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A STUDY OF EARMOULD MODIFICATION EFFECTS ON THE FREQUENCY RESPONSE OF BODY WORN HEARING AIDS

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ABSTRACT

A study was made of the influence of different receivers and the effects of variation of earmould sound bore diameter, length and parallel vents on the frequency response of body worn hearing aids. In order to obtain real ear estimates of the magnitude of the effects, these measurements were made using a modified Zwislocki (IRPI DB-100) ear simulator.

The results indicate that while there may be little value in varying the length of the sound bore, diameter variation could be very helpful in the control of the high frequency response of a hearing aid. A wider diameter of the sound bore results in an improved high frequency response, whereas poorer high frequency response is associated with narrower diameters of the sound bore.

Parallel venting of earmoulds results in a reduction in the low frequency response of a hearing aid. The length and the diameter of the vent determine the amount of the low frequency cut in the response. The shorter length and the wider diameter of the vent result in a greater amount of low frequency reduction. The effects of parallel venting of earmoulds are independent of the frequency response of the receiver.

The study was made using the receivers commonly used with the body worn hearing aids in India. The data of the earmould modification effects may prove useful in predicting the effects of such work in a clinical situation. However, no subjective assessment of earmould modification effects were made in this study.

CHAPTER 1. INTRODUCTION

An earmould primarily couples the receiver of a hearing aid to the ear canal. In so doing it serves as an acoustic transmission channel between the two and exerts a significant influence on the frequency response of a hearing aid. However, the total performance of a hearing aid amplification system is determined by the microphone characteristics, the amplifier characteristics, the receiver-earmould-ear characteristics and the way these elements interact (Lybarger, 1972).

An ideal amplification system should be able to present at the eardrum, normal quiet sounds at above threshold level and normal loud sounds at below discomfort level. Since the impaired hearing threshold goes up without a corresponding increase in the level of discomfort, it results in a reduced dynamic range. Presence of peaks in the frequency response limits the maximum useful gain a user can employ without experiencing occasional discomfort when an intense sound coincides with a peak in the hearing aid response. Moreover, peaks in the amplification system tend to reduce the maximum usable gain because acoustic feedback causes "whistling".

Once the sound is above threshold, the hearing impaired individual is likely to have the frequency response requirements not unlike a normal listener and a truly broadband aid with good low, mid and high frequency balance (upto perhaps 8 KHz) will be most acceptable and give close to the optimum speech discrimination scores (Ewens, 1984). Good quality sound reproduction in hearing aids makes their usage more attractive to those for whom a hearing aid usage is not a necessity, but simply makes hearing easier.

It is not only important that a hearing aid should have a good high frequency response, but also that these high frequencies are efficiently transmitted by the use of tailored transmission tubes - the earmould plumbing, between the aid and the ear. The importance of regarding the hearing aid and earmould as inseparable partners has perhaps been helped by the advent of the in-the-ear aids, where the aid manufacturer had, for the first time complete control of the whole sound processing and delivery system (Wald, 1984).

There are mainly three types earmould fittings to the ear - (1) the receiver-earmould system as used for the button receivers of the body worn hearing aids (Figure 1); (2) the tubing earmould as used for behind-the-ear and the spectacle type of hearing aids (Figure 2); and (3) the hearing aid/earmould system as used for in-the-ear and in-the-canal hearing instruments (Figure 3). The type of hearing aid - earmould fitting determines the magnitude and the quality of its effects on the frequency response of an amplification system.

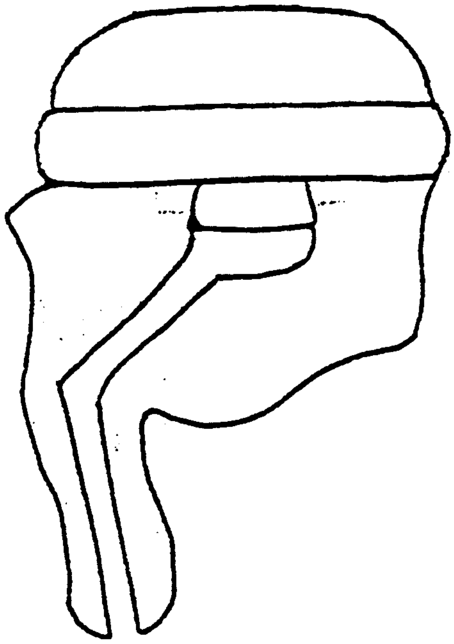
In addition to the modification of the signal transmitted by the receiver, the occlusion of the ear canal by the earmould also results in a loss of the free gain available due to the resonance properties of the ear. This can be reinstated by selective design of the aid and the receiver response, or by clever earmould design.

However, an earmould is often considered as the 'weak link' in the amplification chain. Whereas inappropriate or ill fitting earmolds can seriously degrade amplification, an intelligent choice of earmold characteristics may significantly enhance the amplifying system. The quality of the earmould fit often determines the usable gain of a hearing aid (Tucker and Nolan, 1984). Well fitting earmoulds should be comfortable to wear, have satisfactory appearance and accuracy in following the contours of the ear and able to retain well in the ear. Prevention of sound leakage is neither always necessary nor desirable (Grover, 1984).

The influence of earmoulds in the modification of the frequency response of a hearing aid has been recognized since early 1940's (Berger, 1970). A vast amount of literature is available on the effects of various earmould variables affecting the frequency response of a hearing aid. Although studies have been done for all the three types of earmould systems, those involving the use of the receiver-earmould system of the body worn hearing aids are restricted to the earlier part of this period only.

Perhaps because of the uncertainty about the real ear effects of earmould modification, some investigators proposed that electronic control of frequency response would be a method more preferable to earmould modification (Watson and Tolan, 1949; Lybarger, 1967). Availability of improved instrumentation and measurement techniques has helped in providing information that would permit better generalization of the effect of earmould modification. Though more than 95% of all hearing aids used in the developed countries today are ear level hearing aids, the situation is quite different in most of the developing countries where a large majority of people still use body worn hearing aids.

FIGURE 1.1 The Receiver Earmould



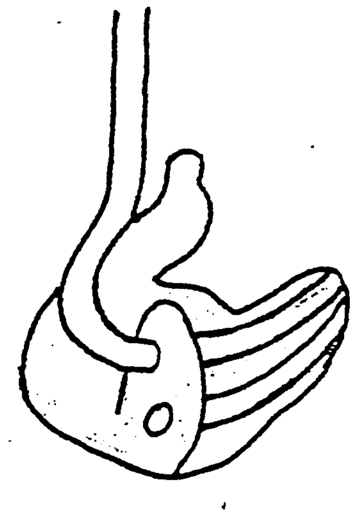


FIGURE 1.2 The Tubing Earmould

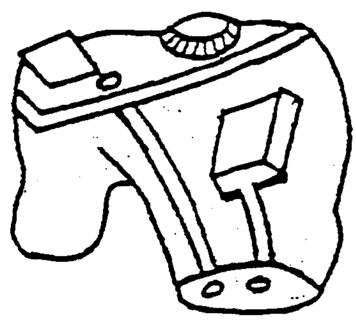


FIGURE 1.3 The Hearing Aid-Earmould

In India, more than ten companies are currently engaged in manufacturing hearing aids. Between them they produce more than 35 models of body worn and more than 10 models of ear level hearing aids. Although exact figures are not available, it is estimated that about 70-80 percent of all the present hearing aid users use the body worn hearing aids. Whereas the ear level hearing aids are available in the private sector, the government sponsored scheme for fitting of hearing aids provides only the body worn hearing aids. Under this scheme, various models (generally 5-6) of body worn hearing aids in three categories - mild, moderate and strong, depending upon their average gain and saturation sound pressure level, are selected every year through an open tender. These are made available for fitting and distribution to various government and voluntary organizations all over India. Though a few of these organizations have excellent infrastructure and facilities available to them, a majority of them do not have any means of measuring the benefits from amplification.

Whereas more than 10 different types (frequency response and impedance values) of receivers were in use with different hearing aids in India until a few years ago, lately, almost all the hearing aid manufacturers have switched over to the use of 'Oticon miniature A' receivers. This eases the situation as very few people knew the effects of switching one receiver with the other on the frequency response of the hearing aid. Availability of a particular receiver, rather than its characteristics, seemed to decide its usage with a hearing aid. Though 'Oticon miniature A' receivers are manufactured in four impedance and three frequency response combinations, only two impedance values (180 and 270 Ohm) and two frequency response characteristics (AP and AN) are currently being used by the hearing aid manufacturers in India. This seems to be due to an over reliance on 'gain' rather than the frequency response that the use of a wide frequency range receiver (AW) is totally ignored. Quite often a more expensive hearing aid has been considered a better hearing aid and more powerful hearing aids generally have been costlier than the less powerful ones. It may also appear relevant therefore, that besides the cosmetic considerations, the use of a hearing aid is resorted to only when it becomes almost impossible to manage without it rather than to make listening easier.

The technical data of the hearing aids, wherever available, are the measured responses in a standard 2 cc acoustic coupler. In the absence of real ear insertion gain/functional gain measurement facilities, these responses seem to be the sole basis for the most good hearing aid fittings.

In spite of the growing attention towards the usefulness of good earmoulds, a majority of hearing impaired persons continue to use their hearing aids with the help of an ear tip rather than a mould. Standard (stock) earmoulds are also used which are available in various sizes. Wherever custom made earmoulds are used, no earmould modifications are attempted largely because of uncertainty about their effects. An acoustic feedback from a hearing aid is almost invariably attributed to the earmould fitting.

Therefore, in view of the present situation of hearing aid use in India and in the light of information available from the more recent studies involving the modification of earmoulds, it appears quite relevant to make systematic investigation of such effects for body worn hearing aid systems.

Aims of the present study

The present study was planned with a specific consideration of the present status and needs in the area of prescription and fittting of body worn hearing aids in India. In particular a study was made of the influence which different receivers and the effects of variation of earmould sound bore diameter, length and parallel venting had on the frequency response of body worn hearing aids.

CHAPTER 2. REVIEW OF LITERATURE

The concepts of acoustic impedance, mass (or inertance), compliance, resistance, and resonances, can be helpful in understanding the acoustic effect of various cavities, holes, tubes and porous acoustic materials as found in earmoulds (Leavitt, 1986). A particular reference is being made to body worn hearing aids while the field is covered in general.

2.1 Acoustic Impedance

Acoustic impedance refers to an opposition to the flow of acoustic energy through an element. It can take two forms: (a) when the acoustic energy is stored and then returned to the source it is called reactive impedance; (b) when the acoustic energy is dissipated it is called resistive impedance. The reactive impedance is determined by the interaction between acoustic mass and acoustic compliance and it changes with frequency. The resistive impedance is relatively constant at all frequencies. Thus the total acoustic impedance of the hearing aid earmould system is determined by the interaction between its acoustic mass, compliance, and resistance.

The air inside a length of tubing behaves as an acoustic mass provided that the tubing is shorter than 1/16 the wavelength of the frequency produced by the hearing aid's receiver. The impedance of a mass of air in a section of tubing is directly proportional to the length of the tube and inversely proportional to the diameter of the tube (Cox, 1979).

An acoustic mass offers less opposition to the flow of acoustic energy at low frequencies. As frequency increases, impedance due to mass increases and the signal is decreased in level at the output. In terms of earmould coupling system, low frequencies pass through the tubing from the hearing aid receiver to the earmould tip with relative ease. However, the high frequency energy encounter more opposition.

An average size vent in an earmould will behave as an acoustic mass permitting relatively unobstructed passage of low frequency acoustic energy out of the vent while providing greater obstruction to the outflow of high frequency energy. High pass effect at the eardrum will result, with the low frequencies that can pass through the vent with relative ease determined by the length and diameter of the vent.

The diaphragm of the hearing aid also has a mass component that can influence the entire earmould coupling system as if it were an additional length of air-filled tubing or acoustic mass (Lybarger, 1972,1978; Cox 1979).

In a body worn hearing aid system the elements that contribute to the acoustic mass are: the diaphragm of the receiver, the tube in the nub of the receiver the sound bore and the vent. The acoustic mass is greater with narrower and longer sound bores than with wider and shorter sound bores.

2.2 Acoustic Compliance

When a vibratory force is applied to the air enclosed in a cavity with rigid walls, the air is compressed and expanded at the frequency of the driving force instead of oscillating as a unit as in the case of an acoustic mass. This pattern characteristic of the acoustic compliance prevails as long as the longest dimension of the cavity is less than 1/16 the wavelength of the driving force. At higher frequencies, however, the air in the enclosed cavity will begin to assume vibratory patterns characteristic of both the acoustic mass and an acoustic compliance. The value of acoustic compliance in a rigid walled cavity is proportional to the volume of the cavity. A highly compliant cavity produces peaks of energy in the hearing aid earmould frequency response which are referred to as the Helmholtz resonances.

The factors contributing to an acoustic compliance are: the cavity in front of receiver diaphragm, the cavity drilled for the snap ring, the cavity of air beyond the tip of the earmould and the mechanical compliance of the receiver diaphragm (Lybarger 1972,1978 and 1979).

2.3 Acoustic Resistance

Acoustic resistance occurs when the air particles collide with each other, with the sides of a tube, or with other obstacles such as acoustic damping elements such as sintered pellets (small metal balls which are heated and fused together under pressure), mesh screens, lambs wool and cotton. The acoustic effect of the obstructing material is highly dependent on the site of placement of the obstruction in the tubing of the coupling system and the amount of resistance it offers to the flow of air. Elements like sintered metal pellets and short cylinders with pinholes should not be used unless an overall reduction of high frequency energy is desirable.

The damping elements smooth the frequency response of the hearing aid earmould system, and control the aid's gain and saturation output. For optimum damping to occur, the acoustic damping element should have a characteristic or surge impedance equal to that of the earmould tubing. When the tubing of the hearing aid earmould system is properly terminated in this way, the transmission of sound down the tube is nearly independent of the length of tubing between the hearing aid's receiver and the damping element. Acoustic damping can reduce feedback problems which may be associated with sharp peaks in the output of the system (Killion 1980, 1984).

Whereas in behind the ear hearing aids the damping elements are usually placed in the 'ear hook', in case of body worn hearing aids, the nub of the receiver appears to be the only safe place from the point of maintenance and cleaning of ear moulds when these are in regular use.

2.4 Acoustic Resonance

Acoustic resonance is produced when the reactance due to acoustic mass is equal and opposite to the reactance due to acoustic stiffness (Cox 1979). Various resonant peaks seen at the output of an earmould coupling system are due to either wavelength resonances, Helmholtz resonances or a combination of the two.

Wavelength resonances are produced when sound travelling down a tube is reflected back due to an impedance discontinuity and it combines with the incoming sound producing standing waves (Cox,1979).

When a tube opens at both ends into the free air it results in a low impedance termination at both ends. A half wave resonance is produced when the wavelength of the incoming frequency is equal to twice the effective length of the tubing. Additional resonant frequencies occur at even and odd integer multiples of this fundamental. A half wave resonance is also produced when a hearing aid receiver with a large volume of air in front of the its diaphragm is coupled by a length of tubing - the sound bore, to the ear canal (Knowles and Killion, 1978).

A length of tubing that is coupled to a very low impedance at one end and a very high impedance at the other end, produces a quarter wave resonance when the wavelength of the incoming signal is equal to four times the effective length of the tube.

Additional resonant frequencies appear only at odd-integer multiples of this fundamental frequency. A 75 mm length of tubing (average length between receiver and medial tip of earmould in Behind the Ear hearing aid) acting as quarter wave resonator would be expected to produce four resonant peaks between 1 and 10 KHz. Expected frequencies of resonance can be calculated with considerable accuracy (Knowles and Killion, 1978; Cox, 1979).

In a body worn hearing aid system the elements that contribute to the acoustic resonance are: the volume of the cavity in front of the receiver diaphragm, the depth of the well below the snap ring and the dimensions of the sound bore.

2.5 Earmould Manufacturing Process

Earmoulds may be made by either a one-stage or a two-stage manufacturing process. In the one-stage manufacturing process, the impression of the ear, after the necessary processing, acts as the final earmould. The advantages of a one-stage process are it is quicker, cheaper, and more accurate. Disadvantages seem to be in their relatively shorter life due to lower mechanical strength and difficulty in fixing the lock spring for the receivers of body worn hearing aids.

The two stage manufacturing process requires taking an ear impression which is used for making a plaster cast, which is used for making the final earmould. After an ear impression has been obtained it has to be sent away for processing, which is a more time consuming process than a one-stage earmould. There are also more possibilities of dimensional inaccuracies due to the nature of the subsequent processing.

Custom earmoulds are made by several institutions and organizations in India as a part of their clinical and rehabilitative services. But still many hearing aid users do not have access to custom made earmoulds and use their hearing aids with a flexible ear tip. The use of ear tips instead of earmoulds results in problems of retaining the receiver in the ear, acoustic feedback and the possibility of a more uncomfortable fitting. At present, almost all earmoulds are made by the two stage manufacturing process in India, which as already mentioned is less satisfactory.

2.5.1 Earmould Impression Materials

Various types of impression materials ranging from the hydrophillic alginates to powder and liquid - ethyl methacrylate and the room temperature vulcanizing silicones (RTV) - condensation and addition silicones are currently in use. To be able to make good custom earmoulds it is important that the earmould impression material must: be accurate and stable over long periods of time; have adequate flow properties; be set in a reasonable time without undesirable side effects; be flexible; have sufficient mechanical strength; be easy to work with; be non-toxic and non-irritant; be compatible with die and cast material; and not be very expensive (Brooks and Nolan, 1984).

In India, ear impressions are taken with alginate materials. Even when the plaster casts are made immediately after an ear impression is taken, the impression would have shrunk a great deal before it could be immersed in plaster. Besides this these materials lack in flexibility and have very poor mechanical strength which is very important in the earmould work.

