EFFECT OF ACOUSTIC COUPLER ON AIDED SPEECH RECEPTION THRESHOLDS AND SPEECH DISCRIMINATION SCORES USING A CROS HEARING AID

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ABSTRACT

EFFECT OF ACOUSTIC COUPLER ON AIDED SPEECH RECEPTION THRESHOLDS AND SPEECH DISCRIMINATION SCORES USING A CROS HEARING AID

by Albert J. Jetty

The major purpose of this study was to investigate the effects of four types of acoustic couplers (conventional, vented, open, and crimped polyethylene tubing) on aided speech reception thresholds and speech discrimination scores of three groups of hard-of-hearing adults.

Group I was composed of ten subjects with conductive hearing impairments. Group II consisted of ten subjects having a sensorineural type hearing impairment with normal hearing in the low frequencies and a precipitous drop for frequencies higher than 500 to 1000 Hertz. Group III was composed of ten subjects having a sensorineural type hearing impairment with a gradually sloping (5 to 10 decibels per octave) configuration with the low frequencies also being affected.

Pure-tone air and bone-conduction thresholds were obtained prior to the speech audiometric tests. Speech reception thresholds and speech discrimination scores were

obtained in the sound-field under unaided and aided conditions, while the nontest ear was occluded by a wax impregnated ear plug. All subjects were tested with the same CROS hearing aid at a gain setting of 35 dB, and all speech discrimination scores were obtained at a 26 dB sensation level.

The data were examined by means of two-way analyses of variance for both speech reception thresholds and speech discrimination scores. Significant differences were further investigated by employing Duncan's New Multiple Range Test.

Results showed that for the conductive hearing impaired subjects, the mean speech reception threshold obtained with the conventional earmold was significantly lower than the mean thresholds obtained with the acoustic modifier and crimped tubing. The mean aided speech discrimination scores showed no significant differences among the four acoustic couplers in the aided condition.

For the group having a sensorineural hearing impairment with a precipitous drop, there were essentially no intercoupler differences in the mean speech reception thresholds obtained with the various acoustic couplers. The mean speech discrimination scores were significantly improved under the aided conditions. The mean unaided speech discrimination score was 69.4 percent in comparison to a mean aided score of 76.8 percent utilizing the conventional earmold. Thus, a gain of 7.4 percent was achieved. The mean speech discrimination score of the modified couplers combined was 87.3 percent, a gain of 17.9 percent over the mean unaided sound-field score and 10.5 percent over the mean score obtained with the conventional earmold. There were no significant intercoupler differences in the mean speech discrimination scores obtained with the modified acoustic couplers.

For the group having a gradually sloping sensorineural hearing impairment, the mean speech reception threshold, utilizing the conventional earmold, was 23.6 dB while the mean combined speech reception threshold of the modified couplers was 28.0 dB. This group obtained a mean unaided speech discrimination score of 79.6 percent and a mean aided score utilizing a conventional earmold of 75.0 percent. The mean speech discrimination score of the modified acoustic couplers combined was 83.3 percent and thus was an improvement of 8.3 percent over the conventional earmold.

The following conclusions were drawn: Persons with conductive hearing impairments obtain better aided speech reception thresholds with the conventional earmold than with the modified acoustic couplers, whereas speech discrimination scores show essentially no differences among coupling conditions. The aided speech reception thresholds of persons having a sensorineural hearing impairment with a precipitous drop are essentially the same under all coupling conditions, whereas speech discrimination is markedly improved with the modified acoustic couplers as opposed to the conventional earmold. Persons with a gradually sloping sensorineural hearing loss obtain better aided speech reception thresholds with the conventional earmold, whereas speech discrimination is improved with the modified acoustic couplers.

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CHAPTER I

INTRODUCTION

The recommendation of a hearing aid in the rehabilitation process of a hard-of-hearing person has become an increasingly important aspect of clinical audiology. A recent National Conference concerning hearing aid evaluation procedures has focused attention on this problem.[1] However, the manner in which the hearing aid is connected to the ear has been neglected even though it is this final acoustic coupling which ultimately determines the response of the instrument. The standard procedure has been to utilize a conventional type earmold irrespective of type of hearing loss or pure-tone audiometric configuration. The only criteria for the earmold was that it provide a tight seal at the ear, so that there was no leakage of the amplified sound to create acoustic feedback. The problem of acoustic feedback has been especially pronounced in ear-level aids because of the close proximity of the microphone and receiver, and little could be done to modify the earmold without creating an even greater problem. However, with the advent of

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[1]"A Conference on Hearing Aid Evaluation Procedures," ASHA Reports, Number 2, 1967.

the CROS[1] type hearing aid, it has become possible to use modified earpieces, since the problem of acoustic feedback is reduced. Research is now needed with various types of acoustic couplers to determine their effects on different types of hearing losses and pure-tone audiometric configurations.

Purpose of the Study

The major purpose of this research was to determine whether variations in the way a hearing aid is acoustically coupled to the ear affects the speech reception thresholds and speech discrimination scores obtained by subjects having different types of hearing losses and audiometric configurations. Specifically, this investigation was concerned with the effects that a conventional (stock) earpiece, a vented earpiece (the Zenith acoustic modifier), an open earpiece, and crimped polyethylene tubing have on the aided speech reception thresholds and speech discrimination scores of subjects having either a conductive hearing loss or a sensorineural type hearing loss. Subjects with a sensorineural type hearing loss had one of two types of audiometric configurations: (1) a precipitous drop for frequencies higher than 500 or 1000 Hertz or (2) a gradually sloping loss with the lower frequencies being affected.

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[1]Earl Harford and Joseph Barry, "A Rehabilitative Approach to the Problem of Unilateral Hearing Impairment: The Contralateral Routing of Signals (CROS)," Journal of Speech and Hearing Disorders, 30 (1965), pp. 121-138.

In addition to the above purpose, the subjective quality of the amplified sound presented through the various acoustic couplers was investigated by obtaining quality judgments from the subjects.

Significance of the Study

In the 1940's investigators such as Schier[1] and Grossman[2] pointed out that the way a hearing aid receiver was coupled to the ear could drastically alter the response characteristics of that aid. Even though this has been an accepted fact for many years, relatively little research has been done in this area.

The present study is significant by virtue of the fact that it is a controlled investigation of the speech reception threshold as a function of the type of acoustic coupler employed. The determination that modified earpieces have a significant effect on the speech reception threshold of hard-of-hearing subjects has ramifications for changing the hearing aid evaluation procedures now employed in many clinics.

Perhaps, the subtle differences among various hearing aids might be better indexed by evaluating their performance with different types of earmolds. That is, where differences

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[1]Mayer B. A. Schier, "The Earpiece--In Testing for and Fitting Hearing Aids," Laryngoscope, 51 (1941), pp. 52-60.

[2]Frederick M. Grossman, "Acoustic Sound Filtration and Hearing Aids," Archives of Otolaryngology, 38 (1943), pp. 101-112.

between two aids were not obvious in the past, differences in performance may show up when they are coupled to the ear in different ways.

Hard-of-hearing persons with certain types of sensori-neural hearing losses often have a great deal of difficulty in discriminating acoustic stimuli. Their problem may be such that a hearing aid is of no benefit to them when a conventional earpiece is employed. Some of these people might be helped by employing a different type of coupling. Discrimination scores might be improved by employing an earpiece that takes advantage of the natural resonance characteristics of the external auditory canal and that does not change the impedance characteristic from the normal state by completely closing the ear canal.

Considerable controversy exists regarding the clinical fitting of hearing aids. In view of this, research which contributes information on this aspect of clinical audiology will make a contribution to this expanding body of knowledge.

Definitions

The following definitions of terms were employed in this investigation:

Acoustic Modifier[1]--With this particular type of earpiece, the portion entering the external auditory canal is almost

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[1]Zenith Radio Corporation trade name for their patented, vented earmold.

entirely removed and the remaining portion is enlarged. Usually two small vents are cut in the flat portion of the mold and communicate with the larger inner opening. The vents have thin discs of wax impregnated lamb's wool inserted in them.

Conventional Earmold or Earpiece--There are actually many different types, but the concern in this study was the fact that the ear canal was completely sealed by the earmold. The earmold is solid, and there are no vents.

Open Earpiece--This type of earpiece is designed so that the contour of the concha is outlined by a plastic rim which has a projection extending into the schaphoid fossa by means of which it is held in position. The lower part of the plastic rim has a small opening into which is inserted the polyethylene tube that delivers the amplified signal. This earpiece does not occlude the ear canal, a fact which is its important feature.

Crimped Tubing--This consisted of a stock piece of polyethylene tubing measuring 2¼ inches in length and 0.077 inches in diameter bent in such a manner (approximately 90 degrees) that it remained in the ear canal during the testing of a hearing aid.

Conductive Hearing Impairment--For purposes of this study, a conductive hearing loss was defined as one where bone conduction thresholds were within the normal range (no greater than 25 dB ISO-1964 Standards) and where there was an air-bone gap of at least 20 dB for the test frequencies 500, 1000, and 2000 Hertz.

High Frequency Sensorineural Hearing Loss--Normal hearing (25 dB or better ISO-1964 Standards) for the low frequencies with a precipitous drop of at least 20 dB for the first octave beginning at 500 or 1000 Hertz. Air and bone conduction thresholds were interweaving.

Gradually Sloping Sensorineural Hearing Loss--This was defined as a progressively greater loss for higher frequencies at a slope of 5 to 10 dB per octave with the loss beginning in the low frequencies. Air and bone conduction thresholds were interweaving.

CHAPTER II

REVIEW OF THE LITERATURE

A review of the pertinent literature includes a brief history of the development of earmolds. The development of hearing aids is also reviewed since they are used in conjunction with earmolds.

The second section of the literature review is concerned with studies of the acoustic properties of the head and external ear and with the principles behind the development of modified earmolds.

Finally, studies concerned with applying the foregoing acoustic principles in experiments with earmolds are reviewed.

History

The development of acoustic couplers to connect the hearing aid receiver to the ear, of necessity, closely parallels the development of hearing aids themselves. Before the turn of the century, hearing aids consisted of sound collecting devices such as the ear trumpet, which collected sound and funneled it into the external ear canal.[1]

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[1]Leland A. Watson and Thomas Tolan, Hearing Tests and Hearing Instruments (Baltimore: Williams & Wilkins Company, 1949), p. 268.

They not only collected sound, but also were resonators which amplified certain frequencies within the speech range and often yielded a 10 to 15 dB gain in acoustic energy reaching the ear.[1]

These sound collecting devices were acoustic couplers, which actually extended the external ear canal and, in so doing, could be expected to change the overall resonance and impedance characteristics of the ear giving rise to changes in the subjective quality of sound in addition to a small amount of amplification. This is supported by the observations of Schier[2] in the early 1920's. He experimented with small ear trumpets, which he made by taking a modeling compound impression of the ear and making a vulcanite reproduction. Various canopies of different sizes, shapes, and openings were vulcanized to it. He found that the variations of size, shape, and cavities gave a different subjective quality to sound.

Kranz,[3] in describing the ear trumpet or "ear horn" as he termed it, stated, "The size of the horn will of course

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[1]Hallowell Davis and S. Richard Silverman, Hearing and Deafness (New York: Holt, Rinehart, & Winston, 1960, p. 266.

[2]Mayer B. A. Schier, "Clinical Phenomena in Conductive Media: The Individual Earpiece," Journal of the Acoustical Society of America, 17 (1945), pp. 77-82.

[3]Fred W. Kranz, Hearing Aids (Elmsford, New York: Sonotone Corporation, 1941), p. 9.

influence its effectiveness, while the shape of the horn will influence the quality of the sound received through it." Thus, for more than twenty-five years there has been recognition that the physical attributes of the acoustic coupler had an important influence on the amplification and quality of the perceived sound.

In 1900, Dr. Ferdinand Alt of the Politzer Clinic in Vienna conceived of and produced the first amplified electrical hearing aid.[1,2] In 1902, the "Oriphone" was produced by C. W. Harper and the "Akouphone" was produced by Miller Reese Hutchinson. These early carbon type hearing aids employed a flat, over-the-ear magnetic receiver kept in place by means of a headband.[3] With this type of receiver there was no need for any coupler to the ear, since the receiver itself covered the ear much like modern earphones.

Although the literature is not clear as to the exact date, the small, button type receiver was developed for use with some of the earlier carbon type hearing aids and later with some of the vacuum tube type hearing aids.[4] The hearing aid companies developed stock connectors or earpieces in order to hold the receiver in the ear. Their acoustic

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[1]Chevalier Jackson, Diseases of the Nose, Throat, and Ear (Philadelphia: W. B. Saunders, 1945), p. 278.

[2]Watson and Tolan, Hearing Tests and Hearing Instruments, p. 270.

[3]Ibid., p. 275.

[4]Ibid., p. 276.

importance was not recognized, and was simply a means of retaining the receiver in the ear. The individually molded earpiece was used only in cases where a person had a problem keeping the receiver in his ear.[1]

Gradually individually fitted earpieces began to be accepted. These were usually made of hard rubber and proved to be inadequate, since it was difficult to control the degree and thoroughness of vulcanization of hard or soft rubbers resulting in inconsistent acoustic qualities from one mold to another. Another problem was the fact that the acoustic properties of rubber tended to change over time due to deterioration, so in the late 1920's and early 1930's the possibility of using other materials was explored. It was Schier[2] who claimed to have developed the first acrylic earpiece. His experiments with miniature hearing trumpets led him to develop a variety of earmolds which would enhance the amplified sound from a hearing aid.

The interest in various types of earmolds to improve sound reception can be understood in light of the fact that early hearing aids were usually of the carbon type. These were bulky and noisy, with a limited frequency range, and almost no tone adjustments.[3] Thus, the development of

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[1]Schier, "Clinical Phenomena," p. 78.

[2]Ibid., p. 79.

[3]Kranz, Hearing Aids, p. 11.

various types of modified earpieces was an attempt to counterbalance the deficiencies of the carbon type amplifier hearing aid.

Acoustic Phenomena

In order to appreciate efforts to improve sound reception through modified earmolds and the principles behind these efforts, it is necessary to review the acoustic properties of the head and external auditory canal, and the acoustic pathway between the transducer and the tympanic membrane.

One of the principle investigators of this area was Bekesy.[1] In 1932 he demonstrated that the sound pressure developed at the surface of the head was quite different from that in the undisturbed sound field and that it increases at the head as the frequency gets higher. He also found a difference in the amount of sound pressure developed at the entrance of the external canal from that developed at the tympanic membrane. His data indicate that the sound pressure at the eardrum may be as much as three times greater in the important speech frequency range between 2000 and 3000 Hertz. The resonance curve determined by Bekesy is, of course, dependent on the medium through which the sound passes, the length and cross-sectional area of the external canal, and the impedance of the tympanic membrane. Any changes in the dimensions of these factors, such as the insertion of an

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[1]George Von Bekesy Cited by Stanley Smith Stevens and Hallowell Davis, Hearing: Its Psychology and Physiology (New York: John Wiley & Sons, Inc., 1938), p. 53.

earmold into the external canal, would result in a change of the resonance curve.

In 1933, Sivian and White[1] carried out an extensive study of minimum audible pressures (MAP) and minimum audible fields (MAF) using pure tones to measure threshold. The MAP threshold is measured under earphones while the MAF was defined as the intensity of the free field measured prior to the insertion of the observer. The sound field into which the observer was placed facing the source was substantially that of a plane progressive wave. The data represent monaural MAF thresholds on 14 ears over the frequency range from 100 to 1500 Hertz and binaural hearing on 13 observers over the frequency range from 60 to 15,000 Hertz.

Their findings indicate the MAP thresholds are from 5 to 12 dB higher (poorer) than MAF, with a maximum difference in the frequency range between 2000 and 4000 Hertz. The average difference was on the order of 6 dB. A number of hypotheses have been offered as an explanation of the discrepency noted between the two kinds of measurements. Probably the most generally accepted explanation is that thresholds become higher as a function of the amount of air enclosed between the transducer and the tympanic membrane.[2]

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[1]L. J. Sivian and S. D. White, "On Minimum Audible Sound Fields," Journal of the Acoustical Society of America, 4 (1933), pp. 288-321.

[2]Tom W. Tillman, Robert M. Johnson, and Wayne O. Olsen, "Earphone versus Sound Field Threshold Sound-Pressure Levels for Spondee Words," Journal of the Acoustical Society of America, 39 (1966), pp. 125-133.

Because of the trapped volume of air, the natural resonance of the external canal and the impedance characteristics of the ear are quite different from the natural state.

The maximum difference noted between MAP and MAF in the frequency range between 2000 and 4000 Hertz should be an important consideration in the fitting of amplification to a sensorineural hearing loss, since it is precisely this important speech frequency range which is most likely affected. It would appear that the acoustic coupler between the hearing aid receiver and the ear should be designed to take advantage of the natural resonance and impedance characteristics of the ear.

Sabine[1] in 1942, studied the resonance characteristics of small cavities from 2.0 to 8.45 cubic centimeters in volume. The acoustic pressure developed in the cavities was compared to that developed at the face of an unapertured baffle. The following results were found:

(a) Cavities of the order of magnitude here considered show marked resonance characteristics, with pressure level amplifications at resonance as great as 20 dB.

(b) For frequencies well below resonance, pressures within the cavity do not differ markedly from those at the face of the unperforated baffle.

(c) For frequencies well above resonance, there is a marked pressure attenuation within the cavity.

(d) The resonant frequency decreases with increasing

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[1]Paul E. Sabine, "On the Acoustic Properties of Small Cavities," Journal of the Acoustical Society of America, 13 (1942), pp. 74-78.

> cavity volume and increasing hole depth, and increases with increasing hole diameter.[1]

The above findings indicate that the differences between MAP and MAF noted by Sivian and White[2] can be expected because of the cavity resonance response of the external ear. This response terminated by the compliance of the tympanic membrane and the attached ossicles is similar to that of the response of the apparatus used by Sabine. In that case the response was terminated by the compliance of the cavities.

This investigation of Sabine's grew out of his attempts to quantify hearing aid performance objectively. The difference in pressure level was determined between a hearing aid microphone placed on the chest of a "dummy" and the diaphragm of a condensor microphone terminating an artificial ear employing a 2 cc coupler mounted in the head of the dummy. Sabine stated: "A very marked difference in results following even slight changes in the coupler dimensions suggested a more thorough going investigation of coupler effects on the results of such measurements."[3] It seems plausible to assume that these effects take place when the dimensions of the acoustic coupler between the hearing aid receiver and ear of a hard-of-hearing person are changed.

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[1]Ibid., p. 77.

[2]Sivian and White, "Minimum Audible Fields," pp. 288-321.

[3]Sabine, "Acoustic Properties of Small Cavities," p. 78.

In 1946, Weiner and Ross[1] measured the sound pressure at different points along the auditory canal of a number of male and female subjects placed in a sound field which was essentially that of a plane progressive wave. The measurements were made by means of a small, flexible probe microphone (Western Electric Type 640-AA condenser microphone). The probe was placed at various locations along the auditory canal. Their data showed that the sound pressure at the tympanic membrane is greater than the free field pressure and reaches a maximum of about 17 to 22 dB near 3000 Hertz. The ear canal, then, acts as an acoustic amplifier over most of the important speech frequency range. The authors attribute the increase in sound pressure at the eardrum over that of a free-field to the combination effect of diffraction by the head and pinna and resonance in the external auditory canal.

A few years later, in 1950, Munson and Weiner[2] studied the variability among methods for determining threshold for pure tones. Included in their study were measurements of MAP and MAF, and their data indicated a discrepancy in which MAF thresholds were lower in sound pressure level by an

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[1]Francis M. Weiner and Douglas A. Ross, "The Pressure Distribution in the Auditory Canal in a Progressive Sound Field," Journal of the Acoustical Society of America, 18 (1946), pp. 401-408.

