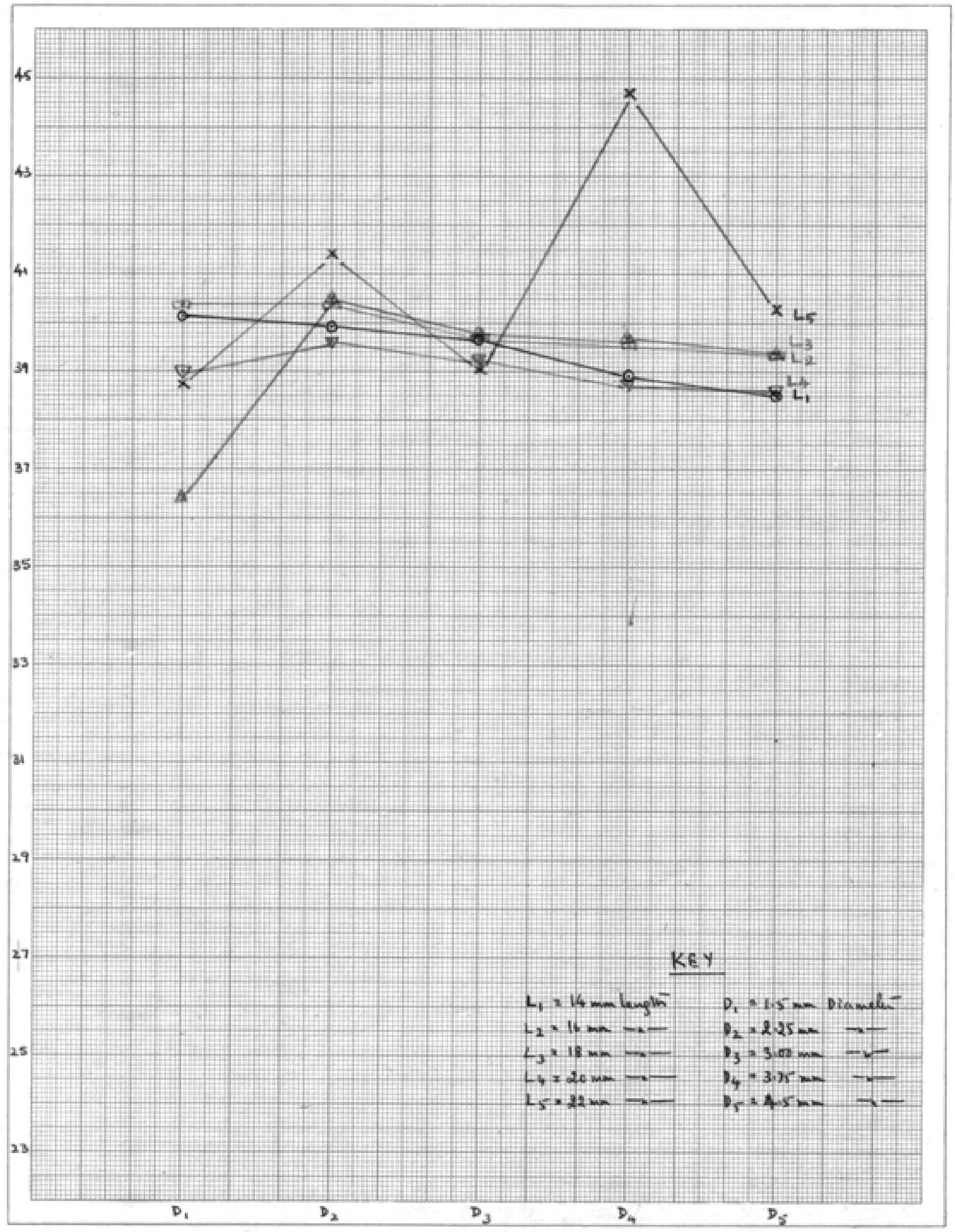
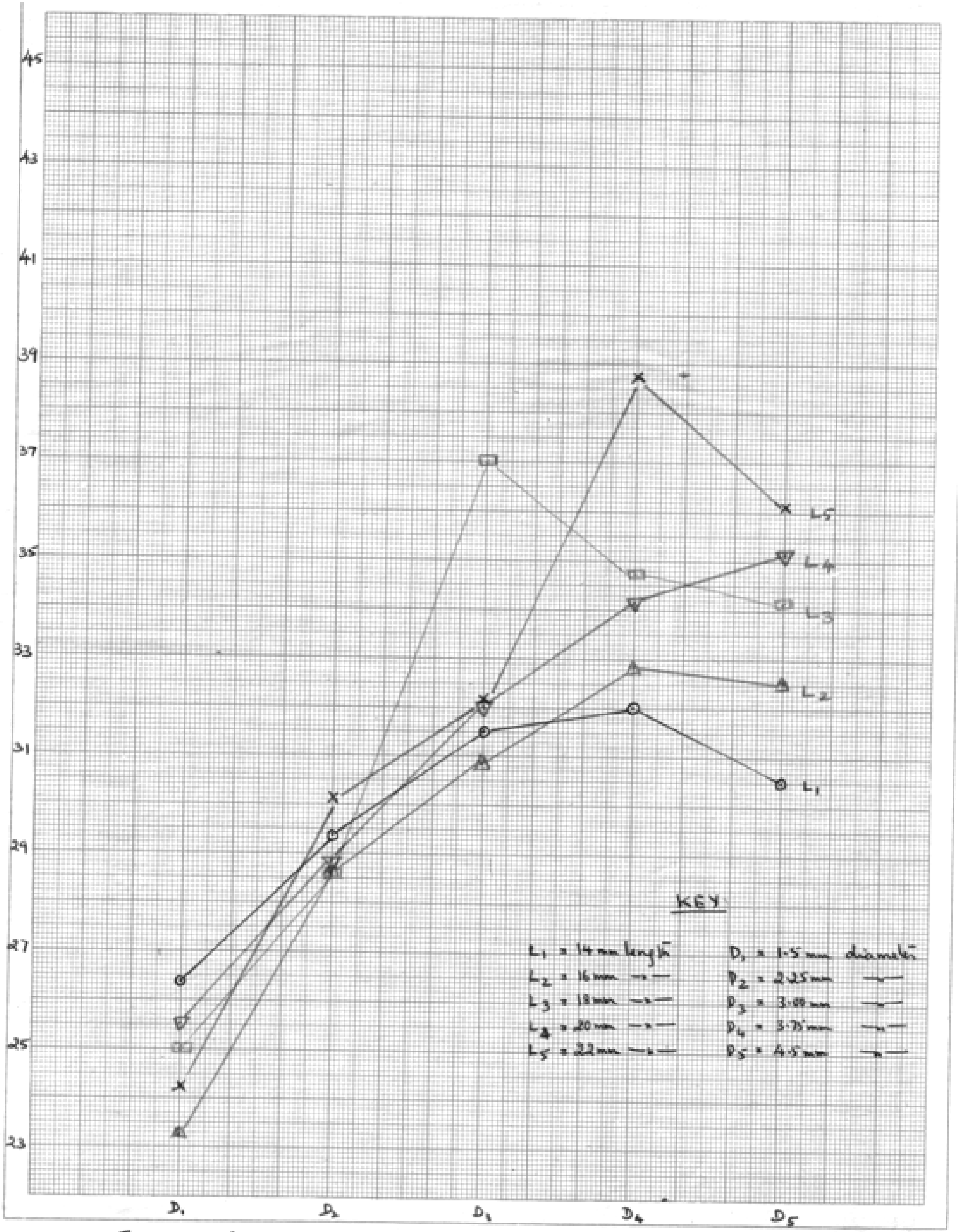


