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THE EVALUATION AND FITTING OF TRANSISTORIZED HEARING AIDS

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THE EVALUATION AND FITTING OF TRANSISTORIZED HEARING AIDS

CHAPTER I

INTRODUCTION

The hearing aid evaluation, as performed in speech and hearing clinics, is designed to assist the audiologist in making the recommendation of a hearing aid for a particular hard-of-hearing patient. Most clinics maintain a large representative stock of the various hearing aids available in their locale. These instruments may be placed in the clinic by the manufacturer, his local dealer, the Veterans Administration or other agencies concerned with the rehabilitation of the hard of hearing.

Briefly, the hearing aid evaluation consists of testing certain aspects of the patient's hearing for speech while he wears a hearing aid. The procedure is performed with several instruments which the audiologist has determined, on the basis of manufacturers' fitting manuals and his own clinical experience, to be likely to result in adequate hearing for the particular patient being tested. On the basis of his test results, the audiologist recommends the type of aid which seems to meet the individual's hearing needs. The recommendation may take the form of a specific fitting; i.e., the recommendation of a particular make, model, tone setting, receiver, type of earmold, etc., or a general fitting; i.e., the recommendation of the approximate strength of aid to be worn, whether a glasses-type or an on-the-body aid, in which ear to wear the aid, etc., depending on the nature of the patient's hearing difficulty.

There are differences of opinion among audiologists regarding hearing aid selection by speech and hearing clinics. No label can be attached to the major philosophies, as each is the product of an evolution in theory by numerous persons at several institutions. It is generally accepted that most clinics follow one of the two or three major philosophies, either directly or with some slight modification.

There are those in the field who assume that each prospective hearing aid wearer is a good candidate for any hearing aid until proven otherwise; i.e., that most people have essentially the same electro-acoustic needs. This group tends to discount the value of the hearing aid evaluation, on the one hand, but suggests that the goal of the evaluation, when executed, is the selection of the best possible instrument for the individual patient. The limits of time and human effort would seem to make this an unreasonable goal.

There are others who suggest that every prospective hearing aid wearer is a problem case until proven otherwise. This group suggests that the hearing aid evaluation is important for the discovery of special problems which the individual might be expected to encounter through the use of a hearing aid. The goal of the evaluation is the selection of a satisfactory aid which will adequately meet most of the person's hearing needs. Most aids will prove adequate in easy listening situations; the justification for the selection procedure is in determining how each of the evaluated instruments will function in more difficult situations; e.g., listening to quiet sounds, operating within the patient's limits of tolerability and reproducing speech in unfavorable circumstances, such as in the presence of background noise.

The evaluation and fitting of hearing aids by speech and hearing clinics has become an established procedure. The tests employed for the selection of an instrument for a particular individual are based on the battery of tests developed during and shortly after World War II, as the need for rehabilitation through hearing aid prosthesis became pronounced due to the influx of wartime aural casualties. In the years since the inception of this program, the need for a general review of our clinical procedures has become apparent.

It is agreed that the validity and reliability of our testing procedures should be such that our tests are sensitive enough to discriminate among hearing aids in arriving at the selection of an aid for a given patient. The consistency with which test results can be reproduced has been revealed as less than desirable. It has been shown that two or more evaluations performed over short time intervals, using the same patients and the same group of hearing aids, frequently result in the recommendation of different fittings. In other words, a group of aids ranked by scores on one group of tests may, if tested again in an identical manner, appear in a completely different rank-order.

It was toward the improvement of clinical test consistency that one portion of the present study was designed. It was felt that the reduction of clinical error, through the use of more highly controlled test procedures, would provide a higher degree of confidence in the selection of hearing aids.

A suspected source of inconsistency has been in the method of adjusting the hearing aid gain control prior to testing. If instruments are not adjusted with precision, it becomes difficult to make a comparison among two or more instruments on the basis of test results which may show considerable variation as a result of this adjustment. The existence of one such uncontrolled variable reduces the confidence which can be placed in the test results.

Aside from the lack of test consistency. there has been some question as to the type of hearing aid frequency characteristic which should be applied to an individual type of hearing loss. This is the much discussed question of selective amplification. Although research data are available for the now obsolete vacuum tube hearing aid, none have been published based on tests with the transistorized hearing aid. There may be no reason to suspect that a real difference should exist in the results obtained with the two types of hearing aid. However, persons who have worn both vacuum tube and transistorized hearing aids often complain of the "harshness" of the transistorized aid. This subjective difference could affect the choice of frequency response for a given hearing impairment.

A second reason for gathering further data on this aspect of the hearing aid was the desirability of obtaining carefully controlled test results on a stratified population. Previous studies used rather heterogenous groups of subjects, usually classified by audiometric configuration. It was felt that more precise conclusions could be drawn from an investigation utilizing selected hearing-loss groups which would serve as controls for each other.

Finally, with so much criticism of the clinical selection procedures, the possibility exists that the prospective hearing aid wearer might select an adequate instrument with as good or better success than could the audiologist. Here again, research was available for the vacuum tube hearing aid, but not for the transistorized aid. The subjective difference between the two could alter the validity of previous findings. The ability of the patient to select an adequate instrument seemed worthy of investigation.

In summary, it was the purpose of this investigation to evaluate certain aspects of present hearing aid evaluation and fitting procedures, and to analyze possible alternative procedures which might contribute to greater precision in our methods of determining hearing aid selection.

CHAPTER II

HISTORY

Introduction

The present historical review is intended to trace the development of the hearing aid evaluation as a clinical procedure. Throughout the early period of this development, major revisions of method were made in an attempt to arrive at a procedure which would select an adequate hearing aid for the hard-of-hearing patient. The present clinical procedures were generally established by 1946 and, except for refinement, have remained much the same since that time.

The historical development reported here includes two major areas: one of these is the hearing aid evaluation procedure itself; the other, the merits of selective frequency amplification. The present study was an investigation of both of these aspects. It was felt that one aspect could not be discussed without constant referral to the other, since a substantial part of the rationale for the clinical selection of a hearing aid depends upon the supposed need for different hearing aid responses for different hearing losses, or at least this was true in the past. If it could be assumed that one type of hearing aid response was suitable for all persons, there would be little justification for the clinical selection of an instrument. Thus, the history of the hearing aid evaluation and of the question of selective amplification have been treated together. In the following chronological presentation, the reader is asked to note the parallel development of these two areas. The chronology is divided into early developments (1927-1944) and modern developments (1945-1960). The former deals primarily with attempts to arrive at a basic procedure, while the latter deals mainly with refinements of the basic procedure.

Early Developments: 1927-1944

In 1927, Fletcher (23) stated the need for a method of selecting the correct hearing aid for the hard of hearing individual, when he said:

> If a person of defective hearing is to select intelligently a set [hearing aid] which will be best suited to him, he must have some simple method of comparison. There are so many types on the market that a selection without some definite criterion is generally a matter of considerable difficulty.

During that same year, Fletcher (24) described a method of selection which had been used experimentally and found to be both simple and reliable in rating hearing aids. A list of 100 monosyllabic words, containing all of the English vowel and consonant sounds, were read to the patient at a fixed distance from the hearing aid microphone. The patient was asked to repeat the words when he could understand them. The discrimination of vowel and consonant sounds was rated separately in percentage scores, the consonant percentage being weighted at twice the value of the vowel percentage, since consonants contribute more to speech intelligibility. When these percentage scores were established, the two were multiplied and the product served as a rating of the patient's discrimination ability.

In 1929 Newhart (56) stated the belief that, for many patients, only one hearing aid could best meet the auditory needs of the individual. He stressed the importance of personal selection, suggesting three important factors in the selection of an instrument: a careful otological examination; an audiometric evaluation; and a thorough trial period of wear of any instrument, previous to its purchase.

Hallpike (28) stated the need for selective amplification in 1934. The pure tone audiogram was considered the most valuable measure available to the otologist in recommending a hearing aid. It was assumed that hearing aids could be produced which would furnish maximum amplification for those frequencies where the greatest hearing loss was found. Hallpike suggested that otologists should consider deafness in the light of tests of function such as the pure tone audiogram. Noting the relationships between the audiogram and the hearing deficiency for speech stimuli, a careful study of the audiogram would give an index of the performance of the ear in the perception of speech. In addition, he suggested that the audiogram could form a basis from which the "prescription" of a hearing aid might be made. He saw the audiogram as a guide in the construction of an individually prescribed hearing aid

> . . . with or without amplifying valves, which have a resonance corresponding to the frequency band of the deafness.

In 1935, Tumarkin (69) drew parallels between the fitting of hearing aids and the fitting of eyeglasses, stating:

> It is clear that to provide an adequate deaf aid for a given patient - even as the oculist and optician together provide a visual aid - two things are necessary: 1) an accurate refraction of his hearing powers, and 2) an instrument designed in accordance with his refraction which will take the ordinary sounds and so magnify them as to compensate for the distortion of his auditory apparatus.
>
> The former can be achieved only by scientific audiometry. The latter can be achieved only by selective amplification.

Also in 1935, Kerridge (44) stated his belief in the need for selective amplification. He pointed out that total loudness was not the most important aspect of the hearing aid; of prime importance was the frequency region amplified. More critical than the amplification of a wide band of frequencies was the amplification of the region in which the greatest hearing loss was found.

In the same year Kluge and Reisig (45) compared the fitting of hearing aids and eyeglasses in much the same manner as Tumarkin (69). They stated that the otologist must use the audiogram in order to prescribe the correct aid, pointing out that techniques were available to produce any frequency response curve necessary. It is now realized that this is only true within very broad limits even if the necessity of such individualized fittings could be assumed.

At this same time Knudsen and Jones (46) held the same general belief. They stated:

> In routine office practice it is now possible to prescribe artificial aids for hearing just as the ophthalmologist prescribes artificial aids for seeing.

They suggested the use of an aided pure tone audiogram in testing the adequacy of a particular hearing aid for the individual patient. Their method consisted of holding the earphone of the audiometer against the hearing aid microphone to obtain aided pure tone thresholds. The aided audiograms measured with each of several hearing aids could then be compared to the unaided audiogram to indicate the relative merits of each instrument. The aided audiogram was considered a quantitative measure of the value to be derived by the patient.

The following year Knudsen and Jones (47) reported that their experiences had shown that some patients reported hearing as well with uniform amplification as they did with selective amplification. They stated the belief that, in fitting a hearing aid, there is the problem of cerebration to be considered and not merely the physical problem of exact selective amplification. It was assumed, however, that the continued use of selective amplification on the part of the patient would result in the cerebral adaptation necessary for normal auditory perception. They again stressed the value of selective amplification, saying it was more than a theoretical concept. With future improvements in hearing aid design it was predicted that

> . . . selective amplification for each individual will be provided in the routine prescribing and constructing of hearing aids.

In 1936, Pope (59) reported that an adequate picture of the feasibility of a given instrument for a particular patient could be obtained by superimposing the response curve of the instrument upon the audiogram. On the other hand, for optimum results and with problem cases, he contended that individual fitting was preferable. He suggested the testing of receivers to divide them into high, low and flat response receivers. If such selective use of receivers did not prove adequate, he proposed a finer fitting which could be accomplished by anyone having an elementary knowledge of physics and acoustics.

Rudiger (63) contended the hearing problem of the individual patient would indicate its own remedy. Physical discomfort would result from uniform amplification if there were regions of normal hearing. To overcome this problem, he suggested that an aid with low frequency emphasis should be recommended in conductive loss cases where the greatest loss was in the low frequencies. Conversely, if the greatest loss was in the high frequencies, as commonly found in cases of sensorineural loss, an instrument with a high frequency response should be prescribed.

Littler (50) pointed out that if high frequency emphasis were utilized rather than flat amplification, there would be no serious detriment to speech discrimination. Whereas, if low frequency emphasis was employed, the ability to discriminate speech would be greatly decreased. At high intensity, he felt that maximum amplification in the middle range of frequencies would be advantageous, due to the shape of the equal loudness contours. He further suggested the testing of the patient under unaided conditions in a sound field, followed by similar tests under aided conditions. It was suggested that the ratio of the two thresholds obtained under these conditions would give an indication of the effective amplification of the hearing aid.