[2]W. A. Munson and Francis M. Weiner, "Sound Measurements for Psychophysical Tests," Journal of the Acoustical Society of America, 22 (1950), pp. 382-386.

average of 6 dB. In 1952, they conducted a more thorough investigation of MAP and MAF in the low frequencies.[1] Using a pair of Western Electric 711A receivers and a large dynamic loudspeaker coupled to a folded horn, measurements were made at 60, 120 and 240 Hertz. The average differences of the MAP/MAF ratio over ten subjects were 13.3 dB, 9.6 dB, and 5.2 dB respectively with higher thresholds by MAP. It is interesting to note that the authors found that a slight air leak caused by a poor fit of the receiver cap over the ear resulted in a drop of sound pressure at low frequencies. This is, of course, the reason why vented earmolds were recommended for high frequency hearing losses, since, in effect, with proper venting the earmold can become a high pass acoustic filter.

Rudmose[2] explained the difference between MAP and MAF at the low frequencies as a function of the mechanical "isolation" between receiver and ear, the quality of the seal, and the volume enclosed between receiver and ear.

The studies concerning MAP and MAF thus far reviewed have all employed sinusoidal stimuli. The next area of concern is the effects of speech on thresholds obtained under

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[1]W. A. Munson and Francis M. Weiner, "In Search of the Missing 6 dB," Journal of the Acoustical Society of America, 24 (1952), pp. 498-501.

[2]Wayne Rudmose, "Free-Field Thresholds vs. Pressure Thresholds at Low Frequencies," Journal of the Acoustical Society of America, 22 (1950), p. 674.

these two conditions. Breakey and Davis[1] made an extensive investigation of the difference between MAP and MAF for speech stimuli. In their experiments they used Psycho-Acoustic Laboratory Test No. 9, which is comprised of spondee words, and Test No. 12, which consists of simple sentences. Ten subjects with normal hearing and ten who were hard-of-hearing were administered the above tests monaurally and binaurally through headphones. In addition, the normal group listened binaurally in a sound field.

Combining all listening conditions for the normal-hearing group, they found that mean thresholds were about 3 dB lower under the sound-field conditions than under PDR-10 earphones. The authors stated:

> The difference of about 3 dB (average of all tests) between field and receiver listening is real, although not so large as would be expected from the classical data on minimum audible pressure and minimum audible field thresholds for pure tones. The smaller difference in the present series may be due in part to the fact that our field is not a "free" field. It is also due in part to the unusually low average threshold found for Test No 9 by receiver listening.[2]

Because of the uncertainties expressed by the authors of the foregoing study, Tillman, Johnson, and Olsen[3]

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[1]M. R. Breakey and Hallowell Davis, "Comparisons of Thresholds for Speech: Word and Sentence Tests; Receiver vs Field and Monaural vs Binaural Listening," Laryngoscope, 59 (1949), pp. 236-250.

[2]Ibid., p. 241.

[3]Tillman, Johnson, and Olsen, "Earphone versus Sound Field," pp. 125-133.

undertook an investigation in an attempt to define the difference between MAP and MAF threshold sound-pressure levels for spondee words. A secondary goal was to determine the effect of earphone type (conventional versus insert type) on MAP and MAF differences.

Two groups of subjects were utilized in this study. The first group was composed of 12 individuals with normal bilateral hearing, and the second group was composed of 10 persons with mild to moderate bilaterally symmetrical hearing losses of the sensorineural type. Monaural thresholds were measured using tape-recorded spondaic words used in the construction of CID Auditory Tests W-1 and W-2. The receiver used was a TDH-39-10Z earphone housed in an MX 41/AR cushion, which enclosed approximately a 6 cc volume of air between its diaphragm and the eardrum, and a Radioear M75 insert type receiver coupled to the subject's ear via a stock earmold, which enclosed approximately a 2 cc volume of air.

The results indicated that the differences between MAP and MAF were essentially the same for both groups of subjects. The average difference between MAF and MAP for the conventional earphones was 7.5 dB, and for the insert earphones this difference increased to 12.5 dB with MAF being lower in both instances.

The authors offered the following conclusions from this experiment:

> First, the "missing 6 dB" initially described by Sivian and White is indeed a real phenomenon and can be demonstrated utilizing speech as well as pure-tone stimuli. Second, the magnitude of the difference between MAP and MAF increases if the pressure thresholds are measured using an insert-type receiver rather than the more conventional earphone. Assuming that, insofar as a spondee test signal is concerned, the volume of air trapped between the earphone diaphragm and the tympanic membrane represents the major difference between the two pressure transducers used in this investigation, one could restate this latter conclusion as follows. The difference between MAP and MAF increases in magnitude as the volume of air enclosed between the pressure transducer and the eardrum decreases in magnitude.[1]

The authors further stated that the difference between MAP and MAF is caused, in part, by diffraction effects and, in part, by impedance mismatches resulting from enclosure of the ear canal by the transducer.

From the studies discussed in this section, especially the last two, the following question was raised for the present research project: "Will subjects obtain lower speech reception thresholds using either an open earmold or crimped tubing rather than the conventional earmold?" It would appear plausible to hypothesize that lower speech reception thresholds can be obtained with the open earmold or crimped tubing, since Tillman, Johnson, and Olsen[2] found a 12.5 dB difference between MAP and MAF using a transducer coupled by a stock earmold enclosing a volume of air of approximately two cubic centimeters. If, in fact, the volume of air

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[1]Ibid., p. 131.

[2]Ibid., p. 130.

enclosed between the transducer and the tympanic membrane is responsible for the difference, then the difference should decrease when an open earmold or crimped tubing are used, since with these couplers a sound-field condition is more closely approached. The absolute magnitude of the difference would not be expected to be as great as that found by Tillman et al., since this experiment was conducted in a sound-field rather than a free-field. By the same token, the expected difference should be greater than the 3 dB found by Breakey and Davis,[1] since the PDR-10 receivers used by them enclose approximately a 6 cc volume of air, and this larger volume would tend to decrease the difference. In other words, the difference in SRT between the standard earmold and the open earmold should be somewhere between 3 dB and 12.5 dB under sound-field conditions.

Modified Earpieces

The foregoing section discussed some of the important principles that must be considered in the transmission of sound to the human ear. A discussion of how these principles were applied to the development of, and experimentation with various types of earmolds is now in order.

In 1936, Littler[2] carried out and discussed a number of

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[1]Breakey and Davis, "Comparison of Thresholds for Speech," p. 242.

[2]T. S. Littler, "Hearing Aids for the Deaf," Journal of Scientific Instruments, 13 (1936), pp. 144-155.

experiments involving the design, use, and testing of apparatus used for hearing aid purposes with hard-of-hearing subjects. He pointed out that a large number of cases have a high frequency hearing loss, such that amplification which has a reduced high-frequency response seriously affects speech intelligibility for these people. From his studies he concluded: "There is a need for improvement in the manner of applying the sounds to the ear, as it seems that the present design of earpiece causes a serious loss in the upper frequencies."[1]

By 1941, Schier[2] had become vehement in his criticism of the quality of custom fitted earmolds. He felt that they fell short of the claims made for them and that they followed commmercial dictates rather than the needs of the individual. He pointed out that a great deal of energy was invested in all things pertaining to the hearing aid itself but that not much thought was given to the earpiece, which could readily change the response of the instrument. His specifications for an earmold, in addition to being small, inconspicuous, and light in weight, included this statement: "That portion known as the actual tip should be as long as comfortable depth of entry into the canal will permit."[3] Further on he

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[1]Ibid., p. 155.

[2]Schier, "The Earpiece," p. 53.

[3]Ibid., p. 53.

stated: "The longer the earpiece tip, the greater and truer the sound conduction."[1]

Other researchers would disagree with Schier's specifications for tip length of an earmold, since lengthening the tip would tend to attenuate the high frequencies and such a mold would not be suited for a high-frequency hearing loss.[2] Schier[3] did feel, however, that filtration in the acoustic path had demonstrated advantages. His filtration consisted of inserting a small device composed of miniature acoustic chambers between the receiver nib and sound channel. He found that "The frequency-response curve of an instrument can be so affected as to modify the relativity of the low, medium, and high frequencies as emitted from receiver."[4] His findings were confirmed by tests conducted at the Sonotone Corporation Laboratories at his request. These tests revealed response curves quite different from one another using various chambered devices in the line between receiver and sound channel. The effects of these devices could be seen as shifts in the peaks of the frequency-response curves from lower to higher frequencies and also by a change in peak intensities.

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[1]Ibid., p. 59.

[2]Thomas H. Halsted and Frederick M. Grossman, "Modern Aspects of the Hearing Aid Problem," New York State Journal of Medicine, 42 (1942), pp. 1944-1950.

[3]Schier, "Clinical Phenomena," p. 80.

[4]Ibid.

In 1941, Halsted and Grossman[1] reviewed the different classes of hearing impairment and discussed the various types of amplification best suited for each. At that time they advocated the individually fitted earmold but did not go into detail as to its specifications.

In a follow-up article published the following year, they made more specific recommendations as to the type of earmold best suited for each of four broad classes of hearing impairment.[2] They stated: "The small air volume between the receiver and the drum and the shape of it has an influence on the final characteristics of the acoustical performance. The same applies to the size, width, and length of the sound-conveying canal of the ear mold."[3]

For Class I, or conductive losses, they recommended an earmold with a long tip and a sound canal of approximately 3 mm. in diameter. The reasoning behind this is that the larger surface area offered by the longer tip makes contact with the walls of the ear canal and hearing is improved by bone conduction, which is normal or near normal.

Class II is a mixed type of loss for which they do not give any recommendations, since they had not observed a

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[1]Thomas H. Halsted and Frederick M. Grossman, "Some Problems Involved in the Fitting of Hearing Aids," New York State Journal of Medicine, 41 (1941), pp. 352-358.

[2]Halsted and Grossman, "Modern Aspects of the Hearing Aid Problem," pp. 1944-1950.

[3]Ibid., p. 1947.

sufficient number of cases.

Class III is an abrupt loss of the high frequencies which is sometimes called "boilermaker's deafness," and Class IV is a more gradual loss of the high frequencies. Both losses are of the sensorineural type. They stated that "The ear mold for Class III and IV should have a short tip, and the sound-conveying canal should be as wide as possible. A small acoustic high-pass filter between receiver and mold improves results."[1]

Grossman[2] experimented with three individual earmolds each having a different diameter sound-conveying canal. Mold One had a conventional canal diameter of 3 mm, Mold Two 1.5 mm and Mold Three a diameter of 5 mm. The length of each was 22 mm. Each of the molds was connected to a vacuum tube hearing aid in succession, and the examiner spoke into the microphone of the aid from a distance of 10 feet. Grossman stated the following about his experiments:

> The conditions of experimentation were chosen in such a way that the hearing aid connected with mold 1 gave good intelligibility. As pointed out, the impression was that the high partial tones were weak. It was quite a strain to make out the consonants, the recognition of which depends primarily on upper partial frequencies. The results with mold 2 were rather startling. Speech sounded less loud than with mold 1, but after adjusting the volume to a comfortable loudness it was almost impossible to understand a single word. The words sounded dull, and the impression was that the

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[1]Ibid., p. 1949.

[2]Frederick H. Grossman, "Acoustic Sound Filtration and Hearing Aids," <u>Archives of Otolaryngology</u>, 38 (1943), pp. 101-112.

> higher frequencies were cut off entirely. On the other hand, when mold 3 was used, speech sounded brighter than when mold 1 was used, and more natural. It is believed that in this experiment the "naturalness" depends on the smallest interference of all three molds with the normal dimension of the aural canal and also on the lack of filter action in mold 3.[1]

Another experiment was performed in which a tube, 5 mm long with a diameter of 4 mm, and having a side branch orifice which had a diameter of 1.2 mm and a length of 1 mm, was placed between the receiver and mold 3. It was found that with this arrangement the loudness was reduced by a considerable amount as compared to when the tube was not used.[2]

From his experiments, Grossman concluded: "The ear mold of present design renders the acoustic line between the receiver and the drum a finite low pass filter. The longer the inserted sound canal of the mold and the smaller its diameter, the stronger is the filter action."[3] He reiterated his earlier conviction that high frequency losses should be fitted with an earmold that has a short tip and a large, straight sound-conveying canal. He also recommended the use of an acoustic high pass filter with this type of loss.

Grossman and Molloy[4] carried out further studies aimed at investigating experimentally variations in the acoustic

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[1]Ibid., pp. 103-104.

[2]Ibid., p. 104.

[3]Ibid.

[4]Frederick M. Grossman and Charles T. Molloy, "Acoustic Sound Filtration and Hearing Aids," Journal of the Acoustical Society of America, 16 (1944), pp. 52-59.

pathway between the hearing aid receiver and the tympanic membrane and to analyze, mathematically, the phenomena involved. Four different earmolds were used in the study. Two were conventional with canal diameters of 2 to 3 mm. The third had a canal diameter of 1½ mm, and a fourth had a diameter of 5 mm. Three had a canal 20 mm in length and the fourth had a canal 18½ mm in length. A brass tube 5 mm long and having a diameter of 4 mm served as a high pass filter between the receiver and earmold. It had a side branch hole 1 mm long with a diameter of 1.2 mm. Two different receivers were used, which were connected to an oscillator. The output of the oscillator was varied continuously by a motor drive. The receiver was connected to the earmold which in turn was coupled to a dynamic microphone. The receiver output was picked up by the microphone and fed to an amplifier and then to a level recorder.

Results of these experiments showed that the narrow mold yielded a broader peak frequency response than the others. For all the earmolds, the low frequencies were reduced with the filter in place. An interesting comparison was that between the conventional earmold with and without the filter. The filtered response showed a rather uniform weaker output of 15 to 18 dB up to 1000 Hertz. With the filter in place the output of the receiver was slightly higher than without the filter between 3000 and 4000 Hertz.

Nichols et al.[1] made a thorough investigation of the effect of leakage between the earpiece and the ear canal by means of individually molded earpieces having micrphone probe-tubes mounted in them. They measured the sound pressure developed in the ear canal at the tympanic membrane as a function of frequency by the earphone under two conditions: (1) with the earpiece sealed to the ear canal by means of beeswax and lanolin and (2) with the earpiece worn normally. Three subjects evidencing a very snug fitting earpiece, a moderately snug fit, and a loose fitting earpiece were tested using a number of different earphones.

Their results showed that the response of the various earphones was increasingly affected as the earmold fit became less snug. The low-frequency responses were weakened. There were no striking differences in the behavior of the various earphones on any particular earmold-ear combination. The authors stated: "The results of these tests indicate clearly that the effects on the response characteristics of a hearing aid due to the relative snugness of fit of an earpiece to the wearer's ear may range in magnitude from practically zero to as much as 15 or 20 dB at low frequencies."[2]

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[1]R. H. Nichols Jr., R. J. Marquis, W. G. Wiklund, A. S. Filler, D. B. Feer, and P. S. Veneklasen, "Electro-Acoustical Characteristics of Hearing Aids," Hearing and Hearing Aids, Sec. I, U. S. Office of Scientific Research & Development Report No. 4666 (Cambridge, Mass.: Harvard University, 1945), pp. 44-68.

[2]Ibid., p. 60.

All of the early studies, cited in this section, indicate that the acoustic stimuli reaching the tympanic membrane of the ear can be drastically changed by modifying the acoustic coupler. Unfortunately, after the initial surge of experimentation with modified earpieces during the early 1940's, interest waned. One of the factors contributing to this loss of interest was the shift in attention to the development of the new vacuum tube hearing aid with the emphasis of modifying the frequency response of the hearing aid itself or the receiver rather than the earpiece.

In 1934, an English firm, the Thomson Houston Company, started to manufacture small, battery-operated vacuum tubes; and in 1937, the first wearable vacuum tube hearing aid in America was developed by Arthur Wengel and marketed under the name Stanleyphone.[1] Single unit vacuum tube hearing aids, however, were not put on the market until 1943.[2] Since the vacuum tube instrument had much better fidelity than the old carbon type, interest was turned toward modifying the response characteristics of the instrument electronically rather than acoustically. Modified earpieces were used infrequently, and the conventional closed earmold became standard equipment with most hearing aids.

The trend toward "mirroring the audiogram" by electronically modifying the output of the hearing aid might have

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[1]Watson and Tolan, Hearing Tests, pp. 280-281.

[2]Ibid., p. 312.

continued without controversy had it not been for an important study published in 1947. This research by Davis et al.[1] became known as the "Harvard Study" and had a profound effect on the hearing aid industry. One of the purposes of this study was to determine what type of hearing aid frequency response could be used most satisfactorily by patients with various types and degrees of hearing loss.

As the result of their very intensive study, the Harvard group concluded that an instrument with a flat frequency response, or a rising 6 dB per octave frequency output, was the most suitable for the majority of hard-of-hearing people. In addition, they outlined certain other specifications to which a hearing aid should conform. With regard to these specifications they wrote:

> It is anticipated that when instruments conforming to the above specifications are produced the problem of individual selection of "fitting" will almost disappear. It will be necessary only to:
>
> (a) Provide a well-fitting earpiece that is comfortable and at the same time provides adequate acoustic seal, and
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> (b) Select a model with adequate acoustic gain and make the appropriate semipermanent adjustment to provide the proper limitation of maximum power output.[2]

From the findings of this study, it is easy to understand why manufacturers tended toward producing hearing aids

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[1]Hallowell Davis, S. S. Stevens, R. H. Nichols, Jr., C. V. Hudgins, R. J. Marquis, G. E. Peterson, and D. A. Ross, Hearing Aids: An Experimental Study of Design Objectives, (Cambridge, Massachusetts: Harvard University Press, 1947), 197 pp.

[2]Ibid., p. 113.

with rather flat frequency responses or with a slight high-frequency tilt. Another factor which contributed to the manufacture of hearing aids having much the same type of frequency response was the utilization of the transistor in hearing aids in the early 1950's. With the advent of the transistor, hearing aids could be made much smaller and still retain considerable power. However, with miniaturization it is more difficult to maintain good fidelity, since the smaller components are incapable of giving the same response as the larger ones. Also, various tone controls and circuitry must be eliminated in order for the aid to be made smaller. The modern, ear-level hearing aid tends to be an instrument equipped with little more than a gain control, thus electrical modification of the frequency response is often impossible.

The earmold as a means of acoustically modifying the output of hearing aids once again became an important consideration; and in 1958, Lybarger[1] offered a thorough discussion of how the earmold's hole diameter, tip length, leakage, and venting affect hearing aid response. In the discussion on venting, he pointed out that indiscriminate venting may reduce the extreme low frequencies, but that the important lows for speech may actually be increased. He also stated that the larger the cavity between the earmold tip and eardrum, the weaker will be the sound pressure

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[1]S. F. Lybarger, "The Earmold as a Part of the Receiver Acoustic System," (Canonsburg, Pennsylvania: Booklet published by Radioear Corporation, 1958), pp. 12.

developed at low frequencies. This last principle is one on which the "acoustic modifier" is based. Also, the length and diameter of the tubing used to connect the receiver of an ear-suspended or glasses type hearing aid to the earpiece can considerably modify the instrument's output. According to Lybarger,[1] by shortening the tube, with diameter held constant, the primary and secondary frequency peaks will be shifted toward the high frequencies. Increasing the length of the tube, with diameter held constant, has the converse effect.

Since in the ear-suspended or glasses type hearing aid the microphone and receiver are in close proximity to one another, there has always been a problem of feedback from any type of leakage. This is a factor which led Lybarger to conclude: "Except to provide a good fit with comfort, the actual earmold part of the receiver-earmold system used in an eyeglass type aid does not offer much possibility of acoustic control."[2]

This last statement, however, is no longer true since the development of the CROS (Contralateral Routing of Signals) hearing aid by Harford and Barry.[3] Lybarger,[4] in a

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[1]Ibid., p. 11.

[2]Ibid.

[3]Earl Harford and Joseph Barry, "A Rehabilitative Approach to the Problem of Unilateral Hearing Impairment: The Contralateral Routing of Signals (CROS)," Journal of Speech and Hearing Disorders, 30 (1965), pp. 121-138.

[4]S. F. Lybarger, "Earmold Acoustics," Audecibel, Winter, 1967.

later publication in which he reiterated the basic principles of earmold acoustics, recognized the CROS as a means of acoustically modifying the amplified signal from an ear-level hearing aid while reducing the problem of feedback.