Figure 4 showing the effect of diameter variation on gain, at different lengths for Middle Frequency Range



<u>Figure 5</u> showing the effect of diameter variation on gain, at different lengths for High Frequency Range

at 3.75mm diameter (D4) at all three ranges can be attributed to interaction of length and diameter. However, the interaction effect is not statistically significant (Table 3).

Effect of Length Variation

Table 2 shows the mean gain of length variation. It shows that taking the entire frequency range into consideration, maximum gain (1.86 dB) is at 22mm. Even frequency rangewise, maximum gain is noticed with 22mm; for low, middle and high frequency ranges, the mean gain is 1.4 dB, 1.81 dB and 2.63 dB respectively. Compared to the standard length, the mean loss is 1 dB for 14mm and for 22mm the mean gain is 0.67 dB.

On the whole, considering the gain for the lengths used 22mm is more effective than others. Another observation is that in general, with the increase in length, there is increase in gain. This is so, even frequency range wise. The gain at middle frequency range, over low frequency range is 0.41 dB and for high frequency loss over that of middle range is 0.82 dB. However, statistically the main effect of length was not significant, ass indicated by the F ratio (Table 3).

Figures 6, 7 and 8 illustrate the effect of length variation on different diameters, for low, middle and high frequency ranges respectively. Comparing the diameter used, the effect of length