2.5.2 Earmould Materials

Methyl methacrylate - the hard acrylic is the material which is most widely used for making earmoulds. It is easily manufactured, takes a good finish, highly durable, and non allergic. Soft acrylic (ethyl methacrylate) is used for flexible and tighter fittings necessary for delivering higher gain. A combination of hard acrylic mould and soft acrylic canal has been utilized for greater user comfort. Silicone moulds are becoming more and more popular because of better flexibility, more comfortable and longer life than soft acrylic moulds. The factors that seem most important in earmould material selection are patient age, allergic considerations, need for a tight seal, pinnae resilliency, need for durability and patient preferance. Except for the way in which it might influence the tightness of the seal in the ear canal, the type of ear mould material does not have any specific acoustic effects (Lybarger, 1958; 1978).

In India almost all earmoulds are made with hard acrylic. The soft acrylics or the silicone based materials are simply not available. There appears to be no choice for either the user or the clinician and even when earmoulds made in other materials are desirable for reasons of use of high amplification, for safety purposes or due to allergy towards this material. This leads to a lack of user satisfaction and may ultimately result in discarding the use of amplification.

2.5.3 Earmould Types

Depending upon the type of hearing aid used earmoulds may be: (a) standard with snap ring for body worn hearing aids; (b) tubing mould for behind the ear and spectacle type; and (c) hearing aid earmould as in in-the-ear type aids. Since the sound path in the three types of earmoulds has very different dimensions, their acoustic effects on the frequency response differ significantly.

Commonly used styles for the tubing earmoulds are the skeleton mould for losses less than about 40 dB and the shell mould for greater losses (Hodgson, 1986). Although earmould style can affect comfort (hence hearing aid user satisfaction) , there is little published research to guide the clinician in this area (Leavitt, 1986).

Within each of the above category, earmoulds may be standard, vented or open type. A standard mould is used when least amount of acoustic modification of the signal is desired or when a high gain aid is needed. Open earmoulds are used for maximum reduction in amplification of low frequency sounds when the hearing aid user has normal or near normal hearing sensitivity in the frequencies or to permit a direct access for the sound to enter the ear canal as in CROS hearing aid fittings. Vented earmoulds permit a control over the low frequency amplification besides giving a feeling of comfort due to pressure equalization and the elimination of occlusion effect.

Only standard earmoulds of body worn hearing aids and the tubing earmoulds of the ear level hearing aids are presently being made in India. Alhough other styles such as skeleton mould, shell mould and canal mould are often used, the earmould modification for control over the hearing aid's frequency response is not being done.

2.5.4 Variability in Individual Earmoulds

Individual earmoulds show large variations in their physical dimensions. The acoustic effects of these variations differ by as much as 15-20 dB (Krarup and Nielsen, 1965; Dalsgaard et al., 1966; and Almqvist et al., 1970; Dalsgaard, 1975). Much of these variations are unintentional and often without realization of their effect.

The basic response curve of a hearing aid is measured through a certain length and inside diameter of tubing into a 2 cc coupler. The assumption is that the hearing aid is coupled to an earmould of dimensions 18mm length and 3mm diameter.

Considerable differences often up to about 15 dB were observed between measurements made with the standard earmould substitute as used in the 2 cc acoustic coupler and the measurements made with the actual earmoulds (Krarup and Nielsen, 1965; Dalsgaard et al., 1966; and Almqvist et al., 1970).

2.6 The Receiver Constants

The frequency response of a receiver is influenced by the effective area, vibratory mass, mechanical compliance and some mechanical resistance of the diaphragm; the volume of air immediately in front of the diaphragm; and the dimensions of the tube in the nub of the diaphragm. The effects of earmould tubing length and diameter, especially for earlevel hearing aids, are related to the type of the receiver used (Lybarger, 1967). However, the receiver characteristics have little effect on the vented and unvented response comparisons (Studebaker and Cox, 1977).

2.7 Earmould Variables Affecting the Frequency Response

2.7.1 The Well Below the Snap Ring

An increase in the cavity below the snap ring reduces the high frequency cut off of the receiver (Dalsgaard, 1966; Lybarger, 1967; Danavox, 1971; Lybarger, 1972). The high frequency response of a earmould (receiver type) would be significantly better if this cavity is reduced to no cavity at all. This cavity should, therefore, be kept as small as possible.

2.7.2 The Length and the Diameter of the Sound Bore

The high frequencies are reproduced better when an earmould with a short and wide canal is used than with a long and narrow canal (Ewertsen et.al., 1957; Lybarger, 1958; Dalsgaard et al., 1966; Lybarger, 1967; Danavox, 1971; Tucker and Nolan, 1986). The variation of diameter of the soundbore has considerably more effect on the frequency response of a hearing aid than the variation in the length (Dalsgaard et al., 1966; Almqvist et al., 1970; Danavox, 1971)

Similar effects are observed for the tubing earmoulds of behind the ear hearing aids. An increase in length or a decrease in the diameter of a tube results in a downward shift of the major resonance peaks and some loss of high frequency output. The internal diameter of the earmould tubing can be varied to raise or lower the gain in certain frequency regions. Varying tubing length is less feasible (Lybarger 1978,1979) and probably less effective. Cox (1979) found only slightly improved high frequency output with shorter earhooks 20-30 mm (internal diameter 1.2 mm and 1.5 mm). Whenever the internal diameter of a section of tubing is changed abruptly, the impedance at the point of this change is altered producing an impedance discontinuity with consequent production of wavelength resonance. The solution to delivering a flat frequency response at the other end of a transmission line is to terminate the transmission line with a resistance equal to the characteristic impedance of the transmission line. A stepped-diameter coupling system not only improves the high frequency output of the hearing aid, but also reduces the peak to valley ratio in the output frequency response curve (Killion, 1980).

2.7.3 Venting

A 1905 patent by Hermann G. Pape is the first mention of venting, and relates to the ear inserts of ear trumpets to prevent reverberation. Later an earmould patent by Henry D. Fiene (1943) included a vent (Berger, 1970). Schier (1945) reported the use of earmould venting for pressure equalization and to attenuate low frequency sounds.

Below a certain frequency , depending on the vent size, low frequencies are attenuated by some 12 dB/octave. The output may be well increased over the unvented condition in the region of the resonant frequency. Parallel and side branch vents produce similar low frequency filtering effects. However, at frequencies well above the resonant frequency, a parallel vent has little effect, although reduced output and irregularities result when the vent is of a side branch type (Grover, 1984). A side branch vent incurs acoustical feedback at a lower gain setting than an equivalent parallel vent. Because a decrease in high frequency output is almost never desired in the fitting of hearing aids, it seems advisable to avoid the use of side branch vents whenever possible (Studebaker and Cox, 1977). In case of small diameter earcanals where it is not possible to drill parallel vents, the sidebranch vent should be drilled to intersect the sound bore as close as possible to the medial tip of the earmould which will maximize the vent's impedance and ensure a minimum amount of high frequency energy loss.

The length of the vent is determined by the vent configuration - parallel or sidebranch, and by the length of the earmould tip. An earmould vent behaves as an acoustic mass which increases in impedance as frequency increases. Thus it offers proportionately more opposition to the flow of acoustic energy out of the vent as frequency is increased. A high pass filtering effect is observed at the medial end of earmould. The absolute effect of venting is a function of the diameter and the length of the vent, configuration - parallel or side branch (Studebaker, 1974; Studebaker and Cox, 1977; Lybarger, 1979; Lybarger, 1980; Wald, 1984; Leavitt, 1986) , and the characteristics of the aid (Tucker and Nolan, 1986). Very small vents 0.64 to 1mm in diameter for a medium length earmould produce no appreciable change in the acoustic signal throughout the range of frequencies typically amplified by the conventional hearing aid (Lybarger, 1979; 1980).

2.7.3.1 Adjustable and Variable Vents

These basically consist of a vent channel that leads to a socket on the face of the earmould into which vent inserts of varying diameters can be pressed (Lybarger 1978). SAV (Select a Vent), PVV (Positive Venting Valve) andVVV (Variable Venting Valve) are three such vents available commercially. Whereas the PVV would permit a greater low frequency filtering effect than the SAV, the VVV allows a continously variable adjustment of the vent diameter by use of a screw type knob located on the face of the earmould.

Johansen (1975) indicated that the average unintentional leakage around a typical earmould can be represented by a vent approx 1.4 mm in diameter by 22 mm long. Cox (1979) pointed out that the suboscillatory feedback effects due to earmould leakage produce unexpected peaks and valleys in the frequency response of the hearing aid earmould system which may result in loudness tolerance problems and complaints by the hearing aid user of unnatural sound quality. Macrae (1982) described a 'highcut cavity vent', which due to reduced sound leage in the mid and high frequencies is more resistant to feedback. Damping of the vent has also been suggested to control feedback problems with vented earmoulds. This would however, result in a reduction in the effective diameter of the vent (Studebaker, 1974).

2.7.4 Damping

Strong peaks in the frequency response are likely to be much more troublesome to someone with a severely limited dynaqmic range, because such peaks limit the maximum useful gain a user can employ without experiencing occasional discomfort when an intense vowel formant peak coincides with a peak in the hearing aid response. Moreover, peaks in the transmission characteristic tend to reduce the maximum usable gain before "whistling" because of acoustic feedback or before changes in the effective frequency response occur as the whistling condition is approached. A novel and elegant method for damping all tubing resonances by use of dampers located near the receiver was described by Carlson (1974). With the high acoustic impedance of a modern broadband receiver, a damping resistor located at the receiver outlet will be safe from earwax but may have little effect on the tubing resonances (Killion, 1980).

The damping material affects the resonances produced by the structures in which the damping material is placed but has relatively little effect on resonances produced by other structures (Studebaker, 1974). Certain damping devices such as chokes or filters placed in the receiver nub or loose cotton or felt in the earmould sound bore tend to reduce the height of the primary peak (Lybarger, 1972).

2.7.5 The Horn Effect

Acoustic transformer or horn effect is produced by progressively increasing the internal diameter of a tube. This results in: (a) shifting the low frequency resonance points upwards in frequency because the flared cross section makes the horn appear shorter than the constant diameter tube at these frequencies and (b) improving the high frequency transmission because when the length of the horn is greater than half the wavelength of the incoming signal, the gradually increasing cross sectional area of the horn causes the output impedance at the mouth of the horn to be significantly reduced.

The larger the cross sectional area at the mouth of the horn, the better the high frequency transmission. This increase in cross sectional area must, however, be made gradually. Rather than eliminating the wavelength resonances produced by the hearing aid's tubing, these could be exploited with acoustically tuned earmoulds to produce additional gain in specific frequency regions. The goal is to improve the acoustic transformer properties of the earmould and produce wavelength resonances in the desired frequency regions by progressively increasing the internal diameter of the coupling system between the hearing aid's receiver and the medial tip of the earmould. Acoustic damping keeps the height of the resonance peaks to a desired level. The magnitude of high frequency improvement depends on the particular hearing aid and earmould, and to some extent on the characteristics of individual ears.

In body worn hearing aid earmoulds the length of sound bore is comparatively small and therefore the horn effect is not applicable. Secondly, the receiver of the body worn hearing aid being of lower impedance, the difference in impedance of the receiver and the ear are also less significant. Due to this the resonance effects are much less than they are in behind the ear hearing aids with longer tube lengths and high impedance receivers.

2.7.6 The Cavity Beyond the Earmould Tip

Cavity size ranges from about 0.4 to 1.0 cm^3 in volume, depending upon the dimensions of the ear canal and the length of the ear mould tip. The walls of this cavity can be considered rigid except for the ear drum. The sum of this cavity and the equivalent volume of the ear drum compliance has been considered to be about 2 cm^3.

Increasing the canal portion to its practical maximum will increase the low frequency response by approx 2 dB as well as provide slightly increased gain over the entire response curve. Conversely shortening the canal tip to its practical minimum will reduce the low frequency output by approx 2 dB. As the tip of the earmould is lengthened the size of the cavity beyond the earmould tip is reduced, increasing overall SPL across the entire frequency range of the aid (Lybarger, 1978). Changing the volume of a closed cavity has little effect except that the sound level in the cavity changes inversely with cavity size. The change in level is fairly uniform across frequency (Dalsgaard, 1966; Danavox, 1971; Studebaker, 1974; Lybarger, 1978; Tucker and Nolan, 1986). However, changing the volume of a vented cavity has an effect which differs substantially with frequency (Studebaker, 1974).

2.8 Acoustic Versus Electronic Control of Frequency Response

A number of studies involving the ear level hearing aids have demonstrated improvements in word discrimination score resulting from variations in earmould acoustics. McClellan (1967) found higher word discrimination scores with the vented than with the unvented mould in five subjects with precipitous high frequency hearing losses. Jetty and Rintelmann (1970) concluded that the vented mould did not improve the word discrimination scores of the conductive group, but did result in an approximately 10% improvement for both precipitous and gradual slope sensory neural subjects. On the other hand, Hodgson and Murdock (1970), Revoile (1968), Dodds and Harford (1968a) and Northern and Hattler (1970) could find no consistent differences in WDS's for any group of subjects under any conditions when they compared ear moulds with different size vents and bores to a standard ear mould. However, the subjects often expressed a subjective preference for the vented over the standard mould (Ross, 1972).

The results are less equivocal when discrimination scores obtained with open or non-occluding moulds are compared to those obtained with standard or vented moulds. Hodgson and Murdock (1970), Dodds and Harford (1968a) and Jetty and Rintelmann (1970) all found that their high frequency loss subjects achieved higher word discrimination scores with the use of open ear mould than with standard moulds (Ross, 1972).

Current aids can be adjusted electronically to provide more precise and reliable low frequency control. However, some acoustic venting may be preferable subjectively. All venting can enhance user satisfaction by reducing overamplification of low frequency energy and consequent upward spread of masking, by providing pressure equalization between the atmospheric air and the air in the cavity medial to the earmould tip thereby additionally reducing the 'plugged ear' sensation and by reducing the occlusion effect which makes the hearing aid user's voice seem overamplified.

Cox and Alexander (1983) found that perceived sound quality and subjective impression of speech intelligibility were better when vented or open earmoulds were used than when the same basic frequency response modifications were made through the hearing aid's tone control with standard unvented earmoulds.

French-St.George and Barr-Hamilton (1978) and Killion (1984) have suggested utilization of a 1 mm parallel vent on all earmoulds to provide enhanced sound quality, barometric pressure equalization,and to reduce the occlusion effect that occurs in the standard unvented earmould. When the periphery of the earmould fits adequately, an increase in oscillatory feedback has not been noted even on high gain aids with this 1 mm vent. These vents are not for the purpose of acoustic modification and have minimal effect on the hearing aid's response (Lybarger 1979, 1980).

Use of acoustic horns appears desirable if there is enough high frequency hearing remaining to make amplification feasible (Hodgson, 1986). Fortunately, the usual trade-off between response smoothness and battery drain can be at least partially circumvented by the use of stepped-bore earmoulds (Killion, 1980).

In the earlier period especially, because of the uncertainty regarding the in-use acoustical effects of earmould vents, some investigators proposed that modifications in the circuitry of the hearing aid would be a preferable method of reducing low frequency output (Watson and Tolan, 1949; Lybarger, 1967).

With the body worn hearing aids the emphasis seemed to be on achieving the earmould sound bore dimensions close to those used for the earmould substitute in the standard 2 cc coupler to be able to match the frequency response designed by the manufacturer of the hearing aid rather than trying to change it for the hearing aid user (Lybarger, 1967; Almqvist et al., 1970). Such efforts to control the frequency response of body worn hearing aids was subsequently phased out by ear-level hearing aids.

2.9 Measurement of the Frequency Response

Electroacoustic measures are basically measurements of the input/output functions. Either a continuously variable sweep frequency tone or a series of closely spaced discrete frequencies at any specified sound pressure level is used as the input signal. Output from the hearing aid is measured by attaching the coupler to the measuring microphone and read by the measuring system. The measurements are typically made in a hearing aid test box.

2.9.1 Measurement Methods

Three different test methods have been described in BS 6083: Part 0 for testing the electroacoustic characteristics of an aid. These are:

2.9.1.1 Pressure Method - it measures the acoustic output of the aid directly in terms of the sound pressure at the microphone of the hearing aid.

2.9.1.2 Comparison Method - a regulating microphone is placed in the soundfield alongwith the hearing aid at the same time and the output from the hearing aid is compared to the sound pressure level seen by the regulating microphone.

2.9.1.3 Substitution Method - a regulating microphone is placed in the hearing aid test box at the point which will be occupied by the hearing aid microphone . The system then generates each test frequency, measures the intensity, and then determines the deviation of that intensity from a nominal desired level. These deviations are then stored. Later, when the hearing aid is occupying the test point, the system provides each test frequency corrected for its deviation so that the hearing aid microphone sees a frequency independent sound pressure level.

The comparison and the substitution methods, in contrast to the pressure method, determine the acoustic output of the aid in terms of the sound pressure of an unobstructed progressive sound wave present at the test point before the aid was located at that point. These two methods, though slightly different in technique yield essentially the same results, whereas different results are obtained by using the pressure method.

2.9.2 Frequency Response Curve

According to ANSI S3.22-1982, frequency responses are determined using a 60 dB sound pressure level input level with the hearing aid set to its reference test gain position (measurements made using a 2 cc acoustic coupler). The response is measured through the frequency range 200-5000 Hz, but may be extended if the hearing aid has such a range of amplification. For AGC aids, volume control is set to full on and 50 dB input sound pressure level is used.

The frequency range is determined by calculating the average gain at 1000,1600,2500 Hz. From the average 20 dB is subtracted and a 20 dB down line is drawn parallel to the abscissa. The frequency range is the range between the lowest and the highest frequency (but no greater than 5000 Hz) at which this line intersects the response curve.

BS 6083: Part O (1984) specifies all measurements to be made using an occluded ear simulator according to IEC publication 711. The frequency response curve is measured through the frequency range 200-8000 Hz. The standard requires that the data should be quoted for only that part of the frequency range over which the output of the hearing aid falls by at least 10 dB when the signal source is switched off.