With this particular type of hearing aid the microphone and receiver are mounted on opposite sides of the head, thus providing effective isolation against feedback. This hearing aid was primarily aimed at helping persons with unilateral hearing losses by electrically transferring a signal from a microphone mounted on the impaired ear to a receiver mounted on the good ear. From the receiver the acoustic signal is carried to an open earpiece by means of a polyethylene tube. The open earpiece is necessary, since the normal or near normal ear has to be left unoccluded to allow reception of sound on that side without the attenuation of an earpiece.

The full import of the CROS hearing aid for helping other than unilateral hearing losses and the use of the open earpiece were not realized by Harford and Barry at that time. Concerning the open earpiece, they reported: "The hearing aids used in this study offered a relatively flat frequency response as reported by the manufacturer. However, it should be stressed that the polyethylene tubing terminated in an open ear canal undoubtedly altered the reported frequency response to some degree."[1] It had not occurred to them that

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[1]Ibid., pp. 129-130.

the open earpiece might be effectively used with certain types of hearing loss to improve the speech reception threshold, discrimination score, or quality of the acoustic signal by not disrupting the natural resonance and impedance characteristics of the ear.

Although many claims have been made as to the effectiveness of modified earpieces, few have been subjected to experimentation. During recent years a few studies have been carried out, but these have been primarily clinical in nature with many variables uncontrolled and yielding conflicting results. However, a review of these studies will shed some light on the effectiveness of modified earpieces.

In 1962, Lewis and Plotkin[1] reported on a study concerning the effects of a vented earmold on speech discrimination scores and tolerance for amplification with a group of 15 subjects with high frequency hearing losses. Each of the subjects had normal hearing out to 500 or 1000 Hertz with a precipitous drop in the higher frequencies. All subjects were tested with the same conventional, body-type hearing aid with an HAIC frequency range of 350-3500 Hertz and an HAIC average gain of 63 dB. Each subject was tested with a standard and a vented earmold, and the resulting speech

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[1]Ernest Lewis and William H. Plotkin, "The Role of the Acoustic Coupler in Hearing Aid Fitting," Unpublished paper presented at the Annual Convention of the American Speech and Hearing Association, Chicago, Illinois, 1962.

reception thresholds and speech discrimination scores were compared.

Results of their investigation showed that speech reception thresholds under the two aided conditions were not significantly different, but PB scores did differ significantly. For the entire group the mean unaided SRT was 24 dB and the mean PB score was 65 percent. Utilizing the conventional earmold, the mean SRT was 5 dB, a gain of 19 decibels, but there was a loss of three percentage points in the mean PB score of 62 percent. With the vented earmold there was an 18 decibel gain in SRT, and a speech discrimination score increase of 10 percent over the mean unaided PB score.

For the purpose of further data analysis, the subjects in the study were divided into two groups: those with PB scores of 70 percent and better, and another group with PB scores below 70 percent. The mean unaided PB score was 77 percent for the sub-group of 70 percent or better. With the conventional earmold this group experienced a 13 percent loss in discrimination from the unaided score, whereas with the vented earmold there was only a 2 percent loss when compared to the unaided score.

The mean unaided PB score was 56 percent for the subgroup with poorer than 70 percent discrimination. This group experienced a four percent gain in discrimination with the conventional earmold and a 19 percent gain utilizing the vented earmold compared to the unaided mean PB score. Thus, it would appear that people with poorer than 70 percent discrimination received the most benefit from vented earmolds. Also, the subjects were able to tolerate greater levels of amplification with the vented earmolds.

McClellan[1] compared the discrimination scores of five subjects utilizing a conventional earmold and the Zenith acoustic modifier in a background of noise. All subjects had normal hearing for frequencies lower than 1000 Hertz with a precipitous drop at 2000 Hertz, sound-field speech reception thresholds of less (better) than 10 dB, and speech discrimination scores of 82 percent or better. The loss at 2000 Hertz had to be 35 dB or more in both ears. The mean unaided discrimination score in quiet for the entire group was 87.6 percent. However, in a background of speech noise (+10 dB S/N) which does not interfere with the discrimination of normal listeners, they obtained a mean unaided PB score of 70.8 percent. This is a decrease in discrimination of 16.8 percent from the quiet situation.

All subjects were tested with a conventional earmold and an acoustic modifier coupled to the same moderate-gain, ear-suspended hearing aid in the background of noise. The results showed that a mean discrimination score of 70.0

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[1]Max E. McClellan, "Aided Speech Discrimination in Noise with Vented and Unvented Earmolds," Journal of Auditory Research, 7 (1967), pp. 93-99.

percent was obtained with the conventional earpiece indicating no improvement. A mean discrimination score of 86 percent was obtained with the vented earmold in noise. This was a gain of 15.2 percent over the mean unaided discrimination score in noise. The author concluded: "This shows that with the vented earmold subjects could achieve a discrimination score in noise equal to that obtained unaided in quiet; thus the vented earmold essentially overcomes the discrimination loss caused by the background noise."[1]

In a clinical study, Dodds and Harford[2] compared the discrimination ability of 35 subjects with high-frequency, precipitous, sensorineural hearing losses employing a conventional earmold, the Zenith acoustic modifier, and an open earpiece. Sixteen different hearing aids were used, including the CROS aid employed with an open earpiece. The same hearing aid was used when comparing the test results between the conventional and vented earmolds for a given subject. Not all subjects were tested with the three types of earpieces, and sub-groups were formed depending on the type of earmolds used during testing. Persons tested with more than two kinds of earmolds were included in more than one group.

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[1]Ibid., p. 97.

[2]Elizabeth Dodds and Earl Harford, "Modified Earpieces and CROS for High Frequency Hearing Losses," Journal of Speech and Hearing Research, 11 (1968), pp. 204-218.

Group I consisted of 18 cases tested with both conventional and vented earmolds. For this group the statistical analysis revealed no significant differences in discrimination scores between the vented and conventional earmolds. The scores were 78.1 percent for the conventional and 77.8 percent for the vented mold.

Group II consisted of 14 cases evaluated with both conventional and open molds. At the .01 level of confidence, statistical analysis revealed a significant improvement in discrimination using an open earmold. These scores were 71.4 percent with the conventional and 81.4 percent with the open earmold, an improvement of 10 percentage points.

Group III consisted of 12 cases tested with both vented and open earpieces. At the .05 level of confidence, statistical analysis revealed that performance with the open earpiece was significantly better. Mean PB score with the vented mold was 74.7 percent, and a mean of 79.8 percent with the open mold was achieved, an improvement of 5.1 percentage points.

Another interesting finding in this study was the fact that the subjects were almost unanimous in their preference of the open earpiece because speech sounded much more "natural" to them.

In an unpublished paper, Harrison[1] has reported on her

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[1]Anne Harrison, "Some Clinical Uses of the Modified Ear Insert in Supplying More Acceptable Amplification for Selected Sensorineural Hearing Impairments," Unpublished paper presented at the Annual Convention of the American Speech and Hearing Association, Chicago, Illinois, 1967.

utilization of modified earpieces in the clinical situation. She found that for individuals with high-frequency hearing impairments above 500 or 1000 Hertz, the conventional earmold often did not prove satisfactory even when coupled with a hearing aid having a high-frequency emphasis. With the use of vented earmolds, however, there were not as many complaints of irritation; and people who had previously rejected the use of a hearing aid were able to benefit from amplification.

Harrison also found that a vented earmold could often be utilized by persons with more extensive cochlear involvement with the low frequencies being affected as well as the high. She stated that "We have found that the modified mold has value for a variety of cochlear impairments along the entire hearing loss continuum."[1] She cited three clinical cases indicating the successful use of modified earmolds. The first case, a thirteen-year-old girl with a high frequency, bilateral hearing loss involving a precipitous drop at 2000 Hertz, had previously been informed that she could not use a hearing aid. However, with a properly vented earmold coupled to an ear-level aid, the girl accepted amplification and her articulation improved markedly within a period of three months.

The second case was a man 39 years of age with a moderately severe, bilateral hearing loss, which had gradually

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[1]Ibid., p. 5.

progressed over a period of 20 to 25 years and was suspected of being noise induced. He had been unable to adjust to a hearing aid in the past but was going to purchase binaural behind-the-ear aids in another attempt at wearing amplification. However, he was still dissatisfied with the quality of the amplification. A recommendation was made for him to utilize vented earmolds. As a result, he reported improvement in the quality of amplified speech and minimal annoyance from background noise and was able to wear the hearing aids in his daily activities.

The third case was a woman 34 years old with a severe high frequency, bilateral hearing loss involving a precipitous drop at 500 Hertz. Using a body type hearing aid with a conventional earmold, the patient was able to derive some benefit from amplification but complained of "sensations of impact at the eardrum while perceiving both speech and certain environmental sounds."[1] After further hearing aid evaluations, a vented earmold coupled to a high gain hearing aid with a high frequency emphasis was recommended. This combination appeared to help with gross environmental and speech discriminations, and overall communication ability was much better with the aid than without it.

The effects of conventional, vented, and open earmolds on high-frequency hearing losses have been investigated by

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[1]Ibid., p. 5.

one or more of the studies mentioned above. Recently, however, some hearing aid dealers and audiologists have been fitting high-frequency hearing losses with CROS aids coupled to the ear by just polyethylene tubing. Schafer[1] has been advocating open ear canal amplification for some time, and during the past four years he and his associates have been using tubing exclusively in conjunction with CROS aids. They report having case files on over 750 people who have been using this arrangement, some of them for more than three years. These people include unilaterals with varying degrees of hearing sensitivity on the better side and many symmetrical bilateral sensorineural losses.

Although polyethylene tubing is being used as a coupler without an earmold, there is no published research indicating its effects on speech reception thresholds and speech discrimination scores of subjects having various types of hearing losses. One purpose of the present research was to obtain objective evidence as to how polyethylene tubing, used as a coupler, compares to the conventional, vented, and open earmolds in its effects on speech reception threshold and speech discrimination.

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[1]Personal communication with Donald W. Schaefer (D. W. Schaefer and Associates, Inc., 25 West Main Street, Madison, Wisconsin), April 16, 1968.

Summary

The review of the literature has shown how earmolds were developed along with hearing aids from the very early ear trumpets to the modern, transistorized aids. The research on auditory phenomena associated with the transmission of an acoustic stimulus to the human ear revealed the principles on which certain types of modified earmolds were based.

The early research on modified earpieces arose out of efforts to enhance the amplification of the inefficient carbon amplifier hearing aids. These studies showed that the frequency response of the acoustic stimulus reaching the tympanic membrane could be modified by changing certain dimensions of the acoustic coupler. Also, the amount of amplification is modified.

It was pointed out that during recent years there has been very little research concerned with modified earpieces. This may, in part, be due to the fact that the use of the CROS aid with other than unilateral hearing losses is, at the time of this writing, a relatively new concept. This type of amplification now makes possible the use of various types of acoustic couplers which could not be utilized in the past due to the problem of acoustic feedback. Further, the few existing studies either need to be expanded and the results verified or subjected to more rigid research controls. A closer study of the more recent research reveals various methodological problems. The study by Lewis and Plotkin[1] did employ fairly good controls, but only two types of acoustic couplers were utilized and only 15 sensorineural subjects with one type of pure-tone, audiometric configuration were investigated. The present study utilized four different acoustic couplers and investigated three types of pure-tone audiometric configurations. These included conductives, sensorineurals with a precipitous drop, and sensorineurals with a gradually sloping configuration. Also, the Lewis and Plotkin study revealed a significant improvement in speech discrimination scores when utilizing the acoustic modifier as opposed to a conventional earmold, whereas the study by Dodds and Harford[2] was a descriptive study of clinical cases and was lacking in experimental design controls for this reason. Another shortcoming is that not all the cases were tested with the three kinds of earpieces: conventional, acoustic modifier, and open earpiece. It is possible that those cases not showing a significant gain in the PB score utilizing an acoustic modifier might have done so with an open earpiece. By the same token, those cases who showed an improved PB score with the open earpiece may also have shown an improved PB score with the acoustic modifier had one been evaluated. The study by

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[1]Lewis and Plotkin, "Role of Acoustic Coupler," p. 9.

[2]Dodds and Harford, "Modified Earpieces," p. 12.

Dodds and Harford[1] does not give any data which compare all three types of acoustic couplers on the same group of subjects. However, the study is an important clinical investigation and clearly reveals the trend for speech discrimination scores to improve when an acoustic coupler is employed which more closely approximates a natural listening situation by leaving the ear canal unoccluded. Their study needs to be subjected to a more standardized procedure, and all of the various types of acoustic couplers should be employed with the same group of subjects. The present investigation was designed with more rigid controls, and all subjects were tested under exactly the same experimental conditions. Further, Dodds and Harford used 16 different hearing aids. The present study utilized a single CROS type hearing aid, thus eliminating any differential effects caused by the use of many types of hearing aids.

Harrison's[2] report of a clinical application of modified earpieces to various types of pure-tone audiometric configurations contained only the subjective impressions of the clinician and the subject as to the improvement in amplified sound offered by vented earmolds. The report does not contain any objective measures of improved speech reception thresholds or speech discrimination scores. The present study presents measures of both speech reception thresholds

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[1]Ibid., pp. 204-218.

[2]Harrison, "Some Clinical Uses of the Modified Ear Insert," pp. 1-6.

and speech discrimination scores as well as a judgment on the part of the subject as to the quality of the amplified sound through the various types of acoustic couplers.

CHAPTER III

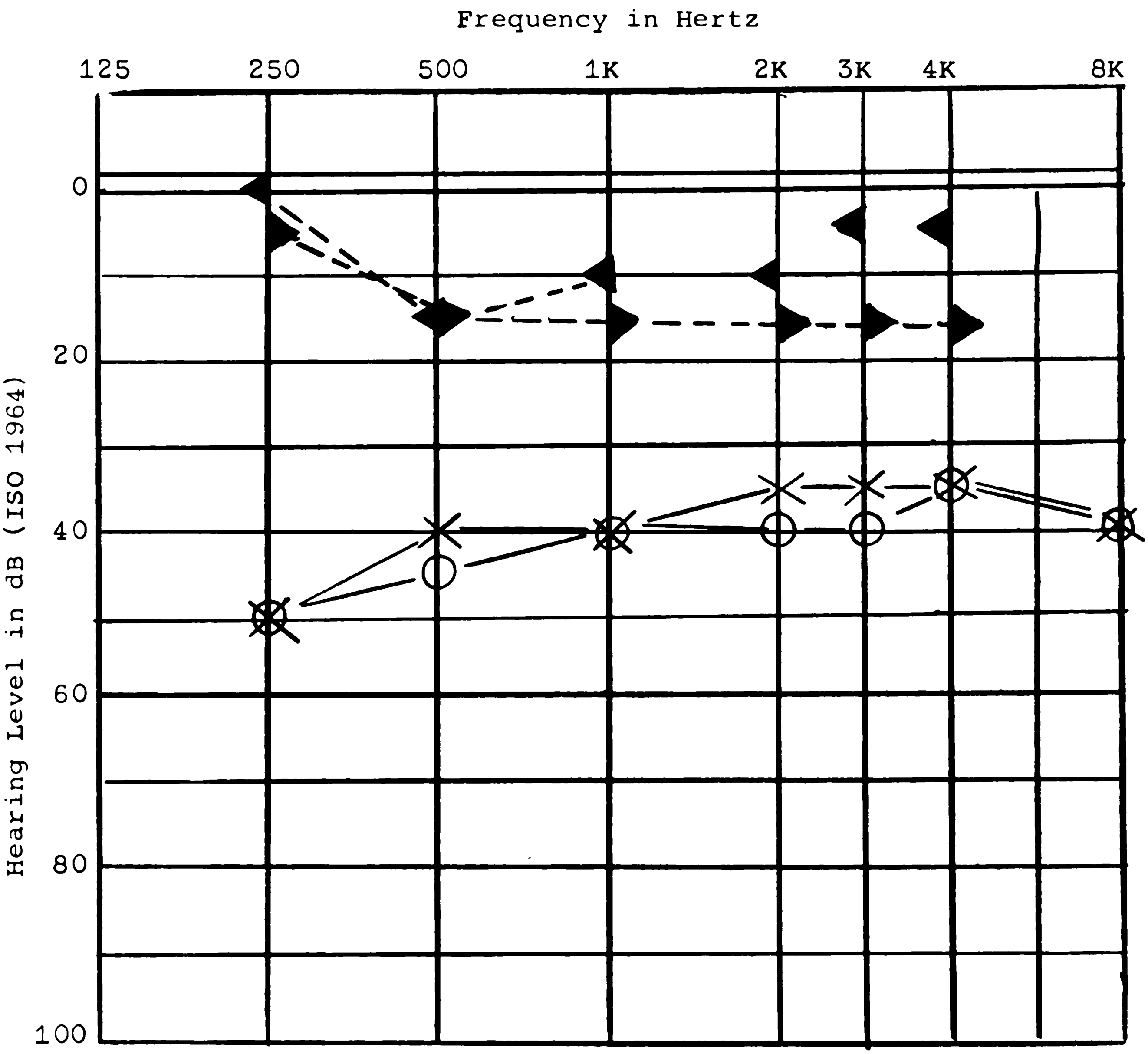
EXPERIMENTAL PROCEDURES

Subjects

Three groups of hard-of-hearing adults served as subjects in this study. Group I consisted of ten persons having a conductive type hearing impairment. This group was composed of six females and four males ranging in age from 17 to 60 years with a mean age of 37.1 years. Each case fulfilled the criteria of having bone conduction thresholds within the normal range (no greater than 25 dB ISO-1964 Standards) and air conduction thresholds which showed an air-bone gap of at least 20 dB for the test frequencies 500, 1000 and 2000 Hertz. Figure 1 shows the mean air and bone conduction thresholds for this group.

Group II consisted of ten persons having a sensorineural type hearing impairment with an audiometric configuration showing a precipitous high frequency drop. This group was composed of ten males ranging in age from 40 to 67 years with a mean age of 51.5 years. Each case fulfilled the criteria of having normal hearing (25 dB or better ISO-1964 Standards) for the low frequencies with a precipitous drop of at least 20 dB for the first octave beginning at 500 or 1000

Figure 1.--Audiogram showing mean air and bone conduction thresholds for Group I (Conductive Impairment). N = 10



Key to Audiogram

	Ear	
	Right	Left
Air Conduction	O	X
Bone Conduction (Masked)	◀	▶

Hertz and bone conduction thresholds which interwove with the air conduction thresholds. Figure 2 shows the mean air conduction thresholds for this group.

Group III consisted of ten persons having a sensorineural type hearing impairment with an audiometric configuration showing a gradually sloping loss with the low frequencies also being affected. This group was composed of one female and nine males ranging in age from 20 to 62 years with a mean age of 51.2 years. Each case fulfilled the criteria of having a progressively greater hearing loss for higher frequencies at a slope of 5 to 10 dB per octave and bone conduction thresholds which interwove with the air conduction thresholds. Figure 3 shows the mean air conduction thresholds for this group.