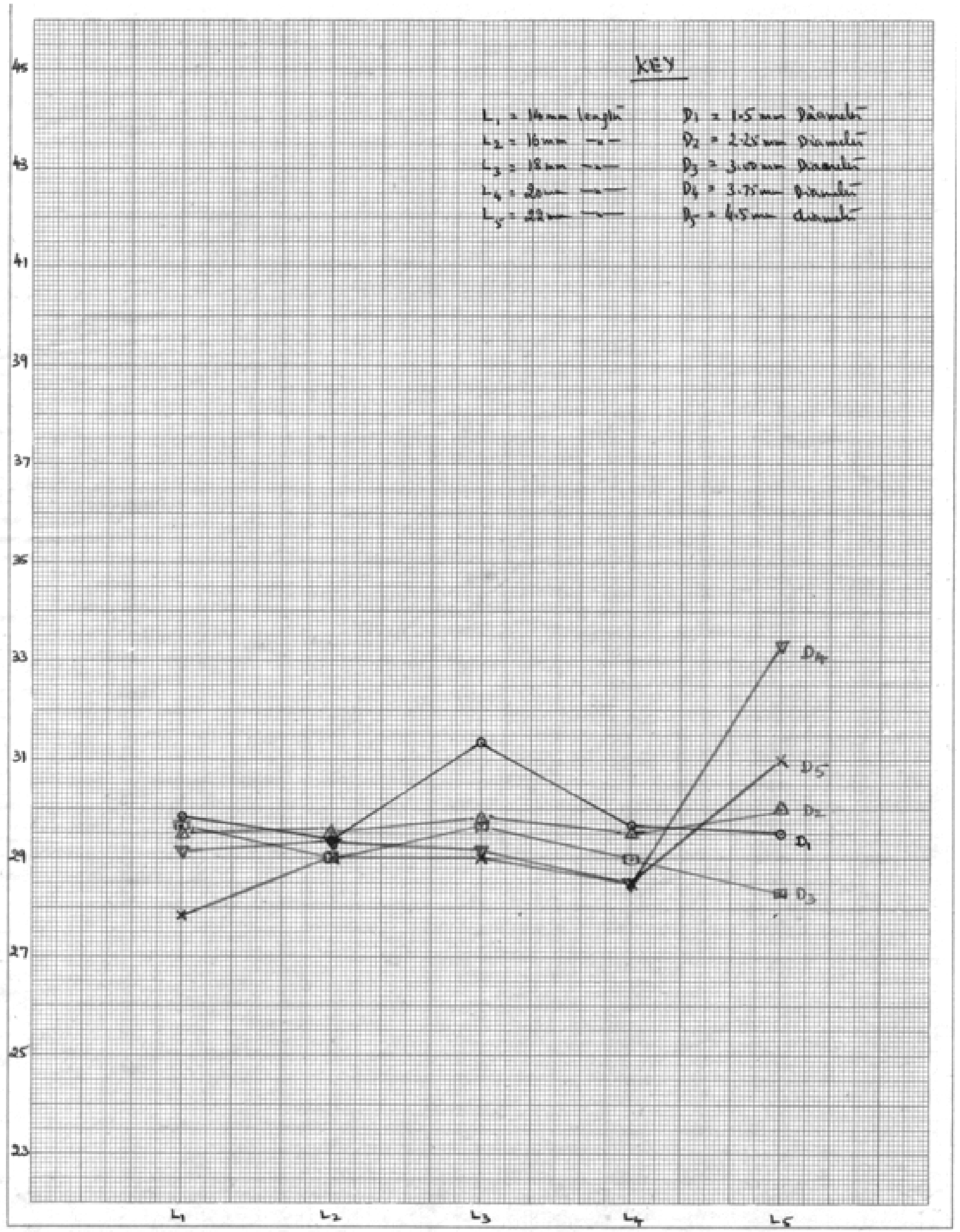


Figure 6 showing the effect of length variation on gain at different diameters for Low Frequency Range

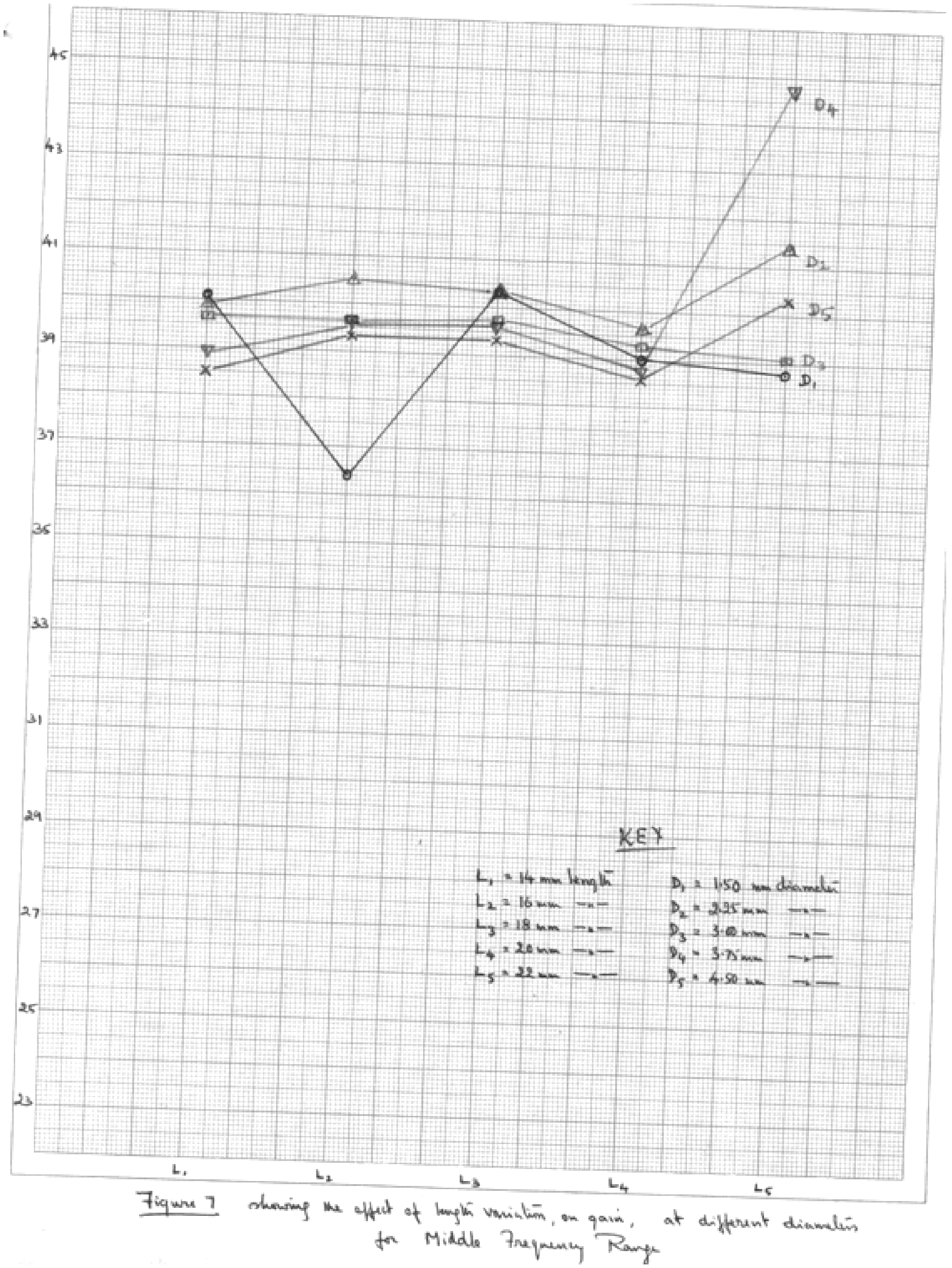


Figure 7 showing the effect of length variation, on gain, at different diameters for Middle Frequency Range