2.9.3 Reference Test Gain

This position is obtained with a 60 dB sound pressure level input signal by adjusting the volume control of the hearing aid until the High Frequency Average gain (average of gain at frequencies 1000, 1600 and 2500 Hz) is equal to the HFA-SSPL90 less 17 dB. If the hearing aid does not have sufficient gain to reach this level, the volume control is set to full on. AGC aids are also set to full on (ANSI S3.22-1982).

The rationale for testing a hearing aid with its volume control adjusted to the reference test gain position is that the long term average sound pressure level of speech approximates 65 dB at a distance of 1 metre from the speaker. The peaks in speech are approximately 12 dB higher than the long term average. With the hearing aid set to the reference test gain control position if the input to the hearing aid were set at 65 dB spl and the resultant output set to 12 dB less than the saturation level, it could be assumed that the speech peaks would not exceed the saturation sound pressure level. The use of the specified 60 dB spl input and a 17 dB volume control set back would give essentially the same value (Kasten and Franks, 1986).

According to BS 6083: Part O (1984), the reference test gain control position is the setting of hearing aid gain control which provides an output sound pressure level in the ear simulator of 15 +/- 1 dB less than OSPL 90 for an input sound pressure level of 60 dB at the reference test frequency which is normally 1600 Hz.

2.10 Difference Between a 2 cc Coupler, an Ear Simulator and the Real Ear Measurements

Traditionally all hearing aid characteristics have been measured on a 2 cc acoustic coupler because of its simplicity, reliability and at least initially, the assumption that the measurements in a 2cc acoustic coupler corresponded well with average real ears (Lybarger, 1967). It has been recognized for a long time now that considerable differences exist between real ear and the 2 cc coupler measurements (Sachs & Burkhard, 1972; Lybarger, 1975; Dalsgaard, 1975). The measurement of the output of a hearing aid in a 2 cc coupler provides an underestimation of the sound pressure levels developed at the eardrum of the listener, and the higher the frequency, the greater is the underestimation. Below 800 Hz, the sound pressure levels in the 2 cc coupler are about 4 dB less than in the average real ear, whereas above 800 Hz, these are lowered further by an additional 3.5 dB/octave (Kasten and Franks, 1986).

Sachs and Burkhard (1972) studied the relationship between the measurements made in 2cc coupler, the modified Zwislocki coupler and the real ear. The average sound pressure levels at the eardrum correspond very well with the sound pressure levels measured using the modified Zwislocki coupler. They concluded that the sound pressure level in an ear simulator is about 4 dB higher in the low frequencies and increases to about 15 dB at 10 kHz and that a response correction curve could be used to convert the 2 cc coupler measurements to Zwislocki coupler and thus to average real ear measurements.

While there is limited value in 2 cc coupler measurements for vented earmoulds, the Zwislocki coupler measurements are quite indicative of the real ear performance (Lybarger, 1975; Studebaker and Cox, 1979; Kasten and Franks, 1986). With parallel vents, a difference of within 2 dB was observed for the entire frequency range between Zwislocki coupler and the real ear measurements (Studebaker, and Cox, 1979). Some prescriptive fitting procedures, such as those of Byrne and Tonisson (1976), Cox (1983) use measured 2 cc coupler values after applying corrections to account for the differences between hard walled couplers and the real ear (Kasten and Franks, 1986).

A Head and Torso Simulator (HATS), as described in the IEC publication 118-8, has become an important tool for investigations on hearing aid output in terms of real ear. However, all measurements taken with HATS and/or a Zwislocki coupler are, at best, simulated average real-ear measurements. By no means may they be applied directly to a potential hearing aid user without some allowances for differences in head size, ear canal size, and middle ear impedance (Kasten and Franks, 1986).

2.11 Summary

During the period up to about 1970 when body worn hearing aids were in maximum use, the facilities for making real ear measurements were virtually non existent and the use of probe microphone techniques did not extend to clinical situations. This resulted in an uncertainity about the possible effects of earmould modification. In particular the use of a standard 2 cc coupler for making all measurements on hearing aids resulted in a gross underestimation of the high frequency response.

With the development of an improved coupler which simulates the normal real ear response more closely, and the availability of equipment for clinical asessment of the real ear insertion gain and the in-situ frequency response, the effects of any earmould modification are instantly available. A knowledge of the precise effects of any earmould modification is essential to its use by a hearing aid dispenser.

In India, majority of the hearing aid users use body worn hearing aids. Custom earmoulds are being made by many institutions all over India, though the facility at present, exists in larger cities only. Most of the clinics and the organizations that fit hearing aids do not have any facilities for measuring the benefit of amplification although accessto the 2 cc coupler frequency response data for most hearing aids is more generally available. The average information available for hearing aid fitting is a pure tone audiogram of the patient and a set of hearing aids to choose from.

A knowledge of the simulated average real ear response or an ear simulator response of the hearing aid along with the acoustic effects of earmould and its modification, even in the absence of real ear measurement facilities, could lead to better hearing aid fittings with improved user satisfaction.

CHAPTER 3. EXPERIMENTAL DESIGN

The main aim of this study was to investigate the influence of different receivers and the earmould variables on the frequency response of body worn hearing aids. It was decided to measure the frequency response of the receivers/hearing aid in a hearing aid test box while the variables under study were carefully controlled. To make the results applicable to real ear fittings, the measurements were made using an ear simulator instead of a 2 cc acoustic coupler. The experiments were designed in such a way so that these could be easily repeated for verification and for making any changes in the variable under study.

3.1 The Equipment Used

The following equipment was used for making the frequency response measurements in the study:

an Audio Test Station B&K type 2118 with a Condenser Microphone Type 4134, a Microphone Preamplifier Type 2642, a modified Zwislocki Ear Simulator IRPI DB100, a 1/2 inch to 1 inch Adapter for 2 cc coupler DB 0225, a 2 cc coupler DB 0138, and an Anechoic Test Chamber Type 4222.

3.2 The Variables Studied

The earmould plumbing factors, the parallel vents, the measurement couplers and their effect on the frequency response of a body worn hearing aid constituted the main variables in the study.

3.2.1 The effects of the measurement coupler on the frequency response of a hearing aid. Measurement of frequency response in a 2 cc coupler vs modified Zwislocki ear simulator.

Earmould sound bore length 18 mm x diameter 3 mm, unvented
receiver types - Oticon AP, AN, and AW

3.2.2 Earmould Plumbing factors. The effects of variation of diameter and length of the earmould sound bore on the frequency response of body worn hearing aids.

3.2.2.1 The effects of the variation of diameter of the earmould sound bore - 1mm, 2 mm, 3 mm and 4 mm (D1, D2, D3 and D4).

3.2.2.2 The effects of the variation of length of the earmould sound bore - 13 mm, 18 mm and 23 mm (L13, L18 and L23).

3.2.2.3 The effects of interaction between the variation of length and the diameter of the soundbore for the following conditions:

L18D1	L18D2	L18D3	L18D4
L23D1	L23D2	L23D3	L23D4
L13D1	L13D2	L13D3	L13D4

3.2.2.4 The effects of interaction between the plumbing factors and the frequency response of the receiver - Oticon AP, AN, and AW.

3.2.3 Parallel Venting. The effects of the diameter and length of the parallel vents on the frequency response of body worn hearing aids.

3.2.3.1 The effects of the diameter of the parallel vent - 1 mm, 2 mm and 3 mm (VD1, VD2 and VD3).

3.2.3.2 The effects of the length of the parallel vent - 15 mm,19.5 mm and 24mm (VL15, VL19.5 and VL24) corresponding to the earmould soundbore length of 13 mm, 18 mm and 23 mm respectively.

3.2.3.3 The effects of interaction between length and the diameter of the parallel vent for the following conditions:

L18D3VL19.5VD1	L18D3VL19.5VD2	L18D3VL19.5VD3
L13D3VL15VD1	L13D3VL15VD2	L13D3VL15VD3
L23D3VL24VD1	L23D3VL24VD2	L23D3VL24VD3

3.2.3.4 The effects of interaction between the parallel vents and the frequency response of the receiver - Oticon AP, AN, and AW.

3.3 Procedure

3.3.1 Earmould Simulators

Twenty one different earmoulds combinations were required in order to study the effects of all the earmould variables listed above, although it was almost impossible to achieve the precise dimensions for the variables under study with the conventionally made custom earmoulds. Therefore to achieve a high level of accuracy in the control of various variables and thereby in the test-retest reliability, it was decided to use precision machined metallic (brass) earmould simulators. Three earmould simulators with sound bore length of 13 mm, 18 mm and 23 mm were made (Figure 3.1). Each earmould simulator had a 4 mm diameter hole drilled through its length.

While separate earmould simulators were used to vary the length of the sound bore, the diameter of the sound bore was varied by inserting flexible tubes of varying diameter into the 4 mm diameter hole of the earmould simulators.

Another set of earmould simulators (Figure 3.2) was made for the vented condition with a drilled parallel vent of 3 mm diameter into which smaller diameter flexible tubes were inserted to reduce the diameter of the vent. The diameter of the sound bore in vented earmould simulators was 3mm (fixed).

A cylindrical brass ring was made, one end of this ring could be screwed on to the ear simulator. The other end had a collar to support the earmould simulator. With the help of this metallic ring it was possible to position the earmould simulators firmly in the appropriate test plane on the ear simulator.

3.3.2 Measurement of the Frequency Response

Two types of conditions were employed for making measurement of the frequency response. The measurement of frequency response of receivers alone was done by driving the receivers with a constant voltage signal from the audio test station. The compressor switch of the audio test station was left in the 'out' position during these measurements. The voltage of the electrical signal was maintained at 100 mV approximately (91 mV as measured) for all measurements. The receiver, the earmould simulator, the ear simulator and the measuring microphone were placed inside the

FIGURE 3.1 The Earmould Simulator

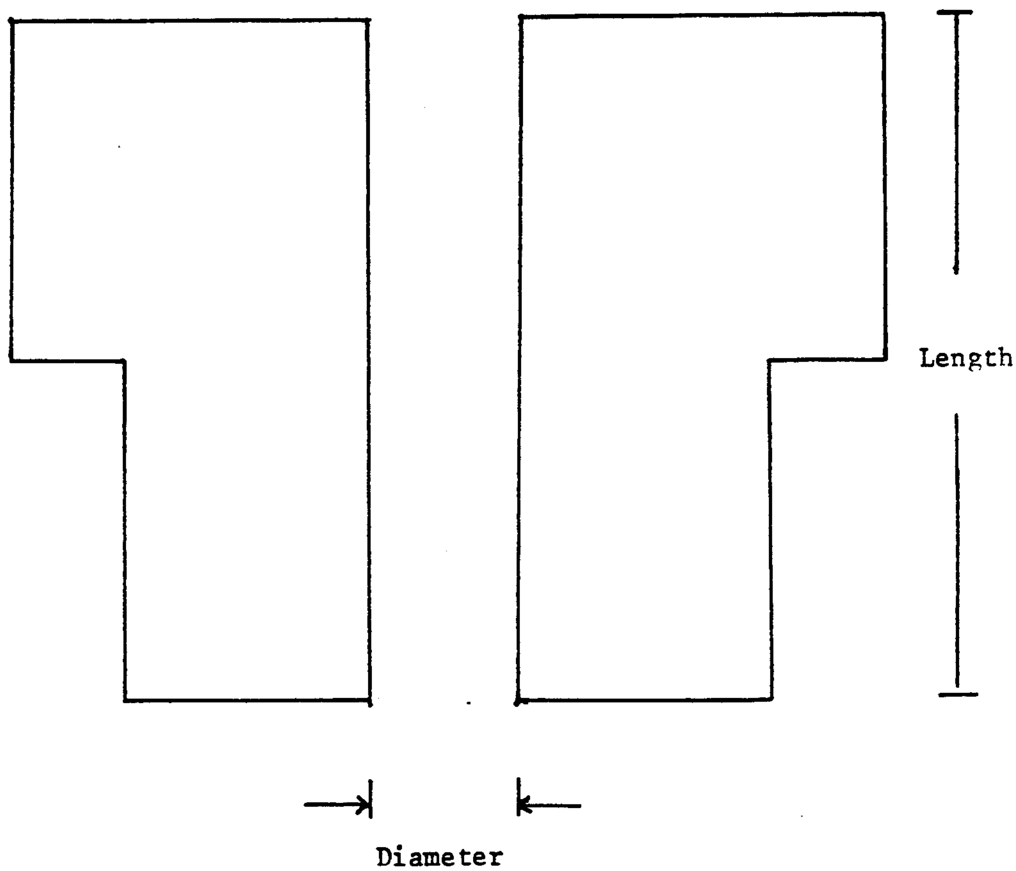
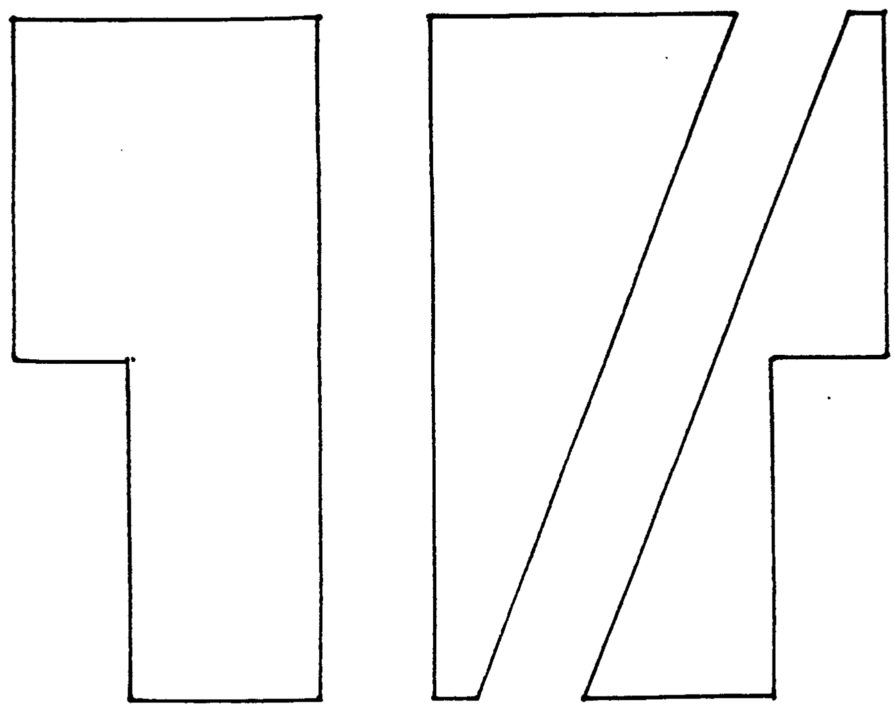


FIGURE 3.2 The Earmould Simulator with a Parallel Vent



anechoic test chamber during measurements. Figure 3.3 shows the block diagram of the measurement condition used for the receivers.

The frequency response of a hearing aid was measured using the substitution method at a constant input sound pressure level of 60 dB. The compressor switch of the Audio Test Station was left in the 'in' position and a compression curve was automatically controlled during each measurement session. The gain control of the hearing aid was kept in the reference test gain position and the tone control in 'normal' position for all the measurements. The hearing aid, the receiver, the earmould simulator, the ear simulator and the measuring microphone were all placed in the anechoic chamber during the measurements. Figure 3.4 shows the block diagram of the measurement condition used for hearing aids.

3.3.3 The Pilot Study

Initially, a pilot study was done to determine the test-retest reliability of measurements. An Indian hearing aid (Elkon model BM 79 with Oticon AP 270 receiver) was used for the pilot study. The frequency response of the hearing aid along with the earmould simulator was measured using the ear simulator. The frequency response was measured for four diameter and three length sizes of the sound bore of the earmould simulators. Each measurement was repeated four times. The receiver, the earmould simulator, and the ear simulator were separated between measurements.

The Main Study

3.3.4 The Diameter of the Sound bore

Frequency response of different receivers was measured while the diameter of the sound bore of the earmould simulator was varied between 1 mm and 4 mm. The receivers were driven by a constant voltage electrical signal. The length of the sound bore was maintained constant at 18 mm during this experiment.

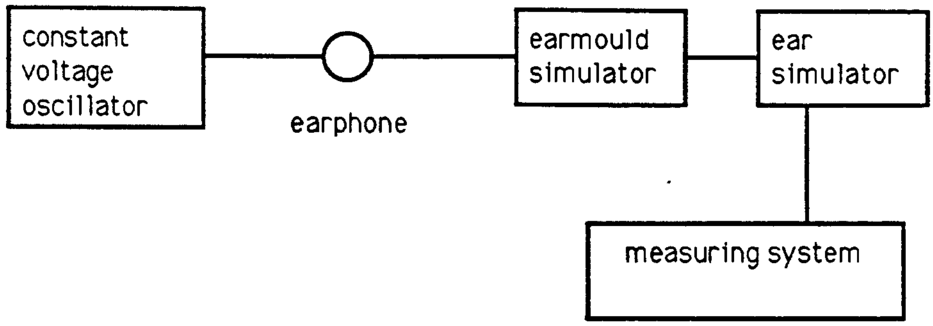


FIGURE 3.3 Experimental set-up for the measurement of frequency response of receivers.