Equipment

The following is a list of the equipment utilized in this investigation:

Test Equipment

- Pure-tone audiometer (Beltone, Model 15C)
- Speech audiometer (Grason-Stadler, Model 162)
- Loudspeaker (Grason-Stadler, Model 162-4)
- Earphones (Telephonics, Model TDH-39-10Z)
- Earphone cushions (Model MX 41/AR)
- Bone Vibrator (Radioear, Model B70-A)
- Tape recorder (Ampex, Model 601)
- Narrow band masking unit (Beltone, Model NB-102)
- 20 decibel attenuation pad
- Commercial test room (Industrial Acoustic Company, Inc. 1200 series)
- Earmolds (Conventional, Acoustic Modifier, Open, and Crimped Polyethylene Tubing)

Figure 2.--Audiogram showing mean air conduction thresholds for Group II (Sensorineural Impairment with a Precipitous Drop). N = 10

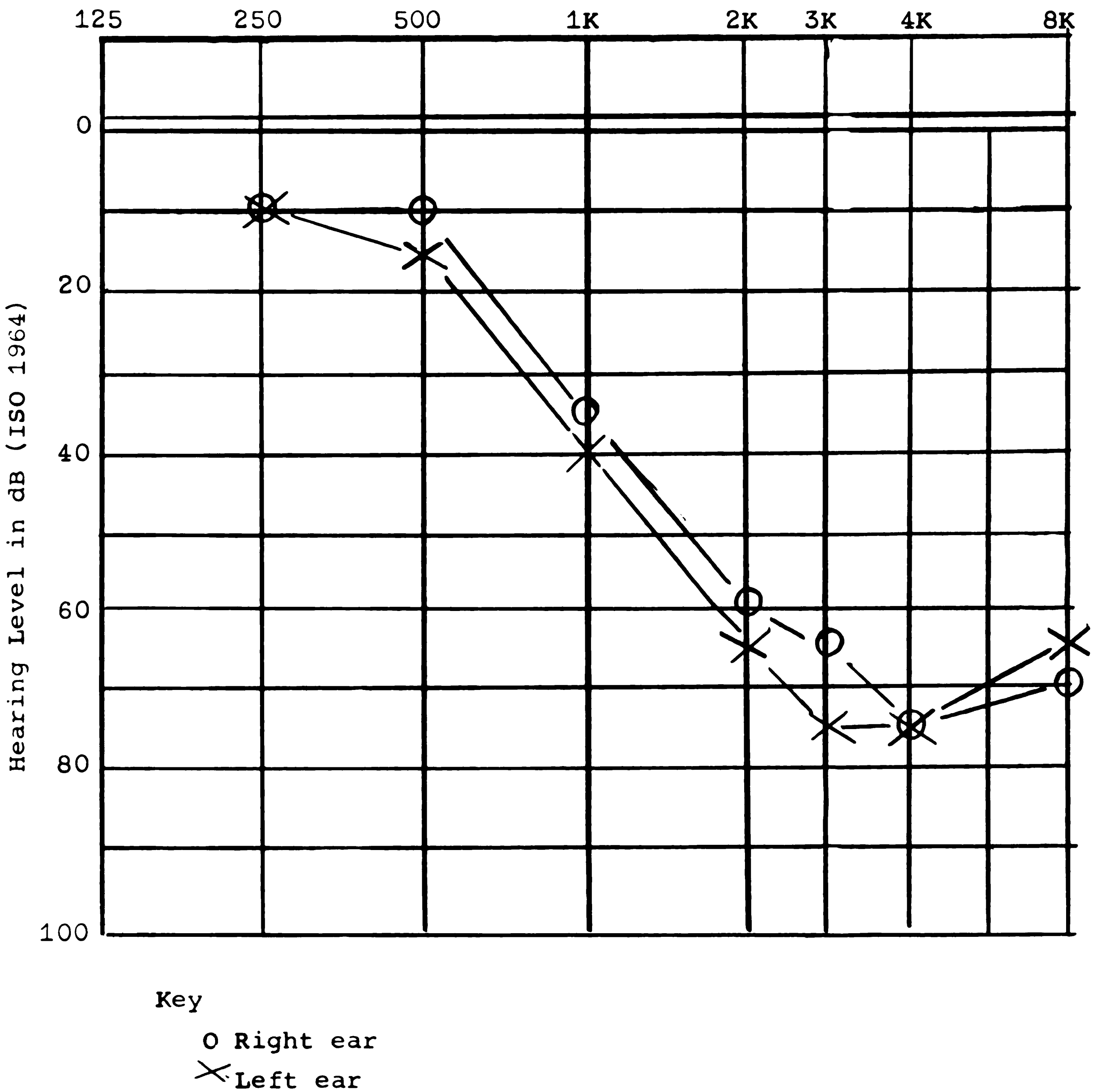
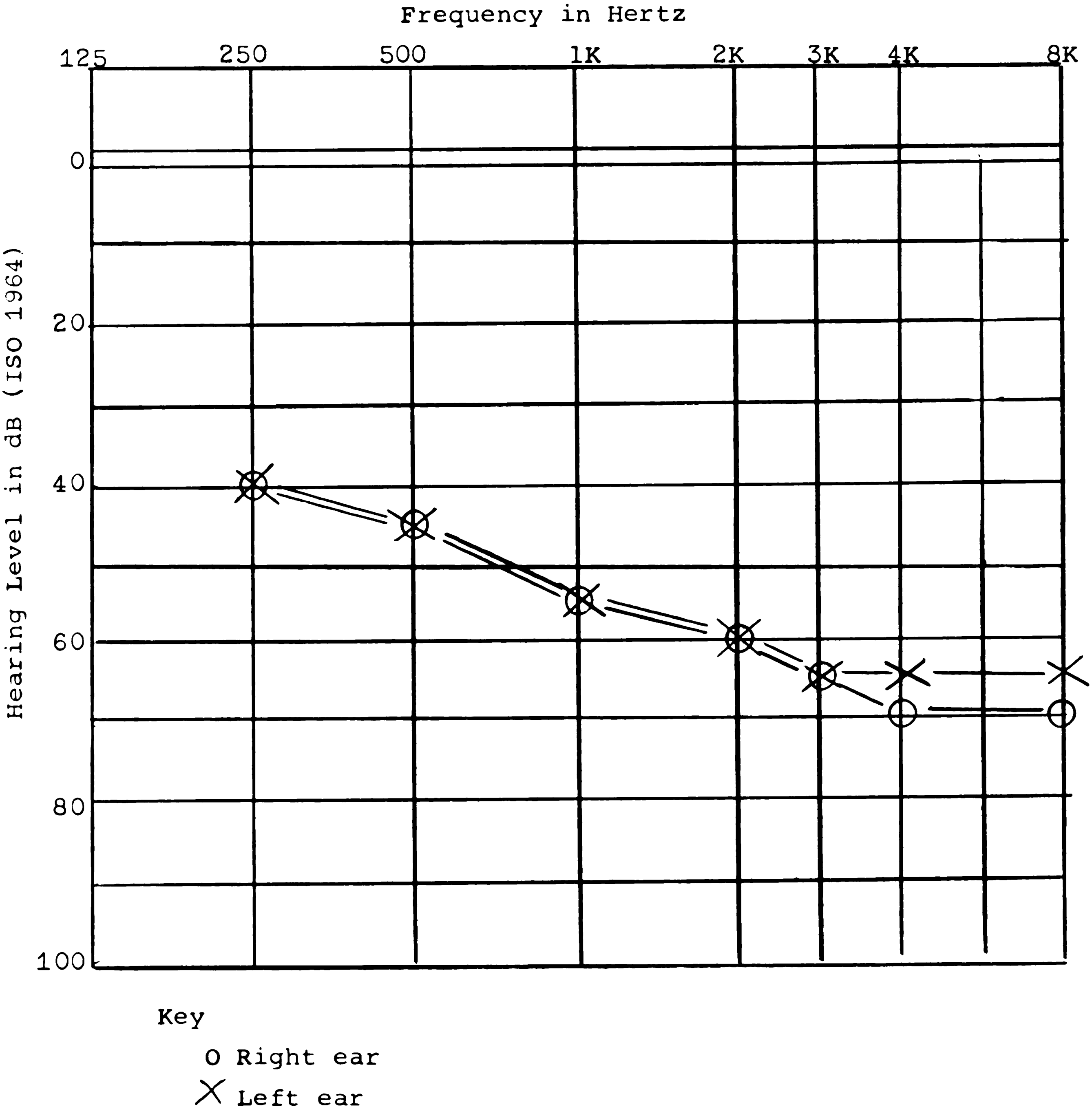


Figure 3.--Audiogram showing mean air conduction thresholds for Group III (Sensorineural Impairment with a Gradually Sloping Loss). N = 10



Calibration Equipment

Sound level meter (Bruel & Kjaer, Type 2203)
Octave band filter network (Bruel & Kjaer, Type 1613)
Artificial ear (Bruel & Kjaer, Type 4152)
Condenser microphone (Bruel & Kjaer, Type 4132, used in conjunction with the artificial ear)
Condenser microphone (Bruel & Kjaer, Type 4131, used for sound-field measurements)
Artificial mastoid (Beltone, Model M5A)
Volt meter contained as an integral part of the audio frequency spectrometer (Bruel & Kjaer, Type 2112)
Pistonphone (Bruel & Kjaer, Type 4220)

Equipment Used for Measuring Frequency Response and Distortion Characteristics of Hearing Aid

Hearing aid test box (Bruel & Kjaer, Type 4212)
Frequency analyzer (Bruel & Kjaer, Type 2107)
Audio frequency spectrometer (Bruel & Kjaer, Type 2112)
Sine-Random generator (Bruel& Kjaer, Type 1024)
Condenser microphone (Bruel & Kjaer, Type 4132)
Level Recorder (Bruel & Kjaer, Type 2305)

For the pure-tone testing necessary in the experiment, a commercially available pure-tone audiometer (Beltone, model 15C) was used to drive TDH-39-10Z transducers housed in MX 41/AR biscuit-type cushions.

For the necessary speech testing, a commercially available speech audiometer (Grason-Stadler, model 162) was used to amplify and attenuate the electrical output of the tape recorder (Ampex, model 601) used to present the tape recorded tests described later under test materials. For a given test condition, the output of the speech audiometer drove one of two transducers: (1) a TDH-39-10Z earphone housed in an MX 41/AR cushion, or (2) a loudspeaker (Grason-Stadler, model 162-4) furnished as an integral component of the speech audiometer.

The speech audiometer used in this research was calibrated so that audiometric zero is defined as being 20 dB above 0.0002 dyne/cm^2. Instead of using the usual 1000 Hertz tone for calibration, "Speech Noise" was used for calibration in the sound-field according to the procedure described by Tillman, Johnson, and Olsen.[1] Their rationale for using speech noise in lieu of a 1000 Hertz signal was that the spectral configuration of the noise closely approximates the spectrum of continuous speech produced by male speakers. This spectrum was drawn as the average of two curves reported in graphic form by Licklider and Miller.[2]

A description of the procedure follows: In order to calibrate the TDH-39 earphone, it is coupled to the condenser microphone (Bruel & Kjaer, Type 4132) of the sound level meter (Bruel & Kjaer, Type 2203) with its associated octave band filter network (Bruel & Kjaer, Type 1613) by means of a standard 6-cc coupler (Bruel and Kjaer, Type 4152). The level of the noise signal at a given attenuator setting is adjusted until it produces a deflection to zero on the speech audiometer VU meter. The resulting acoustic output of the system is measured, and this value is accepted as the intensity of the spondee words at the same attenuator setting under the

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[1]Tillman, Johnson, and Olsen, "Earphone Versus Sound-Field," pp. 128-129.

[2]J. C. R. Licklider, "The Perception of Speech," in Handbook of Experimental Psychology, S. S. Stevens, Ed. (New York: John Wiley & Sons, Inc., 1951), p. 1042.

condition in which the peaks of the words also produced a deflection to zero on the VU meter of the speech audiometer. For example, with the speech audiometer attenuator set at 60 dB, the output of the artificial ear would be 80 dB SPL re 0.0002 microbar.

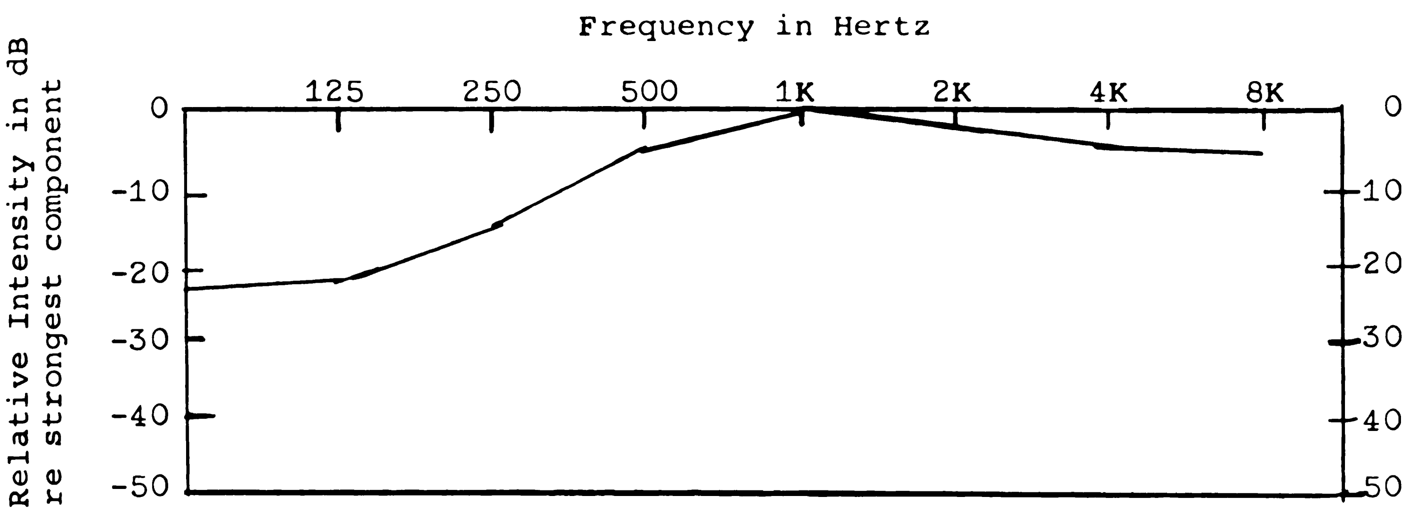
For calibration of the loudspeaker, the condenser microphone (Bruel & Kjaer, Type 4131) was placed four feet from the face of the loudspeaker at a height of 42 inches. The condenser microphone was oriented so that its diaphragm was perpendicular to the floor and ceiling of the rest chamber at a zero degree angle of incidence from the loudspeaker. The intensity of the speech spectrum noise generated by the speech audiometer at a given attenuator setting was then recorded. All measurements were made without the presence of an observer in the field. However, the location of the condenser microphone was approximately where the center of the subject's head would be when a subject was in the test chamber. A pistonphone (Bruel & Kjaer, Type 4220) was used to set the meter needle of the audio frequency spectrometer (Bruel & Kjaer, Model 2112) from which the intensity of the sound-field was read directly in decibels re 0.0002 microbar. Measurements of the overall SPL of the speech noise were made on all days that subjects were tested, and the readings were found to be within plus or minus one decibel of 20 dB re 0.0002 microbar throughout the experimentation. Attenuator linearity was also checked and found to be stable throughout the study.

The acoustic spectrum of broad band white noise through the loudspeaker at an 80 dB SPL re 0.0002 microbar is shown in Figure 4. From this figure it can be seen that the loudspeaker has a fairly flat frequency response from 500 through 8000 Hertz. This response remained constant from the beginning to the end of the study.

Calibration of the pure tone air and bone conduction systems was also checked on all days on which subjects were tested. The Bruel and Kjaer sound level meter and its associated filter network and the artificial ear were used for calibration of the air conduction system. The artificial mastoid was used to calibrate the bone conduction system. Attenuator linearity was checked periodically in all systems and any necessary corrections were applied to the data. The 20 dB attenuation pad was checked in our laboratory prior to beginning this study and was accurate plus or minus one dB.

In addition to the equipment listed above, the Radioear, model 930 CROS type hearing aid was employed. Utilization of the CROS principle was necessary in order to eliminate acoustic feedback when testing with the open earpiece and crimped tubing. The Radioear, model 930 has interchangeable bows; thus, the same hearing aid could be used with all subjects for all conditions of acoustic coupling. All that was necessary was to place the bow containing the pick-up microphone on the ear contralateral to the one which was to receive the amplification.

Figure 4.--The acoustic spectrum of a broad band white noise through the Grason-Stadler Loudspeaker, Model 162-4.



The frequency response of the Radioear, model 930 CROS type hearing aid was obtained in the following manner: The hearing aid was placed in a hearing aid test chamber (Bruel & Kjaer, Type 4212) consisting of an external artificial ear, a regulating microphone, and built-in loudspeaker. The regulating microphone was connected to the microphone amplifier portion of the frequency analyzer (Bruel & Kjaer, Type 2107), which amplified the signal and applied it to the compressor input of the sine-random generator (Bruel & Kjaer, Type 1024). The generator supplied a sine-wave signal to the loudspeaker in the chamber and a condenser microphone (Bruel & Kjaer, Type 4132) was connected to the 2 cc coupler of the artificial ear. The output of the hearing aid was then connected to the 2 cc coupler. The microphone in turn was connected to the microphone amplifier portion of the audio frequency spectrometer (Bruel & Kjaer, Type 2112), and the amplified voltage was led to the input of the level recorder (Bruel & Kjaer, Type 2305) which automatically recorded the frequency response of the hearing aid. The level of the input signal to the hearing aid was 60 dB re 0.0002 microbar. These measurements were made in accordance with the procedures specified by the American Standards Association.[1]

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[1]"American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," American Standards Association, Incorporated, No. S3-3-1960 (1960), p. 12.

The frequency response characteristics of the hearing aid are shown in Figure 5.

In addition, the following characteristics of the hearing aid was determined by the HAIC method.[1]

Maximum Gain. . . . . 48 dB
Maximum Output. . . . . .124.1 dB
Frequency Range . . . . .500-5200 Hz

A comparison of the above measurements with the manufacturer's specifications indicated a frequency response curve nearly identical to that specified, except for slightly more gain between 2000 and 4000 Hertz. Other specifications for this hearing aid model by the HAIC method of computation listed a maximum gain of 52 dB compared to the 48 dB actually measured. The specified maximum output of 124 dB was identical to that measured, and the specified frequency range of 460-4800 Hertz was comparable to the 500-5200 Hertz measured.

The harmonic distortion of the Model 930 was measured in the following manner. The output of the aid was led to the amplifier input of the frequency analyzer (Bruel & Kjaer, Type 2107). The distortion factor was then measured directly by switching the analyzer to "frequency rejection." In this manner, the fundamental was rejected and the remaining total harmonic distortion was read directly in percent from the instrument meter with the switch set in the R.M.S. position.

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[1]S. F. Lybarger, "A New HAIC Standard Method of Expressing Hearing Aid Performance," The Hearing Dealer, February 1961, pp. 16-17.

Figure 5.--Frequency response of the Radioear, Model 930 CROS type hearing aid with an input signal of 60 dB re 0.0002 microbar.

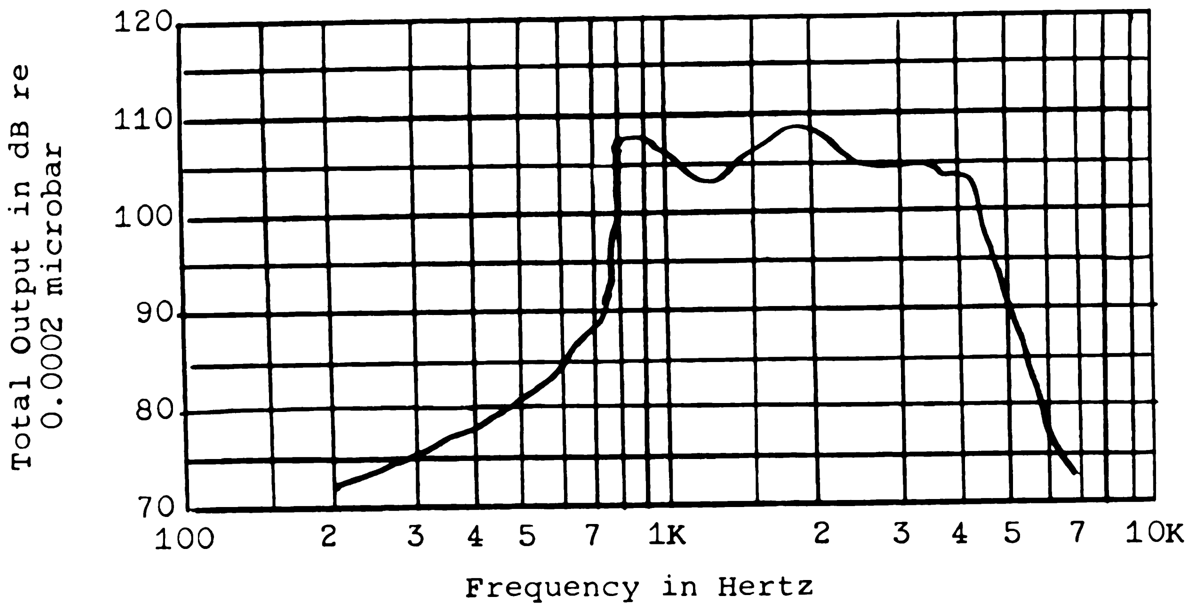

Table I gives the harmonic distortion as determined by the American Standards Association (A.S.A.) method of computation.[1]

Table I.--Percent Harmonic Distortion of A.S.A. Method. Input 75 dB SPL re 0.0002 microbar.