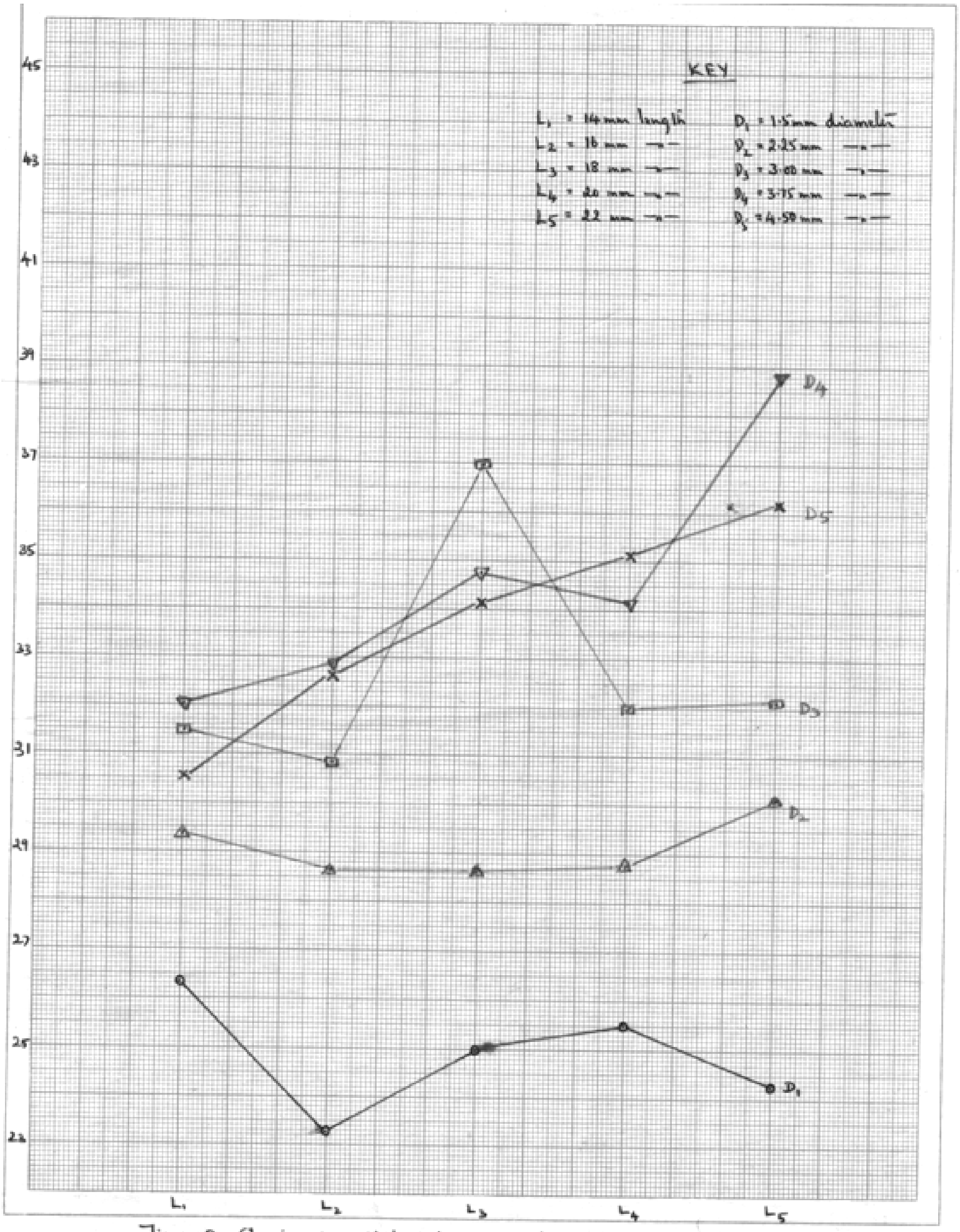


Figure 8 Showing the effect of length variation on gain at different diameter for High Frequency Range

variation is negligible for 2.25 mm diameter (D_2). Figure 8 shows that at high frequency range, with increase in diameter and length, there is increase in gain.

Figure 9 illustrates the effect of length and diameter variation, on gain, for low, middle and high frequency ranges.