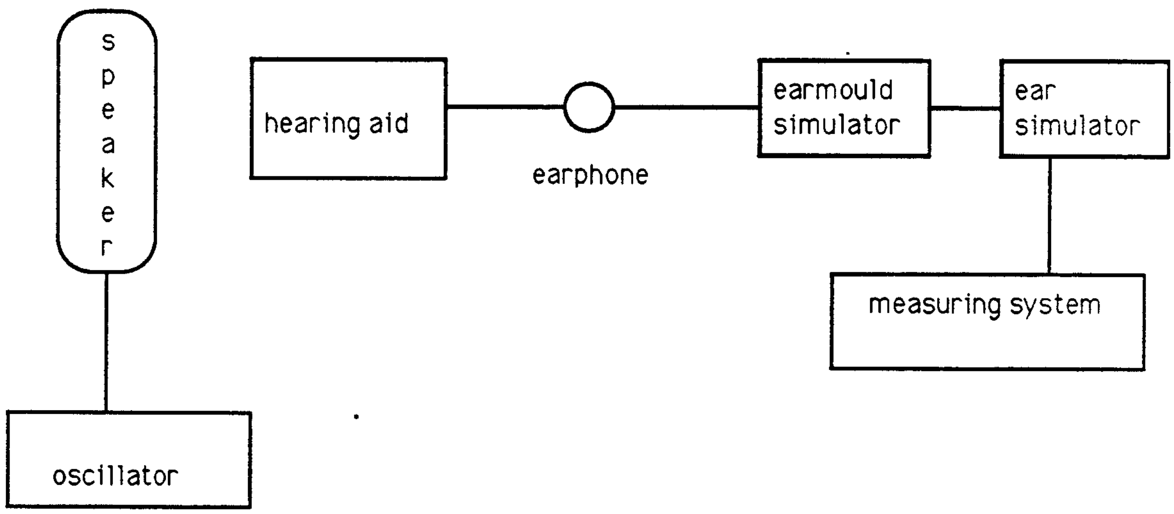


FIGURE 3.4 Experimental set-up for the measurement of frequency response of hearing aids.

3.3.5 The Length of the Sound bore

Frequency response of different receivers was measured while the length of the soundbore of the earmould simulator was varied between 13 mm and 23 mm. The receivers were driven by a constant voltage electrical signal. The diameter of the sound bore was maintained constant at 3 mm during this experiment.

3.3.6 The Diameter and the Length of the Parallel Vent

Frequency response of different receivers was measured while the earmould simulator was varied between a no vent to a 3 mm diameter parallel vent of length 15 mm, 19.5 mm and 24 mm. The diameter of the sound bore was maintained constant at 3 mm. The length of the vent, in the body worn hearing aid earmoulds is dependent on the length of the sound bore. Vent length of 15 mm, 19.5 mm and 24 mm corresponded to the soundbore length of 13 mm, 18 mm and 23 mm respectively.

3.3.7 Difference between a 2 cc Coupler and an Ear Simulator Response

Frequency response of different receivers was measured on a 2 cc acoustic coupler and on the ear simulator. The earmould simulator with the sound bore length of 18 mm and diameter of 3 mm was used for the measurements.

3.3.8 Comparison of Modification Effects on a Hearing Aid with that of the Receiver

Frequency response of Elkon hearing aid was measured with different receivers in a 2 cc acoustic coupler and in the ear simulator with the soundbore length 18 mm and diameter 3 mm of the earmould simulator. The frequency responses of the hearing aid were also measured while the diameter of the sound bore and the diameter and the length of the parallel vents were varied.

3.4 Data Collection

Data was recorded as output at the following frequencies for each of the measurement conditions:

100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 7000, and 8000 Hz.

3.5 Analysis

Output values obtained by measurements in a 2 cc coupler were substracted from those obtained in the ear simulator to give difference between the two measurement conditions. Mean, Standard deviation and Analysis of Variance was done for the values obtained for different receivers.

The condition with earmould sound bore diameter 3mm and the length 18mm was taken as the reference (these dimensions are also used for the earmould substitute used in a standard 2 cc acoustic coupler). The output values obtained in other measurement conditions were compared with the reference values to give the effect of that particular variable. Analysis of variance was done to analyze the data statistically.

Unlike ear-level hearing aids, the length of the vent and the length of the sound bore in a body worn hearing aid are dependent on each other. An unvented condition with a soundbore diameter of 3 mm and length of 13, 18, and 23 mm corresponding to the vent length of 15, 19.5, and 24 mm respectively was taken as the reference. The data obtained in each vented condition was compared with the unvented reference condition to give the effect of particular venting. Analyses of variance were performed on the data.

CHAPTER 4. RESULTS

4.1 The Pilot Study

In the pilot study the frequency response of an Elkon BM-79 hearing aid with an Oticon AP 270 receiver was measured for three length and four diameter conditions of the sound bore. The data under each of these conditions in the frequency range 100 Hz to 8000 Hz was analyzed. Table 4.1 shows the Analysis of Variance for the data.

The table indicates that the repetition of measurements does not result in significantly different data and that the test re-test reliability of measurement is good. The variation of diameter of the sound bore results in a very significant change in the frequency response ($p < 0.001$). Variation of length of the sound bore, on the other hand does not result in a significant change in the frequency response ($p > 0.80$). The interaction effects between frequency and sound bore diameter variation as well as between frequency and sound bore length variation are highly significant ($p < 0.001$) indicating that these effects vary with frequency. There are no significant interaction effects between the variation of sound bore diameter and length ($p > 0.70$). Hence these two variables can be studied independently of each other.

The Main Study

4.2 Diameter of the Sound Bore

The effect on frequency response of variation of sound bore diameter was measured for three Oticon receivers. The length of the sound bore was 18 mm. Table 4.2 shows the Analysis of Variance for the data. The effects of variation of sound bore diameter are highly significant ($p < 0.001$). The interaction effects between frequency and sound bore diameter are also highly significant ($p < 0.001$) indicating that the effects of variation of sound bore diameter vary with frequency. However, the effects of interaction between the frequency response of receiver and the sound bore diameter variation are not significant indicating that these effects are similar for the three receivers used in the study. Table 4.3 to Table 4.5 respectively show the 4 mm minus the 3 mm, 2 mm minus 3 mm and 1 mm minus 3 mm sound bore diameter responses for the three receivers. The high frequency response is better with a 4 mm than with

TABLE 4.1

Analysis of Variance table for the data obtained in the pilot study

Source	DF	SS	MS	F	P
Freq	19	111282.3	5857	3498.16	0.000
Dia	3	2245.5	748.5	447.05	0.000
Length	2	0.7	0.35	0.21	0.804
Repetition	3	6	2	1.19	0.307
FreqxDia	57	10765.7	188.9	112.82	0.000
FreqxLength	38	1092.3	28.7	17.14	0.000
FreqxRptn.	57	12.7	0.2	0.12	1.000
DiaxLength	6	6	1	0.6	0.718
DiaxRptn.	9	3	0.33	0.2	0.993
LengthxRptn.	6	16	2.67	1.59	0.145
Error	759	1270.8	1.67		
Total	959	126701			

TABLE 4.2

Analysis of Variance table for variation of sound bore diameter

Source	DF	SS	MS	F	P
Frequency	15	1575.94	105.062	39.92	0.000
Receiver	2	9.54	4.771	1.81	0.172
Diameter	2	442.17	221.083	84.00	0.000
Freq*Recr	30	203.79	6.793	2.58	0.001
Freq*Dia	30	2021.17	67.372	25.6	0.000
Recr*Dia	4	3.42	0.854	0.32	0.860
Error	60	157.92	2.632		
Total	143	4413.94	30.867		

TABLE 4.3

Effect of variation of diameter of the sound bore

4 mm minus 3 mm diameter response					
	Receiver				
Frequency	AP	AN	AW	Mean	S.D.
200	-1.00	-1.00	-1.00	-1.00	0.00
500	-1.00	-1.00	-1.00	-1.00	0.00
600	-1.00	-1.00	-1.00	-1.00	0.00
700	-1.00	-1.00	-1.00	-1.00	0.00
800	-1.00	-1.00	-1.00	-1.00	0.00
900	-1.00	-1.00	-1.00	-1.00	0.00
1000	-2.00	-1.00	-2.00	-1.67	0.58
1500	-4.00	-2.00	-2.00	-2.67	1.15
2000	0.00	-3.00	-2.00	-1.67	1.53
2500	-4.00	0.00	-3.00	-2.33	2.08
3000	-2.00	-1.00	0.00	-1.00	1.00
4000	5.00	8.00	5.00	6.00	1.73
5000	4.00	3.00	4.00	3.67	0.58
6000	5.00	4.00	5.00	4.67	0.58
7000	0.00	4.00	-4.00	0.00	4.00
8000	0.00	0.00	0.00	0.00	0.00

TABLE 4.4

Effect of variation of diameter of the sound bore

2 mm minus 3 mm diameter response					
Receiver					
Frequency	AP	AN	AW	Mean	S.D.
200	0.00	0.00	0.00	0.00	0.00
500	1.00	1.00	0.00	0.67	0.58
600	1.00	0.00	0.00	0.33	0.58
700	2.00	1.00	1.00	1.33	0.58
800	2.00	1.00	1.00	1.33	0.58
900	3.00	2.00	1.00	2.00	1.00
1000	3.00	2.00	0.00	1.67	1.53
1500	-1.00	2.00	0.00	0.33	1.53
2000	-4.00	0.00	3.00	0.33	3.51
2500	-1.00	-6.00	-4.00	-3.67	2.52
3000	-10.00	-2.00	-10.00	-7.33	4.62
4000	-8.00	-8.00	-8.00	-8.00	0.00
5000	-6.00	-7.00	-8.00	-7.00	1.00
6000	-7.00	-6.00	-8.00	-7.00	1.00
7000	-10.00	-6.00	-10.00	-8.67	2.31
8000	0.00	0.00	0.00	0.00	0.00

TABLE 4.5

Effect of variation of diameter of the sound bore

1 mm minus 3 mm diameter response					
		Receiver			
Frequency	AP	AN	AW	Mean	S.D.
200	0.00	0.00	0.00	0.00	0.00
500	2.00	2.00	2.00	2.00	0.00
600	2.00	1.00	2.00	1.67	0.58
700	4.00	3.00	3.00	3.33	0.58
800	5.00	3.00	3.00	3.67	1.15
900	7.00	4.00	3.00	4.67	2.08
1000	6.00	4.00	2.00	4.00	2.00
1500	-8.00	0.00	0.00	-2.67	4.62
2000	-9.00	-8.00	-2.00	-6.33	3.83
2500	-11.00	-13.00	-12.00	-12.00	1.00
3000	-18.00	-8.00	-17.00	-14.33	5.51
4000	-14.00	-14.00	-13.00	-13.67	0.58
5000	-10.00	-12.00	-12.00	-11.33	1.15
6000	-11.00	-11.00	-13.00	-11.67	1.15
7000	-18.00	-16.00	-13.00	-15.67	2.52
8000	2.00	-6.00	0.00	-1.33	4.16

either a 2 mm or a 1 mm diameter of the sound bore. There appears to be some variability in the magnitude of effect between the three receivers at certain frequencies.

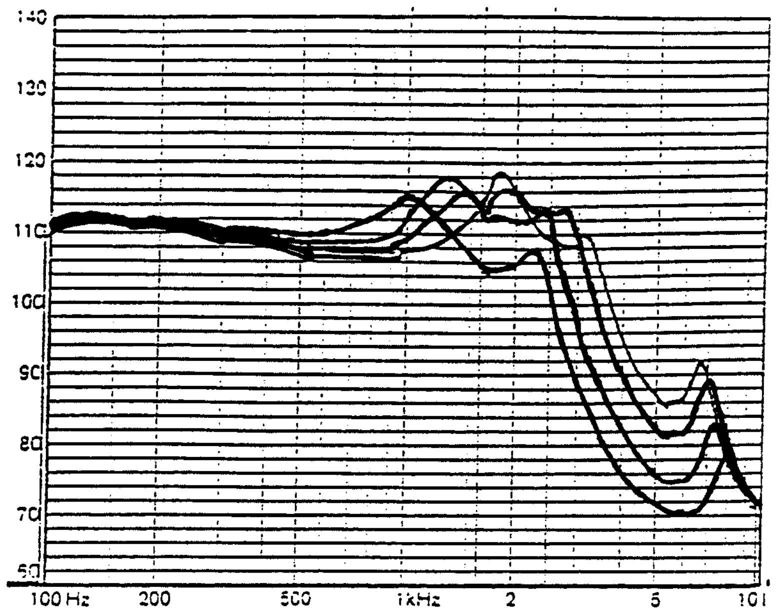
Figures 4.1, 4.3 and 4.5 show the frequency responses of the AP 270, AN 270 and AW 270 receivers respectively, measured with different diameter sizes of the sound bore. The effects of sound bore diameter variation in comparison with a 3 mm sound bore diameter response are plotted in Figures 4.2, 4.4 and 4.6 for the three receivers respectively. As can be seen from these figures, the difference in response betwen the various diameter sizes is very large at high frequencies. The high frequency response is better with the wider sound bore and poorer with the narrower sound bores. At frequencies below 1000 Hz, the response is slightly better with narrower bores and poorer with the wider bore. The difference in frequency response for different diameter sizes reduces gradually towards the low frequency end.

4.3 Length of the Sound Bore

Table 4.6 shows the Analysis of Variance for the data obtained by variation of length of the sound bore. The overall effects of variation of length are not significant statistically ($p > 0.80$). However, the interaction effects between frequency and the variation of sound bore length are significant ($p < 0.001$). It indicates that the effects of variation of sound bore length vary with frequency. Table 4.7 and Table 4.8 show the effect of sound bore length variation at different frequencies for the three receivers. For frequencies upto 1000 Hz, the effects of variation of sound bore length are within 2 dB. At higher frequencies, the effects go up to as much as -11 dB at 7000 Hz.

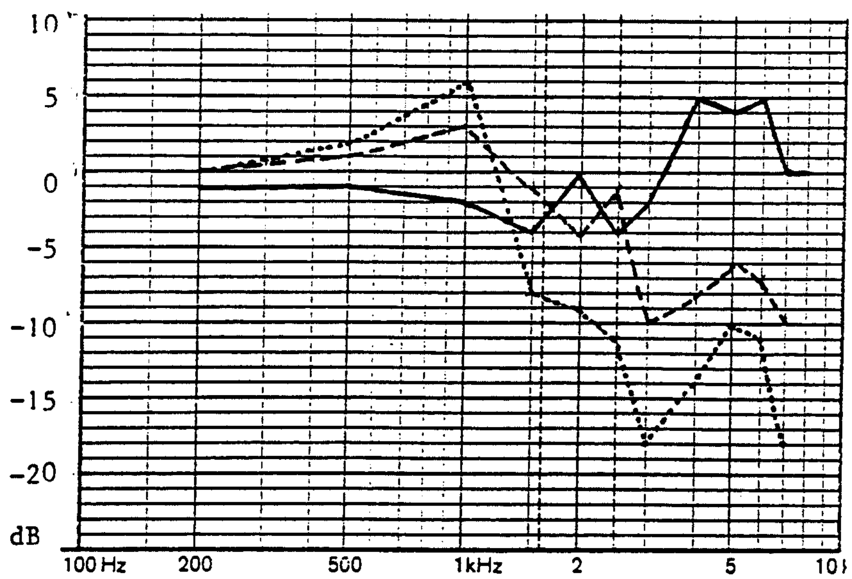
Figures 4.7, 4.9 and 4.11 show the frequency response of receivers AP 270, AN 270 and AW 270 respectively, measured with different lengths of the sound bore. The effects of sound bore length variation for three receivers are plotted in Figures 4.8, 4.10 and 4.12 respectively. Though larger effects appear at higher frequencies there does not appear to be any definite pattern related to the variation in length of the sound bore.