SPL* at Coupler	Frequency in Hertz 500	700	900	Average
80	4.2	3.4	2.2	3.3
90	9.4	2.4	1.2	4.3
100	24.0	3.2	1.0	9.4
Saturation	40.0	5.4	2.0	15.8

*In dB re 0.0002 microbar.

Test Environment

The test room and all audiometric equipment were located in the basement of the Michigan State University Auditorium Building. The loudspeaker and earphones used in the testing of subjects were situated in the test room (IAC, 1200 Series); and during all conditions of this experiment, the subjects were seated in this room.

Previous measurements of the ambient noise in the sound-treated room using the sound level meter on the C scale have shown the noise to be 42 decibels SPL re 0.0002 microbar.

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[1]"American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," p. 13.

Also, an octave band analysis of the ambient noise level had indicated that the greatest amount of ambient noise (40 dB average) is found in the octave bands below 100 Hertz. For the frequencies from 100 to 8000 Hertz, the ambient noise level averages 14 dB. These levels were sufficiently low so as not to interfere with the tests administered.

The pure-tone audiometer, speech audiometer, tape recorder, and narrow band masking generator were situated in an adjoining control room which communicates with the sound-treated room by means of a window and a two-way electronic communications system, which is an integral part of the speech audiometer.

Test Materials

The unaided and aided speech reception thresholds were obtained with tape-recorded spondee word lists. These were the same words used in CID Auditory Test W-1 and consist of six scramblings of a single list of 36 spondaic words.[1] These words were recorded on magnetic tape by a male talker with a General American dialect who monitored the level of his vocal productions on a VU-meter so that the two syllable peaks of each word drove the meter to the same deflection plus or minus one decibel as that produced by a 1000 Hertz calibration tone on the same tape.

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[1]Ira J. Hirsh, Hallowell Davis, S. Richard Silverman, Elizabeth G. Reynolds, Elizabeth Eldert, and Robert W. Benson, "Development of Materials for Speech Audiometry," Journal of Speech and Hearing Disorders, 17 (1952), pp. 321-337.

The unaided and aided speech discrimination scores were obtained with NU Auditory Test No. 6.[1] This test consists of four lists of 50 monosyllabic words patterned after the CNC lists developed by Lehiste and Peterson[2] in 1959 and revised by them in 1962.[3] These lists were recorded on magnetic tape by the same male talker mentioned above who monitored his vocal output by means of a VU-meter. The carrier phrase, "You will say" preceded each test word. The last word of the carrier phrase was monitored and the CNC word was said naturally. Four additional lists, necessary for the experimental conditions in the present study, were made from scramblings of the original four. In other words, two forms (A and B) were used. Form B was constructed by re-recording Form A and cutting and splicing the tape so that the words appeared in a different order than in Form A.

The four CNC lists were standardized earlier by Rintelmann and Jetty[4] on ten young adult subjects with normal

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[1]Tom W. Tillman and Raymond Carhart, "An Expanded Test for Speech Discrimination Utilizing CNC Monosyllabic Words (NU Auditory Test No. 6)," U. S. School of Aerospace Medicine--Technical Research, 66-55, 1-12, June, 1966.

[2]I. Lehiste and G. E. Peterson, "Linguistic Considerations in the Study of Speech Intelligibility," Journal of the Acoustical Society of America, 31 (1959), 280-286.

[3]G. E. Peterson and I. Lehiste, "Revised CNC Lists for Auditory Tests," Journal of Speech and Hearing Disorders, 27 (1962), pp. 62-70.

[4]William F. Rintelmann and Albert J. Jetty, "Reliability of Speech Discrimination Testing Using CNC Monosyllabic Words," Unpublished Study, Michigan State University, 1968.

hearing following the procedures outlined by Tillman and Carhart.[1] The results were comparable to those obtained by Tillman and Carhart and the lists were equivalent plus or minus 4 percent at a 24 dB sensation level. The results of the standardization at a 24 dB sensation level are given in Appendix A.

Test Procedures

The following tests were administered to each subject:

Pure tone air and bone conduction, both ears monaurally with routine masking by bone conduction.

Unaided speech reception threshold, both ears monaurally, and in a sound-field.

Unaided speech discrimination, both ears monaurally, and in a sound-field.

Aided speech reception threshold and speech discrimination in one ear under each of the following conditions:
(1) Conventional earmold
(2) Acoustic modifier
(3) Open Earpiece
(4) Crimped tubing

The unaided tests were administered in the order listed above. The aided tests were presented according to a predetermined rotation procedure.

Masking was used routinely during bone conduction testing. The masking agent was supplied by a narrow band masking generator (Beltone, Model NB-102). Previous analysis of this masking generator had indicated that the band widths,

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[1]Tillman and Carhart, "An Expanded Test for Speech Discrimination," pp. 4-7.

determined at the level 3 dB down from the peak intensity, were all greater than the critical band widths defined by Fletcher.[1,2] The effective masking for a zero dB hearing level was determined at each band by applying the critical band data of Fletcher in the manner described by Sanders and Rintelmann.[3] Bone conduction thresholds were determined by the Hood Technique.[4]

During this preliminary testing, the subjects were seated in the sound-treated room, and sound-field measurements were made with the subject seated so that the midline of his forehead was four feet from the face of the loudspeaker at a zero degree azimuth. One loudspeaker was used for all unaided and aided sound-field measurements. A schematic diagram of the test environment is shown in Figure 6.

All pure tone air and bone conduction thresholds were determined by the Revised Hughson-Westlake Technique as described by Carhart and Jerger.[5]

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[1]Harvey Fletcher and W. A. Munson, "Relation Between Loudness and Masking," Journal of the Acoustical Society of America, 9 (1937), pp. 1-10.

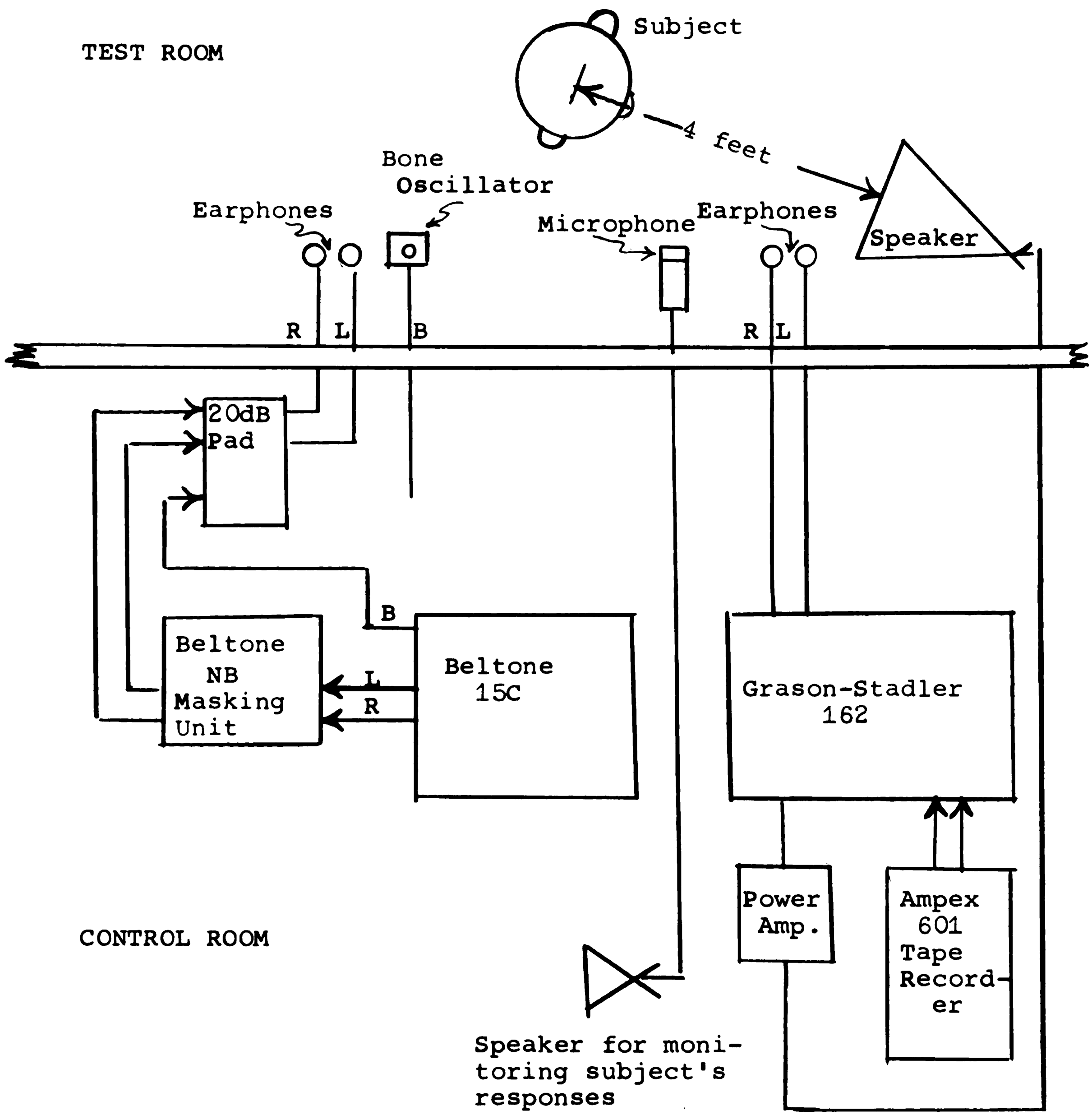
[2]Harvey Fletcher, "Auditory Patterns," Review of Modern Physics, 12 (1940), pp. 47-65.

[3]Jay W. Sanders and William F. Rintelmann, "Masking in Audiometry," Archives of Otolaryngology, 80 (1964), pp. 541-556.

[4]J. D. Hood, "Principles and Practice of Bone Conduction Audiometry," Laryngoscope, 70 (1960), pp. 1211-1228.

[5]Raymond Carhart and James F. Jerger, "Preferred Method of Clinical Determination of Pure-Tone Thresholds," Journal of Speech and Hearing Disorders, 24 (1959), pp. 330-345.

Figure 6.--Schematic diagram of the test environment showing placement of equipment and location of the subject during testing.



The unaided and aided speech reception thresholds were obtained with the recorded speech materials described earlier. Threshold was determined by the method described by Tillman and Carhart.[1] In this method the following procedures are followed:

Initially two test words are presented at a level 10 to 20 dB above the estimated SRT. The intensity of the signal is then attenuated by 2 dB and two more words are presented. The initial presentation level is selected so that the subject correctly repeats a minimum of five of the first six test words. The procedure of attenuating in 2 dB steps and presenting two words at each step is continued until the subject either fails to respond or responds incorrectly to six consecutive test words. Threshold is then computed by subtracting the number of words correctly repeated from the intensity of the signal at the starting level and adding one decibel to compensate for the fact that the 50 percent criterion is not fully met via this procedure. Since the attenuator of the speech audiometer is calibrated in 2-dB steps, in the case of an odd-integer spondee threshold, the reference intensity used was the level 1-dB higher than the actual SRT.

It has been demonstrated that the threshold for spondee words may vary considerably over time as the test items are

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[1]Tillman and Carhart, "An Expanded Test for Speech Discrimination," pp. 5-6.

repeated and is apparently a function of the person's familiarity with the test vocabulary.[1] All of the subjects used in this study had received previous speech audiometric tests. In this respect, they all had about the same familiarity with the spondee words. However, the intervening time between their last tests and this experiment varied, so all were exposed to the spondees immediately prior to unaided threshold measurement. This was accomplished by the examiner reading the words to each subject prior to testing. The following instructions were given:

> Before actually beginning testing, I am going to read you a list of 36 two-syllable words. They will be presented at a level so that you should be able to hear them comfortably. Please repeat each word aloud. These words are the same ones that will be used during the testing, although they will be in different order. Please pay careful attention to the words so that you will become familiar with them.

Upon completion of the above, the subject was told that the actual testing would now begin and the following instructions were given:

> You will now hear a man's voice saying the same two-syllable words you have just heard. The words will begin at a loudness level at which you will be able to hear them easily, but they will eventually get very faint. Your task is to repeat as many of the words as you possibly can. Even though the word may be very faint if you think you know what it is, repeat it aloud. Are there any questions?

The unaided and aided speech discrimination scores were obtained with the recorded monosyllabic words described

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[1]Tom W. Tillman and James F. Jerger, "Some Factors Affecting the Spondee Threshold in Normal-Hearing Subjects," Journal of Speech and Hearing Research, 2 (1959), pp. 141-146.

under "Test Materials." The words were presented at a 26 dB sensation level (SL) re the SRT for all test conditions. The following instructions were given to the subjects:

> During the next test you will hear a man's voice saying one-syllable words. These are common words, which will be very familiar to you. The words will be presented at a sufficient loudness level, so that you will be able to hear them easily. They will not become fainter as in the previous test. Your task is to repeat aloud as many of the words as you possibly can. If you think you know what a word is, but are not quite sure, go ahead and repeat what you think it might be. Are there any questions?

Upon completion of the speech tests under earphones, they were repeated in the sound-field under the unaided and aided conditions with the various types of acoustic couplers. The subject was seated facing the loudspeaker at a distance of four feet.

Only one ear of each subject was tested in the sound field under the unaided and aided conditions. This was accomplished by occluding the non-test ear with a Flent ear plug. The details of this procedure are described below. The subjects were chosen so that they had a bilateral hearing loss which was fairly symmetrical. The choice of which ear to test in the sound-field unaided and aided with the acoustic couplers was based on the following criteria applied to the results obtained under earphones:

(1) The ear yielding the better discrimination score was selected as the test ear for subjects with a discrimination score poorer than 90 percent. A score differing by 4 percent or greater between the ears was considered significantly different. When the discrimination score yielded by the better ear was 90 percent or greater, the poorer ear was chosen for amplification irrespective of SRT.

(2) If the speech discrimination score was within 4 percent between ears, then the ear with the better SRT was chosen. A 4 dB or greater difference in SRTs was considered as significant.

(3) If the discrimination scores and SRTs were equal, then the ear selected was the one which helped balance the number of right and left ears chosen for amplification.

Speech reception thresholds and speech discrimination scores for the sound-field unaided and aided conditions were obtained using the same procedures as outlined previously; however, in order to rule out participation of the contralateral ear, the threshold was raised by occluding the ear canal with a wax impregnated ear plug (Flent). Since the subjects had fairly symmetrical hearing losses, the attenuation of the Flent coupled with the already existing hearing loss provided the isolation necessary to rule out participation of the contralateral ear in the test situation. Previous to their utilization in this study, the amount of attenuation provided by these ear plugs was investigated using three subjects with normal hearing. Monaural unoccluded pure-tone air conduction thresholds and speech reception thresholds were obtained, and then these same thresholds were obtained with the ears occluded by the ear plugs. The results are given in Appendix B. The attenuation provided for speech was approximately 33 dB.

The gain of the hearing aid remained at the same setting during all of the experimental conditions for all subjects. This was necessary in order to rule out the influence of different gain settings on the obtained results. A limiting factor to the amount of gain that could be utilized was the acoustic feedback produced under the condition of maximum leakage. When the Radioear, Model 930 with crimped tubing is worn, acoustic feedback can be completely eliminated by turning the gain control down somewhat from its maximum position. The setting which eliminated acoustic feedback was determined by the investigator placing the aid on himself and turning the gain control down until the feedback was eliminated. The gain control was then sealed by tape at this setting and was not disturbed throughout the investigation. The HAIC maximum gain determined at this setting was 35.1 dB. The equipment used and the procedure for measuring gain were described earlier in this chapter.

In order to prevent acoustic leakage, which could result from using a stock earpiece, the conventional earmold was sealed as well as possible to the ear canal by Glastrip,[1] a commercially available compound. Glastrip is provided in powder form but becomes a pliable, clay-like substance when mixed with water. Another possible source of leakage was where the nub at the end of the polyethylene tubing snaps into the earmold, so this junction was also sealed with the same compound.

In order to eliminate test order effects, the four accoustic couplers were tested according to a predetermined

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[1]Glastrip is available from Coe Laboratories, Inc., 6033 Wentworth Avenue, Chicago, Illinois.

rotation procedure. The spondee lists and CNC lists were also rotated so that they were not always presented in the same order or with the same coupling condition.

Upon completion of testing with the first two acoustic couplers, the subject was asked which he preferred, number one or number two, as far as the subjective quality of the amplification was concerned. This preference was noted. The third acoustic coupler was then tested and the subject was asked to state his preference between this one and the previously chosen one. Through this process of elimination, the subject was able to arrive at a decision as to which coupler he preferred.

The first coupling condition under which a subject was tested was repeated. This yielded test and retest scores for both speech reception thresholds and speech discrimination scores for each subject under one of the coupling conditions. The correlation between these two scores was then used as an estimate of the reliability of the measures.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter is divided into five sections. The first section presents a descriptive summary of the results obtained for the various experimental conditions. The second section contains a discussion of the reliability of the obtained measures. The next two sections contain the statistical analysis of the speech reception thresholds and speech discrimination scores. The final section is a discussion of the clinical significance of the obtained results.

Descriptive Summary of Results

The means, medians, standard deviations, and ranges of the speech reception thresholds (SRTs) recorded for the three groups aided utilizing the four acoustic couplers and unaided in the sound-field are shown in Table II.

From the table it can be observed that the threshold variability of the three groups differs markedly. This however, is not unexpected, since from the standpoint of hearing sensitivity, these three groups are not very homogeneous. However, it should be noted that for all three groups the variability about the mean threshold remains relatively constant from one coupling condition to another.

Table II.--Means (M), Medians (Med), Standard Deviations (SD), and Ranges of Speech Reception Thresholds* Obtained for Three Groups of Subjects Under One Unaided and Four Aided Listening Conditions

GROUP	LISTENING CONDITION				
	Unaided SF	Conventional	Acoustic Modifier	Open Earpiece	Crimped Tubing
Conductive					
M	35.6	11.0	13.9	12.7	14.1
Med	32.5	9.5	12.0	11.5	12.0
SD	9.0	5.7	6.7	5.2	6.2
Range	30	21	25	18	22
Sensorineural (Precipitous)					
M	23.8	14.5	14.8	12.5	14.7
Med	24.0	14.5	14.5	12.0	13.0
SD	9.1	3.0	4.9	3.4	4.4
Range	34	10	16	13	14
Sensorineural (gradual Slope)					
M	45.7	23.6	28.1	25.6	30.3
Med	47.5	24.5	30.0	25.5	32.5
SD	8.2	8.7	8.0	8.3	8.6
Range	26	31	25	25	28

*In dB re speech audiometric zero.

The means, medians, standard deviations, and ranges of the speech discrimination scores recorded for the three groups aided utilizing the four acoustic couplers and unaided in the sound-field are presented in Table III.

Examination of Table III reveals that the speech discrimination of the three groups is substantially different. Again, this is not an unexpected outcome, since the three groups are not very homogeneous with respect to their ability to understand speech. However, note that for all three groups the variability about the mean speech discrimination score remains relatively constant from one listening condition to another.

With respect to within group variability, the group with the conductive hearing impairment is much more homogeneous than the other two groups. The group having a sensorineural hearing impairment with a precipitous drop shows more variability, with respect to speech discrimination, in the unaided condition than in the aided utilizing the four acoustic couplers. In other words, the scores become much more homogeneous under the aided conditions. This is not true for the other two groups.