Table 3

Table of Analysis of Variance

	Sum of Squares	D.F.	M.S.	F.Radio
Diameter	113.15	4	28.28	0.80
Length	36.45	4	9.11	0.25
Interaction	72.93	16	4.55	0.12
Error	1752.05	50	35.04	
Total	1974.58	74		

Discussion

The findings of this investigation are in general in agreement with the observation by some authors, that compared to the standard, shortening of the length or increasing the diameter brings about reduction in the gain of hearing aid response at low

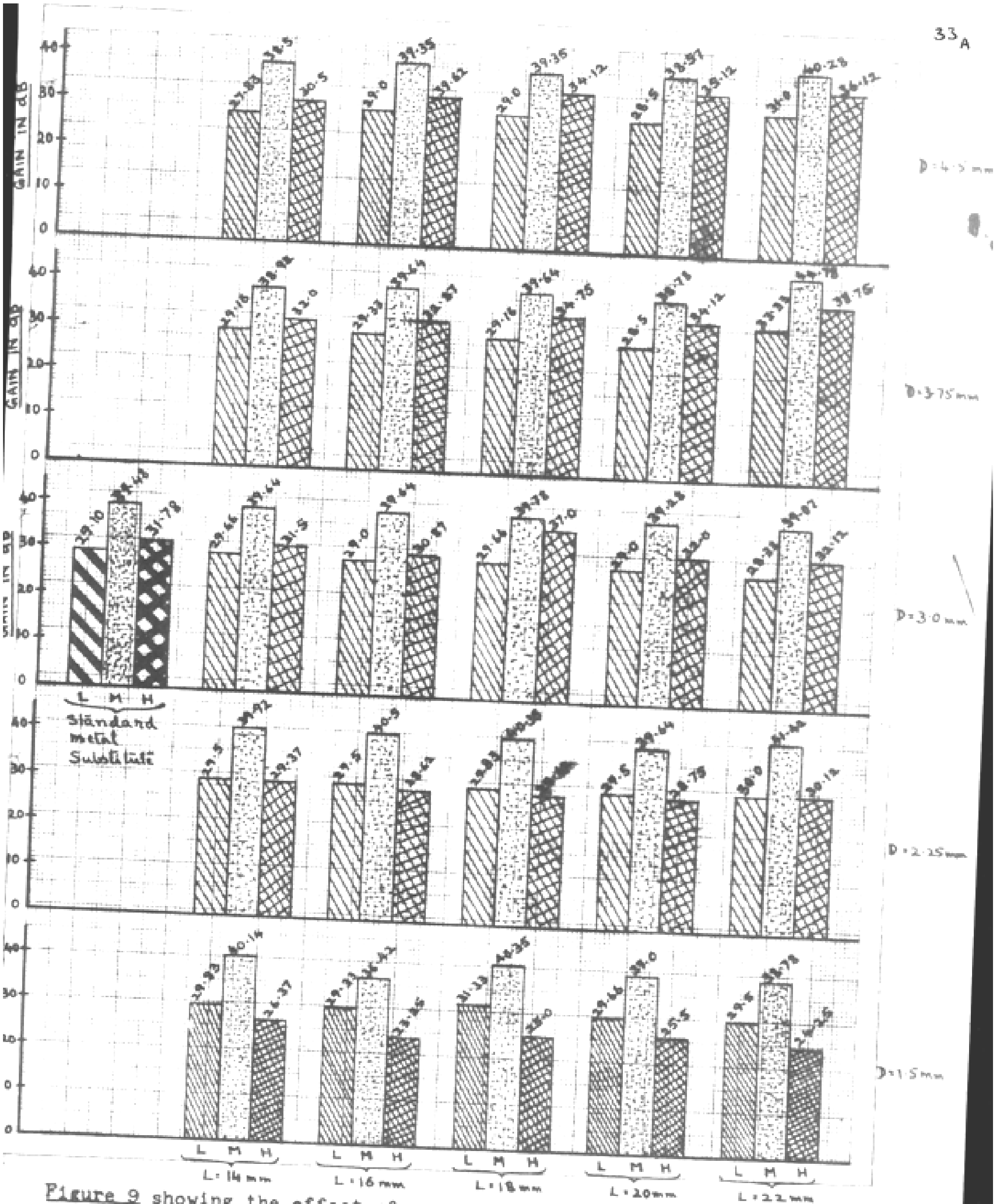


Figure 9 showing the effect of variations in Length and Diameter, on gain for Low, Middle and High Frequency ranges.

frequencies (Harvey, 1969; Lybarger, 1972; Curran, 1973). Comparing the report by Lyberger (1972), that by shortening the earmold tip to the maximum, low frequency response might be expected to drop by about 2 dB and maximum increase in the earmold tip to the maximum, low frequency response might be expected to drop by about 2 dB and maximum increase in the earmold tip might increase the low frequency response by about 4 dB; though there is no contradiction, the present findings do not fully support it. Referring to Table 2, comparison of the response of minimum length (14 mm) with that of standard length shows a mean gain of 0.60 dB towards the standard length. Comparison of response between maximum length (22mm) and minimum length (14 mm) in low frequency range shows that there is a mean gain of 1.4 dB in favor of maximum length. Comparison of the result of this study with the report of Lybarger (1972) becomes difficult because of the possible differences in length employed.

However, the above comparison demands consideration of other factors. While the data in the present study is based on objective evaluation using 2 cm^3 coupler, it is assumed that the report by Lybarger (1972) is based on response obtained using human subjects. Reduction or increase in length of the earmold in human ear brings about increase or decrease respectively in the volume of air between the earmold tip and the eardrum. This change in volume is bound to affect the sound pressure level for low frequencies. But in the present study increase or decrease in length does not change the 2 cm^3 Volume in the metal coupler. Hence the frequency response curves measured at the 2 cm^3 coupler need not necessarily agree with the one received by the ear (Harvey, 1969). Moreover, Lyberger (1972) has considered frequencies including 750 Hz as low frequency range while in the present study, frequencies from 200 to 400 Hz formed the low frequency range.