On the basis of an investigation in 1937, Ewing, Ewing and Littler (21) concluded that there was a need for an objective method of assessing the hearing level for speech. According to them, the chosen method should be independent of: (a) the vocal characteristics of the tester; (b) the subjective loudness judgments made by the patient; and (c) the acoustic conditions of the test room. They recommended the use of pure tone testing to meet these requirements, provided correct interpretations could be made regarding the relationship between pure tone thresholds and speech discrimination ability. Although they contended that this relationship and the prediction of discrimination ability from the audiogram was reliable, later research has shown the audiogram to be a poor predictor of speech discrimination ability.

On the subject of selective amplification, these same investigators reported that each of their patients gained greatest benefit from a hearing aid with uniform amplification over the range from 200 to 8000 cps.[1] They felt that, until hearing aid design had become more advanced, it would not be possible to correct for deafness in those instances where the greatest loss was in the high frequencies. They, too, held hope for the use of selective amplification.

Ansberry (3), another advocate of selective amplification, compared the fitting of hearing aids to the fitting of eyeglasses. Rather than using the pure tone audiogram as a basis for prescribing an instrument, Ansberry recommended the testing of a hearing aid which had been individually constructed for the hard of hearing person on the basis of his hearing loss. The result would be a practical approach, rather than a theoretical approach, to the fitting problem. He stated that the fitting of a hearing aid

> . . . for those who can be helped is not complete until a test is made of the "fitted" instrument to see whether or not it is satisfactory. This test should be made with pure tones and with speech sounds.

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[1]Present transistorized hearing aids have a frequency range of approximately 300 to 4000 cps.

In 1938, Hayden (33) suggested that an aided pure tone audiogram be made and compared to the unaided pure tone thresholds. This concept was not new. He described a method of determining the response curve of a hearing aid which is not unlike that presently employed in this type of measurement. Pure tones of known intensity were presented to the hearing aid and the intensity of the output measured in decibels. In this manner, various combinations of microphones, amplifiers and receivers could be tested and the response curves determined for each arrangement.

In another article published in the same year, Hayden (34) discussed the use of a master hearing aid in the selection of hearing aids. The master hearing aid incorporated response settings comparable to those which could be obtained with any combination of microphones, amplifiers and receivers available in one particular commercially available, wearable instrument. There were 288 possible output curves with the master hearing aid. Pure tone testing was utilized to find the adjustment of the master hearing aid which resulted in the closest approximation of the normal threshold curve. This was termed "base-fitting" and was considered desirable during this period.

After the selection of the component parts by the above method, the custom hearing aid was assembled and worn by the patient as a "trial frame" fitting, a correlation to the fitting of eyeglasses. Hayden reported that, of 100 patients evaluated with the master hearing aid, 92 preferred the otologist's prescription to the other 287 possible output curves. Hayden further contended that amplification should be peaked in the areas of greatest hearing loss and that this could be verified by further clinical experience, although laboratory findings had not yet proven this point to the physicists' satisfaction.

McFarlan (51) used a rather unusual method for recommending the proper hearing aid. A disc recording of speech was presented at a speed of 78 rpm and the percentage of correct responses noted. The test was then repeated with the turntable speed increased. The result was an increase in the frequency of all sounds, thus, "the low tones fade, and the high tones become conspicuous." The percentage of correct responses was also recorded for this test. Both tests were presented at an intensity "slightly above the patient's threshold." McFarlan found that most patients had a better score when the play-back speed was increased. Thus, he felt that the test was of great value in advising patients on the selection of a hearing aid.

In 1938, Jones and Knudsen (43) showed signs of altering their earlier concepts (46,47) when they stated:

> . . . the prescribing and fitting of hearing aids will never become as intricate as the art of prescribing and fitting eyeglasses; that is, the kinds and gradations of sound amplification needed are fewer than the many kinds and gradations of light refraction.

They suggested that many persons would do better with uniform amplification than any other type of response. For persons with normal or nearly normal hearing for the low frequencies, selective amplification was deemed advisable. They reported

> . . . the primary requisite for every hearing aid is high quality amplification, that is, amplification which is free from the "peaked" responses and nonlinear distortions which have been so characteristic of the carbon type portable aid used in the past. . . . The audiometric tests ordinarily will indicate the approximate type of amplification with which the patient will hear best; but this should be confirmed, or modified as required, by actual speech tests, which will reveal the type of amplification with which each patient will hear best.

West (75) stressed the use of free field pure tone tests as opposed to placing the earphone of the audiometer to the hearing aid microphone. It was felt that the aided audiogram would serve as an index of the aided threshold of hearing. It was further suggested that testing with speech stimuli be accomplished and that the final selection of an aid should be based on the adequacy of the hearing aid in reproducing clear speech.

In 1939 Holmgren (36) published a comprehensive review of hearing aids and tests for their selection. On the basis of this review of clinical and experimental aspects, he concluded that both pure tone and speech testing were necessary in the evaluation of hearing aids. He pointed out the fallacy of allowing the patient to judge how the aid sounds to him. Like more recent researchers, he contended that over a period of years the hard of hearing person becomes accustomed to an altered sound perception, even though he might realize that his hearing with an aid is not normal. If selective amplification were to be applied to the loss, the patient could be expected to experience difficulty in recognizing the sounds of speech. If selective amplification could give better speech discrimination but uniform amplification resulted in a fitting more pleasing to the patient (as often occurs), Holmgren suggested the patient try the more pleasing amplification response for a short period, then switching to the more selective instrument when he had become accustomed to amplified sound. This method of fitting is still widely utilized, particularly in the commercial field, and has proven quite satisfactory. Holmgren summarized this point by stating:

> The amplified sound seems [to the patient] qualitatively changed. The patient does not feel that it sounds as it should. Adaptation to the degree of selective amplification which gives the best intelligibility must take place successively.

Holmgren recommended the use of selective amplification for all cases where the greatest loss was in the high frequency range. In those cases where the loss was throughout the frequency range, he recommended uniform amplification.

Perwitzschky (58) in 1939 stated the belief, so popular a few years earlier, that the ideal hearing aid must incorporate selective amplification to enhance the deficient frequency ranges while not amplifying those frequency regions which were not affected.

Berry (4) suggested tests for the use of the otologist in evaluating a hearing aid which the patient had selected and worn in his daily environment for a trial period. He advocated the use of speech tests consisting of numbers, nonsense syllables and prose, which were to be presented under conditions controlled "as carefully as time and circumstance would permit." He warned of the need to consider the masking effect which would be presented by amplified background noises.

In 1940, McFarlan (52) quoted research to support his contention that hearing aids should be evaluated by using speech stimuli rather than pure tone stimuli. He stated that the degree of deafness determined by pure tone testing could not predict the amount of difficulty to be encountered in listening to speech. Since the hearing aid was designed to make speech more audible, the practical stimulus for testing the adequacy of the hearing aid should be speech. He proposed the use of recorded speech tests rather than spoken words so as to control the stimulus to a greater degree.

In 1940, Watson and Knudsen (73) tested several patients using speech intelligibility tests with a series of different hearing aid frequency response curves. They reached the same conclusion, as had been stated previously by Holmgren (36); namely, that the patient is a poor judge in selecting a hearing aid suited to his needs. They found that patients tended to choose a frequency response which amplified the areas where he already heard best. In addition, they found that the patient frequently stated that he heard poorly with the response curve which actually resulted in the highest intelligibility score. They suggested that it was necessary to accustom the patient to the output curve with which he performed best. In effect, the problem was to re-educate the patient to his improved hearing.

At about the same time, Sabine (64) stated:

> The first question of the prospective user of a hearing aid as to which of the various instruments that he may buy will most nearly meet his particular needs can best be answered by diagnosis by a competent otologist after careful audiometric tests. Such a diagnosis will answer the question . . . as to what portion of the frequency range appears to require the greatest amplification in order to supply best the patient's individual defects. The otologist is not in a position today to 'fit' the patient's ears with the precision with which the ophthalmologist might 'fit' his eyes. . . .

Day (17), in 1940, stated that selective amplification in carbon type hearing aids was impossible and that the most efficient aid was one which incorporated uniform amplification with a minimum of peaks. He recommended that the patient be advised to try several instruments in his home environment, evaluating each aid with speech articulation tests.

In 1941, Halsted and Grossman (29) classified hearing losses by the physiology and pathology of the transmission and perception of sound.

The classifications were an attempt to fit hearing aids by hearing loss type. They realized few cases would fall exclusively into any one classification but that, in most cases, one class would dominate in any hearing loss. They felt that for each basic type of loss there were amplifiers and receivers which could be expected to furnish the best result.

Kranz and Rudiger (48) reported their findings, based on their experiences in the commercial hearing aid field. They reported their use of the audiogram which was compared with hearing aid frequency response curves to select the proper instrument. Most of their cases responded best to gradually increasing intensity in the upper frequency range. The proper fitting was accomplished by utilization of the correct combination of instrument, tone control and receiver. They reported successful fittings in 80% of their cases.

They also reported:

> There are a number of cases in which the hearing loss has been of long duration so that the subject has built up an interpretation of speech based on a distorted frequency reception. In some of these cases, the fitting of the hearing aid has to be adapted to give somewhat the quality of sound to which the subject has become accustomed and it will be only after a period of re-education of normal sound vocabulary that the subject reaches the place where the fitting indicated by his audiogram will prove to be most satisfactory for him.

Bunch (6) commented in 1942 on the advent of vacuum tube hearing aids. He felt that the selection of a hearing aid could be based upon the otologist's audiometric tests and his knowledge of hearing aid responses which would most nearly amplify the affected frequency range while suppressing frequencies which required no amplification. Here is noted an apparently renewed optimism for selective amplification coming with the availability of a new type of instrument.

In 1943, Hughson and Thompson (39) wrote:

> In the fitting of any hearing aid the psychologic makeup of the individual patient must be studied and appraised. The use of hearing aids is a form of therapy. This being the case, the function of fitting aids belongs distinctly to the otologist.

In 1944, Fest (22) pointed out the need for special speech tests and testing methods in the evaluation of hearing aids. He felt that a comparison of unaided and aided pure tone audiograms was not adequate for this purpose; however, speech tests of that period often contained serial material or conversation and were frequently presented under uncontrolled conditions which destroyed their validity. He suggested the use of scientifically constructed word lists which would contain all areas of the essential frequency range and which could be presented under controlled conditions.

Hughson and Westlake (40) agreed that the first of the series of aids evaluated in the selection procedure could be one which complemented the audiogram, but they did not advocate aided pure tone thresholds as the determining factor in selection. Speech reception ability was stressed by them as the logical criterion for hearing aid recommendation.

Also in 1944, Hughson and Reger (38) repeated the contention that gain in the ability to understand speech was of prime concern when selecting a hearing aid. Even though a certain degree of selective amplification was possible, they believed there could be no set rule for audiogram compensation, since success with a hearing aid had to be considered an individual matter.

Watson (71), however, felt pure tone tests were the most reliable measure for prescribing hearing aids. Speech tests, due to their variation in intensity and quality, were thought to lack the necessary precision for this type of measurement and could, therefore, best serve as a valuable adjunct to pure tone testing. The use of speech stimuli was not thought to allow the patient a fine enough judgment between instruments. Watson's opinion was that speech measured only the patient's understanding and not the ease with which he understood.

Modern Developments: 1945-1960

In 1945, Truex (68) described the method of hearing aid selection utilized by the army at Deshon General Hospital. Originality had been encouraged in the army program in the hope that research would result in improvements in the selection procedure. Those at Deshon felt that adequate speech reception was the goal of the hearing aid fitting, and the selective process employed at Deshon was based on this assumption. Pure tone audiograms were used only to indicate which ear should be fitted and whether an air conduction or bone conduction receiver should be utilized.