Reliability

Before considering the differences among the various means obtained in this experiment, it is necessary to examine the reliability of the measures on which these comparisons

Table III.--Means (M), Medians (Med), Standard Deviations (SD), and Ranges of Speech Discrimination Scores* Obtained for Three Groups of Subjects Under One Unaided and Four Aided Conditions

GROUP	LISTENING CONDITION				
	Unaided SF	Conventional	Acoustic Modifier	Open Earpiece	Crimped Tubing
Conductive					
M	95.0	92.6	94.6	93.6	92.2
Med	96	92	95	94	92
SD	2.4	2.5	2.5	3.3	2.9
Range	8	10	8	10	10
Sensorineural (Precipitous)					
M	69.4	76.8	87.2	87.0	88.0
Med	70	75	87	85	87
SD	8.7	5.2	3.9	4.7	4.4
Range	32	17	16	14	14
Sensorineural (Gradual Slope)					
M	79.6	75.0	85.0	80.0	84.8
Med	80	75	88	79	85
SD	10.5	9.3	8.4	10.4	9.8
Range	40	30	30	34	38

*In percent correct.

are to be based. As indicated in Chapter III, the first coupling condition under which a subject was tested was repeated. Since the total number of subjects was 30 and the four coupling conditions were rotated, each coupler was retested a total of either seven or eight times. This yielded test and retest scores for both speech reception thresholds (SRTs) and speech discrimination scores for each subject under one of the coupling conditions.

The Spearman rank-order correlation coefficient was used to investigate the reliability of the repeated measurements in this investigation. The use of this statistic requires that both scores be measured in at least an ordinal scale so that individuals can be ranked in two ordered series.[1] This was achieved for both the test and retest scores of the SRTs and speech discrimination scores, and no further assumptions were necessary for the use of this statistic.

An overall correlation was obtained for both SRTs and speech discrimination scores by combining the test and retest scores for all four couplers across the three groups of subjects. A correlation of .59 was obtained for the SRTs and a .93 for the speech discrimination scores. Although both correlations are significant beyond the .01 confidence level, the correlation for the speech discrimination scores

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[1]Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences (New York: McGraw-Hill Book Company, Inc., 1956), p. 202.

is substantially higher than that of the SRTs. This agrees with the findings of McConnell et al.[1] in their investigation of the test-retest reliability of clinical hearing aid tests. They did an immediate test-retest of the aided speech reception thresholds and speech discrimination scores of 40 hearing impaired subjects using the W-1 spondee words and the W-22 PB words. A Pearson Product Moment Correlation of .67 was obtained for the SRTs and a .83 for the PBs. After a period of two weeks or more aided SRTs and PB scores were again obtained. This time a correlation of .48 was found for the SRTs and .92 for the PBs. McConnell et al. attributed the lower reliability of threshold measurement, in part, to the increased familiarity of the subjects with the test words from test to retest. Tillman and Jerger[2] have also reported such an effect.

Since the speed reception threshold measured in the present study was that intensity level at which a subject responded to only 50 percent of the items, it is reasonable to expect some variation in responses at this point. This also holds true for speed discrimination scores at very low sensation levels as found by Tillman and Carhart[3] in the

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[1]Freeman McConnell, Eileen F. Silber, and Douglas McDonald, "Test-Retest Consistency of Clinical Hearing Aid Tests," Journal of Speech and Hearing Disorders, 25 (1960), pp. 273-280.

[2]Tillman and Jerger, "Some Factors Affecting Spondee Threshold," pp. 141-146.

[3]Tillman and Carhart, "An Expanded Test for Speech Discrimination," pp. 1-12.

development of NU Auditory Test No. 6 and later by Rintelmann and Jetty.[1] In other words, it is not unreasonable to expect lower correlations close to the listener's threshold than when speech audiometric material is presented at high sensation levels.

Further in the present study, an examination of SRTs from the first coupling condition and the repetition of the same condition reveals that SRTs tended to be lower for the repetition. Thus, 18 (60%) subjects had SRTs that were lower for the repeated condition, 6 (20%) subjects obtained the same thresholds, and 6 (20%) had higher thresholds. In other words, a little more than half of the subjects showed improvement in the retest SRT while the remainder of the subjects did not. These results suggest that the familiarity factor was operating in the present study even though the subjects had been familiarized with the spondee words before testing was begun. Another possible explanation is that the subjects became more adept at listening through the CROS hearing aid from test to retest and were thus able to obtain lower thresholds during the retest. Since the aid remained at the same gain setting, it is also possible that some of the subjects became more tolerant of the degree of amplification by the time they had reached the retest condition. At any rate, it appears that some improvement in SRTs occurred in the retest because of familiarity with the task.

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[1]Rintelmann and Jetty, "Reliability of Speech Discrimination," Unpublished Study, Michigan State University, 1968.

Correlation coefficients were also obtained for each of the four acoustic couplers across all three groups of subjects and are displayed in Table IV.

Table IV.--Coefficients of Correlation (Spearman Rank-Order) Between Test and Retest for Each of the Four Acoustic Couplers Across All Three Subject Groups

	ACOUSTIC COUPLERS			
	Conventional (N = 8)	Acoustic Modifier (N = 7)	Open Earpiece (N = 7)	Crimped Tubing (N = 8)
SRT	.96*	.70	.71**	.95*
Speech Discrimination	.90*	.97*	.97*	.91*

*Significant at .01 level.
**Significant at .05 level.

Again, it can be seen that the correlations for the SRTs are somewhat lower for two of the coupling conditions. However, from the array of high positive correlation coefficients, it may be concluded that the speech reception thresholds and speech discrimination scores obtained in this study were sufficiently reliable to allow comparisons from one coupling condition to another to be made with confidence.

Speech Reception Thresholds

In order to test the differences among the mean speech reception thresholds obtained in this investigation, the following null hypothesis was postulated:

> There are no significant differences among the mean aided speech reception thresholds obtained with the conventional earmold, acoustic modifier, open earpiece and crimped polyethylene tubing regardless of the kind of hearing loss or pure-tone, audiometric configuration.

In order to determine the significance of differences among the variables in this comparison, a two factor analysis of variance with repeated measures on one factor was employed.[1] The repeated measures were on acoustic couplers (Couplers). The second factor was subject groups (Groups): the group of subjects with a conductive hearing impairment (Conductives); the group having a sensorineural impairment with a precipitous drop (Sensorineural Precipitous); and the group having a sensorineural impairment with a gradually sloping loss (Sensorineural Gradually Sloping). The two factors were arranged in a two dimensional table of a 4 x 3 design. The four columns represented acoustic coupling conditions, whereas the three rows represented subject groups. The obtained speech reception thresholds were the criterion measures entered in the resulting twelve cells. The F-ratio was used in testing the statistical significance of the variance attributable to the two main effects and the two-way interaction. The analysis of variance was conducted on a Control Data Corporation 3600 Digital Computer.[2]

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[1]B. J. Winer, Statistical Principles in Experimental Design (New York: McGraw-Hill Book Co., 1962), pp. 319-335.

[2]Agricultural Experiment Station, "Stat Series Description No. 14: Analysis of Variance with Equal Frequency in Each Cell," (East Lansing, Michigan State University, 1968).

The mean speech reception thresholds used in the comparison are shown in Table II, page 71, and a summary of the analysis is given in Table V.

Table V.--Summary of Two-Way Analysis of Variance Comparing the Effects of Differences in Kind of Hearing Loss and Type of Acoustic Coupler on Speech Reception Thresholds

Source of Variance	Sum of Squares	DF	Mean Square	F Statistic
Type of Hearing Loss (A)	4799.217	2	2399.608	14.295*
Z=C+AC	4532.250	27	167.861	
Couplers (B)	226.967	3	75.655	16.921*
A x B	125.383	6	20.897	4.674*
Z=ABC+BC	362.150	81	4.471	
Total	10045.967	119		

*Significant beyond the .01 level.

As shown in Table V, the F-statistic was significant beyond the .01 confidence level for the two main factors and the interaction between these two factors. Thus, the null hypothesis of no difference among the means was rejected. A number of observations can be made about the analysis of variance. First, the type of hearing loss affects the speech reception thresholds obtained. Second, the type of acoustic coupler affects the obtained SRTs when considered over the different kinds of hearing loss. Third, there is an interaction between kind of hearing loss and type of acoustic coupler, indicating that the magnitude and direction of the effects of coupler conditions on the SRTs differ according to kind of hearing loss.

The presence of significant interaction indicates possible effects which are due to peculiar combinations of the two variables under consideration. Thus, caution must be used in making predictions from knowledge of only one factor. Hays[1] stated: "When interaction effects exist, the best estimate one can make of a difference attributable to one factor depends on the particular level of the other factor." In other words, in order to predict how well a hearing impaired person will do with a particular acoustic coupler, we must know what kind of hearing loss or pure-tone audiometric configuration he has. Since these factors are usually known before a hearing aid evaluation is attempted, the interaction observed in the present statistical design is only of passing interest and its implications need not be explored further.

The significant F-ratios shown in Table V were investigated by employing Duncan's New Multiple Range Test in a comparison of the treatment means.[2] All means were compared, but the interest of this investigation is concerned with the

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[1]William L. Hays, Statistics for Psychologists (New York: Holt, Rinehart and Winston, 1963), p. 390.

[2]Allen L. Edwards, Experimental Design in Psychological Research (New York: Holt, Rinehart and Winston, 1960), pp. 136-141.

comparison of the treatment means within each group of subjects. The results of the comparison within the conductive group are shown in Table VI.

Table VI.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for SRTs#
Within the Conductive Group

	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	11.0	13.9	12.7	14.1
Conventional Earmold		2.9*	1.7	3.1*
Acoustic Modifier			1.2	0.2
Open Earpiece				1.3

#In dB re speech audiometric zero.
*Significant at .01 level.

From Table VI it can be seen that the mean SRT obtained with the conventional earmold is significantly different statistically from that obtained with the acoustic modifier and the crimped polyethylene tubing. The differences of about 3 dB are in the direction of a lower mean SRT with the conventional earmold, and although the difference was not statistically significant, the mean SRT with the conventional earmold was also lower than with the open earpiece by about 2 dB. The mean SRTs obtained with the acoustic modifier, open earpiece, and crimped tubing were not significantly different from one another.

The tendency for SRTs within the conductive group to be somewhat lower with the conventional earmold can be understood in terms of the amount of sound pressure developed in the ear canal. An examination of the mean audiogram (Figure 1, page 46) for this group reveals that the loss of hearing sensitivity is greater for the lower frequencies. The longer tip on the conventional earmold allows greater sound pressure to be developed in the ear canal at low frequencies, whereas with the modified couplers the sound pressure is reduced at the lower frequencies due to venting and an increase in the size of the cavity between the earmold and the tympanic membrane. Lybarger[1] stated that a reduction in the size of this cavity by an earmold tip would produce an improvement in low-frequency output of about 3 dB. Greater lower frequency output could also be expected if the effects of leakage are reduced. Thus, in the present study, a combination of the above factors were probably working to enhance the sound presure developed in the ear canal with the conventional earmold resulting in lower SRTs.

The results of Duncan's New Multiple Range Test, employed in investigating significant differences among mean SRTs within the sensorineural precipitous drop group, are shown in Table VII.

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[1]Lybarger, "Earmold Acoustics," p. 4.

Table VII.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for SRTs#
Within the Sensorineural Precipitous Drop Group (.01 Significance Level)

	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	14.5	14.8	12.5	14.7
Conventional Earmold		0.3	2.0	0.2
Acoustic Modifier			2.3	0.1
Open Earpiece				2.2

#In dB re speech audiometric zero.
*Significant at .01 level.

From Table VII, it can be seen that there were no statistically significant differences at the .01 confidence level among the mean SRTs for this group. In contrast to the conductive group, and examination of the mean audiogram (Figure 2, page 48) for this group reveals normal hearing in the low frequencies with a hearing loss for the high frequencies. Since thresholds were already within the normal range, the increase in sound pressure in the ear canal offered by the conventional earmold was not great enough to lower the threshold significantly from those obtained with the modified couplers. Another possible explanation may be hypothesized from the discrimination scores obtained from this group.

Table III shows that this group obtained significantly higher mean discrimination scores when the modified earpieces were employed. Since the discrimination function does play a part in determining threshold with spondee words, it is quite possible that the improved discrimination obtained with the modified couplers was enough to offset any advantage in greater sound pressure at the low frequencies offered by the conventional earmold.

The results of Duncan's New Multiple Range Test applied to the differences among the mean SRTs within the sensorineural gradually sloping group are displayed in Table VIII.

At the .01 confidence level, Table VIII shows that the mean SRT obtained with the conventional earmold was significantly different from the mean SRTs obtained with the acoustic modifier and the crimped tubing. Again, these differences of 4.5 dB for the acoustic modifier and 6.7 dB for the crimped tubing are in the direction of a lower mean SRT with the conventional earmold, and although not significant at the .01 confidence level, the mean SRT for the conventional earmold was 2 dB lower than with the open earpiece.

Table VIII also shows that the mean SRT obtained with the open earpiece was significantly lower (4.7 dB) than that obtained with the crimped tubing. The largest difference (6.7 dB) was found between the conventional earmold where the ear canal is completely sealed and the crimped tubing where it is open. The mean audiogram (Figure 3, page 49) for this

Table VIII.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for SRTs Within the Sensorineural Gradually Sloping Group

	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	23.6	28.1	25.6	30.0
Conventional Earmold		4.5*	2.0**	6.7*
Acoustic Modifier			2.5**	2.2**
Open Earpiece				4.7*

#In dB re speech audiometric zero.

*Significant at .01 level.

**Significant at .05 level.

group shows a loss of hearing sensitivity in the low frequencies as well as in the higher frequencies. Again, the tendency for SRTs to be lower with the conventional earmold can be explained by the greater sound pressure obtained in the low frequencies with the conventional earmold. Since with this group there is a loss of hearing sensitivity for the low frequencies, there is greater dependency of the SRT on the amount of sound pressure in the ear canal at these frequencies than is the case with the sensorineural precipitous drop group where low frequency thresholds are normal. Although both the conductive group and the sensorineural gradually sloping group obtained lower mean SRTs with the conventional earmold as opposed to the modified couplers, the differences are greater for the sensorineural gradually sloping group. This outcome may be explained in terms of the discrimination scores obtained with these groups. An examination of Table III, shows that the mean speech discrimination scores for the sensorineural gradually sloping group are lower under all listening conditions than those of the conductive group. Since the SRT is somewhat dependent on discrimination ability, the poorer speech discrimination of this group does not allow as much compensation for the loss of sound pressure at the low frequencies as is the case with the conductive group.

When the .05 confidence level is considered, then all of the means for the sensorineural gradually sloping group are significantly different from one another. There is apparently more variability within this group than within the other two groups. This variability is attested to by the larger standard deviations obtained with each of the acoustic couplers for this group as shown in Table II.

Speech Discrimination Scores

In order to test the differences among the mean speech discrimination scores obtained in this investigation, the following null hypothesis was postulated:

> There are no significant differences among the mean speech discrimination scores obtained under all listening conditions regardless of the kind of hearing loss or pure-tone, audiometric configuration.

The analysis of variance for the mean speech discrimination scores was the same design as for the SRTs except that the mean unaided sound-field speech discrimination scores were added to the listening condition factor (Couplers). This resulted in a two dimensional table of a 5 x 3 design. The five columns represented the coupling conditions, whereas the three rows represented subject groups. The obtained speech discrimination scores (means) were the criterion measures entered in the resulting 15 cells, and the F-ratio was used in testing the statistical significance of the variance attributable to the two main effects and the two-way interaction.

The mean speech discrimination scores used in the comparison are shown in Table III, and a summary of the analysis is given in Table IX.

As shown in Table IX, the F-statistic was significant beyond the .01 confidence level for the two main factors and the interaction between these two factors. Thus, the null hypothesis of no differences among the mean speech discrimination scores was rejected.

Again, a number of observations can be made about the analysis of variance. First, the type of hearing loss affects the obtained speech discrimination scores. Second, the type of acoustic coupler affects the obtained speech discrimination scores when considered over the different kinds of hearing loss. Third, there is an interaction between kind of

Table IX.--Summary of Two-Way Analysis of Variance Comparing the Effects of Differences in Kind of Hearing Loss and Type of Acoustic Coupler on Speech Discrimination Scores

Source of Variance	Sum of Squares	DF	Mean Square	F Statistic
Type of Hearing Loss(A)	5075.413	2	2537.707	17.787*
Z = C + AC	3852.160	27	142.672	
Couplers(B)	1657.440	4	414.360	15.526*
A x B	1828.320	8	228.540	8.563*
Z = ABC + BC	2882.240	108	26.687	
Total	15295.573	149		

*Significant beyond the .01 level.

hearing loss and type of acoustic coupler, indicating that the magnitude and direction of the effects of coupling conditions on the speech discrimination scores differ for the different kinds of hearing loss. The observed interaction is not of any important concern in this study for the same reasons discussed earlier for the SRTs.

The significant F-ratios shown in Table IX were further investigated by employing Duncan's New Multiple Range Test in a comparison of the differences between treatment means.[1] All means were compared, but the interest of this investigation was concerned with the comparison of the treatment means

[1]Edwards, Experimental Design in Psychological Research, pp. 136-141.

within each group of subjects. The results of the comparison within the conductive group are shown in Table X.

Table X.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for Speech Discrimination Scores# Within the Conductive Group

	Unaided SF	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	95.0	92.6	94.6	93.6	92.2
Unaided SF		2.4	0.4	1.4	2.8
Conventional Earmold			2.0	1.0	0.4
Acoustic Modifier				1.0	2.4
Open Earpiece					1.4

#In percent correct.
*Significant at .01 level.

As indicated in Table X, the mean speech discrimination scores obtained under all of the listening conditions were not significantly different statistically from one another at the .01 confidence level. Normal speech discrimination is usually found with conductive impairments, and evidently the acoustic couplers utilized in this study had no adverse effects on this discrimination ability.

The results of Duncan's New Multiple Range Test applied to the differences between the mean speech discrimination scores within the sensorineural precipitous drop group are displayed in Table XI.

Table XI.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for Speech Discrimination Scores Within the Sensorineural Precipitous Drop Group

	Unaided SF	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	69.4	76.8	87.2	87.0	88.0
Unaided SF		7.4*	17.8*	17.6*	18.6*
Conventional Earmold			10.4*	10.2*	11.2*
Acoustic Modifier				0.2	0.8
Open Earpiece					1.0

#In percent correct.
*Significant at .01 level.

Table XI shows that the mean aided speech discrimination scores were all significantly higher than the mean unaided scores at the .01 confidence level. The 7.4 percent higher discrimination score obtained with the conventional earmold over the unaided sound-field indicates that there may be a certain amount of frequency-response tilting occurring with the combination of the conventional earmold and the CROS hearing aid. Again, referring to the mean audiogram

(Figure 2, page 48) for this group, it can be seen that the greatest loss of hearing sensitivity for the important speech range occurs from 1000 to 4000 Hertz. An examination of Figure 5, page 57 showing the frequency response of the hearing aid used in this study, reveals that it is precisely those frequencies at which the hearing loss is greatest that the aid yields the greatest amount of amplification. Thus, it appears that the pure-tone audiometric configuration of this group in combination with an aid, which gave greater amplification in the mid frequencies yielded a statistically significant increase in the mean speech discrimination score over that obtained unaided in a sound-field.

From Table XI, it can also be seen that the mean speech discrimination scores obtained with the modified acoustic couplers were all significantly higher than the mean discrimination score obtained with the conventional earmold. This outcome is a reasonable expectation when it is remembered that the conventional earmold, much like a low-pass filter, transmits low frequency sounds to the tympanic membrane without a reduction in their strength. At the same time the strength of high frequency sounds is reduced by the long narrow channel tip of the conventional earmold. A person with a sensorineural precipitous drop hearing loss experiences a discrimination problem because of the sharp difference between his hearing sensitivity for low frequency sounds and his sensitivity for high frequency sounds. When amplification is used in conjunction with a conventional earmold the low frequencies partially mask the high frequencies. However, all of the modified acoustic couplers utilized in the present study provided a means for the low frequency sounds to escape to the outside atmosphere, and they had no long channel tips to reduce the high frequency transmission. Thus, when these modified couplers were used in conjunction with a CROS hearing aid, the subjects in this group obtained higher speech discrimination scores than with both the unaided condition and the conventional coupler condition.