FIGURE 4.1 Variation of Sound Bore Diameter - Receiver AP 270



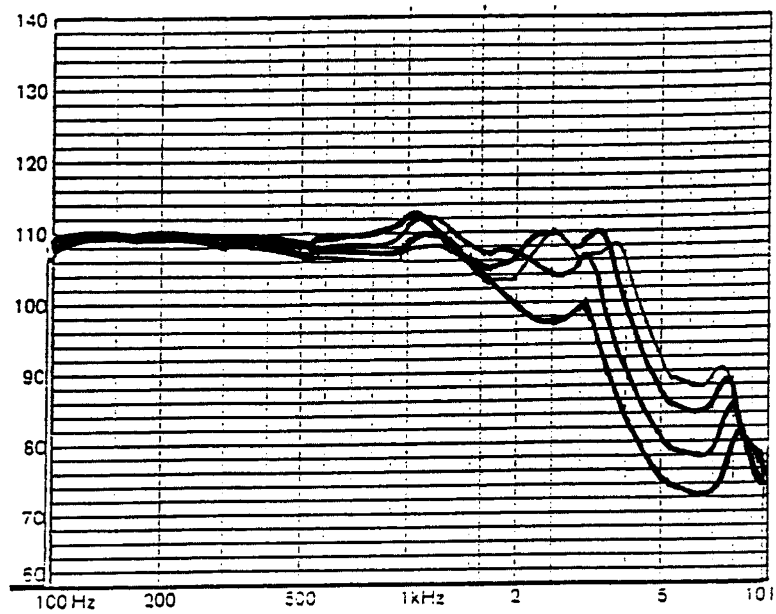
4 mm   3 mm   2 mm   1 mm

FIGURE 4.2 Effects of Sound Bore Diameter Variation



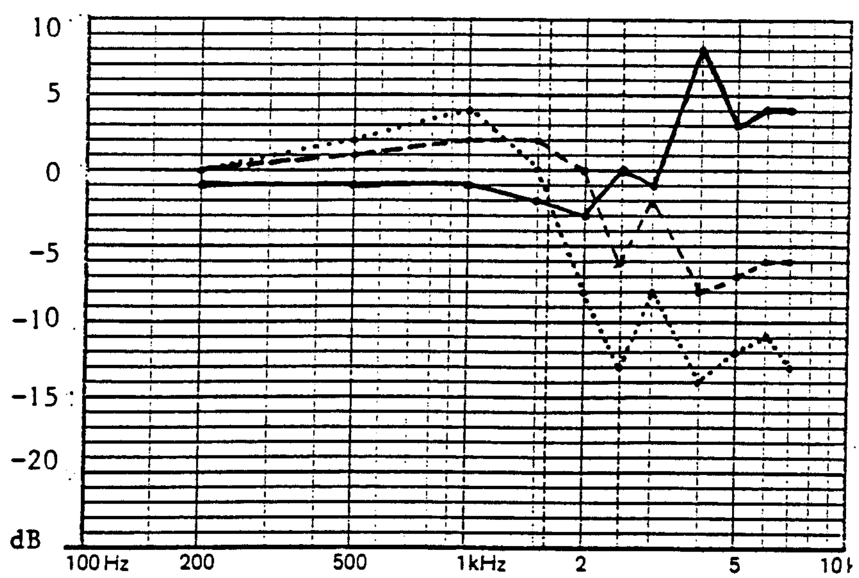
4 mm ---- 2 mm .... 1 mm

FIGURE 4.3 Variation of Sound Bore Diameter - Receiver AN 270



____ 4 mm ____ 3 mm ____ 2 mm ____ 1 mm

FIGURE 4.4 Effects of Sound Bore Diameter Variation



____ 4 mm ---- 2 mm .... 1 mm

FIGURE 4.5 Variation of Sound Bore Diameter - Receiver AW 270

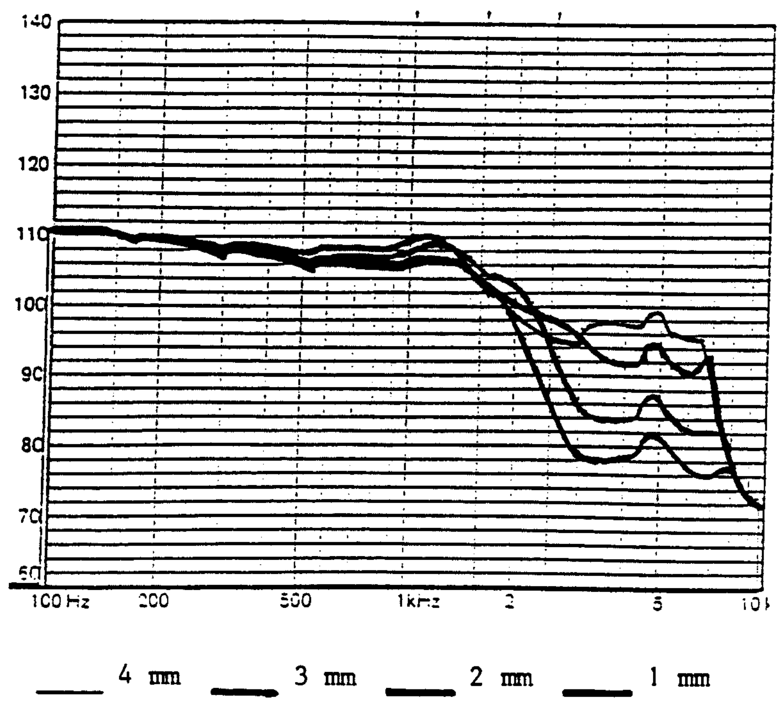


FIGURE 4.6 Effects of Sound Bore Diameter Variation

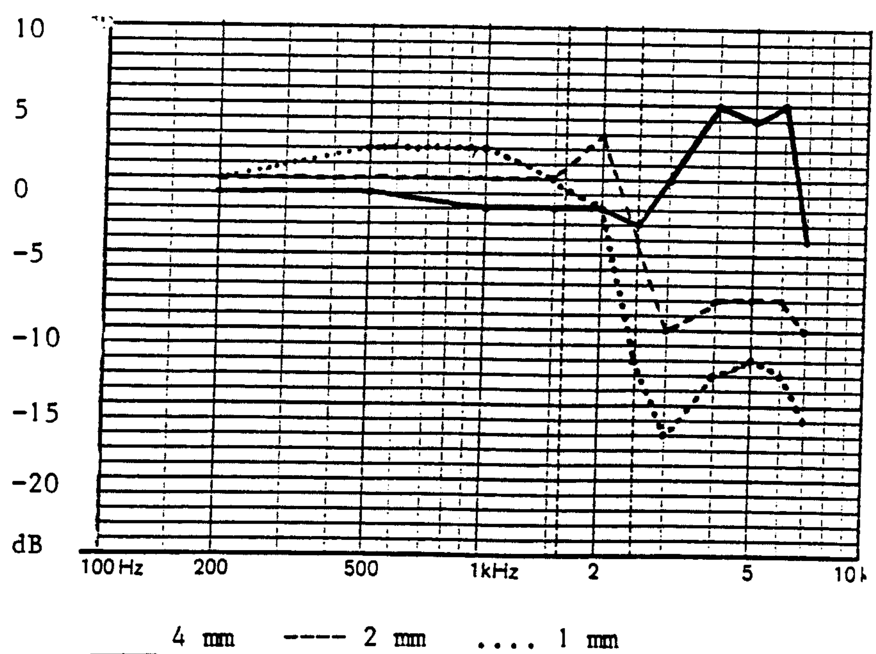


TABLE 4.6

Analysis of Variance table for variation of sound bore length

Source	DF	SS	MS	F	P
Frequency	15	198.823	13.2549	2.94	0.006
Receiver	2	1.333	0.6667	0.15	0.863
Length	1	0.260	0.2604	0.06	0.812
Freq*Recr	30	238.333	7.9444	1.76	0.063
Freq*Length	15	321.573	21.4382	4.76	0.000
Recr*Length	2	2.583	1.2917	0.29	0.753
Error	30	135.083	4.5028		
Total	95	897.990	9.4525		

TABLE 4.7

Effect of variation of sound bore length

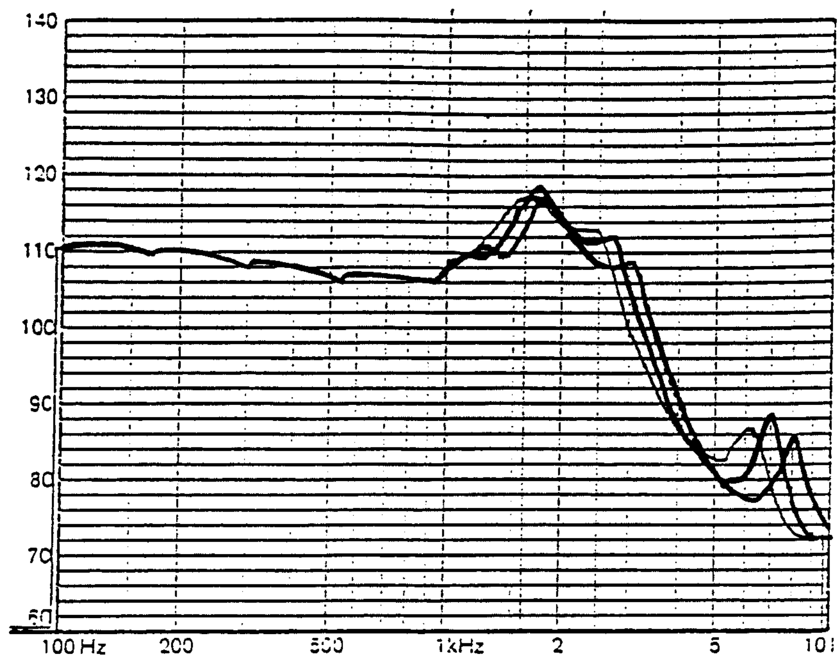
23 mm minus 18 mm length response					
Receiver					
Frequency	AP	AN	AW	Mean	S.D.
200	0.00	0.00	-1.00	-0.33	0.58
500	0.00	0.00	0.00	0.00	0.00
600	0.00	0.00	0.00	0.00	0.00
700	0.00	0.00	0.00	0.00	0.00
800	0.00	-1.00	0.00	-0.33	0.58
900	0.00	-1.00	-1.00	-0.67	0.58
1000	-1.00	-2.00	-1.00	-1.33	0.58
1500	3.00	0.00	1.00	1.33	1.53
2000	0.00	2.00	3.00	1.67	1.53
2500	1.00	-1.00	0.00	0.00	1.00
3000	-4.00	0.00	-5.00	-3.00	2.65
4000	-2.00	-4.00	-2.00	-2.67	1.15
5000	3.00	-1.00	-1.00	0.33	2.31
6000	7.00	4.00	4.00	5.00	1.73
7000	-9.00	4.00	-8.00	-4.33	7.23
8000	-3.00	-8.00	-3.00	-4.67	2.89

TABLE 4.8

Effect of variation of sound bore length

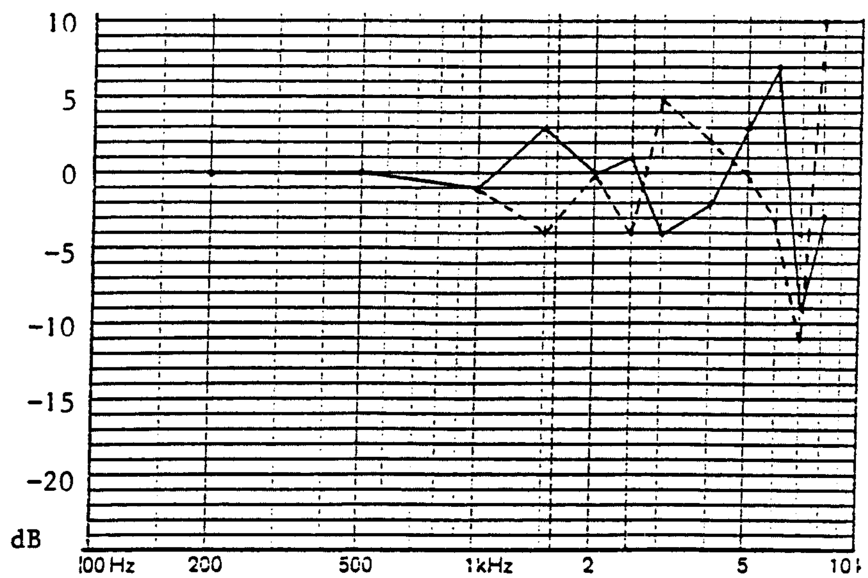
13 mm minus 18 mm length response					
	Receiver				
Frequency	AP	AN	AW	Mean	S.D.
200	0.00	0.00	0.00	0.00	0.00
500	0.00	0.00	0.0	0.00	0.00
600	0.00	0.00	-1.00	-0.33	0.58
700	0.00	-1.00	0.00	-0.33	0.58
800	0.00	-1.00	0.00	-0.33	0.58
900	0.00	-1.00	0.00	-0.33	0.58
1000	-1.00	-2.00	0.00	-1.00	1.00
1500	-4.00	-2.00	-1.00	-2.33	1.53
2000	0.00	-1.00	-1.00	-0.67	0.58
2500	-4.00	0.00	-3.00	-2.33	2.08
3000	5.00	-2.00	0.00	1.00	3.61
4000	2.00	6.00	1.00	3.00	2.65
5000	0.00	1.00	0.00	0.33	0.58
6000	-3.00	0.00	-3.00	-2.00	1.73
7000	-11.00	-4.00	-5.00	-6.67	3.79
8000	10.00	-4.00	8.00	4.67	7.57

FIGURE 4.7 Variation of Sound Bore Length - Receiver AP 270



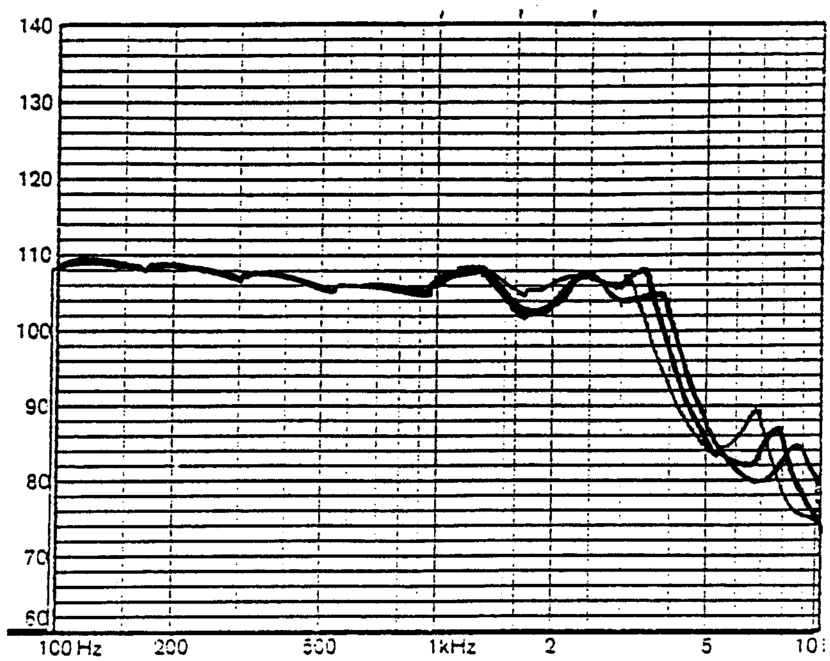
____ 23 mm ____ 18 mm ____ 13 mm

FIGURE 4.8 Effects of Sound Bore Length Variation



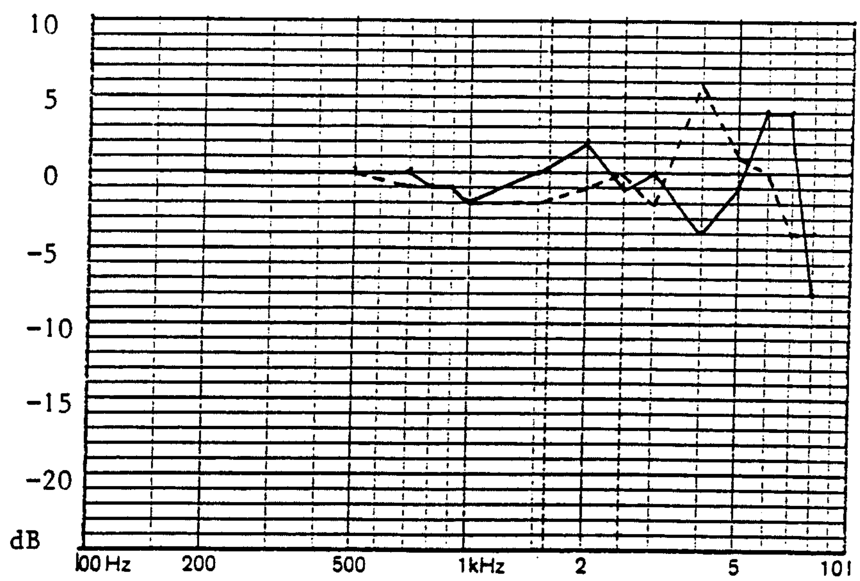
____ 23 mm ---- 13 mm

FIGURE 4.9 Variation of Sound Bore Length - Receiver AN 270



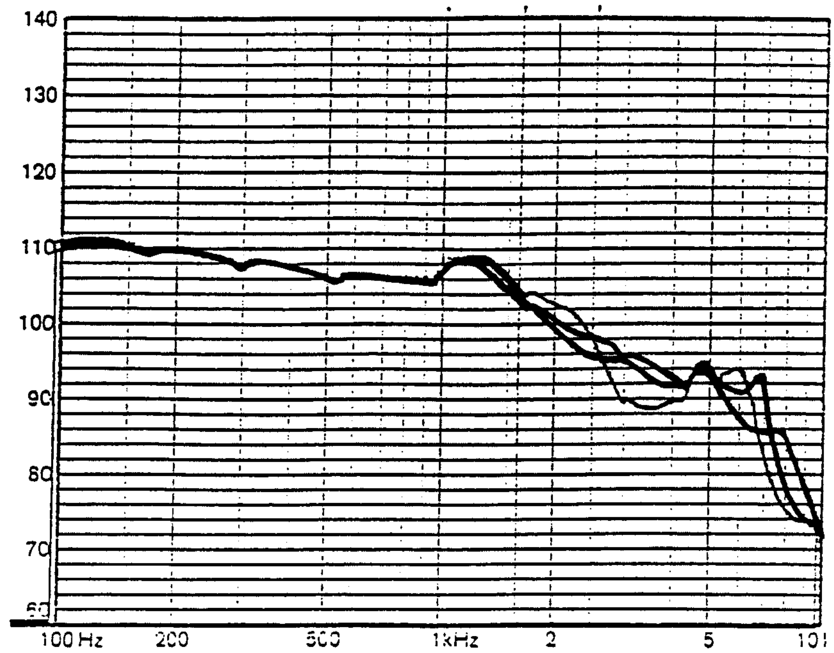
23 mm 18 mm 13 mm

FIGURE 4.10 Effects of Sound Bore Length Variation



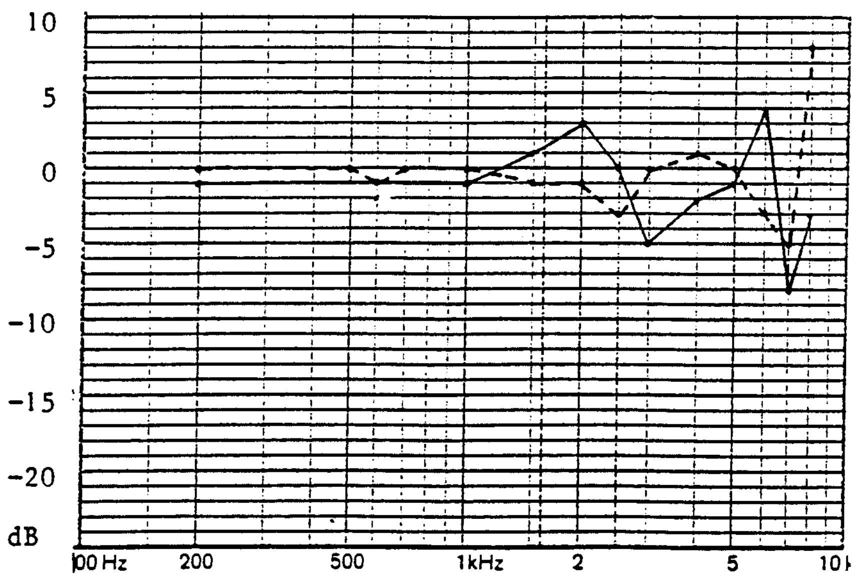
23 mm ---- 13 mm

FIGURE 4.11 Variation of Sound Bore Length - Receiver AW 270



23 mm   18 mm   13 mm

FIGURE 4.12 Effects of Sound Bore Length Variation



23 mm   ---- 13 mm

4.4 Parallel Vents

Table 4.9 shows the Analysis of Variance for the data obtained by the addition of parallel vents. The effects of variation of vent diameter, vent length and the interaction effects between these two variables are all highly significant statistically ($p < 0.001$). However, the interaction effects between the receiver and the vent diameter or the vent length are not significant statistically ($p > 0.95$ and $p > 0.80$ respectively). The results indicate that the effects of the diameter and the length of the parallel vents are not dependent on the frequency response of the receiver.The interaction effects of frequency with vent length ($p < 0.001$) and vent diameter ($p < 0.001$) are highly significant, indicating that these effects are frequency dependent.