In a series of articles published in 1946, Carhart (8,9,10) and Carhart and Thompson (13) recommended methods to be used in hearing aid selection. These works were based on the research and experience at Deshon. Carhart stated:

> It is no longer possible to assume that an adequate hearing aid will be insured simply because the instrument's response curve complements the audiogram. (10)

In place of audiogram fitting, Carhart recommended the use of speech tests. The testing procedure began with unaided speech tests which included the speech reception threshold, the speech discrimination score, and the unaided tolerance limit for speech. Tests were then performed with each of several hearing instruments during the selection process. The test sequence was as follows: aided speech threshold and tolerance limit with the gain control of the aid adjusted to a comfortable listening level; speech threshold and tolerance with the gain control set at full volume; determination of the level of white noise and of sawtooth noise which would make speech reception impossible; redetermination of the threshold for speech with the gain control set at a comfortable level; and, finally, the aided speech discrimination score.

The speech reception threshold was used to determine the residual loss for speech while wearing a particular instrument. An aid was considered adequate when this residual loss did not exceed 15 db. Differences in residual loss of greater than six decibels between two instruments were considered significant. As the residual loss exceeded 15 db, as was often found in severe hearing losses, it became more significant as the basis for the selection of a particular instrument.

The speech discrimination score was determined by using the Phonetically Balanced Word Lists prepared by the Harvard Psycho-Acoustic Laboratory. These words were presented at an intensity level 25 db above the speech reception threshold. Differences of eight percent or more between two hearing aids were considered significant, with a difference of such magnitude warranting the selection of the aid yielding the better discrimination score, other things being equal.

The criteria for an acceptable hearing aid (8) were that: (a) it provide adequate sensitivity; (b) it provide adequate tolerance for relatively loud sound; (c) it provide adequate performance in the presence of noise; (d) it provide adequate sound discrimination; (e) it did not present special problems; (f) the patient could emotionally accept the aid; (g) it was of reputable manufacture; (h) local service was available. The first four items could be measured in the clinical evaluation, and selection was generally based on these four criteria. It was felt that these criteria would provide the patient with the correct amplification and the adequate hearing he required. If two or more instruments proved satisfactory, selection could be based on local service, cost, convenience and aesthetic considerations.

That the research program at Deshon was fruitful is attested to by the fact that 14 years later these same methods are used in the clinical evaluation of hearing aids. Relatively minor changes have been made, but the basic tests, the method of adjusting the aid, and the goals of evaluation have remained essentially the same.

In 1946, Davis and others (15,16) showed that attempts to return the audiometric configuration to the normal curve by selective amplification had shown no consistent improvement in the ability to discriminate speech. The audiogram, it was felt, was of value in determining the amount of amplification required by the patient but could not be used in the determination of a beneficial frequency response setting. They stated:

> The patient's audiogram is often misleading as a guide to the selection of a hearing aid. Experimental evidence seems to show that the principle of 'selective amplification' to compensate for impairment of hearing is fallacious. (16)

In their second article (<u>16</u>), based on the same study, the authors questioned the reliability of having the patient adjust the gain control of the hearing aid to a comfortable listening level for a speech sample presented at a 40 db hearing level. They wrote:

> The theoretical validity of the method [of hearing aid evaluation] rests on the ability of patients to make consistent settings of the gain control when they are instructed to set them to 'the most comfortable level.' If they do not, any true differences in the effectiveness of various instruments may be canceled or even reversed by the variability of the patient's setting of the gain control. . . . Our own skepticism as to the possibility of obtaining sufficient consistency of the gain-control settings by patients was increased by a set of experiments performed by one of us. . . . The results indicated a degree of variability, both for hard-of-hearing patients and for normal subjects, so great as to vitiate any differences which might reasonably be expected to appear between instruments.

Carhart (<u>11</u>) answered these charges by revealing the results of investigations on this very problem. On the basis of 1219 threshold comparisons by 413 patients, Carhart reported a mean difference on test-retest threshold of 0.43 db with a standard deviation of 3.91 db. This mean difference, however, was obtained by subtracting the second threshold from the first threshold. Thus the magnitude of the differences was not revealed since a difference in one direction served to cancel a difference in the opposite direction. When the direction of threshold shift was disregarded, a mean of 2.67 db was reported. Eighty-two percent of all threshold differences fell between plus four and minus four decibels. Carhart concluded:

> A reliability of $\pm$ 4 db is relatively high for a clinical situation. The accuracy which we expect from good routine audiometry is + 5 db. Thus, it seems fair to conclude that the comfort level method has sufficient reliability to justify its use as a clinical means of setting volume control on a psychophysical basis.

In 1946, Hull (41) suggested that so-called objective methods of evaluating and selecting hearing aids were of little value. He recommended that the hard-of-hearing individual rely on the reputation of the manufacturer and the local hearing aid dealer in selecting a wearable instrument. Feeling that most aids met a standard of excellence, he concluded that, "no one can go very far wrong."

A further publication, based on the work at the Harvard Psycho-Acoustic Laboratories and at Central Institute for the Deaf, appeared in 1946 (32). The reported findings revealed that there were fewer differences among hearing aids than had been anticipated previously. The indications were that selective amplification was relatively unimportant and that selection of an instrument would depend upon the patient's preference.

In 1947, the "Harvard Report" (14) was published in full. This project, the most extensive investigation of hearing aids and the principles of selection to date, was completed by the Harvard Psycho-Acoustics Laboratory and Central Institute for the Deaf. The results of the investigation refuted the classical assumption made by the advocates of selective amplification. The report stated:

> We believe . . . that we have disproved the fundamental assumption of the desirability of 'selective amplification' based on the characteristics of the individual's audiogram.

Eighteen subjects, representing all types of hearing loss, were extensively tested using a master hearing aid which provided five different frequency response characteristics. In summarizing the relationship between the audiogram and the frequency response of the hearing aid, the report stated:

> The consistent superiority of moderate high-tone emphasis in making speech intelligible to hard-of-hearing ears disproves the popular theory that the best frequency pattern for a hearing aid is one which compensates for a patient's individual hearing loss by 'mirroring' his audiogram. Selection of frequency patterns for our subjects by this old rule, according to the general slopes of their audiograms, would lead to the proper choice in only 40% of our cases. As a practical matter, the best choice for all ears lies only between a flat pattern and moderate high-tone emphasis.

And later, summarizing rules for fitting:

> We have found three simple rules that are about 90% successful [in predicting which frequency response will result in the best discrimination score]. . . . The three rules are:
> (a) Use the HP-6[2] (or possibly HP-4 or HP-5) pattern for everyone.
> (b) Use the HP-6 pattern unless the quality of the Flat pattern is definitely preferred by the patient.
> (c) Use the Flat pattern for all patients with flat or rising audiograms and the HP-6 for all those whose audiograms slope downward between 250 and 4000 cps at more than 2 db per octave.
>
> Compression amplification . . . may modify these rules and allow greater concessions to the quality preferences of patients; but in any case it seems clear that the choice will always lie between HP-6 and Flat, or an intermediate slope such as HP-3 or 4.

Also in 1947, Watson (72) related that selecting an aid by patient preference was totally inadequate. He pointed out that most patients tended to select an instrument which amplified the sounds he already heard and did not amplify the sounds which he could not hear. The implication was that the patient wanted a louder sound but would not tolerate a change in subjective quality. This supported the contention that the patient desired that sound reception to which he had become accustomed, whether or not it provided adequate hearing. Watson further stated that patients tended to choose a "mellow" instrument

[2]HP-6 refers to a frequency response where the intensity output increases in the high frequencies at the rate of six decibels per octave. This type of abbreviation will be used frequently below.

which amplified low or middle frequencies rather than one which amplified the higher frequency range. The latter response generally offered better discrimination of speech but was rejected by the patients as being harsh in quality.

In 1948, Hudgins and others (37) reported a study which compared two commercially available hearing aids to a master hearing aid similar to that used at Harvard. The results of the study indicated that all patients performed better with uniform high fidelity amplification which provided adequate gain and a wide frequency response. These findings essentially confirmed those of the Harvard Report (14).

West (74) wrote in 1948 that only general principles could be provided for the recommendation of a particular hearing aid. He contended, however, that aids constructed to an individual prescription were superior to "ready-built" instruments. This opinion was not in agreement with earlier reported findings.

Pothoven (60) reported his clinical findings regarding the fitting of hearing aids in 1948. Of 190 patients fitted by air conduction instruments, 188 were found to perform best with a flat response instrument or one providing a slight high frequency emphasis.

Licklider and Pollack (49) found that low frequency emphasis was never desirable due to the distortion introduced by peak clipping. They reported that where an HP-6 response would result in 97% intelligibility, an LP-6[3] response gave an intelligibility score of only 15%.

In 1949, Watson and Tolan (70) summarized the more recent

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[3]LP-6 is an abbreviation for "low pass six" indicating increased intensity in the low frequency range by six decibels per octave.

literature on selective amplification. The hard-of-hearing person with a non-uniform loss soon becomes accustomed to distorted reception and, when fitted with an aid, prefers uniform amplification of incoming sound rather than a selective amplification. Most hearing aid users (75%) have better speech discrimination with a uniform amplification. On the other hand, a slight, high frequency emphasis, it was reported, would provide good discrimination over a wider intensity range and in the presence of environmental background noises. For those cases with sharply dropping audiograms through the speech range, an HP-6 or HP-9 should provide greater assistance than a uniform response. Finally, where low gain or peak clipping limits the acoustic output of an instrument, it was felt that an HP-6 response would prove superior to a flat frequency response for nearly all patients.

Hedgecock (35) and Sheets and Hedgecock (65) reported on the feasibility of selective amplification with a commercially available vacuum tube aid. Three settings of the instrument were utilized. These approximated a flat response, a seven decibel per octave high emphasis (HP-7), and a 14 db per octave high emphasis (HP-14). The experimental findings showed no significant differences between uniform amplification and selective amplification, the subjects performing as well with one frequency pattern as with the others. The most adequate results were obtained using either the flat or seven decibel per octave high frequency emphasis settings of the instrument.

Hedgecock further found that 81.3% of his subjects obtained a lower threshold for speech with the aid they preferred. The preferred aid resulted in the best discrimination score for 72.0% of his subjects.

Of the aids preferred by the subjects, about an equal number chose the Flat and HP-7 responses, while a significantly smaller number of subjects chose the HP-14 setting. He concluded that, within the limitations of the study, patient judgment was "a fairly reliable guide to the selection of suitable patterns of amplification."

In 1950, Hardy (31) reported the goal of the hearing aid evaluation was

> . . . to find the aid that gives the patient the greatest benefit in power and in discrimination, as demonstrated under controlled conditions in quiet and in noise, and that is most acceptable to him from every other point of view. The objectives to be achieved are . . . 1) adequate amplification, 2) within the limits of tolerance, 3) reproduced with fidelity, 4) with enough sensitivity to promote ready discrimination, 5) all incorporated into a convenient, wearable instrument.

In 1950, Carhart (7) stressed the need for the formulation of a clear and realistic policy for university and hospital clinics engaged in hearing aid selection. He suggested that the primary task of a clinic be confined to a detailed analysis of the patient's problems and to his prognosis as a hearing aid user. The clinic should not attempt to find a "best" hearing aid fitting but should determine the need for amplification and discover the special problems which hearing aid use might present to the individual. The goal of the evaluation procedure should be to select one or more instruments which meet the requirements of the patient as reasonably as possible in the light of his needs and special problems. The audiologist should attempt to give the patient insight into hearing aid use and its limitations. Carhart felt that most persons could wear an aid without its presenting any special problems. For these individuals, clinical evaluation was considered to be unnecessary. It is the patients who present special problems who benefit from the selection procedures utilized in university and hospital clinics. The otologist should refer these problem cases to the clinic and should refer other hearing aid candidates to a competent dealer.