The mean speech discrimination scores obtained with the acoustic modifier, open earpiece, and crimped tubing were not significantly different from one another. Evidently the varying degrees to which the ear canal was left unoccluded by these couplers was not great enough from one coupler to another to index any difference in discrimination ability, at least within the limitations of the present experiment.

The results of Duncan's New Multiple Range Test applied to the differences between the mean speech discrimination scores within the sensorineural gradually sloping group are displayed in Table XII.

As indicated in Table XII, at the .01 confidence level the mean unaided sound-field speech discrimination score is not significantly different from any of the mean aided scores. However, the mean speech discrimination scores obtained with the acoustic modified and crimped tubing are significantly

Table XII.--Duncan's New Multiple Range Test Applied to the Differences Between Treatment Means for Speech Discrimination Scores# Within the Sensorineural Gradually Sloping Group

	Unaided SF	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Means	79.6	75.0	85.0	80.0	84.8
Unaided SF		4.6	5.4**	0.4	5.2**
Conventional Earmold			10.0*	5.0	9.8*
Acoustic Modifier				5.0**	0.2
Open Earpiece					4.8**

#In percent correct.

*Significant at .01 level.

**Significant at .05 level.

higher than the mean score obtained with the conventional earmold. This occurred because the mean score with the conventional earmold was somewhat lower than the mean unaided sound-field score increasing the magnitude of the distance between the mean score obtained with the conventional earmold and those obtained with the acoustic modifier and crimped tubing.

When the results are considered at the .05 confidence level, then the mean unaided speech discrimination score is significantly lower than the mean scores obtained with the acoustic modifier and crimped tubing. Also at this level of confidence, the mean scores obtained with the acoustic modifier and crimped tubing are significantly higher than the mean score obtained with the open earpiece. The mean speech discrimination scores obtained with the acoustic modifier and crimped tubing are not significantly different from one another.

It is evident that the high frequency emphasis provided by the modified acoustic couplers does provide somewhat improved speech discrimination with sensorineural hearing losses having a gradually sloping loss of five to ten dB per octave. However, there is greater variability within this group than in the other two groups studied, and modified acoustic couplers cannot be used indiscriminately since not all subjects obtained better speech discrimination scores with them.

Clinical Significance

In this section the mean differences in the data and their clinical implications are discussed. However, before clinical differences are considered it is necessary to determine what constitutes a clinically significant difference for both the SRTs and speech discrimination scores.

Tillman and Carhart[1] in investigating the SRTs of a group of ten subjects with normal hearing found thresholds to be within four to five dB from test to retest. The SRTs

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[1]Tillman and Carhart, "Some Factors Affecting the Spondee Threshold," p. 145.

tended to be lower for the retest, a result which the authors attributed to word familiarity. McConnell, Silber, and McDonald[1] studied the reliability of clinical hearing aid tests. The hearing aid worn during the retest was the same model but not the same aid as on the first test. They found that differences in SRTs were six dB or less on the second test for 25 of the 37 subjects studied. Chaiklin and Ventry[2] compared 2-dB and 5-dB methods of obtaining SRTs and found that for the 2-dB method 27 (93%) subjects out of 29 had test-retest differences from 0 dB to plus or minus 6 dB. While for the 5-dB method all subjects had test-retest differences within plus or minus 5 dB. Prior to beginning the present study, Rintelmann and Jetty[3] obtained test-retest SRTs while examining the list equivalency of a magnetic tape recording of N.U. Auditory Test No. 6. Ten young adults with normal hearing served as subjects, and speech reception thresholds were measured with the same tape recorded spondee words used in the present study. At least one week intervened between the first and second tests, and it was found that all subjects had test-retest differences in SRTs no greater than 4 dB.

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[1]McConnell, Silber, and McDonald, "Test-Retest Consistency," p. 279.

[2]Joseph B. Chaiklin and Ira M. Ventry, "Spondee Threshold Measurement: A Comparison of 2- and 5-dB Methods," Journal of Speech and Hearing Disorders, (1964), pp. 47-59.

[3]Rintelmann and Jetty, "Reliability of Speech Discrimination Testing," Unpublished Study.

From the foregoing studies it can be concluded that test-retest differences in SRTs will usually range from 0 to 6 dB. Thus, for the present study a difference in SRT of greater than 6 dB was considered to be clinically significant.

To establish what constituted a clinically significant difference in speech discrimination scores, information from the preliminary list equivalency study of N.U. Auditory Test No. 6, mentioned above, was used. The results of this study at a 24 dB sensation level are given in Appendix A. The greatest difference in mean discrimination scores from test to retest was 3 percent for list III. The standard errors of measurement for the four lists ranged from 2.82 percent to 4.51 percent with a mean standard error of measurement across all lists of 3.52 percent. From this information it was concluded that for the purpose of this study a difference in a discrimination score of greater than 4 percent would be considered a clinically significant difference.

In order to facilitate the discussion in this section, the mean SRTs obtained under the various listening conditions for the three groups are shown in Table XIII.

Speech reception thresholds under earphones for the conductive group ranged from 14 to 57 dB with a mean SRT of 42 dB for the right ear and 37.1 dB for the left ear. The unaided sound-field SRTs ranged from 26 to 56 dB with a mean SRT of 35.6dB. Referring to Table XIII, a comparison of the

Table XIII.--Mean Speech Reception Thresholds* Obtained for Three Groups of Subjects Under One Unaided and Four Aided Listening Conditions

GROUP	LISTENING CONDITION				
	Unaided SF	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Conductive	35.6	11.0	13.9	12.7	14.1
Sensorineural (Precipitous)	23.8	14.5	14.8	12.5	14.7
Sensorineural (Gradual Slope)	45.7	23.6	28.1	25.6	30.3

*In dB re speech audiometric zero.

unaided scores to the aided for the conductive group reveals that significantly lower SRTs were obtained in the aided conditions with all four acoustic couplers. Intercoupler differences in SRTs were not clinically significant, and the small existing differences could probably be overcome by adjusting the gain control of the hearing aid. This is an important outcome, since it reveals that any of the various acoustic couplers can be utilized with persons having conductive hearing impairments with comparable results concerning SRT.

Speech reception thresholds under earphones for the sensorineural precipitous drop group ranged from 5 to 47 dB with a mean SRT of 24.4 dB for the right ear and 24.6 dB for the left ear. The unaided sound-field SRTs ranged from 8 to 42 dB with a mean SRT of 23.8 dB. Referring to Table XIII again, comparison of these thresholds to the aided thresholds reveals significantly lower SRTs for this group. This is important, since it shows that the SRTs offer no contraindication to the use of modified acoustic couplers with persons having sensorineural hearing losses with precipitous drops beyond 500 or 1000 Hertz.

For the sensorineural gradually sloping group, the speech reception thresholds under earphones ranged from 29 to 66 dB with a mean SRT of 47.1 dB for the right ear and 50.5 dB for the left ear. The unaided sound-field SRTs ranged from 30 to 56 dB with a mean SRT of 45.7 dB. This group had the greatest loss of hearing sensitivity and, as shown in Table XIII although the aided mean SRTs are lower than the unaided, they are not as low as those obtained with the other two groups. Intercoupler variability was also greater within this group. The mean SRT obtained with the conventional earmold was 6.7 dB lower than that obtained with the crimped tubing. This is a clinically significant difference and indicates that caution must be used in recommending the use of crimped tubing with individuals who have a loss of hearing sensitivity in the low frequencies, since the lack of sufficient sound pressure developed in the ear canal at low frequencies seriously affects the SRT.

The mean speech discrimination scores obtained under the various listening conditions for all three groups are shown in Table XIV.

Speech discrimination scores under earphones for the conductive group ranged from 86 to 100 percent with a mean score of 93.6 percent for the right ear and 95.6 percent for the left ear. A comparison of these scores with those shown in Table XIV reveals no significant differences between the mean unaided scores under earphones and the mean unaided sound-field. There are also no significant differences between the mean unaided and mean aided scores nor among the mean scores obtained with the various acoustic couplers. Since there were also no significant differences among the

Table XIV.--Mean Speech Discrimination Scores* Obtained for Three Groups of Subjects Under One Unaided and Four Aided Listening Conditions

GROUP	LISTENING CONDITION				
	Unaided SF	Conventional Earmold	Acoustic Modifier	Open Earpiece	Crimped Tubing
Conductive	95.0	92.6	94.6	93.6	92.2
Sensorineural (Precipitous)	69.4	76.8	87.2	87.0	88.0
Sensorineural (Gradual Slope)	79.6	75.0	85.0	80.0	84.8

*In percent correct.

mean aided SRTs for this group, it appears that persons with conductive hearing losses can be fitted with any of the types of couplers used in this study, and personal preference or type of hearing aid may dictate the one chosen.

Each subject within the conductive group was asked for his subjective preference for the various acoustic couplers. Five subjects preferred the conventional earmold, two preferred the crimped tubing, one preferred the acoustic modifier, one preferred the conventional earmold and open earpiece equally, and one preferred the open earpiece and crimped tubing equally. The fact that the conventional earmold was preferred by half the subjects may be due to the loss of hearing sensitivity in the low frequencies found in this group. Amplification through the conventional earmold may sound more natural, since the low frequencies are not filtered out. However, since the crimped tubing was preferred by some subjects and since it yielded mean SRTs and speech discrimination scores which were not significantly different from the mean scores obtained with the other couplers, it could conceivably be used with some people having conductive hearing losses. It may be possible to utilize the crimped tubing in conjunction with a CROS type hearing aid with conductive losses having a chronic drainage problem, since the crimped tubing in no way occludes the ear canal.

Speech discrimination scores under earphones for the sensorineural precipitous drop group ranged from 38 to 78 percent with a mean score of 59.6 percent for the right ear and 57.6 percent for the left ear. A comparison of these scores with those shown in Table XIV reveals that there is a significant improvement in the mean speech discrimination score obtained unaided in the sound-field from that obtained under earphones. There is also a significant mean improvement under all of the aided conditions as opposed to the mean unaided sound-field score. With the conventional earmold the mean speech discrimination score was 7.4 percent higher than the mean unaided sound-field score. The reasons for this difference were discussed above under the statistical results for this group. With the modified acoustic couplers, the increase in the mean discrimination scores from the mean unaided sound-field are even more substantial, 17.8 percent for the acoustic modifier, 17.6 percent for the open earpiece, and 18.6 percent for the crimped tubing. A comparison of the mean discrimination score obtained with the modified acoustic couplers to the mean score obtained with the conventional earmold shows a 10.4 percent increase for the acoustic modifier, 10.2 percent for the open earpiece, and 11.2 percent for the crimped tubing. These are all clinically significant differences and indicate that the high frequency emphasis provided by these couplers is probably an important factor in the improved speech discrimination scores for this group.

There were no significant differences among the mean discrimination scores obtained with the modified acoustic couplers employed in this study. Evidently the degree to which the high frequency emphasis was changed from coupler to coupler was not great enough to make significant differences in the mean discrimination scores obtained with the sensorineural precipitous drop group. Of interest also is the fact that no subject obtained a better discrimination score with the conventional earmold as opposed to any of the modified acoustic couplers. This would seem to underscore the importance of utilizing modified acoustic couplers during hearing aid evaluations with persons showing audiometric patterns similar to the subjects in this group.

As for subjective coupler preference within the sensorineural precipitous drop group, five subjects preferred the acoustic modifier, two preferred the crimped tubing, one preferred the open earpiece, one preferred the conventional earmold and acoustic modifier equally, and one had no preference. Thus, the subjective preference of this group for the modified acoustic couplers was almost unanimous.

Summarizing the results for the sensorineural precipitous drop group, there were no significant differences among the mean SRTs obtained with the various acoustic couplers, mean speech discrimination scores were significantly improved with the modified couplers, and they were subjectively preferred over the conventional earmold by

9 out of the 10 subjects in this group. These results suggest the clinical importance of utilizing the modified couplers with persons having a high frequency hearing loss with normal hearing in the low frequencies.

For the sensorineural gradually sloping group, speech discrimination scores under earphones ranged from 36 to 90 percent with a mean score of 73.6 percent for the right ear and 67.4 percent for the left ear. A comparison of these scores with those shown in Table XIV reveals that the mean unaided sound-field discrimination score is somewhat higher than the mean scores obtained under earphones. Unlike the other two groups, however, the mean speech discrimination score obtained aided utilizing the conventional earmold is 4.6 percent lower than the unaided sound-field score. This, in effect, increased the magnitude of the difference between the mean speech discrimination score obtained with the conventional earmold and those obtained with the modified acoustic couplers. The mean discrimination score obtained with the acoustic modifier was 10 percent higher, with the open earpiece it was 5 percent higher, and with the crimped tubing it was 9.8 percent higher. These differences are all clinically significant according to the definition employed at the beginning of this section.

Comparing the mean speech discrimination scores obtained with the modified acoustic couplers to the mean score obtained unaided in the sound-field reveals that there was a 5.4 percent higher score for the acoustic modifier and 5.2 percent for the crimped tubing, both of which are clinically significant differences. There was essentially no difference between the unaided sound-field discrimination score and the one obtained with the open earpiece.

Subjective acoustic coupler preference for the sensorineural gradually sloping group showed that five subjects preferred the crimped tubing, three preferred the acoustic modifier, one preferred the conventional earmold and acoustic modifier equally, and one subject had no preference. It is interesting to note that half the subjects preferred the crimped tubing even though the mean SRT was significantly higher with this coupler than with the conventional earmold. However, this choice is not difficult to understand if it is based on the person's feeling that the words were more clear, since the mean speech discrimination score obtained with the crimped tubing was significantly higher than that obtained with the conventional earmold. The speech discrimination task was always presented at a 26 dB sensation level so that the words were at the same level across couplers. Another factor which may have influenced the preference of acoustic couplers was the fact that the speech discrimination task was always presented after obtaining the SRT, and then after both of these tests the person was asked to state his preference. Thus, it is very probable that the preference was based on the discrimination task and not on the spondee task.

A summary of the sensorineural gradually sloping group results indicates that mean SRTs may be significantly higher when the acoustic modifier and crimped tubing are utilized as acoustic couplers. However, mean speech discrimination scores obtained with all the modified couplers also tend to be significantly higher than the mean score obtained with the conventional earmold. Variability within this group was greater than in the other two, and an examination of individual scores within the group reveals that not all subjects received significantly higher SRTs with the modified acoustic couplers and, by the same token, not all received higher speech discrimination scores with the modified couplers. Thus, it appears that caution must be used in recommending modified couplers to those patients evidencing a gradually sloping audiometric pattern.

CHAPTER V

SUMMARY AND CONCLUSIONS

The basic purpose of this research was to evaluate the effects of the acoustic coupler on the aided speech reception thresholds and speech discrimination scores of hard-of-hearing subjects. The effects of the kind of hearing loss and pure-tone audiometric configuration were also investigated.

Summary

A CROS type hearing aid utilizing a conventional, vented, open earpiece, and crimped polyethylene tubing was employed in obtaining speech reception thresholds and speech discrimination scores for three groups of hard-of-hearing adults. Group I was composed of ten subjects with a conductive hearing impairment. Group II consisted of ten subjects having a sensorineural hearing loss with normal hearing in the low frequencies and a precipitous drop for frequencies higher than 500 or 1000 Hertz. Group III was composed of subjects having a gradually sloping, (5 to 10 dB per octave) sensorineural type hearing loss. Pure-tone air and bone conduction thresholds were obtained prior to the speech tests. Speech reception thresholds and speech discrimination scores were obtained in the sound-field under unaided and aided conditions while the nontest ear was occluded by a wax impregnated ear plug. All subjects were tested with the same CROS hearing aid at a gain setting of 35 dB re the HAIC method of determining gain. All speech discrimination scores were obtained at a 26 dB sensation level. Retest discrimination scores and SRTs were obtained on all subjects for a single aided condition.

Results indicated that for Group I, the mean speech reception threshold was significantly lower with the conventional earmold than with the modified couplers. The mean aided speech discrimination scores showed no significant differences from the mean unaided score nor were there significant differences among the means obtained with the four acoustic couplers in the aided condition.

For Group II, there were no significant differences among the mean speech reception thresholds obtained with the various acoustic couplers. The mean speech discrimination score was significantly improved under the aided conditions. The mean unaided speech discrimination score was 69.4 percent in comparison to a mean aided score of 76.8 percent utilizing the conventional earmold. Thus, a gain of 7.4 percent was achieved. The mean speech discrimination score of the modified couplers combined was 87.3 percent, a gain of 17.9 percentage points over the mean unaided sound-field condition and 10.5 percentage points over the mean score yielded by the conventional earmold. There were essentially no intercoupler differences in the mean speech discrimination scores obtained with the three types of modified acoustic couplers.

The mean speech reception threshold for Group III, utilizing the conventional earmold was 4.5 dB lower than that obtained with the acoustic modifier and 6.7 dB lower than the mean speech reception threshold obtained with the crimped tubing. Although not statistically significant, the mean speech reception threshold obtained with the conventional earmold was also 2 dB lower than with the open earpiece. When the .05 confidence level was considered, then all of the means were significantly different from one another probably due to the greater variability found within this group. Group III had a mean unaided speech discrimination score of 79.6 percent and a mean aided score utilizing the conventional earmold of 75.0 percent. Thus, a loss of 4.6 percent was found. The mean discrimination score obtained with the acoustic modifier was 85.0 percent, which was a gain of 5.4 percent over the mean unaided sound-field score and a 10 percent gain over the mean obtained with the conventional earmold. The mean discrimination score obtained with the open earpiece was 80.0 percent, which was not significantly different from the mean unaided sound-field score but was a 5 percent gain over the mean discrimination score yielded by the conventional earmold.

The crimped tubing yielded a mean discrimination score of 84.8 percent, which was an increase of 5.2 percent over the mean unaided sound-field score and an increase of 9.8 percent over the mean discrimination score obtained with the conventional earmold.

Conclusions

Within the limitations of the present study, the following conclusions appear warranted:

1. Persons with conductive hearing impairments tend to obtain lower aided speech reception thresholds with the conventional earmold than with the acoustic modifier, open earpiece, or crimped tubing. This outcome is probably due to greater sound pressure being developed in the ear canal at the low frequencies with the conventional earmold.

2. There are no significant intercoupler differences in aided speech reception thresholds obtained with the acoustic modifier, open earpiece, and crimped tubing for persons with a conductive hearing impairment.

3. There are no significant intercoupler effects on the aided speech discrimination scores obtained for persons with a conductive hearing impairment.

4. The modified acoustic couplers can be successfully employed with persons having a conductive hearing impairment provided that sufficient gain (satisfactory SRT) is achieved.

5. There are no significant intercoupler differences among the aided speech reception thresholds of persons having sensorineural hearing losses with precipitous drops.

6. Significantly better aided speech discrimination scores are obtained with the acoustic modifier, open earpiece, and crimped tubing than with the conventional earmold by persons having a sensorineural hearing loss with a precipitous drop.

7. There are no significant intercoupler differences in aided speech discrimination scores obtained with the acoustic modifier, open earpiece, and crimped tubing by persons having a sensorineural hearing loss with a precipitous drop.

8. Modified acoustic couplers can be successfully used by persons having sensorineural hearing losses with a precipitous drop. Because of the significant improvement in speech discrimination scores offered by these couplers, they should be used routinely in hearing aid evaluations with persons showing this particular pure-tone audiometric configuration.

9. Aided speech reception thresholds obtained with the conventional earmold are significantly lower than with the acoustic modifier, open earpiece, and crimped tubing for persons having a gradually sloping sensorineural hearing impairment.

10. Aided speech discrimination scores tend to be better with the acoustic modifier, open earpiece, and crimped

tubing than with the conventional earmold for persons having a gradually sloping sensorineural hearing impairment.