The investigation shows that at low frequency range, the effect of variations in length and diameter on gain is minimum, when compared to the gain in the middle and high frequency ranges. So, there is not much scope in employing variations in length and diameter to bring about effective response modification at low frequencies.

One of the purposes of this study was to know whether variations in length and diameter can be made without affecting the hearing aid response. This study shows that considering the complete range. employing lengths 14mm and 16 mm with 2.25 diameter produce the minimum effect on the frequency response of the hearing aid.

- o0o-

CHAPTER V

SUMMARY AND CONCLUSIONS

An objective study of the effects of variations in length and diameter of the acoustic coupler sound bore, on the frequency response of the hearing aid was carried out. Twenty Five acrylic substitute earmolds, with five variations in length and five in diameter were used. The data was collected using Hearing Aid Test Box (Bruel and Kjaer 4217). 2 cm^3 coupler (DB 0138), condenser microphone (Bruel and Kjaer 4144), Frequency Analyzer (Bruel and Kjaer 2107) and one Danaid I hearing aid with Danavox Sub-Minor receiver. The data was used in terms of Means and their standard deviation, alongwith graphic representation. Analysis of variance was applied to findout the statistical significance of the effect of diameter and length variation.

The following conclusions seem warranted :

1. Modification of the standard diameter of the sound bore does not affect the gain of a hearing aid.
2. Modification of the standard length does not affect the gain.
3. For the dimensions of the length and the diameter used in this study. there is no interaction between length and diameter.
4. For 3.00 mm diameter, of the lengths used, maximum gain was noticed with 18mm length can be attributed to interaction of length and diameter.

Clinical Implications

Though statistically no significant effect of diameter and length variations were noticed, the mean as well as graphic representations, show significant effect on gain in the response curve. The study implies that effect of variations in diameter is more significant than that of length and as such more attention is called for proper control of diameter.

Suggestions for further study

The data provided by this study can form the basis for application on human ears, to find the extent to which the findings of this study can be compared. For this purpose, use of the same length and diameter variation is advisable.

The study provides further scope to try other modifications, such as the effect of the cavity which houses the snap ring of the acoustic coupler, to find out further desirable deviation in the total performance of the hearing aid.

The significance of the interaction between length and diameter in this study calls for further study to find out the various combinations of lengths and diameters which give maximum desirable effects.

Studies on the effect of vents can be studied in a similar way.

The effect of bend in the sound bore of the acoustic coupler can be done on similar lines. This seems to be relevant as the sound bore in the actual acoustic coupler is always bent and not straight.

The effect of surface quality of the sound bore can form one of the aims for a further study.

In clinical practice it is often found that the bore diameter of the acoustic coupler is not even throughout the length. It would be of clinical significance to find whether this effects the response pattern of the hearing aid.

Limitations

Usefulness of this study depends upon how far it can be beneficially applied in routine clinical practice.

There are some differences in the structure of the actual acoustic couplers and the substitute couplers made use of in the study. Sound bore in the actual coupler would be usually bent, while it is straight in the substitute coupler, In the actual coupler, the bore diameter is usually not likely to be even throughout its length and also the inside surface would be comparatively rough. But in the substitute coupler, the diameter is even throughout its length and the inside surface is smooth. In actual couplers a cavity is made to fix the snap ring which holds the receiver. This cavity may have some additional effect on the response curve of the hearing aid, depending on the size of this cavity. Moreover, while in the actual acoustic coupler the sound from the receiver pass through two bends before reaching the ear cavity, there is no obstruction for the sound till it reaches the diaphragm of the condenser microphone, in the case of substitute couplers. Further, even though the results were not statistically significant, it is possible that when earmolds with these modifications are used by an individual, the resulting gain may make a significant difference.

In addition to the above differences, frequency response curves measured at the 2 cm^3 coupler may not necessarily agree with the one received by the ear (Harvey, 1969; Studebaker and Zachman, 1970). The conditions in terms of size and shape of the ear canal and the impedance of the ear drum is bound to change from person to person and these in turn affect the hearing aid response curve. All these factors bring about limitations on the application of the findings of this study on actual ear and show that modifications in length and diameter can’t be made blindly without considering these factors.

Thus in the application of the findings of this study in making custom acoustic couplers the various factors mentioned above must be taken into consideration.

- oOo –

BIBLIOGRAPHY

Ackerman, Joseph F - The Deep Canal Earmold : NHAJ (National Hearing Aid) Feb ‘72

American National Standards Institue : Computation of the Loudness of Noise, (Ref : Audiology Vol. 14, No. 3 (1975) P. 266) 53.4 (Washington, 1968)

Bentzen Ole - Scandinavian Audiology – Vol 1, No.3(1972)

Boothroyd, A (1965) - The Provision of Better ‘Earmolds for Deaf Children’ – Journal of Zaryngology and Otology, 79, 320

Bresson, K - Open earmold treatment Vs. closed – Scandinavian Audiology Supplement No. 1 (1971)

Bulmer, D - Cold Cure Acrylic Moulds – British Journal of Audiology, Vol. 7, No. 1, ‘73

Cooper, W.A, Franks, J.R. McFall, R.N & Goldstein, D.P - Variable Venting Valve for Earmolds – Audiolgoy – Vol. 14, No. 3, 1975, May/June

Curran, James R - Improving Speech Intelligibility with Earmold Modifications : National Hearing Aid J., March, 1973.