In 1952, Groen and Tappin (26) reported the results of their research at Utrecht University and their clinical experience at the Institute for the Deaf in Amsterdam. Five hearing aids were evaluated on 300 patients in an attempt to discover an optimum response pattern. Their results agreed with those of previous investigations in that they found little success in compensating for high frequency loss by supplying a high frequency emphasis. Most of their clinical patients preferred a response which gave "some reduction in the lower tones," a flat response from 1000 to 3500 cps and a cut-off frequency of about 4000 cps. They found response curves which included sharp peaks of greater than five decibels to be unpopular with their hard-of-hearing patients.

Glorig (25) is another who stressed the importance of response characteristics. He gave an excellent discussion of the problems involved in selective amplification when he wrote:

> When an audiogram shows loss of nerve function it signifies that not only is the auditory threshold affected: the power of the cochlea to discriminate is also disturbed. This presents a difficult problem since the hearing aid merely amplifies sounds. The sound power of speech is produced by the vowels whose frequencies are below 1000. To discriminate speech the consonants (1000 to 3500 [cycles]) must be received in their true frequency relations. If the intensity is made great enough, even the vowels will become distorted. Originally many individuals attempted to select hearing aids by using a mirror image of the audiometric curve. This placed the amplification in the area of the less sensitive frequencies. From the previous discussion it is obvious why this type of response failed.

Mueller (54) described an office procedure for evaluating hearing aids by live voice testing. He had concluded that this lengthy procedure was a waste of time since aids were not differentiated, and he finally settled on the testing of one instrument merely to see how well the patient would function with an aid. If the patient seemed a good candidate, he was instructed in the care and use of an aid, was counseled, and was sent out to purchase one on the physician's recommendation.

In 1956, Ewertsen (20) reported the national requirements for hearing aids in Denmark. It had been found that a six decibel rise per octave from 200 to 3000 cps would give a superior speech discrimination score regardless of the type of hearing loss or the configuration of the audiogram. This response is now required in all instruments dispensed through the national program in Denmark. Ewertsen stated:

> It is merely an illusion when the advertisements claim that a hearing aid should be fitted according to the patient's audiogram; it is impossible to hear speech at the tone threshold--intelligibility is not achieved except at 20-30 db above this threshold.

Miller (53) attacked the presently employed methods for the clinical evaluation of hearing aids, calling this "one of the weaker services of the Audiology Clinic." He stated that

> . . . it is a waste of time to place several current instruments in competition with each other to find the 'best' one for the patient. . . . In view of the findings reported regarding the reliability of hearing aid evaluations and the desire of many patients to themselves select one of the many appropriate hearing aids available, a 'general' type of recommendation is suggested.

Winchester (76), in discussing changes in the rehabilitation of the hearing handicapped, reported that

> . . . there is now going on within our professional ranks a

> critical re-evaluation and scrutiny of present techniques of hearing aid selection. Recent research in this regard has cast doubt upon the effectiveness of clinical procedures now in use.

He cited the lack of test-retest reliability in the hearing aid evaluation procedure as one of the major faults of our present techniques. He suggested the possibility that different or additional psycho-acoustic measures might be necessary in selecting an instrument suited to an individual hearing loss.

Shore, Bilger and Hirsh (66) reported that most of the adult patients seen in the Audiology Clinic at Central Institute for the Deaf did not require extensive evaluation procedures for the selection of an adequate instrument. Many of their recommendations have been made on the basis of price, size and service.

In reviewing present evaluation procedures, they suggested that we do not know the reliability of the measures by which we hope to differentiate one aid from another. They specifically questioned the reliability of the speech reception threshold as measured with recorded spondee lists. Unless this reliability is known, they felt that we cannot determine when differences between two hearing aids are significant and when they are not.

In their recently reported research, they have attempted to answer this and other questions regarding the reliability of our measures. Using subjects with conductive, mixed and sensori-neural losses, they performed tests with four commercially available hearing aids. Each subject was tested twice with each of the four hearing aids. One test utilized the best theoretical frequency response setting of the aid for the individual's hearing loss; the other, the poorest theoretical frequency response setting. The measures obtained were the speech reception threshold, the discrimination score in quiet and the discrimination score in noise. Each subject underwent the test procedure, as outlined above, on four different days. The results of the investigation revealed that differences attributable to different hearing aids were shown by less than half of their subjects on the speech threshold, less than one third of their subjects on discrimination in quiet, and for no subject on discrimination in noise.

They concluded that the reliability of the speech reception threshold, the speech discrimination score in quiet, and the speech discrimination score in noise were "not good enough to warrant the investment of a large amount of clinical time with them [these tests] in selecting hearing aids." They felt there were differences among the hearing aids used in the study but felt that the results of the investigation suggested that the use of conventional speech measures were not reliable enough to detect these differences.

Summary

There are at least four basic evolutions which have taken place concurrently in the preceding historical outline: the evolution of the hearing aid selection from an otological service to an audiological service; the evolution from pure tone to speech stimuli in the selection procedure; the evolution from hearing aid prescriptions to the actual testing of aids on the prospective wearer; and the evolution from selective amplification to two or three standard amplification patterns.

One notes the early contention by members of the medical profession that the fitting of hearing aids was a medical problem and, as such, was the duty of the otologist. As the procedure became more involved and more time consuming, it became evident that such procedures could not be properly handled in a busy otological practice. The development of audiology as a profession made it possible for these services to be handled by persons whose training included not only a study of hearing pathology but the psychological aspects of deafness and the physical characteristics of hearing aids as well.

Perhaps contributing to this change was the final realization that pure tones could not be used to evaluate the efficiency of a hearing aid. One notes the evolution from pure tone to speech stimuli as a measure of hearing aid function. This change was slow to occur and probably came about as the result of many failures in attempting to return the audiogram to the normal threshold by means of amplification. Early investigators seemed overly optimistic as to the type of amplifier that could be designed for an instrument small enough and light enough to be worn comfortably on the body. Of course, in the end, it was the admission that the aid was being worn to enable the patient to hear speech that led to the use of speech stimuli as a measurement device.

Paralleling the above developments was the change in the selection method itself. Until the end of World War II one finds the word "prescription" being used, and one notes the continued correlation between hearing aid fitting and eyeglass fitting. It is apparent that deficiencies of the eye and the ear are corrected in far different ways. For the eye, the term prescription is appropriate and the correction is to normal or near-normal vision, except where nerve damage is involved.

For the ear the correction is not so exact, nor can it be, since frequently it is damage to the endings of the nerve itself which has caused the deficiency. It is realized that an evaluation of several possible corrections may be necessary. Hearing aid fitting is an individual matter in the sense that two persons displaying identical hearing problems may require different types of correction.

Finally, one notes the change from selective amplification to uniform or gradual high frequency amplification. Attempts at selective amplification were based on the assumption that the resolving powers of the ear could be returned to the normal level if appropriate sounds could be made louder. Intensive research and clinical experience have shown this to be untrue and unnecessary. As stated above, such amplification is not available even if this assumption were valid. Such an ideal does not take into account those pathologies where the site of lesion may be in the cochlea or the higher auditory pathways. It is impossible to stimulate a dead nerve fiber by increasing the intensity of the stimulus.

The four evolutions dealt with here are impossible to separate; each one has affected the others. On the one hand is noted the early concepts of otological handling, prescription fitting, pure tone testing and selective amplification which have evolved to the present concepts of audiological handling, fitting by evaluation, speech testing and uniform or rising amplification.

It seems apparent from the recent literature on hearing aids and their evaluation that all of the answers are not yet known, but the lack of research in this area over the past few years has been overcome, and several researchers have now begun to seek improved methods for hearing aid selection.

CHAPTER III

SUBJECTS, EQUIPMENT AND PROCEDURES

Introduction

The present study was designed to investigate the clinical evaluation and fitting of hearing aids. Experimental measurements were performed on each of four groups of subjects: (a) subjects displaying flat conductive hearing losses, (b) subjects with gradually sloping conductive losses, (c) subjects with flat sensori-neural losses, and (d) subjects having gradually sloping sensori-neural losses.

The purpose of the study can be discussed most appropriately in terms of the specific questions it sought to answer. These questions were:

1. Can test-retest consistency of the speech reception threshold and speech discrimination score be improved by changing the method of adjusting the hearing aid gain control prior to the administration of these tests?
2. Does the frequency response of the hearing aid significantly affect the ability to discriminate speech?
3. Is there a particular type of aided audiometric configuration which constitutes a good fitting as judged

by the aided speech discrimination score?

4. Can the patient select the type of amplification which most adequately meets his needs?

The first phase of the study was designed to investigate the possibility of achieving a more consistent method of hearing aid gain control adjustment so that test-retest scores for the same hearing aid, and among several different hearing aids, could be more readily compared.

Accepted clinical procedure suggests that the subject adjust the hearing aid gain control of each instrument to a comfortable listening level for speech stimuli presented at 40 db hearing level. During the normal hearing aid evaluation period, the subject is required to make many of these subjective comfort-level adjustments. In utilizing comfort settings, inconsistencies have been noted in the test-retest values obtained for the speech reception threshold (SRT) and/or the speech discrimination score with the same hearing aid. This lack of duplication is unfortunate since these measurements are of prime importance in the selection of a specific hearing aid.

Davis and his associates (16) have indicated that the weakness of our present hearing aid evaluation procedure could be found in the setting of the gain control of the hearing aids. They suggested that these inconsistencies may be due to the inability of the subject to find the same comfortable loudness, which may cover a wide range of intensities and/or quality adjustments. When utilizing the comfort setting procedure, the test, in reality, may measure the subject's ability to adjust the gain control on various instruments.

Carhart (11), however, determined experimentally that, using a comfortable loudness setting, his subjects could reset the hearing aid gain control to a consistent level with a speech reception threshold being reliable within four db, 68% of the time. The subjects for Carhart's study were military hospital patients enrolled in an intensive program of aural rehabilitation. Empirical data gathered by the present investigator, using clinical patients as subjects, did not reveal the degree of accuracy which was reported by Carhart.

The purpose of the second phase of the study was to gather additional data relative to the question of selective amplification, e.g., should amplification be emphasized in the high frequency range for persons whose greatest hearing loss is in this range? This portion of the study was designed to determine which of three hearing aid frequency response curves would result in the best aided speech discrimination score for each of the four hearing loss types used in the investigation.

The Harvard Report (14) suggested that a hearing aid with either a flat frequency response or a rising frequency response of six db per octave (HP-6) would result in the optimal speech discrimination score for all types of hard-of-hearing persons. This investigation by the Harvard Acoustical Laboratory utilized a high fidelity response master vacuum tube hearing aid that possessed these frequency response specifications. Present commercial hearing aids, however, do not possess an output signal with the fidelity of the Harvard master hearing aid; and the application of the Harvard Report to clinical procedures must be approached with caution. Only through experimentation involving the frequency responses of current commercially available hearing aids can recommendations be made as to the desirability of selective amplification.

The third phase of the present investigation was intended to study the relationship between the aided speech discrimination score and the aided audiometric configuration. Since pure tone stimuli presented in a free field generate standing waves in clinical sound-treated rooms, narrow bands of filtered thermal noise were substituted for pure tones.

Davis and his associates (16) have stated that the audiogram is of little use in the clinical selection of hearing aids. They proposed that the audiogram be used to determine the amount of amplification needed for a patient, but not to determine the type of frequency response setting that should be utilized.

In direct contrast, some hearing aid manufacturers have emphasized the importance of a pure tone audiometric examination as the basis of frequency response selection for hearing aids, in their fitting manuals distributed to local dealers. One manufacturer issues special charts containing the frequency response for each hearing aid and receiver combination. The local distributor is to superimpose the frequency response upon the audiogram to determine the correct hearing aid and receiver to result in an assumed aided threshold configuration at audiometric zero.