11. Modified acoustic couplers can be employed successfully with sensorineural hearing impairments showing a gradually sloping audiometric configuration, but caution is indicated, since there appears to be greater variability among persons showing this audiometric pattern.

12. In general, the conventional earmold is subjectively preferred by half of the persons having conductive hearing impairments; whereas, the other half of this group of subjects prefers modified earpieces. On the other hand, persons with sensorineural hearing losses almost unanimously prefer modified acoustic couplers.

13. Modified acoustic couplers used in conjunction with the CROS principle of amplification are valuable in fitting hearing aids to clinical cases with various kinds of hearing losses and pure-tone audiometric configurations.

Recommendations for Further Research

The present study should be repeated in a background of noise. Various types of noise such as broadband white noise, speech noise, and speech babble could be used. This might prove to be a way of indexing any differences that may exist among the various types of modified acoustic couplers that were not evidenced in the present study with the group having a sensorineural hearing loss with a precipitous drop for frequencies higher than 500 or 1000 Hertz.

Further investigation should be made of the effects of different kinds of hearing aids used in conjunction with the modified acoustic couplers. This should include hearing aids having different frequency response characteristics such as low or high frequency emphasis, since certain combinations of frequency response and acoustic couplers may prove to be beneficial as far as improved speech discrimination is concerned.

Methods should be explored whereby the response characteristics of a hearing aid can be measured when it is terminated by various acoustic couplers. When such methods are devised, then the electro-acoustical characteristics of the hearing aid could be related to the clinical results obtained with persons having various kinds of audiometric configurations. Perhaps, with the use of a coupler simulating the human ear canal, measurements could be made to determine any changes in frequency response when the closed canal is compared to measurements made with the open canal. This would give a better understanding of the change in the frequency response characteristic as influenced by various acoustic couplers.

The optimum length of crimped polyethylene tubing penetration for comfort and maximum benefit needs to be examined if this type of acoustic coupler is to receive further clinical use.

Because of the variability found within the sensorineural gradually sloping group in the present study, further investigation should be made of the effects of modified acoustic couplers with subjects showing this type of audiometric configuration.

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APPENDICES

APPENDIX A

RESULTS OF RESEARCH PROJECT WITH N.U. AUDITORY TEST NO. 6

Prior to beginning the present study, the reliability of speech discrimination testing using CNC monosyllabic words was investigated by Rintelmann and Jetty.[1] The purposes of this study were to confirm the results obtained by Tillman and Carhart[2] and to determine if comparable results would be obtained when the words were spoken by a different speaker.

The four lists comprising N.U. Auditory Test No. 6 were recorded on magnetic tape by a male speaker with a General American dialect who monitored his vocal output by means of a VU-meter. The carrier phrase, "You will say" preceded each test word. The last word of the carrier phrase was monitored and the CNC word was said naturally. The speaker was located in an IAC room and the words were recorded on an Ampex, model AG350-1 console type tape recorder.

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[1]Rintelmann and Jetty, "Reliability of Speech Discrimination Testing Using CNC Monosyllabic Words," Unpublished Study, Michigan State University, 1968.

[2]Tillman and Carhart, "An Expanded Test for Speech Discrimination," pp. 1-12.

Ten young adults with normal hearing served as subjects and the test-retest procedures employed were those outlined by Tillman and Carhart. Each of the four lists was presented to the subjects at six sensation levels (-4, 0, 8, 16, 24, and 32 dB) relative to the speech reception threshold obtained with recorded spondee words. At least one week intervened between the test and retest.

The results obtained were comparable to those found by Tillman and Carhart with normal hearing subjects. Only the statistical data at the 24dB sensation level are given in Tables XV through XVIII, since it is the level closest to the 26 dB sensation level used in the present study.

Table XV.--Median (Med), Mean (M), and Standard Deviations (SD) of Speech Discrimination Scores Obtained with N.U. Auditory Test No. 6 at a 24 dB Sensation Level for Ten Subjects with Normal Hearing During the First Test Session. (Scores Represent Percent of Items Correctly Repeated)

	List I	List II	List III	List IV
Med	93	94	85	91
M	92.2	93.0	87.4	92.0
SD	3.5	4.1	4.6	3.7

Table XVI.--Median (Med), Mean (M), and Standard Deviations (SD) of Speech Discrimination Scores Obtained with N.U. Auditory Test No. 6 at a 24 dB Sensation Level for Ten Subjects with Normal Hearing During the Retest Session. (Scores Represent Percent of Items Correctly Repeated)

	List I	List II	List III	List IV
Med	94	93	92	95
M	93.4	92.6	90.4	94.4
SD	3.6	3.1	4.7	2.8

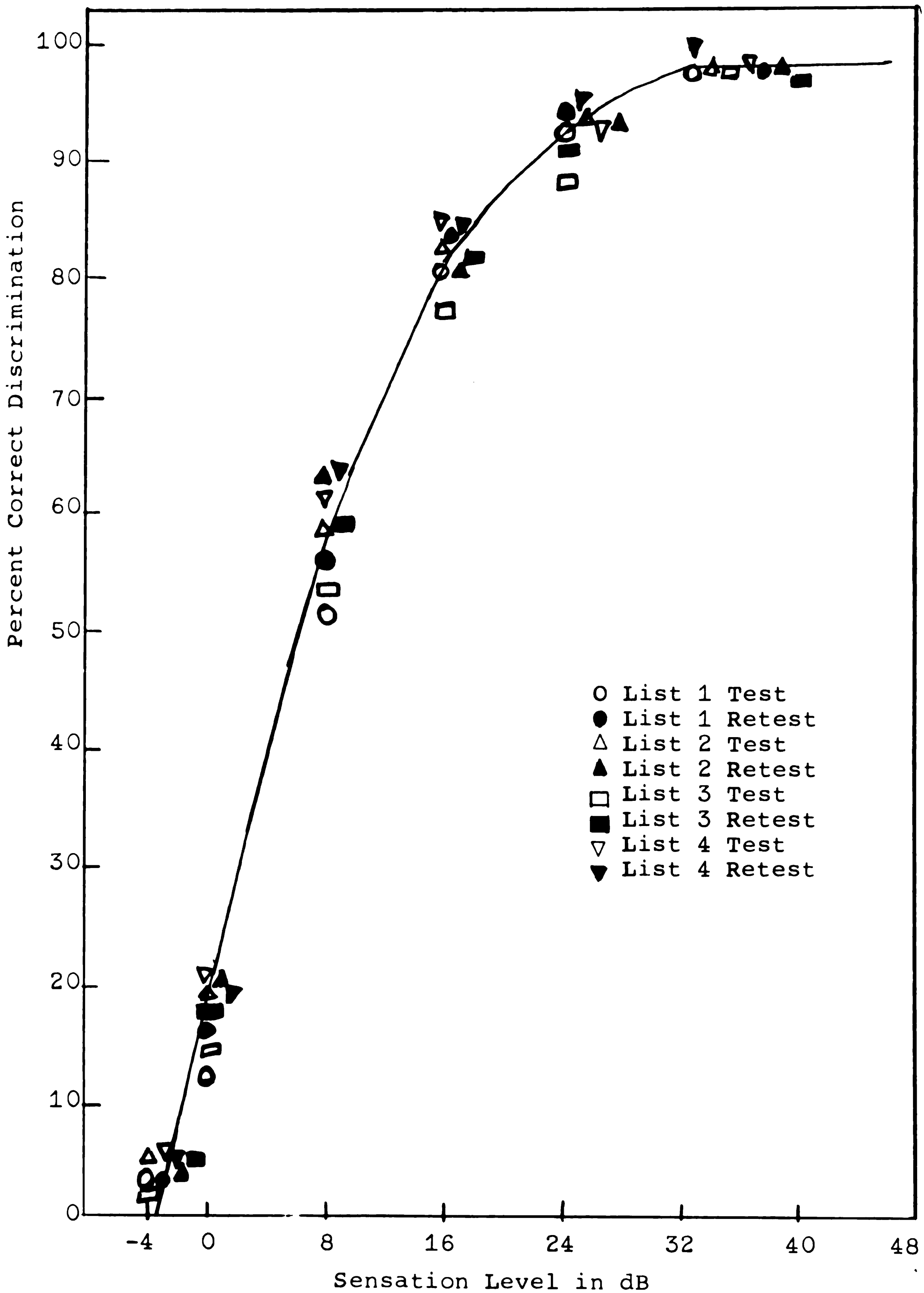
Table XVII.--Difference Between Mean Discrimination Scores From Test to Retest at a 24 dB Sensation Level for Ten Normal Hearing Subjects on N.U. Auditory Test No. 6 (Negative Difference Indicates Higher Score in Retest than in Test Session)

List I	List II	List III	List IV
-1.2	0.4	-3.0	-2.4

Table XVIII.--Coefficients of Correlation (Pearson r) and Standard Error of Measurement (S_e) Between Test and Retest for N.U. Auditory Test No. 6 Administered to Ten Subjects With Normal Hearing at a 24 dB Sensation Level

	List I	List II	List III	List IV
r	.71	.75	.74	.73
S_e	2.96	2.82	4.51	3.79

Figure 7.--Mean discrimination scores yielded by ten normal hearing subjects for Lists I, II, III, and IV of N.U. Auditory Test No. 6 during both test and retest sessions.



APPENDIX B

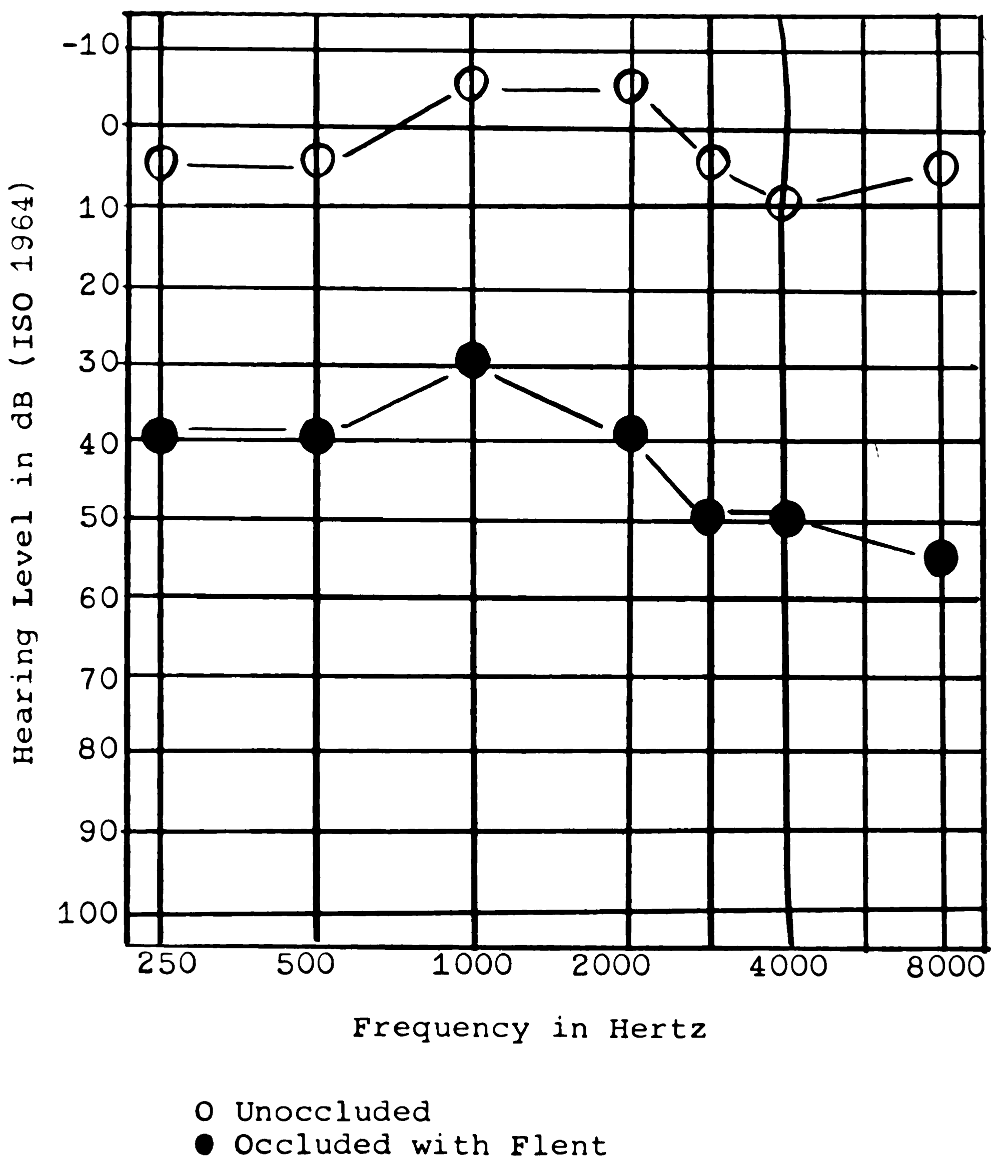
ATTENUATION PROVIDED BY WAX IMPREGNATED EAR PLUGS (FLENTS) FOR PURE TONES AND FOR SPONDEE WORDS

Prior to their utilization in the present study, the attenuation provided by wax impregnated ear plugs (Flents) for pure tones and speech was determined. Three young adults with normal hearing served as subjects.

The following procedures were employed: Monaural air-conduction thresholds were determined under earphones for each ear, and then spondee thresholds were determined monaurally under earphones for each ear using tape recorded spondee words. The ear with the better SRT was chosen as the test ear.

The unoccluded sound-field SRT for the test ear was determined while the nontest ear was occluded by an ear plug and covered with a Willson Sound-Barrier Earmuff. The nontest ear remained occluded in this fashion throughout the remainder of the speech testing. The test ear was then occluded with an ear plug and the SRT was redetermined. Finally, the pure-tone thresholds of the test ear were again measured. This time, however, the ear was occluded with a Flent which had remained in the ear from the previous test condition. By following the foregoing procedures, once the

Figure 8.--Mean audiogram of three subjects with normal hearing showing attenuation provided by wax impregnated ear plugs (Flents) for pure tones. (Thresholds ISO-1964 Standards)



Flent was placed in either the test or nontest ear it remained there until all testing was completed.

The amount of attenuation provided by the ear plugs for pure tones is shown in Figure 8, and the attenuation provided for spondee words is given in Table XIX.

Table XIX.--Unoccluded and Occluded Speech Reception Thresholds Showing Attenuation Provided by Wax Impregnated Ear Plugs (Flents) for Spondee Words (Thresholds in dB re Audiometric Zero)

Subject	Unoccluded SRT	Occluded with Flent SRT	Attenuation
1	-6	28	34
2	3	37	34
3	-6	29	35

Mean attenuation for spondee words = 34.3 dB

APPENDIX C

SUMMARY SHOWING DATA FOR EACH SUBJECT

Group I (Conductive)

Sub-ject No.	Age	Sex	Ear	Under Earphones		Unaided Sound Field		Conventional Earmold		Acoustic Modifier		Open Earpiece		Crimped Tubing		Repeat of First Aided Condition	
				SRT	PB	SRT	PB	SRT	PB	SRT	PB	SRT	PB	SRT	PB	SRT	PB
1	37	F	R*	31	90	32	92	11	94	13	98	8	96	12	94	10	94
			L	39	96											(Conventional)	
2	48	M	R	57	96											(Crimped Tubing)	
			L*	36	94	31	98	11	94	10	98	9	94	10	98	10	98
3	31	F	R	40	92											(Open Earpiece)	
			L*	29	94	32	96	6	92	8	96	12	98	11	90	6	94
4	40	M	R	46	100											(Acoustic Modifier)	
			L*	36	96	30	96	8	92	14	94	11	90	11	94	10	94
5	54	F	R	33	98											(Conventional)	
			L*	48	100	45	98	12	98	16	96	12	98	15	90	12	98
6	46	M	R*	56	86	56	90	27	88	33	92	26	88	32	88	34	90
			L	53	92											(Crimped Tubing)	
7	18	F	R*	44	94	44	96	8	92	12	94	12	94	15	90	11	90
			L	50	96											(Open Earpiece)	
8	20	F	R*	26	92	26	94	8	90	12	96	11	92	10	94	12	94
			L	14	96											(Acoustic Modifier)	
9	60	F	R	37	96											(Conventional)	
			L*	33	98	32	96	12	94	11	90	18	96	12	94	9	94
10	17	M	R	50	92											(Crimped Tubing)	
			L*	33	94	28	94	7	92	10	92	8	90	13	90	10	94

*Aided test ear.

Continued

Group II (Sensorineural Precipitous Drop)

Subject No.	Age	Sex	Ear	Under Earphones SRT	Under Earphones PB	Unaided Sound Field SRT	Unaided Sound Field PB	Conventional Earmold SRT	Conventional Earmold PB	Acoustic Modifier SRT	Acoustic Modifier PB	Open Earpiece SRT	Open Earpiece PB	Crimped Tubing SRT	Crimped Tubing PB	Repeat of First Aided Condition SRT	Repeat of First Aided Condition PB
1	57	M	R	22	38											(Open Earpiece)	
			L*	29	64	29	66	11	76	11	86	12	86	12	88	9	88
2	40	M	R*	21	60	23	58	13	70	13	84	12	84	13	84	12	82
			L	16	38											(Acoustic Modifier)	
3	66	M	R*	47	76	42	76	20	74	21	88	17	88	22	84	22	76
			L	32	62											(Conventional)	
4	40	M	R	20	52											(Crimped Tubing)	
			L*	29	68	25	86	12	84	11	90	12	96	12	94	10	96
5	40	M	R	21	52											(Open Earpiece)	
			L*	13	70	14	66	16	74	16	80	12	84	13	86	13	82
6	40	M	R*	16	70	18	76	13	88	12	96	9	96	12	98	13	94
			L	20	46											(Acoustic Modifier)	
7	67	M	R*	31	76	30	70	16	74	20	88	13	84	19	86	17	76
			L	51	66											(Conventional)	
8	62	M	R*	5	78	8	70	10	78	6	86	6	84	8	88	5	86
			L	7	66											(Crimped Tubing)	
9	59	M	R	35	38											(Open Earpiece)	
			L*	29	38	29	54	17	72	22	88	19	86	22	84	19	86
10	44	M	R	26	56												
			L*	20	58	20	72	17	78	16	86	13	82	14	88	14	84

*Aided test ear.

Continued

Group III (Sensorineural Gradually Sloping)

Subject No.	Age	Sex	Ear	Under Earphones SRT	Under Earphones PB	Unaided Sound Field SRT	Unaided Sound Field PB	Conventional Earmold SRT	Conventional Earmold PB	Acoustic Modifier SRT	Acoustic Modifier PB	Open Earpiece SRT	Open Earpiece PB	Crimped Tubing SRT	Crimped Tubing PB	Repeat of First Aided Condition SRT	Repeat of First Aided Condition PB
1	59	M	R*	58	80	56	76	29	74	36	90	34	62	38	86	34	86
			L	66	52											(Conventional)	
2	62	M	R*	54	68	49	68	41	58	38	84	36	80	42	82	43	84
																(Crimped Tubing)	
3	55	M	R*	30	84	31	86	11	88	14	94	11	96	16	94	10	94
			L	45	92											(Open Earpiece)	
4	49	M	R	50	36											(Acoustic Modifier)	
			L*	47	50	46	74	22	72	26	92	25	90	30	92	26	86
5	54	M	R*	56	80	54	80	28	82	32	78	33	78	35	84	25	86
			L	57	66											(Conventional)	
6	55	M	R	44	90											(Crimped Tubing)	
			L*	53	88	50	100	20	86	30	86	23	78	32	88	33	82
7	59	M	R*	50	56	46	60	28	62	33	82	32	84	33	80	32	84
			L	48	38											(Open Earpiece)	
8	54	M	R	48	84											(Acoustic Modifier)	
			L*	51	82	47	84	20	70	30	64	26	66	36	60	28	66
9	45	M	R*	52	72	48	80	27	76	29	90	24	74	27	84	24	78
			L	48	70											(Conventional)	
10	20	F	R*	29	86	30	88	10	82	13	90	12	92	14	98	12	96
			L	40	86											(Crimped Tubing)	

*Aided test ear.