Dodds, Elizabeth & Harford, Earl - Follow-up report on Modified Earpieces and CROS for High Frequency Hearing Losses JSHR Vol. 13 (1970) pp. 41-43

Ewing & Ewing - Hearing Aids, Lipreading and Clear Speech University of Manchester (1967)

Frequency Analyzer Type 2107 – Booklet Published by Bruel & Kjaer

Green, D.S. & Ross M. - The Effect of a Conventional on a non-occluding (CROS type)earmold on the freq. response of hg. aid – JSHR Vol. 11, 638-647 (1968)

Green, D.S. - Non-occluding earmolds with CROS & IROS hg. aids, Arch. OTolaryng, Vol.89, 512-522 (1969)

Harvey, Andy B - The Earmold as a fitting tool – National Hg. Aid J – Jan ‘69

Hearing Aid Test Box Type 4217 – Booklet published by Bruel and Kjaer

Hodgson, William R & Murdock, Charles Jr. - Effect of the Earmold on Speech Intelligibility in hearing aid use – JSHR Vol. 13 (1970) p. 290 – 297

Jetty, Albert J - Rintelmann, William, F Acoustic Coupler effects on Speech Audio- & metric Scores using a CROS Hearing Aid – JSHR Vol. 13 (1970) pp. 101-113

Konkle, Dan F & - Bess, Fred H Custom-made Vs Stock Earmolds in Hearing Aid Evaluations – Archieves of Otolaryngology Feb ’74 – Vol. 99. No. 2 – Maico Audiological Library Series Vol. XII Report five

Ling, Danial - Conventional Hg. Aids – an overview – Volta Review, 73, 6, Sept ’71. pp. 343-352, 375-383

Labarger, S.F. - The earmold as part of the receiver acoustic system : Booklet published by Radioear Corpn (1958)

Labarger, S.F. - Earmold Acoustics - *******, 16, 9-19 (1967)

Lybarger, Samuel F - Clinical Audiology – Ed. Katz Chap on Earmolds The Williams & Wilkins Co. (1972)

Major Miklos - Acoustical Deviation and Effect. Nat. Hearing Aid J, 1969, 22, 8-9, 28-29

McClellan, Max E - Aided Sp. discrimination in noise with vented and unvented earmolds J. Aud. Res. 7, 93-9 (1967)

Nelson, H Birk - Effects of open Vs closed earmold treatment Scandinavian Aud. 3, 147-151

Newby, Hayes A; - Audiology, Appleton- Century Crofts, New York (1972)

Northern, Jerry L- & Hattler, Karl W Earmold Influence on Aided Speech Identification Tasks – JSHR Vol. 13, No. 1, p. 162-172

Studebaker, G.A. & - Zachman, T.A. (1970)	Investigation of the acoustic of earmold vents – JASA – Vol. 47, 1107-1115
Weatherton, M.A. & - Goetzinger, C.P.	The Effects of various modified earmolds on hg. sensitivity : J of Aud. Res Vol. 11, No. 1, Jan ‘71

APPENDIX I

Length	Diameter	Frequency in Herts																	
		200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	L	M	N
14mm	1.50mm	86.5	89.5	-	93.5	95.5	97	99.5	100.5	103	106	99.5	95.5	93.5	80	76.5	89.83	100.14	86.37
	2.25mm	86	89.5	-	93	95	96.5	98.5	100	101	105	103.5	100	97.5	84	76	89.5	99.92	89.37
	3.00mm	86.5	89.5	-	93	95	96.5	99	99.5	100.5	104	103	102.5	99	88.5	76	89.66	99.64	91.5
	3.75mm	86	89	-	92.5	94	96	98.5	99	100	103	102	102.5	98.5	90	77	89.16	98.92	92
	4.5mm	83.5	87.5	-	92.5	94.5	96	98	98.5	100	101.5	101	102	97.5	90	72.5	87.83	98.5	90.5
16mm	1.50mm	86	89.5	-	92.5	94	94.5	96	97	98	100	95.5	92.5	91	77.5	72	89.33	96.42	83.25
	2.25mm	86	89.5	-	93	95.5	97	99	100	102	106.5	103.5	100	98	83.5	73	89.5	100.5	88.62
	3.00mm	85.5	89	-	92.5	94.5	96.5	98.5	100	100.5	104.5	103	101.5	98.5	88.5	75	89	99.64	90.87
	3.75mm	86	89.5	-	92.5	94.5	97	99	100	100.5	103.5	103	104.5	100.5	90	76.5	89.33	99.64	92.87
	4.5mm	85.5	89	-	92.5	94.5	96.5	98	99.5	100.5	103.5	103	103	99.5	93.5	74.5	89	99.35	92.62
18mm	1.50mm	89	90	-	95	93.5	99	100	103.5	104	106	96.5	94	91.5	80.5	74	91.33	100.35	85
	2.25mm	86.5	89.5	-	93.5	95.5	97	99	100	101.5	106	103.5	99	97.5	83	75	89.83	100.35	88.62
	3.00mm	87	88.5	-	93.5	92.5	99	99.5	100	102	101	104.5	105	103	100	80	89.66	99.78	97
	3.75mm	86	89	-	92.5	94.5	96.5	99	100	100.5	104	103	104	100.5	96.5	78	89.16	99.64	94.75
	4.5mm	85.5	89	-	92.5	94.5	96.5	98.5	99.5	100.5	103.5	102.5	103.5	100.5	94	78.5	89	99.35	94.12
20mm	1.50mm	87	89	-	93	91.5	97	99.5	102	103	104.5	95.5	93	94	80	75	89.66	99	85.5
	2.25mm	87	89	-	92.5	91	97	99	101	101	107	101.5	98.5	97	84.5	75	89.5	99.64	88.75
	3.00mm	86.5	88.5	-	92	90.5	96.5	98.5	100.5	100	105.5	103.5	101	100	89.5	77.5	89	99.28	92
	3.75mm	86	88	-	91.5	90	96.5	98.5	100	100	104	102.5	103	101	92.5	80	88.5	98.78	94.12
	4.5mm	86	88	-	91.5	90	96	98	100	100	103.5	102.5	103.5	101	95	81	88.5	98.57	95.12
22mm	1.50mm	87	88.5	-	93	92	97.5	100	103.5	103	102.5	93	91.5	90	80	75.5	89.5	98.78	84.25
	2.25mm	86.5	90	-	93.5	96	98	100	101.5	103.5	108.5	102.5	99.5	99.5	84.5	77	90	101.42	90.12
	3.00mm	86	87.5	-	91.5	90	96.5	98	100	100	105.5	105.5	101	101	89.5	77	88.33	99.07	92.12
	3.75mm	90	92	-	98	96	101.5	103	107	106	111	109	109	107.5	98.5	80	93.33	104.78	98.75
	4.5mm	88.5	90	-	94.5	92.5	98.5	99.5	101	101	105.5	104	105	104	97	78.5	91	100.28	96.12