Previous research intended to correlate aided and unaided pure tone thresholds has generally been unsuccessful. In instances where success was achieved in attaining an aided pure tone threshold at the zero hearing level, there was no consistent improvement in the discrimination of speech. Hedgecock (35) reported that a personal preference for tonal quality was one of the influential factors to be considered in obtaining speech test scores for any subject when varying frequency response settings were utilized in the evaluation. For example, a person with a marked sensori-neural hearing loss may benefit from a frequency response setting that will amplify the more impaired high frequency speech sounds but may prefer the tonal quality which a low frequency emphasis will give.

The fourth phase of this investigation was designed to assess the capabilities of hard-of-hearing individuals in selecting an adequate hearing aid without the benefit of an audiologist's recommendation. Most previous studies have concluded that the patient cannot properly select an aid which meets his acoustic needs. These results, however, cannot be applied to the transistorized hearing aid without supporting data.

Subjects

Four experimental groups were utilized in this investigation: one group consisted of subjects displaying flat conductive hearing losses; a second group contained subjects with sloping hearing losses, primarily conductive in nature; a third group was made up of persons with flat sensori-neural hearing losses; the fourth group consisted of subjects with sloping sensori-neural hearing losses.

The files of the University of Oklahoma Speech and Hearing Center served as a source of potential experimental subjects. All available audiometric records from a five year period were examined in the process of obtaining the 40 subjects whose audiometric configuration, age, duration of hearing loss, and length of hearing aid use met the rigid criteria imposed by the experimental design. In addition, it was necessary that the persons selected live in the Oklahoma City area and be willing to donate the approximate three and one-half hours of time required for the test.

Certain criteria were applied to the selection of all subjects, regardless of the audiometric configuration group to which they were assigned. To avoid subjects who might present a speech or language deficiency, it was required that the hearing loss was first noted after the acquisition of speech and language skills. In addition, the hearing loss must have been noted before the age of 50. It was felt this requirement would reduce the likelihood of including any case in which presbycusis might have been a major causative factor. The age limits, at time of testing, were restricted to the range of 18 to 65 years. This range was chosen so as to include only adults, and to minimize the inclusion of any person who might display phonemic regression.

Due to the inclusion of free field measurements in the investigation, each subject was required to show an average hearing loss of at least 30 db at 500, 1000, and 2000 cps in the better ear.

Finally, it was specified that each subject used in the study had to have worn a hearing aid with success for a period of at least six months. It was assumed that those persons with experience as hearing aid users would be more reliable and would show less practice effect in the aided portions of the test procedure. In addition, this insured that each subject would possess a custom earpiece which was considered necessary for the experimental procedure.

The final selection consisted of 40 subjects, 25 male and 15 female. No attempt was made to control the distribution of the sexes. The age range of the subjects was from 20 years to 65 years, with an average age of 46.1 years. The group varied in the duration of hearing loss from three years to 50 years, with a mean duration of 19.1 years. The length of time a hearing aid had been worn ranged from one year to 24 years, with an average of 8.5 years of successful hearing aid use. Twenty subjects wore the hearing aid in the right ear, while 20 wore the aid in the left ear. There was no attempt to control the number of right or left ears in the study.

As stated previously, a prime consideration for selection was based on the pure tone audiogram taken from the case file. Final selection, however, was based on the results of pure tone tests made at the time the subject appeared to participate in the study. It was necessary to dismiss two subjects following this screening procedure, since they had shown a change in hearing acuity which excluded them from assignment to any of the four experimental groups. Ten subjects were selected for each group. The criteria for assignment to each of the experimental groups are shown below.

Flat Conductive Group

Subjects chosen for this group were limited to relatively flat losses by air conduction pure tone testing. No greater than a 15 db difference was allowed in air conduction thresholds for pure tones in adjacent octaves over the range from 250 to 4000 cps, and there could be no more than a 25 db difference between the best and poorest thresholds for the five frequencies in this range.

Bone conduction thresholds were limited to a 15 db loss at three of the five frequencies from 250 to 4000 cps. No subject was included in this group who showed greater than a 25 db loss by bone conduction at any of the five frequencies.

The median threshold values for air and bone conduction for the flat conductive hearing loss group are shown in Figure 1. The median, rather than the mean, was utilized as a measure of central tendency, due to the inclusion of subjects in some groups who were unable to hear one or more of the pure tone stimuli at the maximum output of the research equipment. The group showed a mean speech reception threshold of 42.9 db and a mean speech discrimination score of 99.0%.

The 10 persons in this group ranged in age from 20 to 64 years, with an average age of 44.1 years. The average duration of hearing loss for the group was 20.2 years, and they had worn hearing aids for an average of 8.0 years. The group was made up of four males and six females. Five of the subjects wore the hearing aid in the right ear, five in the left ear.

Sloping Conductive Group

Subjects selected for this group were limited to a minimum 10 db per octave drop in hearing acuity over the frequency range from 500 to 4000 cps and a maximum difference in threshold of 20 db in adjacent octaves from 250 to 4000 cps. The maximum allowable difference between the pure tone thresholds at 125 and 8000 cps was 50 db.

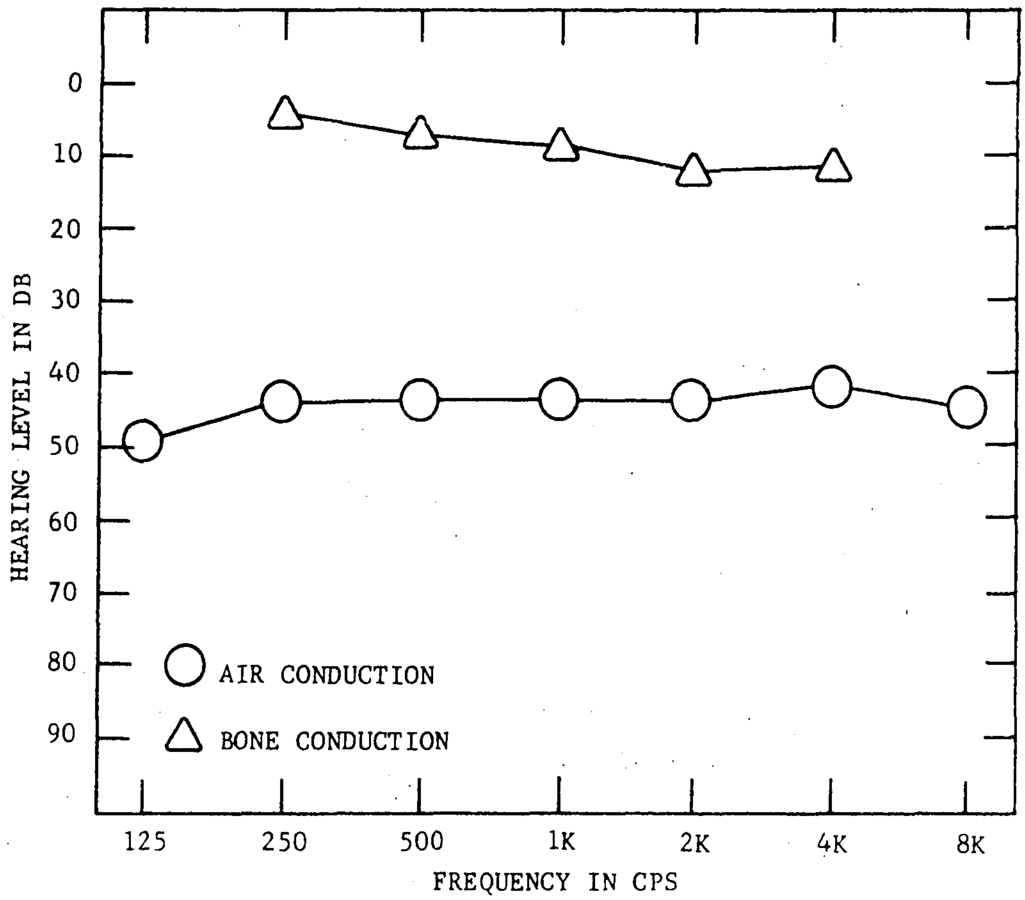

Fig. 1.--Median hearing levels in decibels re USPHS norms at seven test frequencies for the flat conductive group by air and bone conduction.

Bone conduction thresholds were limited to a maximum loss of 15 db at 250 and 500 cps and a maximum loss of 30 db at 1000 cps. In addition to pure tone threshold criteria, all subjects included in this group were required to attain an unaided speech discrimination score of at least 90% for the ear to be tested during the investigation. This restriction was designed to minimize the possibility of selecting subjects for whom cochlear involvement was a major causative factor. The median threshold values for the sloping conductive hearing loss group are shown in Figure 2. Mean values for the speech reception threshold and speech discrimination score were 43.1 db and 93.8% respectively.

The 10 subjects chosen for this group ranged in age from 24 to 63 years, with an average age of 42.4 years. The average duration of the hearing loss was 19.2 years, while the average duration of hearing aid use was 10.8 years. The group included seven male subjects and three female subjects. Five of these subjects wore the hearing aid in the right ear and five wore the aid in the left ear.

Flat Sensori-Neural Group

For purposes of this investigation, sensori-neural hearing loss was defined as a loss which yielded interweaving air and bone conduction threshold configurations between 250 and 4000 cps. Any subject reporting a history of middle ear pathology was excluded from the sensori-neural groups.

The thresholds for pure tones by air conduction were limited to no greater than a 15 db difference in adjacent octaves in the range from 250 to 4000 cps and no greater than a 25 db difference between the best and poorest thresholds in this range. The median pure tone threshold

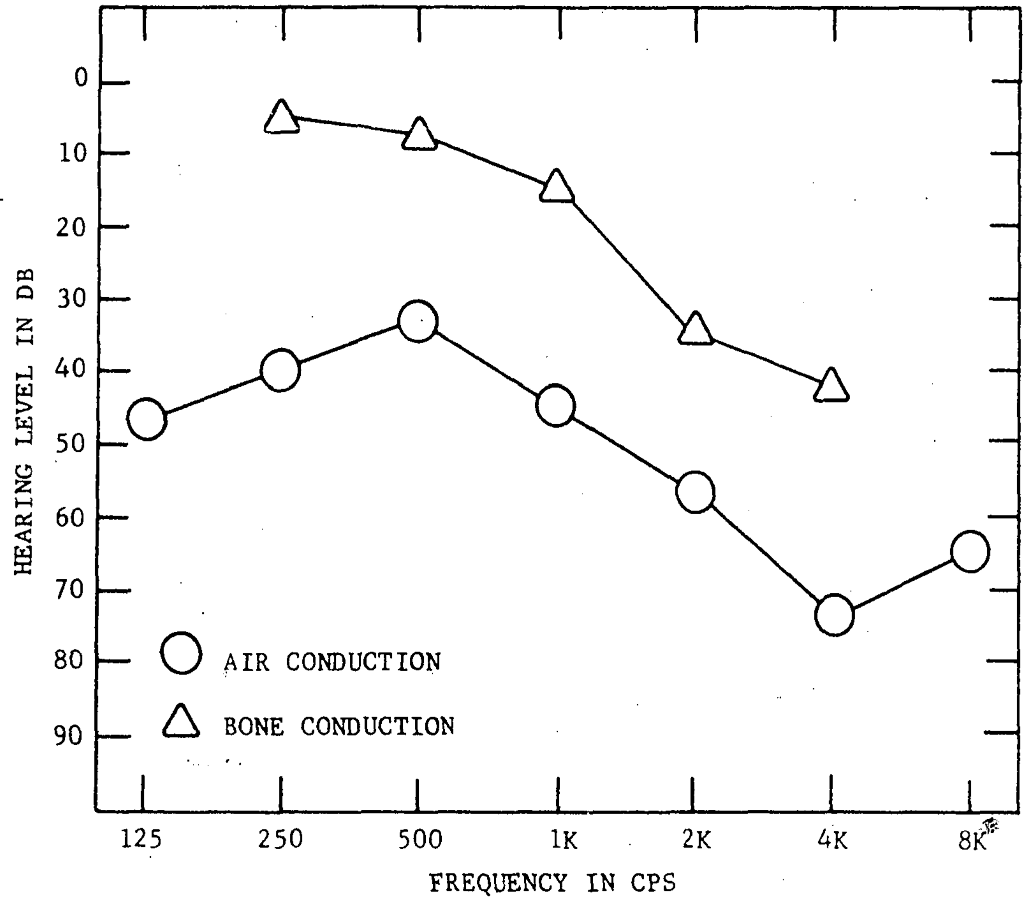

Fig. 2.--Median hearing levels in decibels re USPHS norms at seven test frequencies for the sloping conductive group by air and bone conduction.

values for the flat sensori-neural hearing loss group are shown in Figure 3. This group had a mean speech reception threshold of 45.8 db and a mean speech discrimination score of 83.8%.