Table 4.10 shows the Mean venting effects (the vented minus unvented response) for different vent length and vent diameters used in this study. Figures 4.13, 4.15 and 4.17 show the frequency response of a receiver for the three vent lengths of 15 mm, 19.5 mm and 24 mm respectively. The effects of parallel venting for the three vent lengths, each for three sizes of vent diameters are plotted graphically in Figures 4.14, 4.16 and 4.18 respectively. It is evident that the degreee of low frequency cut in the response is dependent on both the diameter and the length of the vent. The wider and the shorter vents result in a greater low frequency cut.

4.5 Difference Between a 2 cc Coupler and an Ear Simulator Frequency Response

Table 4.11 shows the Analysis of Variance table for the difference in frequency response measured on a 2 cc acoustic coupler and a modified Zwislocki ear simulator. The three receivers do not differ significantly ($p > 0.10$) from each other for the measured response differences between the two couplers.

Table 4.12 shows the ear simulator minus 2 cc acoustic coupler frequency response for the three receivers. The differences in frequency response between the ear simulator and the 2 cc acoustic coupler are below 3 dB for frequencies upto 800 Hz, beyond which they start increasing until upto 7000 Hz.

4.6 Comparison of Modification Effects on a Hearing Aid with that of the Receiver

4.6.1 Difference between a 2 cc coupler and an ear simulator frequency response

Table 4.13 shows the difference in frequency response measured in two couplers for Elkon BM-79 hearing aid with Oticon receivers AP 270, AN 270 and AW 270. Table 4.14 shows one-way Analysis of Variance on the data obtained with two systems, the receivers alone and complete hearing aid with the receivers. It indicates that there are no significant differences ($p > 0.40$) between the data obtained with receiver alone and that obtained with a complete hearing aid for the difference in frequency response measured in a 2 cc coupler and an ear simulator.

Table 4.15 shows a more detailed analysis of the data. It indicates that there are significant differences ($p < 0.01$) between the two systems. However, an interaction effect between the frequency and the two systems ($p < 0.05$) though not significant, is indicative of the differences between the two systems to be related to frequency. A comparison of Table 4.13 with Table 4.12 shows that there is a good agreement between the two systems at all the frequencies except at the two extreme end, 100 Hz and 8000 Hz.

Figures 4.19, 4.21 and 4.23 show the two frequency response curves of receivers AP 270, AN 270 and AW 270 respectively, measured on the ear simulator and the 2 cc acoustic coupler. Similar frequency response curves with the complete hearing aid with same receivers are shown in Figures 4.20, 4.22 and 4.24.

4.6.2 Variation of sound bore diameter

Table 4.16 shows the one-way Analysis of Variance for the difference in 4 mm minus 1 mm diameter frequency response for complete hearing aid and the receivers alone. It shows no significant difference ($p > 0.80$) between the two systems.

More detailed Analysis of Variance for the data is presented in Table 4.17. It indicates that there are significant differences between the two systems ($p < 0.001$). There is also a significant interaction effect between frequency and system ($p < 0.02$). Table 4.18 shows a comparison of difference in 4 mm minus 1 mm sound bore diameter frequency response for the two systems. There appears to be good agreement between the two systems at most of the frequencies for all the three receivers. The

TABLE 4.9

Analysis of Variance table for variation of diameter and length of parallel vents

Source	DF	SS	MS	F	P
Frequency	13	55691.4	4283.96	3E+03	0.000
Vent diameter	2	2530.8	1265.41	905.27	0.000
Receiver	4	40.7	10.18	7.29	0.000
Vent length	2	159.0	79.49	56.87	0.000
Freq*V.dia	26	8291.8	318.91	228.15	0.000
Freq*Rec	52	97.8	1.88	1.35	0.060
Freq*V.length	26	715.9	27.53	19.70	0.000
V.dia*Rec	8	3.4	0.42	0.30	0.965
V.dia*V.length	4	77.0	19.26	13.78	0.000
Rec*V.length	8	6.3	0.78	0.56	0.810
Error	484	676.5	1.40		
Total	629	68290.7	108.57		

TABLE 4.10

Table showing the Mean Venting Effects

	Vent Length								
Frequency	24 mm			19.5 mm			15 mm		
	Vent Diameter								
	1 mm	2 mm	3 mm	1mm	2 mm	3mm	1 mm	2 mm	3mm
100	-16	-24	-32	-22	-28	-34	-20	-27	-36
150	-9	-17	-25	-13	-20	-28	-14	-22	-30
200	-2	-11	-19	-6	-14	-22	-7	-15	-23
300	6	-1	-11	6	-4	-14	3	-8	-17
400	5	7	-4	7	5	-7	8	0	-10
500	3	6	3	4	9	-1	5	7	-5
600	2	5	7	3	7	4	4	9	0
700	1	3	7	2	4	7	3	6	5
800	2	2	5	1	3	6	2	4	6
900	2	2	4	1	2	5	2	3	5
1000	1	1	3	0	2	4	1	3	5
1500	0	0	1	0	0	1	1	1	3
2000	0	0	0	0	0	0	1	1	2
2500	0	0	0	0	0	0	0	0	0

TABLE 4.11

Analysis of Variance table for difference in frequency response measured on a 2 cc acoustic coupler and an ear simulator

Source	DF	SS	MS	F	P
Frequency	19	1280.85	67.4132	97.40	0.000
Receiver	2	3.03	1.5167	2.19	0.126
Error	38	26.30	0.6921		
Total	59	1310.18	22.2065		

TABLE 4.12

Difference in frequency response of three Oticon receivers measured on a 2 cc acoustic coupler and an ear simulator

Frequency	Receiver Type				
	AP	AN	AW	Mean	S.D.
100	2.00	3.00	3.00	2.67	0.58
150	2.00	3.00	2.00	2.33	0.58
200	2.00	2.00	2.00	2.00	0.00
300	2.00	2.00	2.00	2.00	0.00
400	2.00	2.00	3.00	2.33	0.58
500	3.00	3.00	3.00	3.00	0.00
600	3.00	3.00	3.00	3.00	0.00
700	3.00	3.00	3.00	3.00	0.00
800	3.00	4.00	4.00	3.67	0.58
900	3.00	4.00	4.00	3.67	0.58
1000	4.00	5.00	5.00	4.67	0.58
1500	5.00	7.00	7.00	6.33	1.15
2000	9.00	7.00	8.00	8.00	1.00
2500	8.00	8.00	8.00	8.00	0.00
3000	11.00	9.00	10.00	10.00	1.00
4000	12.00	12.00	13.00	12.33	0.58
5000	12.00	14.00	14.00	13.33	1.15
6000	13.00	15.00	16.00	14.67	1.58
7000	17.00	17.00	15.00	16.33	1.15
8000	11.00	9.00	13.00	11.00	2.00

FIGURE 4.13 Parallel Venting - Vent Length 15 mm

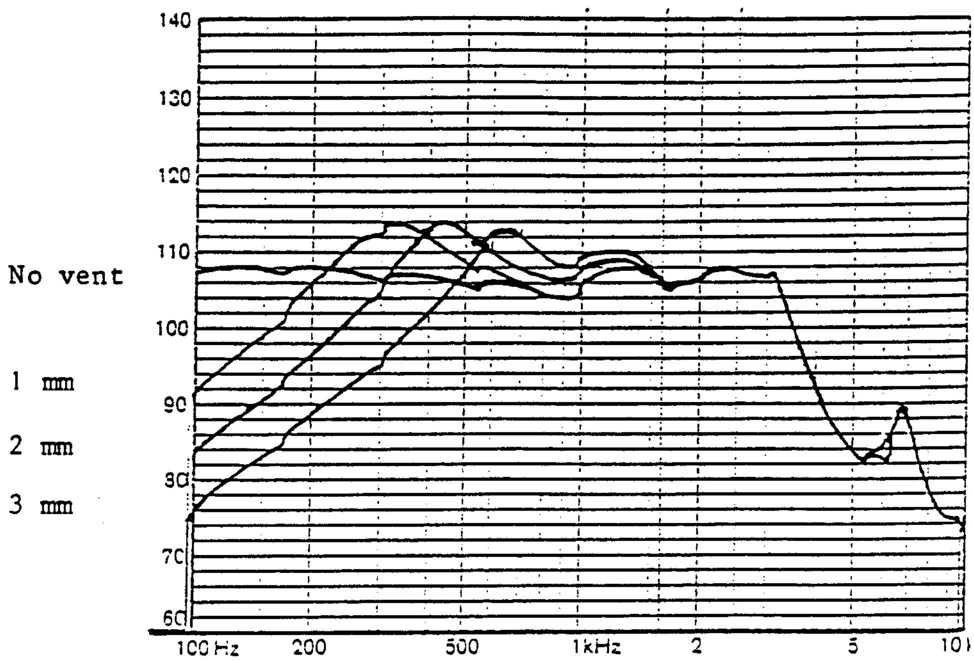


FIGURE 4.14 Vented minus Unvented Response

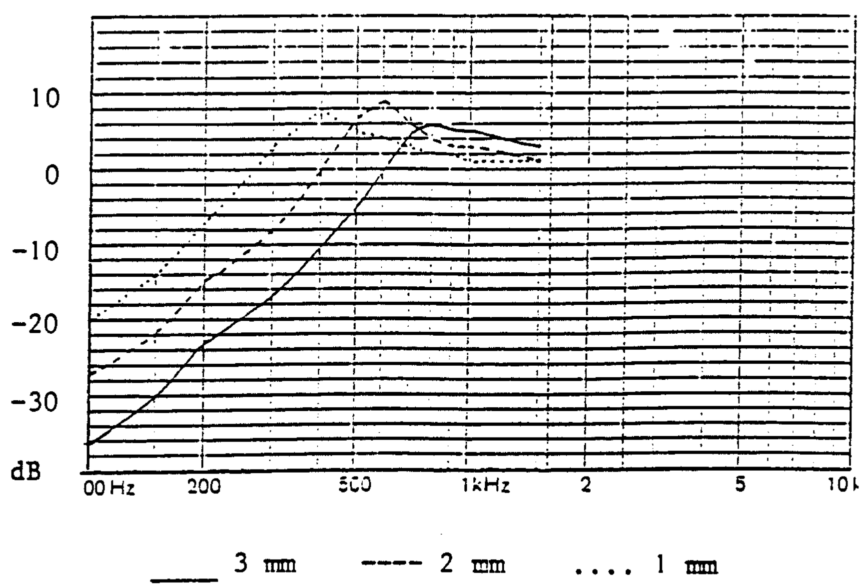


FIGURE 4.15 Parallel Venting - Vent Length 19.5 mm

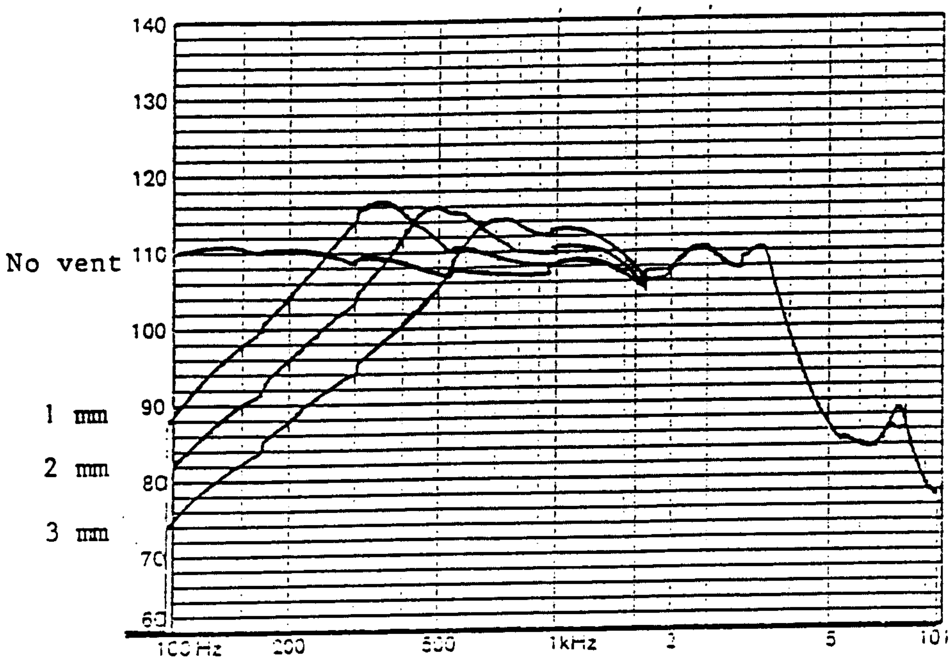


FIGURE 4.16 Vented minus Unvented Response

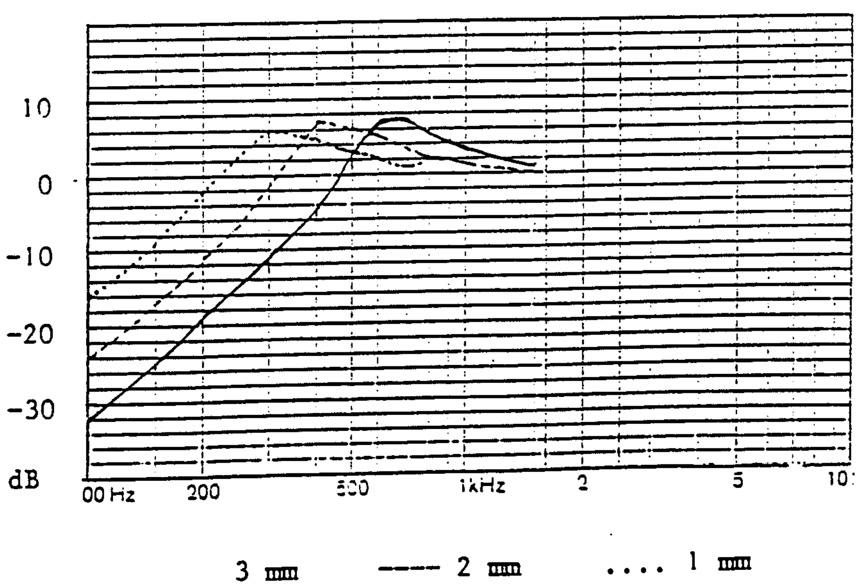


FIGURE 4.17 Parallel Venting - Vent Length 24 mm

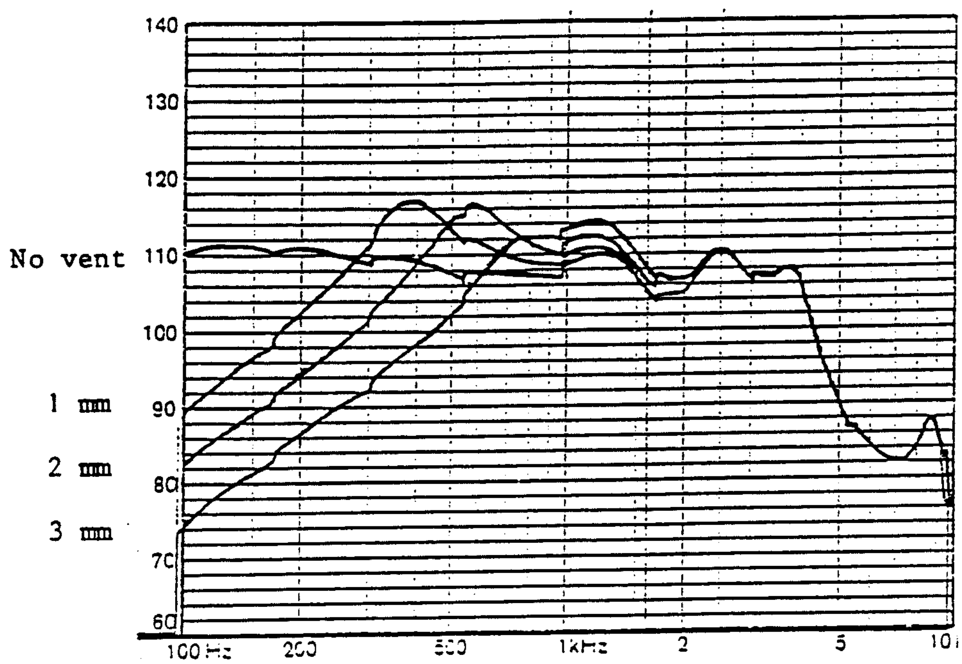
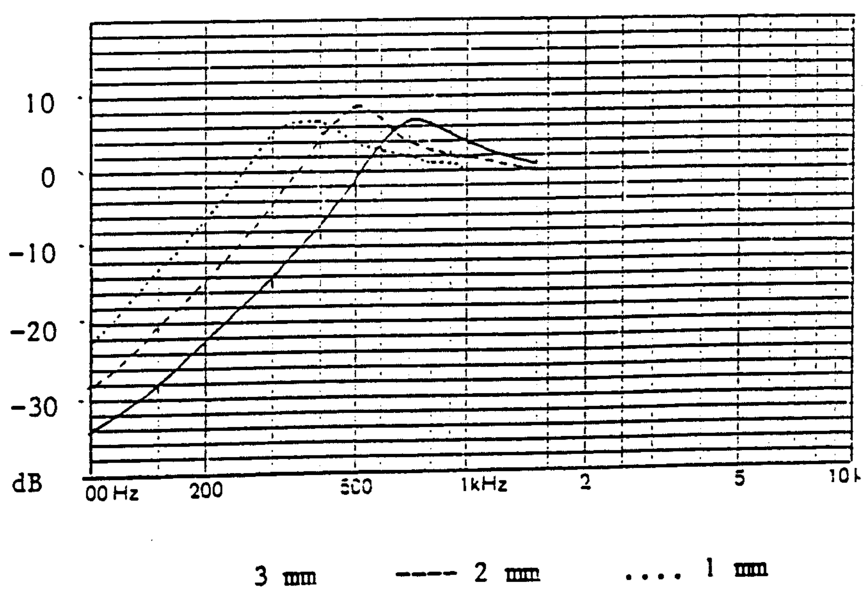


FIGURE 4.18 Vented minus Unvented Response



maximum difference between the responses of the two systems is 3 dB at four frequencies for receiver AP 270. The difference in response is within 2 dB for the other two receivers at all the frequencies.