Appendix I : Raw Data showing the output in dB SPL for constant length with varied diameters at different frequencies.

		Frequency in Herts																	
Di - meter	Len- gth	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	L	M	N
1.50m	14mm	86.5	89.5	-	95.5	95.5	97	99.5	100.5	103	106	99.5	95.5	93.5	80	76.5	89.83	100.14	86.3
	16mm	86	89.5	-	92.5	94	94.5	96	97	98	100	95.5	92.5	91	77.5	72	89.33	96.42	83.2
	18mm	89	90	-	95	93.5	99 97	100	103.5	104	106	96.5	94 93	91.5	80.5	74	91.33	100.35	85
	20mm	87	89	-	93	91.5	97.5	99.5	102	103	104.5	95.5	91.5	94 90	80	75	89.66	99	85.5
	22mm	87	88.5	-	93	92		100	103.5	103	102.5	93			80	75.5	89.5	98.78	8425
1.25m	14mm	86	89.5	-	93	95	96.5	98.5	100	101	105	103.5	100	97.5	84	76	89.5	99.92	89.3
	16mm	86	89.5	-	93	95.5	97 97	99	100	102	106.5	103.5	100	98	83.5	73	89.5	100.5	88.6
	18mm	86.5	89.5	-	93.5	95.5	97 98	99	100	101.5	106	103.5	99	97.5	83	75	89.83	100.35	88.6
	20mm	87	89	-	92.5	91		99	101	101	107	101.5	98.5	97	84.5	75	89.5	99.64	88.7
	22mm	86.5	90	-	93.5	96		100	101.5	103.5	108.5	102.5	99.5	99.5	84.5	77	90	101.42	90.1
1.00m	14mm	86.5	89.5	-	93	95	96.5	99	99.5	100.5	104	103	102.5	99	88.5	76	89.66	99.64	91.5
	16mm	85.5	89	-	92.5	94.5	96.5	98.5	100	100.5	104.5	103	101.5	98.5	88.5	75	89	99.64	90.8
	18mm	87	88.5	-	93.5	92.5	99	99.5	100	102	101	104.5	105	103	100	80	89.66	99.78	97
	20mm	86.5	88.5	-	92	90.5	96.5	98.5	100.5	100	105.5	103.5	101	100	89.5	77.5	89	99.28	92
	22mm	86	87.5	-	91.5	90	96.5	98	100	100	105.5	103.5	101	101	89.5	77	88.33	99.07	92.1
.75mm	14mm	86	89	-	92.5	94	96	98.5	99	100	103	102	102.5	98.5	90	77	89.16	98.92	92
	16mm	86	89.5	-	92.5	94.5	97	99	100	100.5	103.5	103	104.5	100.5	90	76.5	89.33	99.64	92.8
	18mm	86	89	-	92.5	94.5	96.5	99	100	100.5	104	103	104	100.5	96.5	78	89.16	99.64	94.7
	20mm	86	88	-	91.5	90	96.5	98.5	100	100	104	102.5	103	101	92.5	80	88.5	98.78	94.1
	22mm	90	92	-	98	96	101.5	103	107	106	111	109	109	107.5	98.5	80	93.33	104.78	98.7
1.50m	14mm	83.5	87.5	-	92.5	94.5	96	98	98.5	100	101.5	101	102	97.5	90	72.5	87.83	98.5	90.5
	16mm	85.5	89	-	92.5	94.5	96.5	98	99.5	100.5	103.5	103	103	99.5	93.5	74.5	89	99.35	92.6
	18mm	85.5	89	-	92.5	94.5	96.5	99.5	99.5	100.5	103.5	102.5	103.5	100.5	94	78.5	89	99.35	94.1
	20mm	86	88	-	91.5	90	96	98	100	100	103.5	102.5	103.5	101	95	81	88.5	98.57	95.1
	22mm	88.5	90	-	94.5	92.5	98.5	99.5	101	101	105.5	104	105	104	97	78.5	91	100.28	96.1

Appendix II

Raw data showing the output in db SPL for constant diameters with varied length at different frequncies