These subjects ranged in age from 36 to 65 years, with an average age of 48.5 years. The group had an average duration of hearing loss of 17.8 years and had worn a hearing aid for an average of 6.5 years. The group included four females and six males. Six wore the aid in the right ear and four in the left ear.

Sloping Sensori-Neural Group

Subjects for this group displayed pure tone audiograms with a minimum drop in acuity of 10 db per octave over the four-octave range from 250 to 4000 cps. A maximum difference in threshold between adjacent octaves of 20 db was allowed. The maximum drop that was permitted from 125 to 8000 cps was 50 db. As in the flat sensori-neural loss group, by definition, air conduction and bone conduction thresholds were interweaving from 250 to 4000 cps. No subject was included whose history revealed a middle ear pathology. Median pure tone threshold values are shown in Figure 4. Mean values for the speech reception threshold and speech discrimination score were 45.7 db and 75.6% respectively.

The 10 subjects selected for the sloping sensori-neural hearing loss group included eight males and two females. The average age for the group was 49.2 years, ranging from 33 to 60 years. The average duration of hearing loss was 19.2 years, while the duration of hearing aid use averaged 8.7 years. Six subjects wore their aid in the left ear, four in the right ear.

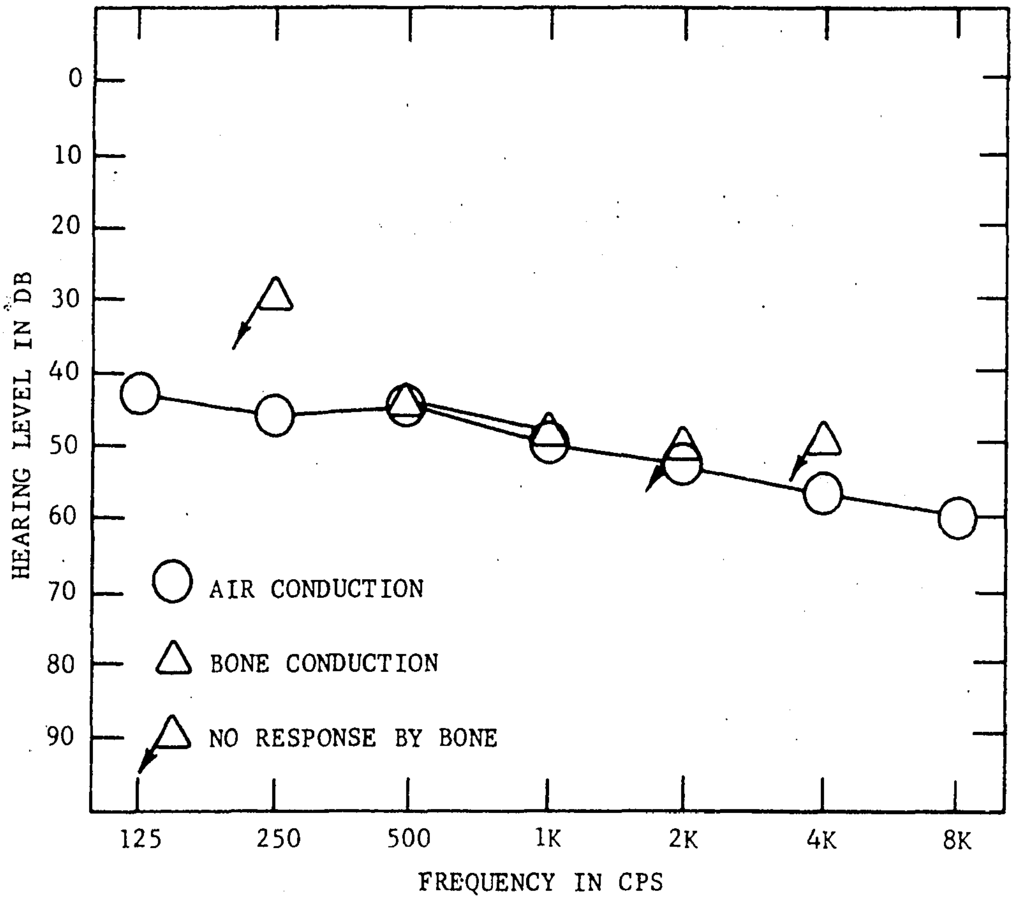

Fig. 3.--Median hearing levels in decibels re USPHS norms at seven test frequencies for the flat sensori-neural group by air and bone conduction.

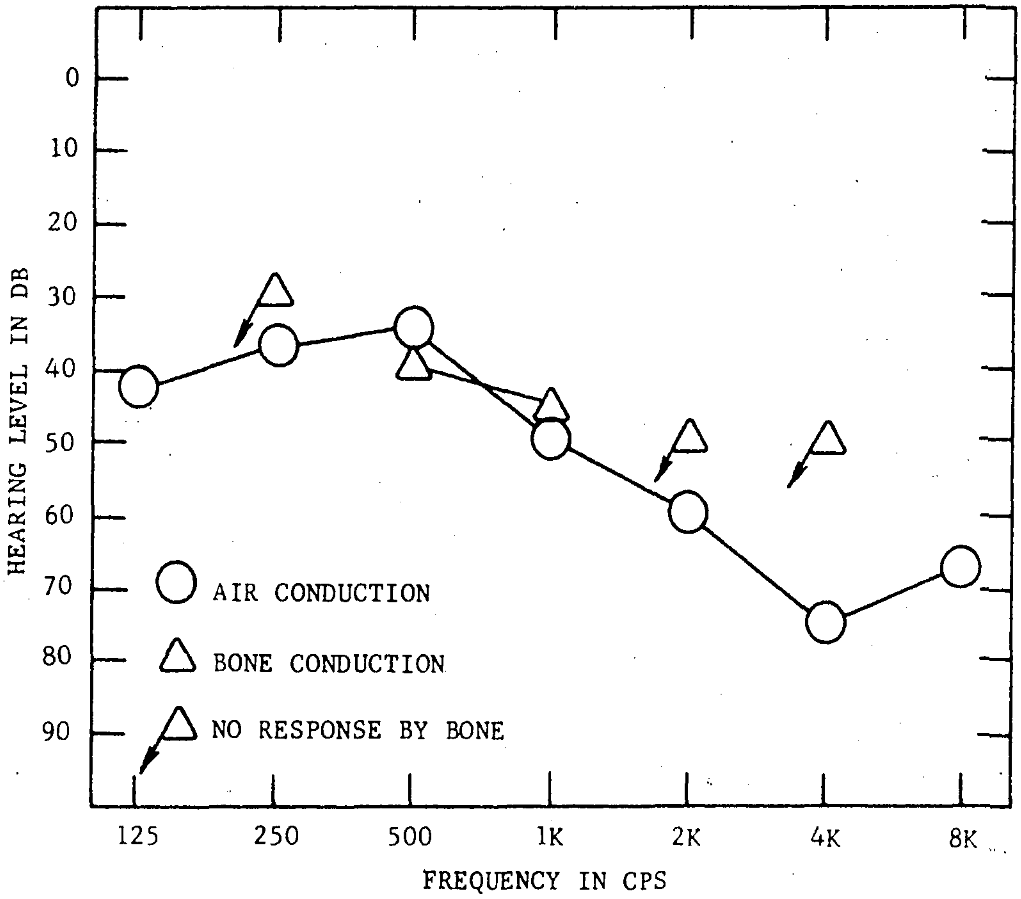

Fig. 4.--Median hearing levels in decibels re USPHS norms at seven test frequencies for the sloping sensori-neural group by air and bone conduction.

Equipment

All tests, both preliminary and experimental, were administered in a specially constructed, sound-isolated research suite in the University of Oklahoma Speech and Hearing Center. The ambient noise level in the test room was below the minimum level measurable on the "C" scale of the sound level meter, 31 db *re* 0.0002 microbar. However, the level had been previously estimated at 23 db *re* 0.0002 microbar.

Screening Apparatus

Pure tone testing. A commercially available pure tone audiometer (Beltone, Model 10-A), feeding either of two earphones (Telephonic, Type 39-10Z) or a low impedance hearing-aid-type bone conduction oscillator, was employed in obtaining air and bone conduction audiograms before accepting potential subjects for one of the four experimental groups. The earphones were mounted in MX-41/AR cushions and held in a standard headband. The same earphone was used for all pure tone tests by air conduction. The other earphone covered the non-test ear during all air conduction tests and was used only to present masking noise, when necessary. The bone conduction oscillator was held in a standard oscillator headband. During bone conduction tests, an earphone covered the non-test ear only when masking was presented to overcome lateralization.

The acoustic output of the air conduction system of the audiometer was calibrated by the use of an audiometer calibration unit (Allison, Model 300) employing a calibrated condenser microphone (Altec, Model 21-D) and an NBS-9-A coupler. The calibration was carried out at one week intervals during the period of the investigation. In addition, voltage readings for a 1000 cps tone were made daily, using a vacuum tube voltmeter (Ballantine, Model 300).

The bone conduction system of the audiometer was calibrated in the following manner. Air and bone conduction thresholds were measured at octave intervals from 250 to 4000 cps for five normal-hearing subjects in a sound-treated room. An attenuator providing a loss of 20 db was inserted in both air and bone conduction circuits prior to the measurement of these thresholds. This procedure allowed thresholds to be recorded at levels below that indicated by the -10 db setting on the hearing loss dial. The mean air and bone conduction thresholds for the five listeners were computed for the five test frequencies. The amount by which the mean bone conduction threshold deviated from the mean air conduction threshold at a given frequency represented the correction factor which it was necessary to apply to the bone conduction system at that frequency to bring it into proper calibration. Correction factors were made to the nearest five decibel interval; thus, no correction was made if the deviation between mean air and bone conduction thresholds was less than 2.5 db.

Speech testing. Preliminary hearing tests utilizing speech stimuli were presented, using a partially transistorized custom-built speech audiometer. Live-voice signals were fed to a single earphone (Telephonic, Type 39-10Z) which was mounted in an MX-41/AR cushion and held in a standard headband. A similar dummy earphone and cushion covered the ear not under test. Attenuation of the signal was provided in one decibel steps over a range of 130 db. The VU meter on the equipment provided a means of monitoring the live-voice stimuli used in the screening procedure.

Measurements made prior to the experiment demonstrated that the speech unit of the research console equalled or surpassed all specifications listed in the American Standards Specifications for Speech Audiometers (2), with one exception. The specification lists 22 db (SPL referred to 0.0002 microbar in an ASA type-1 coupler) as the norm for the speech reception threshold. The output of the speech unit was adjusted to produce 29 db SPL re 0.0002 microbar with the hearing level dial of the audiometer set at zero. This adjustment was made in order to obtain the 13 db relationship between the pure tone and speech audiometric norms, which has been suggested by Jerger and others (42) as the proper relationship to be specified for audiometric standards.

Experimental Test Apparatus

Narrow band noise. To obtain threshold values for bands of noise, the signal from a thermal noise generator, an integral part of the research console, was fed to an amplifier (MacIntosh, Model MC-30, Type A-116-B). This signal was then fed through two variable electronic filters (Spencer-Kennedy, Model 302), one of which had both sections set to high-pass and the other with both sections set to low-pass the signal at the desired nominal cut-off frequencies. The filtered signal was returned to the research console, monitored on the VU meter, and passed through the attenuator pads to the earphone (Telephonic, Type 39-10Z) previously described.