4.6.3 Parallel Venting

Table 4.19 shows one-way Analysis of Variance for the difference in 3 mm vented minus the unvented frequency response for the complete hearing aid and the receivers alone. It indicates that there are no significant differences in the effects of venting between the receivers and the complete hearing aid ($p > 0.57$).

A further detailed Analysis of Variance is presented in the Table 4.20. Accordingly, the venting effects in the two systems are significantly different from each other ($p < 0.001$). However, the interaction effects between frequency and the system are also highly significant ($p < 0.001$). This indicates that the differences in the effects of venting between the receivers and the complete hearing aid are significant at certain frequencies.

Table 4.21 shows the comparison of venting effects for the two systems as a function of frequency. It is quite apparent that there are large differences between the two systems at frequencies 100 Hz and 150 Hz. But at frequencies 200 Hz and above the effects of venting measured on the receivers alone are similar to those measured with the complete hearing aid.

TABLE 4.13

Difference in frequency response of Elkon BM-79 hearing aid with three Oticon receivers measured on a 2 cc acoustic coupler and an ear simulator

Frequency	Receiver Type				
	AP	AN	AW	Mean	S.D
100	3.00	3.00	8.00	4.67	2.89
150	2.00	3.00	4.00	3.00	1.00
200	2.00	3.00	2.00	2.33	0.58
300	3.00	3.00	3.00	3.00	0.00
400	3.00	3.00	3.00	3.00	0.00
500	3.00	3.00	3.00	3.00	0.00
600	3.00	3.00	4.00	3.33	0.58
700	3.00	3.00	4.00	3.33	0.58
800	3.00	4.00	3.00	3.33	0.58
900	3.00	4.00	4.00	3.67	0.58
1000	4.00	5.00	6.00	5.00	1.00
1500	8.00	7.00	8.00	7.67	0.58
2000	7.00	6.00	8.00	7.00	1.00
2500	8.00	8.00	8.00	8.00	0.00
3000	11.00	9.00	11.00	10.33	1.15
4000	14.00	13.00	13.00	13.33	0.58
5000	13.00	14.00	15.00	14.00	1.00
6000	15.00	16.00	17.00	16.00	1.00
7000	18.00	17.00	16.00	17.00	1.00
8000	12.00	18.00	15.00	15.00	3.00

TABLE 4.14

Oneway Analysis of Variance for the difference in frequency response between complete hearing aid and the receivers alone measured on a 2 cc acoustic coupler and an ear simulator

Source	DF	SS	MS	F	P
System	1	14.0	14.0	0.58	0.447
Error	118	2838.8	24.1		
Total	119	2852.8			

Level	N	Mean	S.D.
1	60	6.617	4.712
2	60	7.300	5.090

Pooled Standard Deviation = 4.905

TABLE 4.15

Analysis of Variance table for difference in frequency response between complete hearing aid and the receivers alone measured on a 2 cc acoustic coupler and an ear simulator

Source	DF	SS	MS	F	P
Frequency	19	2725.96	143.471	157.87	0.000
Receiver	2	9.87	4.933	5.43	0.008
System	1	14.01	14.008	15.41	0.000
Freq*Recr	38	38.47	1.012	1.11	0.371
Freq*System	19	29.49	1.552	1.71	0.079
Recr*System	2	0.47	0.233	0.26	0.775
Error	38	34.53	0.909		
Total	119	2852.79	23.973		

TABLE 4.16

Oneway Analysis of Variance for the difference in 4 mm minus 1 mm sound bore diameter frequency response between complete hearing aid and the receivers alone

Source	DF	SS	MS	F	P
System	1	5.5	5.5	0.06	0.800
Error	94	8031.2	85.4		
Total	95	8036.7			

Level	N	Mean	S.D.
1	48	4.375	9.321
2	48	4.854	9.165

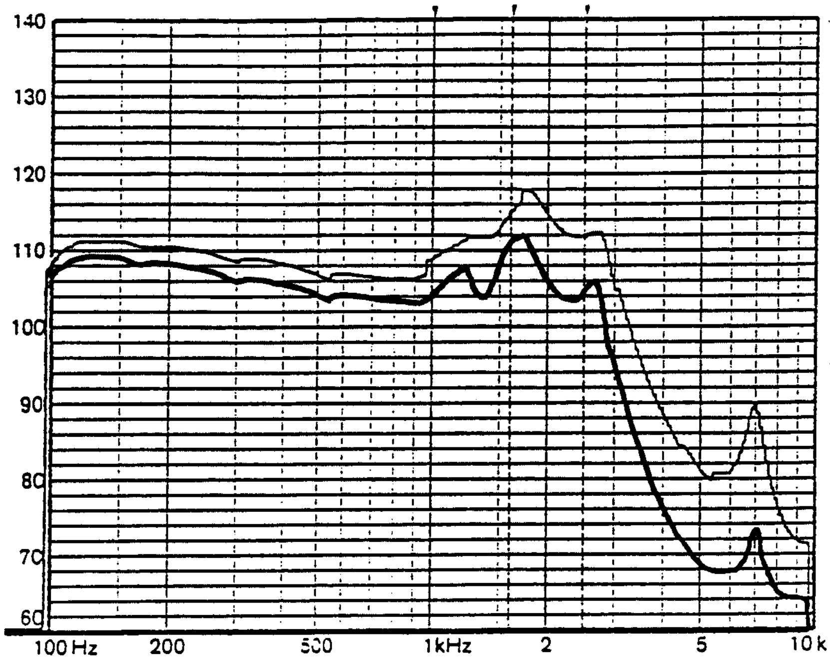
Pooled Standard Deviation = 9.243

TABLE 4.17

Analysis of Variance table for the difference in 4 mm minus 1 mm sound bore diameter frequency response between complete hearing aid and the receivers alone

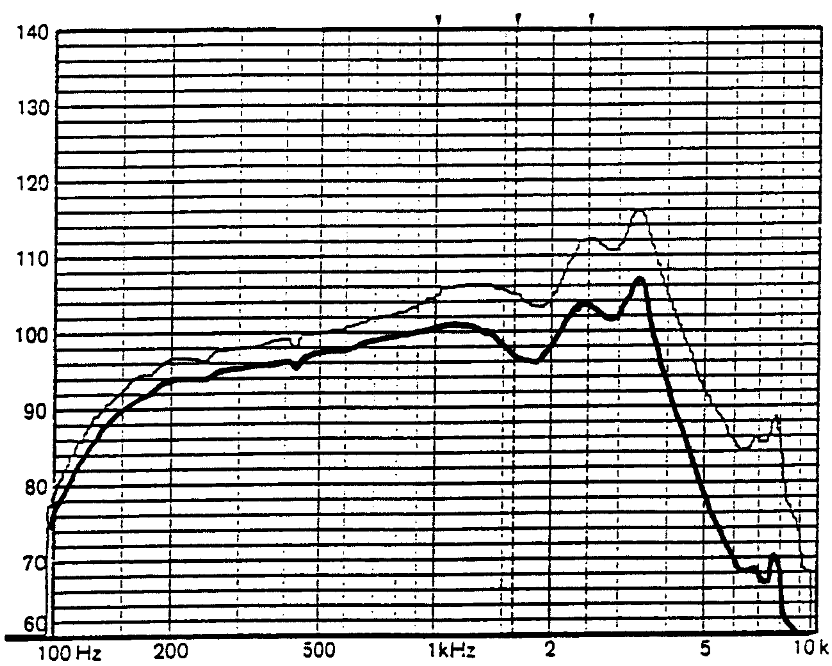
Source	DF	SS	MS	F	P
Frequency	15	7498.91	499.927	1E+03	0.000
Receiver	2	7.58	3.792	8.48	0.001
System	1	5.51	5.510	12.32	0.001
Freq*Recr	30	493.75	16.458	36.80	0.000
Freq*System	15	16.99	1.133	2.53	0.015
Recr*System	2	0.58	0.292	0.65	0.528
Error	30	13.42	0.447		
Total	95	8036.74	84.597		

FIGURE 4.19 Frequency Response - Receiver AP 270



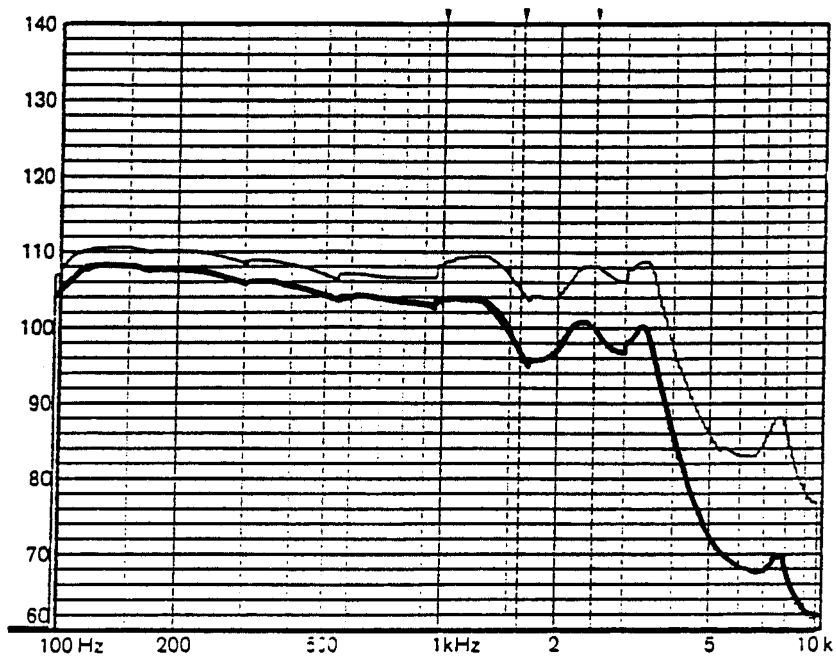
Ear Simulator   2 cc Coupler

FIGURE 4.20 Frequency Response - Hearing Aid with AP 270



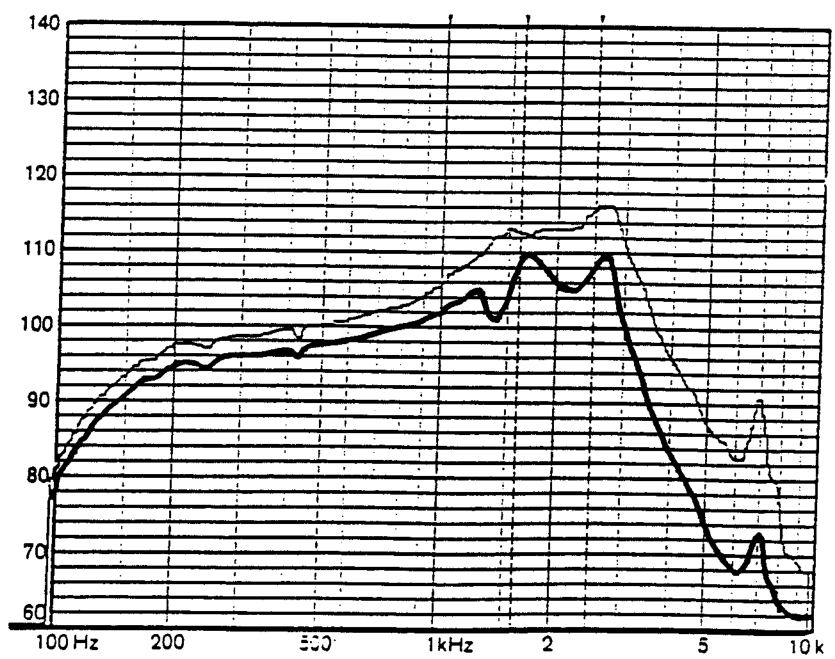
Ear Simulator   2 cc Coupler

FIGURE 4.21 Frequency Response - Receiver AN 270



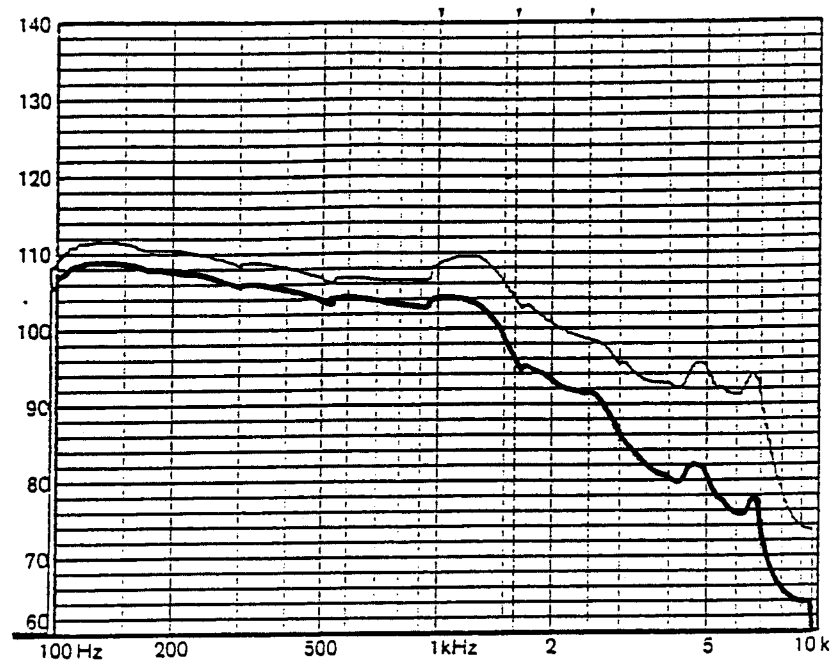
____ Ear Simulator ____ 2 cc Coupler

FIGURE 4.22 Frequency Response - Hearing Aid with AN 270



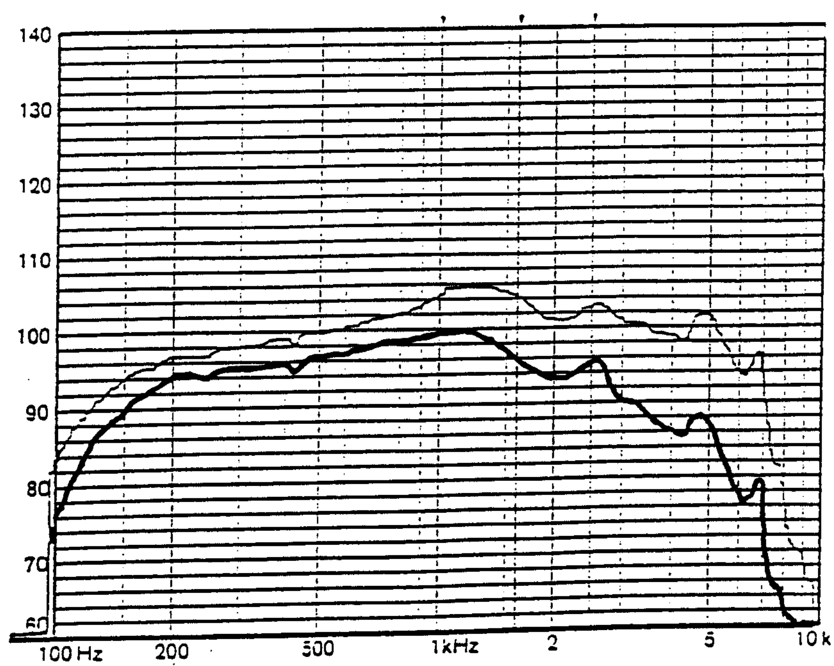
____ Ear Simulator ____ 2 cc Coupler

FIGURE 4.23 Frequency Response - Receiver AW 270



Ear Simulator 2 cc Coupler

FIGURE 4.24 Frequency Response - Hearing Aid with AW 270



Ear Simulator 2 cc Coupler

TABLE 4.18

The difference in 4 mm minus 1 mm sound bore diameter frequency response between complete hearing aid and the receivers alone

Frequency	AP 270		AN 270		AW 270	
	Aid	Recr	Aid	Recr	Aid	Recr
200	-1	-1	-1	-1	-1	-1
500	-2	-3	-2	-3	-2	-3
600	-3	-3	-3	-2	-3	-3
700	-6	-5	-3	-4	-4	-4
800	-7	-6	-3	-4	-4	-4
900	-5	-8	-4	-5	-4	-4
1000	-5	-8	-4	-5	-3	-4
1500	6	4	-1	-2	-2	-2
2000	8	9	5	5	1	0
2500	8	7	12	13	9	9
3000	21	20	8	7	17	17
4000	19	19	22	22	19	18
5000	17	14	16	15	17	16
6000	17	16	15	15	19	18
7000	15	18	16	17	11	12
8000	0	-2	8	6	0	0

TABLE 4.19

Oneway Analysis of Variance for the difference in 3 mm vented minus unvented frequency response between complete hearing aid and the receivers alone

Source	DF	SS	MS	F	P
System	1	47	47	0.32	0.571
Error	82	11950	146		
Total	83	11998			

Level	N	Mean	S.D.
1	42	-5.55	13.17
2	42	-4.05	10.86

Pooled Standard Deviation = 12.07

TABLE 4.20

Analysis of Variance table for the difference in 3 mm vented minus unvented frequency response between complete hearing aid and the receivers alone

Source	DF	SS	MS	F	P
Frequency	13	11379.1	875.312	2E+03	0.000
Vent length	2	62.2	31.083	57.63	0.000
System	1	47.2	47.250	87.60	0.000
Freq*Vlenth	26	219.8	8.455	15.68	0.000
Freq*System	13	272.6	20.968	38.87	0.000
Vlenth*System	2	2.6	1.321	2.45	0.106
Error	26	14.0	0.539		
Total	83	11997.6	144.549		

TABLE 4.21

The difference in 3 mm vented minus unvented frequency response between complete hearing aid and the receivers alone

Vent length	24 mm		19.5 mm		15 mm	
Frequency	Aid	Recr	Aid	Recr	Aid	Recr
100	-18	-31	-34	-20	-21	-36
150	-23	-25	-24	-27	-25	-30
200	-19	-20	-21	-21	-27	-24
300	-11	-12	-13	-14	-14	-17
400	-3	-4	-7	-7	-9	-11
500	4	4	-1	0	-3	-5
600	8	8	4	4	2	0
700	7	8	8	8	5	5
800	4	5	6	6	6	6
900	3	4	5	5	6	6
1000	3	2	4	4	5	5
1500	0	0	0	0	3	3
2000	1	0	1	0	2	2
2500	0	0	0	0	2	0

CHAPTER 5. DISCUSSION

5.1 The Pilot Study

The results of the pilot study clearly indicate a high level of test retest reliability. This implies that in these kind of experimental situations it is not necessary to repeat the measurements several times to obtain reliable results. This kind of observation has been made by many researchers earlier and is reflected, to some extent, in the widespread use of 2 cc acoustic coupler for the measurement of the frequency response. The use of an ear simulator for measuring the frequency response also does not seem to impair the repeatability of the measurements. While within laboratory repeatability of measures is excellent, there appear to be little mention of the inter laboratory reliability studies and studies involving the use of different makes of equipment for the measurement of frequency response.