During certain portions of the procedure, the filtered thermal noise was presented through a speaker (Jensen, Model ST-162) mounted in a base reflex enclosure (Jensen, Type C-4873). A switch on the research console allowed selection of earphone or speaker presentation. This system is shown schematically in Figure 5.

The response of the filter system was determined prior to the investigation and again at the completion of the study. Figure 6 shows the frequency response characteristics of the filter system with the filters adjusted to produce the four pass-bands of noise employed for threshold determination.

The characteristics of the filter system were plotted by means of an audio-oscillator (Hewlett-Packard, Model 201-C) and two vacuum tube voltmeters (Ballantine, Model 300). The first voltmeter was used to monitor the output voltage of the oscillator which was held constant throughout the range of frequencies fed to the filter system, while the second voltmeter was bridged across the output of the filter system and used to read the voltage at any given frequency relative to the input voltage. Readings were made over the frequency range covered by the band to the point above and below the nominal cut-off points where the signal showed 60 db of attenuation.

Daily calibration checks were made using a sound level meter (General Radio, Type 759-B). The microphone of the sound level meter was placed a distance of one meter from the speaker, and wide band thermal noise was presented at 80 db _re_ 0.0002 microbar. The sound level meter was adjusted to the "C" scale, and readings were made in decibels _re_ 0.0002 microbar. The filter system was then introduced, and readings were repeated for each of the noise bands. No greater than a 2.4 db range of variation in level was noted for any signal over the period covered by the study, and the variation showed no systematic

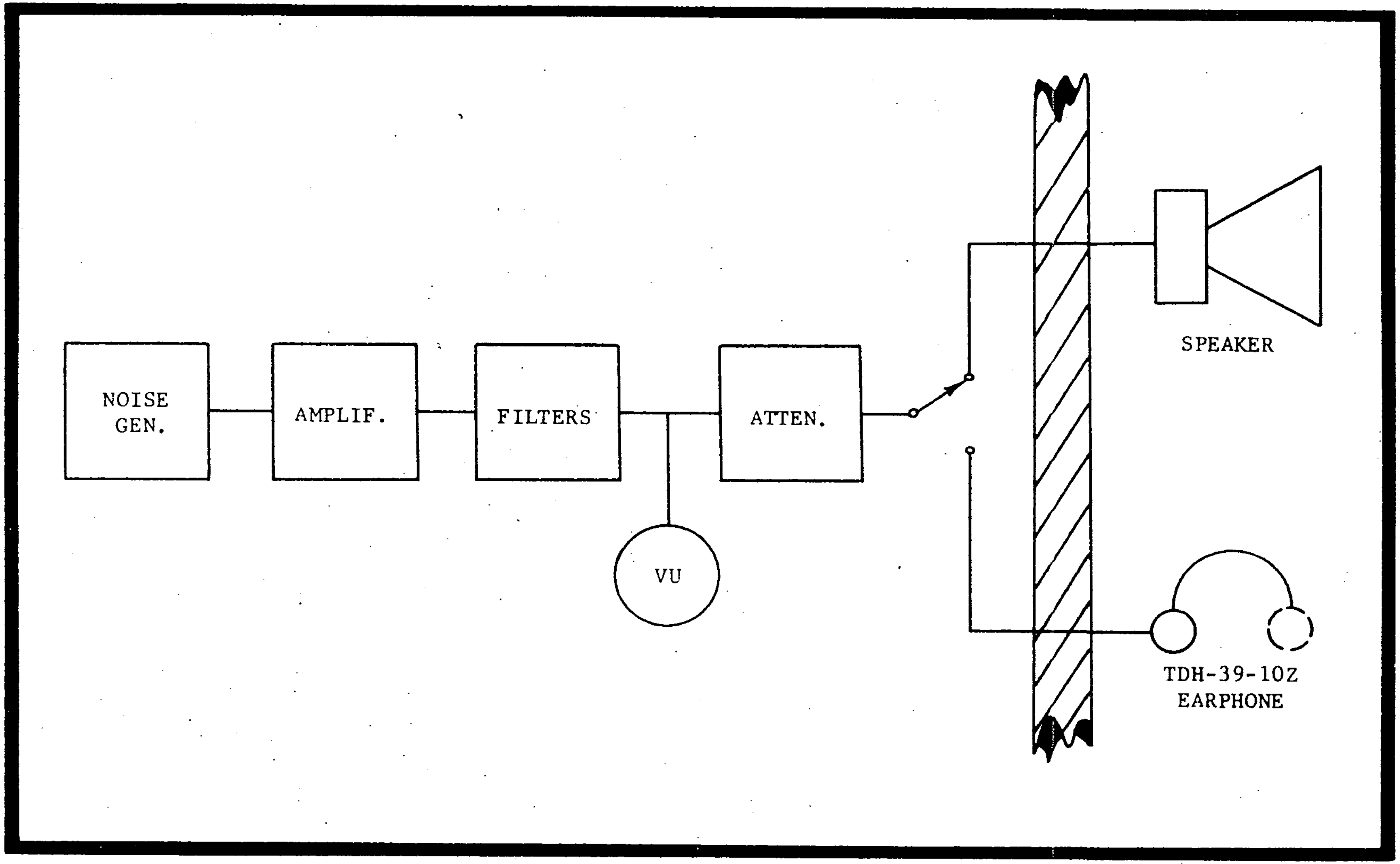

Fig. 5.--Simplified block diagram of the apparatus for the presentation of filtered bands of thermal noise.

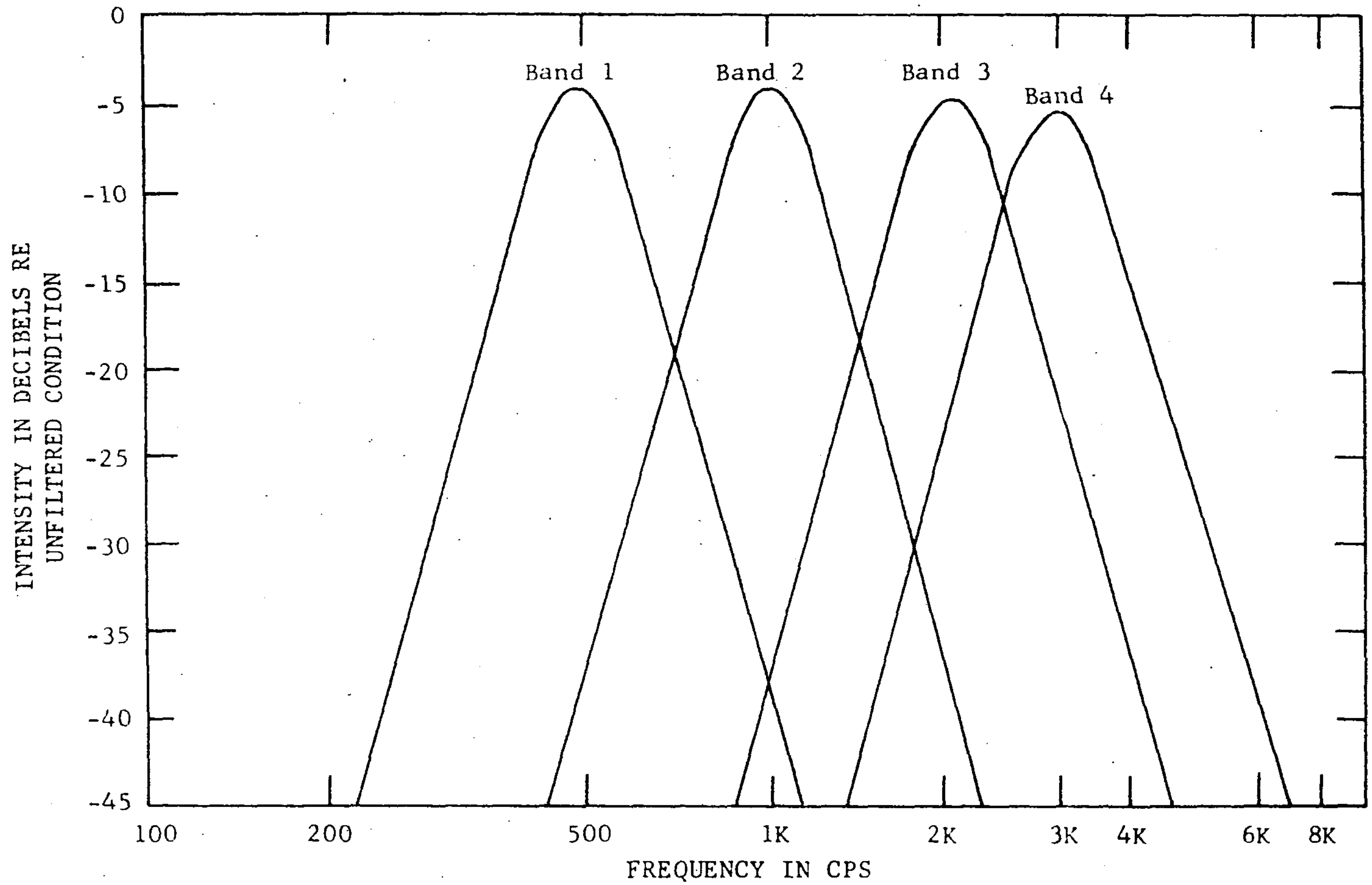

Fig. 6.--Frequency response characteristics of the filter system for four narrow bands of filtered thermal noise. Nominal center frequencies were: band one, 500 cps; band two, 1000 cps; band three, 2000 cps; band four, 3000 cps.

pattern over time. The range of variation for each noise band is shown in Table 1.

TABLE 1.--Acoustic output of noise bands with wide band noise adjusted to an output of 80 db re 0.0002 microbar. Figures are given for initial calibration, maximum positive and negative variation from these levels over the period of the investigation, and the total range of variation in decibels

	Noise Band				
	500	1000	2000	3000	500-20000
Acoustic Output	48.0	53.0	52.3	51.5	63.1
Maximum Positive Variation	49.0	53.8	53.1	52.3	64.8
Maximum Negative Variation	47.0	51.9	50.9	50.0	62.4
Total Range of Variation	2.0	2.1	2.2	2.3	2.4

With the high-pass and low-pass sections of the filter system adjusted to the nominal cut-off frequency, the insertion loss was taken as the amount of attenuation provided at the center frequency of the band, since the response sloped abruptly downward from either side of this point. The rejection rate of the filter system was computed by noting the attenuation provided at one octave intervals from the cut-off frequencies. The rejection rate was approximately the same for all bands. Both high-pass and low-pass rejection rates approximated 36 db per octave.

500-2000 cycle noise band. A 500-2000 cycle band of filtered thermal noise was also employed in the investigation. This signal, in addition to passing through the apparatus described above, was fed through an electronic switch, an integral part of the console. The resulting filtered noise signal was repeated regularly, once every 860 msec., with a duty cycle of 50%. The rise and decay time of the noise burst was 75 msec.

Determination of the output characteristic of the filter system for the 500-2000 cycle band was made in the same manner as described above for the narrow bands of noise. The filter output characteristic is shown in Figure 7. The variation in this signal, as shown in Table 1, covered a range of 2.4 db during the period of the investigation.

Speech testing. Recorded spondee words (C.I.D., Test W-1) were employed for the measurement of speech reception thresholds. Similarly, speech discrimination scores were determined, using recorded phonetically balanced word lists (C.I.D., Test W-22). A recording of connected discourse (Technisonic Studios, Fulton Lewis, Jr.) was also employed in the experiment. The recordings were presented through the phonograph system of the speech console. Those portions of the console utilized in this system included a 2.5 mil diamond stylus exerting a pressure of eight grams held in a Pickering Fluxvalve cartridge. The recordings were played on the console turntable (Garrard, Model 301).