The results of the pilot study also indicated that the influence of sound bore diameter on the frequency response is independent of the length of the sound bore and vice versa.

The use of the metallic earmould simulators, in place of plastic earmoulds, was done with the assumption that the acoustic effects of the modifications machined in brass will replicate those made in earmould plastics. It has been shown that, except for the way in which it might influence the tightness of the seal in the ear canal, the type of the earmould material used does not have any specific acoustic effects (Lybarger, 1958; 1978).

The Main Study

5.2 The Diameter of the Sound Bore

The results of the effects of variation of sound bore diameter are in general agreement with the findings of the earlier investigators. The effects of variation of sound bore diameter on the frequency response are also highly significant and there is a definite pattern in the effects of the sound bore diameter. A wider diameter of the sound bore results in an improvement in the high frequency response. A reduction in high frequency response is related to the use of a narrower sound bore diameter. A knowledge of the exact magnitude of effects due to various sizes of the sound bore diameter can be helpful in making a predictable control of the frequency response. This information can be used in conjunction with the prescriptive formulae in a more meaningful hearing aid preselection work.

Though Analysis of Variance on the data does not indicate any overall significant interaction effects between the frequency response of the receiver and the effects of sound bore diameter variation, it can be seen from the Tables 4.3 to 4.5 that at certain frequencies, the effects on the three receivers are very different. It can be seen from Figures 4.1, 4.3 and 4.5 that an increase in the sound bore diameter, while improving the high frequency response, also tends to shift the peaks in the frequency response towards the high frequency end. This may result in variable effects of sound bore variation at some frequencies for earphones with different frequency response characteristics. This is likely to be so, especially when the frequency response is 'peaky' as against relatively 'flat'. It would, therefore, be more appropriate to use the data for the particular receiver while making any predictions about the frequency response due to a variation in the sound bore diameter. For the same reasons these results may not be applicable with the same degree of accuracy for receivers other than the three types on which measurements have been made in this study.

5.3 The Length of the Sound Bore

The results of this study do not show any significant effect of variation of sound bore length on the overall frequency response of a receiver. However, it is also clearly indicated that the effects of variation in sound bore length are frequency dependent. Tables 4.7 and 4.8 indicate that these effects appear at frequencies beyond 1000 Hz. Unlike the effects of variation of sound bore diameter, there appears to be no definite pattern related to an increase or decrease of sound bore length for any range of frequencies. However, as can be seen from the Figures 4.7, 4.9 and 4.11, the variation in sound bore length, does seem to shift the peaks in the frequency response. The peaks are shifted towards the high frequency end for a reduction in the sound bore length and towards the low frequency end for an increase in the sound bore length. The magnitude of the effect is very small, especially, in comparison to that of variation in sound bore diameter.

The size of the cavity beyond the earmould tip (up to the eardrum) depends upon the length of the earmould tip. A shorter length of the earmould tip results in a larger cavity while the size of this cavity would be smaller with longer tip of the earmould. It has been shown by researchers in the past that changing the volume of this cavity changes inversely with the cavity size and this change in level is fairly uniform across the frequency range (Dalsgaard, 1966; Danavox, 1971; Studebaker, 1974; Lybarger, 1978; Tucker and Nolan, 1986). Hence, in the present study, no attempt was made to vary the size of the cavity beyond the earmould tip concomitant to the variation in the length of the sound bore. However, since changing the volume of a vented cavity is reported to affect the frequency response (Studebaker, 1974), there is a need to study these effects further.

The length of the sound bore in a receiver earmould system of body worn hearing aid is usually determined by factors such as the size of the ear canal, the comfort and the adequacy of fit. For these reasons also it may be best not to try to control the frequency response by varying the length of the sound bore.

5.4 Parallel Venting

The results indicate very significant effects of the vent diameter and the vent length on the frequency response. Whereas the effects of venting vary with frequency, these do not differ significantly with the frequency response of the receiver. The diameter and the length of the vent determine the degree of the low frequency cut. In general, wider diameter and shorter length of the vent result in greater low frequency reduction. An appropriate combination of the vent length and the vent diameter could be chosen for the desired change in the frequency response.

The length of the vent, however, in receiver earmoulds of body worn hearing aids, unlike moulds for the ear level aids, depends on the length of the sound bore. Therefore, any change in the length of vent must be viewed alongwith a change in the sound bore length as well.

5.5 Difference Between a 2 cc coupler and an Ear Simulator Frequency Response

There is an underestimation of the frequency response when measured on a standard 2 cc acoustic coupler. There do not appear to be any significant differences in the degree of this underestimation for the different receivers used in this study. The difference in frequency response between the two couplers increases with the frequency. Table 4.12 can be used to convert the 2 cc coupler frequency response data to an ear simulator frequency response. As it has been shown by several investigators earlier that the ear simulator frequency response data show good general agreement with the average real ear in situ response of a hearing aid, this kind of conversion of data will have a better application value.

5.6 The Applicability of the Results on Hearing Aids

5.6.1 Converting 2 cc coupler frequency response to an ear simulator frequency response

The frequency response of a hearing aid is measured in the frequency range 200 Hz to 8000 Hz (BS 6083: Part 0, 1984). The results obtained by making measurements on the receivers agree very closely with that obtained by making measurements on complete hearing aids in this whole range except at frequency 8000 Hz. Therefore this data can be applied for converting the measured 2 cc coupler frequency response to an ear simulator frequency response.

5.6.2 Variation of Sound Bore Diameter

As can be seen from Table 4.18, there is very good agreement between the data obtained by making measurements on receivers alone and those made on complete hearing aids. Whereas at most frequencies the difference in response is only 1 dB, at no frequency the difference between the two exceeds 3 dB. Therefore, the results of the study have good application in making predictions of the effects of variation in sound bore diameter on the frequency response of a hearing aid.

5.6.3 Effects of Parallel Venting

Table 4.21 shows that there are large differences in data for the receivers and the complete hearing aids for frequencies 100 and 150 Hz. However, for frequencies 200 Hz upwards, the difference is negligible. This perhaps is related to the frequency range of the hearing aid. If the frequency range of a hearing aid does not extend to very low frequencies, the effects of venting are not likely to extend to those frequencies in the same way as they would for a hearing aid which amplifies low frequencies. But seen from a practical point of view, if there is not enough amplification at low frequencies, there will not be any need to reduce it either.

CHAPTER 6. CONCLUSIONS

The earmould exerts a very significant influence on the frequency response of a hearing aid. In body worn hearing aids, the diameter of the earmould sound bore can be varied to modify the high frequency response of the aid. A wider diameter of the sound bore results in improved high frequency response and a narrower diameter of the sound bore results in a poorer high frequency response.

Variation of sound bore canal length does not lead to any substantial change in the frequency response of a hearing aid. Also, since it is mainly determined by factors related to an adequate fit of the mould in the ear, it would be best left unaltered rather than varied to gain any control over the frequency response of a hearing aid.

Parallel venting of earmoulds results in a reduction in the low frequency response of the body worn hearing aids. The degree of the low frequency cut in response is related to the diameter and the length of the parallel vent. The shorter and the wider parallel vents result in a greater low frequency reduction.

Selecting the exact dimensions of the earmould sound bore and the parallel vents results in a predictable effect on the frequency response of a body worn hearing aid. The findings of the study along with the prescriptive formulae may have implications in the preselection work of body worn hearing aid fittings.

Further Research

Based on the results of this study, further research ought to concentrate on evaluating the real ear effects of variation of earmould sound bore diameter and parallel vents. Once the effects of earmould modification are substantiated by the real ear measurements, these can be presented in the form of a guide which could become a useful clinical tool in selecting the appropriate values of earmould variables for the specific requirements of an individual hearing aid user.

A study of the permissible range of earmould parameters related to age of the user and/or size of the ear canal may provide useful information about the types of earmould modification possible in different groups of hearing aid users.

An approach to hearing aid fitting using the dimensions of the earmould variables and thereby their effects on the frequency response in conjunction with the prescriptive formulae could be investigated.

It would also be important to investimate the subjective judgements of the earmould modification effects. The specific questions that need to be answered are: Does the variation in earmould parameters result in a noticeable effect? Are there preferences for any specific earmould parameters? Are these preferences related to the type of hearing impairment?

REFERENCES

Almqvist, B., Ekelund, S., Holst, H.E. 1970. "Ny Proppteknik" (New Earmould Technique), Nordisk Audiologi, No. 4/5.

American National Standards Institute. Specification for hearing aid characteristics. ANSI S3.22. 1982. New York.

Bergenstoff, H. 1975. Acoustical performance of earmoulds - survey of published investigations. Scandinavian Audiology (Supplement 5) 86-110.

Berger, K.W. 1970. The hearing aid: its operation and development. Detroit: National Hearing Aid Society, pp. 98-111.

British Standards Institution. Hearing Aids. Part O. Methods for measurement of electroacoustical characteristics BS 6083: 1984 Part 0. London.

Brooks, D. and Nolan, M. 1984. Good Fitting Earmoulds. in Wald, M., Harris, G., Ewens, S., and Grover, B.(Eds.) The Earmould - current practice and technology. Hearing Aid Audiology Group, British Society of Audiology, Reading, Berks.

Byrne, D. and Tonisson, W. 1976. Selecting the gain of hearing aids for persons with sensorineural hearing impairments. Scandinavian Audiology 5, 51-59.

Carlson, E.V. 1974. Smoothing the hearing aid response. J.Aud.Eng.Soc. 22, 426-429.

Cox, R. 1979. Acoustic aspects of hearing aid - earcanal coupling systems. Monographs Contemporary Audiology, 1.

Cox, R. 1979. Combined effects of earmould vents and suboscillatory feedback on hearing and frequency response. Ear & Hearing, 3, 12-17.

Cox, R.M., and Alexander, G.C. 1983. Acoustic versus electronic modifications of hearing aid low frequency output. J.Am.Aud.Soc. 4, 190-196.

Dalsgaard, S.C., Johansen, P.A. and Chisnall, L.G. 1966. On the frequency response of earmoulds. J. Auditory Tech., 5, 2-15.

Dalsgaard, S.C. 1975. Survey of problems involved in the manufacture and use of earmoulds. Scandinavian Audiology (Supplement 5) 9-22.

Danavox Application Note on Hearing Aid Earphones. 1971. Denmark.

Dodds, E. and Harford, E. 1968. Modified earpieces and CROS for high frequency hearing losses. J.S.H.R., 11, 204-218.

Ewertsen, H.W., Ipsen, J.B. and Nielsen, S.C. 1957. On acoustical characteristics of the earmould. Acta Otol., 47,312.

Ewens, S. 1984. Earmould plumbing. in Wald, M., Harris, G., Ewens, S., and Grover, B.(Eds.) The Earmould - current practice and technology. Hearing Aid Audiology Group, British Society of Audiology, Reading, Berks.

French-St. George, M. & Barr-Hamilton, R.M. 1978. Relief of the occluded ear sensation to improve earmould comfort. J.Amer Aud.Society , May.

Grover, B. 1984. Venting. in Wald, M., Harris, G., Ewens, S., and Grover, B.(Eds.) The Earmould - current practice and technology. Hearing Aid Audiology Group, British Society of Audiology, Reading, Berks.

Hodgson, W.R. and C. Murdock. 1970. Effect of the ear mould on speech intelligibility in hearing aid use. J.S.H.R., 13, 290-297.

Hodgson, W.R. 1986. Hearing aid evaluation. in William R. Hodgson (Ed.) Hearing Aid Assessment and Use in Audiologic Habilitation. Third Edition. pp.152-169. Williams & Wilkins, Baltimore.

Jetty, A.J. and Rintelmann, W.F. 1970. Acoustic coupler effects on speech audiometric scores using a cross hearing aid. J.S.H.R., 13, 101-114.

Kasten, R.N. and Franks, J.R. 1986. in William R. Hodgson (Ed.) Electroacoustic characteristics of Hearing Aids. pp. 38-70. Hearing Aid Assessment and Use in Audiologic Habilitation. Third Edition. Williams & Wilkins, Baltimore.

Krarup, B. and Nielsen, S. 1965. "Lydtryksmalinger i øregangen" (Sound pressure measurement in the auditory meatus), Nordisk Audiologi, Nos. 3 and 4.

Killion, M. 1980. Problems in the application of broadband hearing aid earphones. in Studebaker, G., and Hochberg, I. (Eds.) Acoustical Factors Affecting Hearing Aid Performance. University Park Press, Baltimore.

Killion, M. 1984. Proceedings of the 14th International Hearing Aid Seminar, San Diego, CA., February.

Knowles, H.S. and Killion, M.C. 1978. Frequency characteristics of recent broadband receivers. J.Audio Tech. 17, 86-89.

Leavitt, R. 1986. Earmolds: Acoustic and Structural Considerations. in William R. Hodgson (Ed.) Hearing Aid Assessment and Use in Audiologic Habilitation. Third Edition. pp.71-108. Williams & Wilkins, Baltimore.

Lybarger, S.F. 1958. The earmould as a part of receiver acoustic system. Radioear Voice 28, 2-12.

Lybarger, S.F. 1967. Earmould Acoustics. Audecibel, Winter, 9-20.

Lybarger, S.F. 1972. Earmoulds. pp. 602-623. in J.Katz, ed. Handbook of Clinical Audiology, ed.1, Williams & Wilkins, Baltimore.

Lybarger, S.F. 1975. Comparison of earmould characteristics measured on the 2 cc coupler, the zwislocki coupler and real ears. Scandinavian Audiology suppl. 5, 65-85.

Lybarger, S.F. 1978. Expanding the usefulness of adjustable vent inserts. Hear. Instrum. 29, 18-19.

Lybarger, S.F. 1978. Earmold venting as an acoustical control factor. paper presented at the Conference on Acoustical Factors Affecting Hearing Aid Measurement and Performance, Graduate School of the City of University of New York, June 14-16.

Lybarger, S. 1979. Controlling hearing aid performance by earmould design. in Larsow, V. et.al. (Eds.) Auditory and Hearing Prosthetics Research, pp 101-132. New York, Grune & Straton.

Lybarger, S.F. 1980. Earmould venting as an acoustic control factor. pp. 197-217. in G.A. Studebaker and I.Hochberg, eds. Acoustical Factors Affecting Hearing Aid Performance. University Park Press, Baltimore.

McClellan, M.E., 1967. Aided speech discrimination in noise with vented and unvented earmoulds. J. Auditory Res., 7, 93-100.

Northern, J.L. and Hattler, K.W. 1970. Ear mould influence on aided speech identification tasks. J.S.H.R., 13, 162-172.

Revoile, S.G. 1968. Speech discrimination ability with ear inserts. Bull.Pros.Res., 10, 198-205.

Ross, M. 1972. Hearing Aid Evaluation. in J.Katz (Ed.) Handbook of Clinical Audiology, ed.1, pp. 624-655. Williams & Wilkins, Baltimore.

Sachs, R.M. and Burkhard, M.D. 1972. Insert earphone pressure response in real ears and couplers. Journal of Acoustical Society of America, 52, 183 (A).

Schier, B.A. 1945. Clinical phenomena in conductive media: the individual earpiece. JASA 17, 77-82.

Studebaker, G.A. 1974. The acoustical effect of various factors on the frequency response of a hearing aid receiver. Journal of the Audio Engineering Society, 22, 5, 329-334.

Studebaker, G.A., and Cox, R.M. 1977. Side branch and parallel vent effects in real ears and in acoustical and electrical models. J.Am. Aud. Soc. 3, 10-17.

Tucker, I. and Nolan, M. 1984. Educational Audiology. Croom Helm, London.

Wald, M. 1984. Introduction. in Wald, M., Harris, G., Ewens, S., and Grover, B.(Eds.) The Earmould - current practice and technology. Hearing Aid Audiology Group, British Society of Audiology, Reading, Berks.

Watson, L.A. and Tolan, T. 1949. Hearing tests and hearing instruments. The Williams & Wilkins Co., Baltimore.