The signal was fed to one of the four matched amplifiers (MacIntosh, Model MC-30, Type A-116-B) of the console, then to the VU meter and attenuators, and finally presented to the subject through a coaxial extended range speaker (Jensen, Model ST-162) mounted in a base reflex enclosure (Jensen, Type C-4873).

Presentations of the phonetically balanced word lists were accompanied by wide band thermal noise presented through a separate channel of the console and fed to a second speaker (Jensen, Model

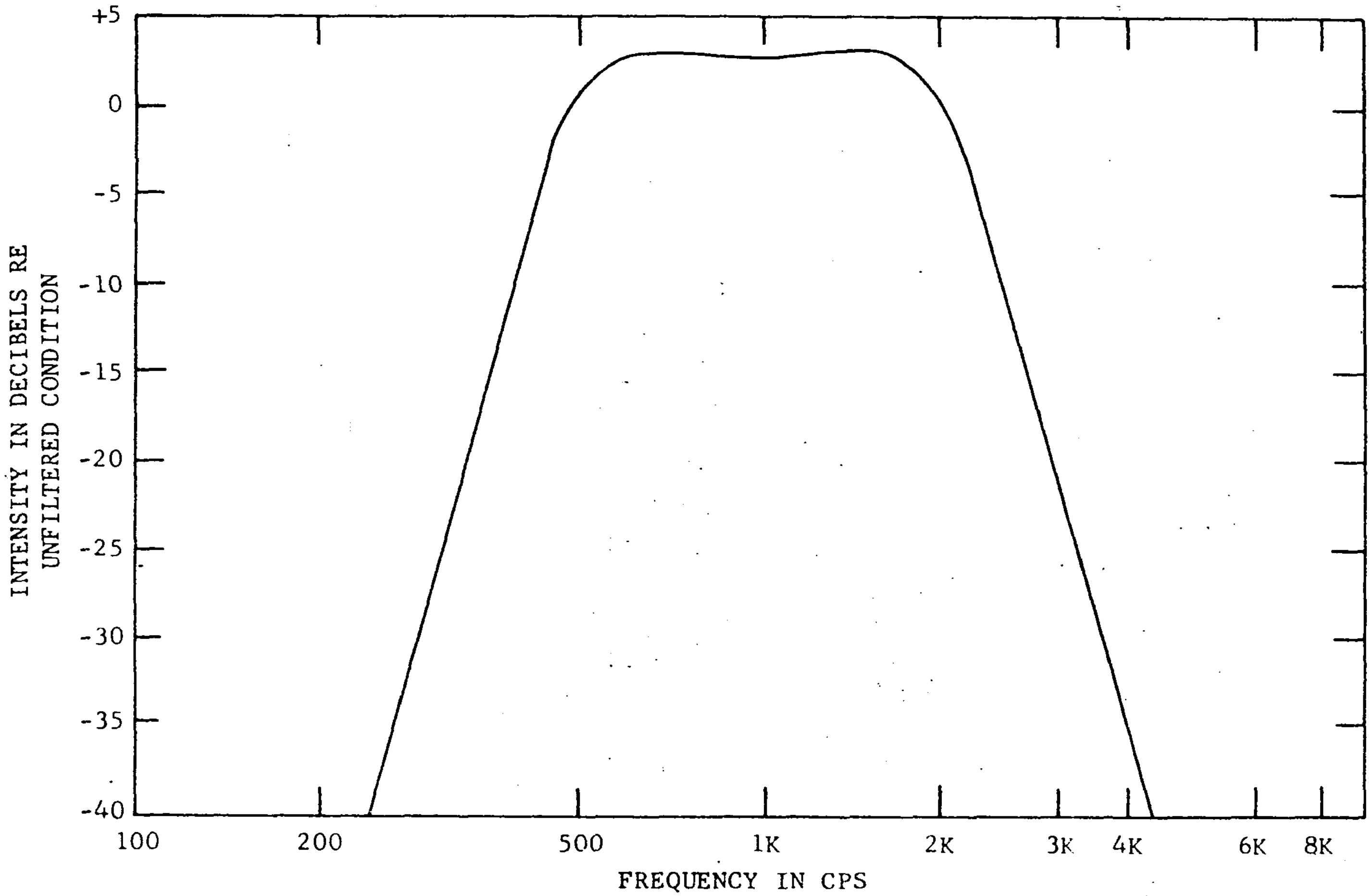

Fig. 7.--Frequency response characteristics of the filter system for a two-octave band of filtered thermal noise with nominal cut-off frequencies of 500 and 2000 cps.

ST-675) mounted in an enclosure (Jensen, Type C-5057) placed directly above the speaker through which the test signal was being presented. A simplified block diagram of this portion of the experimental apparatus is shown in Figure 8.

The equipment described above was calibrated prior to the study by presenting the signals to a group of 10 listeners with normal hearing and computing mean threshold values. In addition, a daily check was made of the acoustic output of the console, as described earlier.

All experimental equipment described to this point was housed in the control room of the research suite, with the exception of the earphone and speakers which were located in the subject test-room. The two rooms were connected by an observation window and an appropriate talk-back system.

In order to relate all experimental findings to normal hearing level, all signals to be used in the study were presented to 10 normal-hearing young adult listeners prior to the course of the experiment.

Hearing Aids

Three commercially available transistor hearing aids (Radioear, Model 850) were employed in the investigation. The choice of this particular instrument was based on clinical experience. This hearing aid was considered versatile in its range of both frequency and intensity output. In addition, it had been found both durable and reliable, two factors considered necessary for this research. Previous use of the hearing aid with clinical patients had shown it to give good hearing results with a variety of hearing loss types. The three instruments

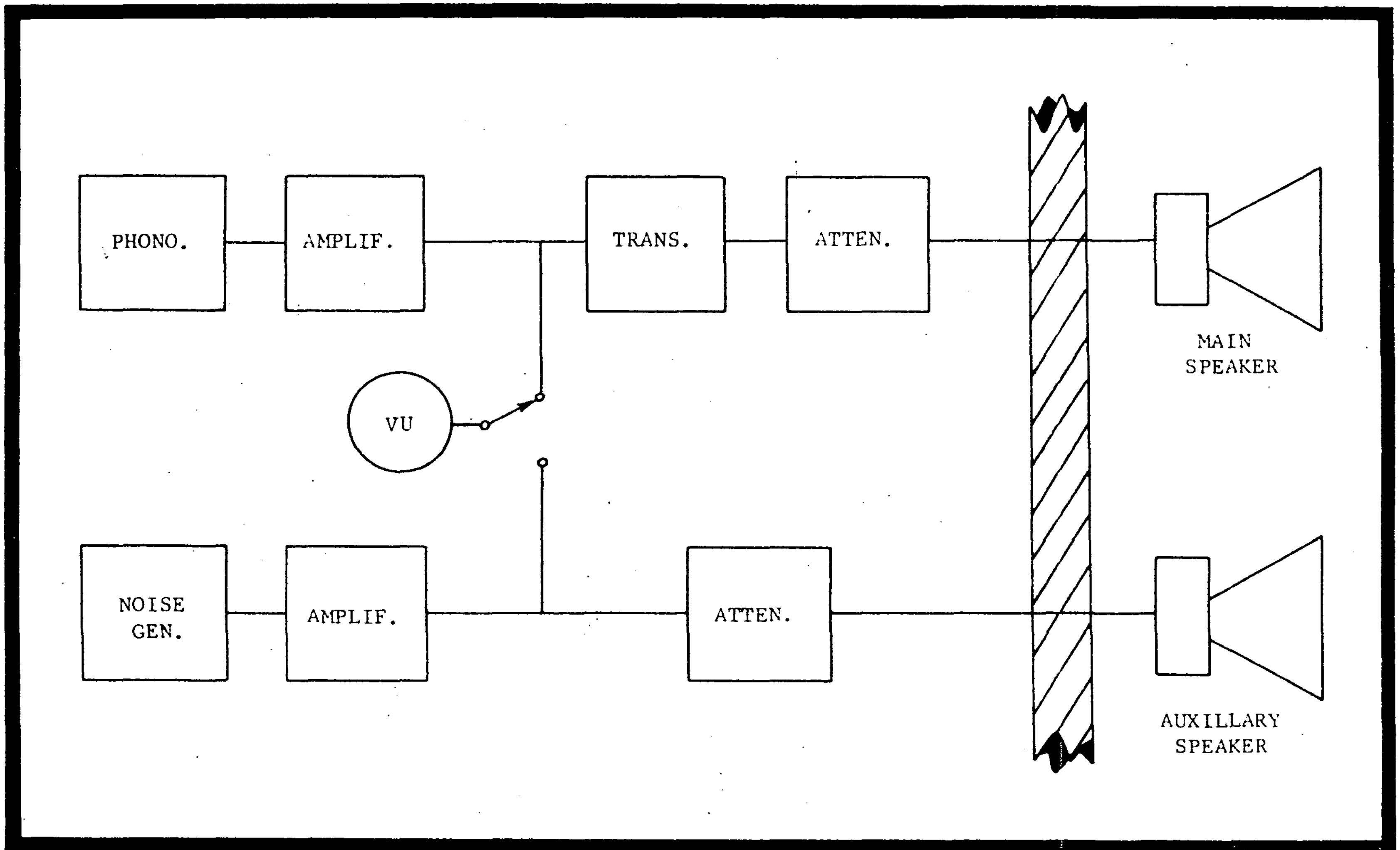

Fig. 8.--Simplified block diagram of the apparatus for the presentation of recorded speech tests.

used in the study were identical, except for the frequency response adjustments and the receivers utilized with each. The manufacturer's specification manual (62) was followed in adjusting one hearing aid to give a uniform amplification response, a second to produce a moderate high frequency rise of six db per octave, and the third to present maximum amplification of the high frequencies, a rise of 15 db per octave. The instruments, thus adjusted, were labeled "Flat," "HP-6," and "HP-15" respectively, and are referred to in this manner below.

The Flat aid utilized a saturation output setting of "A" with the high frequency setting on "cut." The low frequency tube of the microphone was open. A relatively flat receiver (Radioear, Type M-75) was utilized.

The HP-6 hearing aid used an internal saturation output setting of "B", a high frequency setting of "N", and a low frequency tube of the microphone was left open. This aid employed a flat response receiver (Radioear, Type M-70).

The HP-15 instrument used an internal saturation output setting of "B" and a high frequency adjustment of "N". The low frequency tube of the microphone was closed. A high frequency response receiver (Radioear, Type M-74) was used with this instrument.

All three instruments were used with a maximum power setting of "3", and all used the same type of 1.3 volt mercury battery (Mallory, Type RM-401).

Response curves of the hearing aids were determined prior to the initiation of the experiment and again upon the completion of the study. These data were determined by the manufacturer, using methods recommended by the American Standards Association (1). The acoustic output of the instruments showed insignificant changes over the period covered by the experiment. The differences noted between measurements made before and after the period of the study were so small as to be largely accounted for by temperature differences between the two tests and normal experimental error in this type of measurement (61). The complete output data for the three instruments are presented in Appendix B, while the frequency response curves of the three instruments are shown in Figure 9.

During the testing, the hearing aid being evaluated was held by a rubber band on a baffle board, with the back of the hearing aid placed against the board with its microphone facing the sound source. The baffle board was a piece of three-quarter inch acoustic tile measuring one foot square. The board was suspended from the ceiling of the room by a three-quarter inch pipe and was positioned one meter from the front of the speaker. The baffle board was designed to produce the approximate same effect on the response of the hearing aid as that produced by the human body as described by Hanson (30) and by Nichols and his associates (57).

Procedures

This study was designed to investigate certain aspects of hearing aid evaluation and fitting procedures as performed in speech and hearing clinics. Four subject groups were used: (a) subjects with flat conductive losses, (b) subjects with gradually sloping conductive losses, (c) subjects with flat sensori-neural losses, and (d) subjects

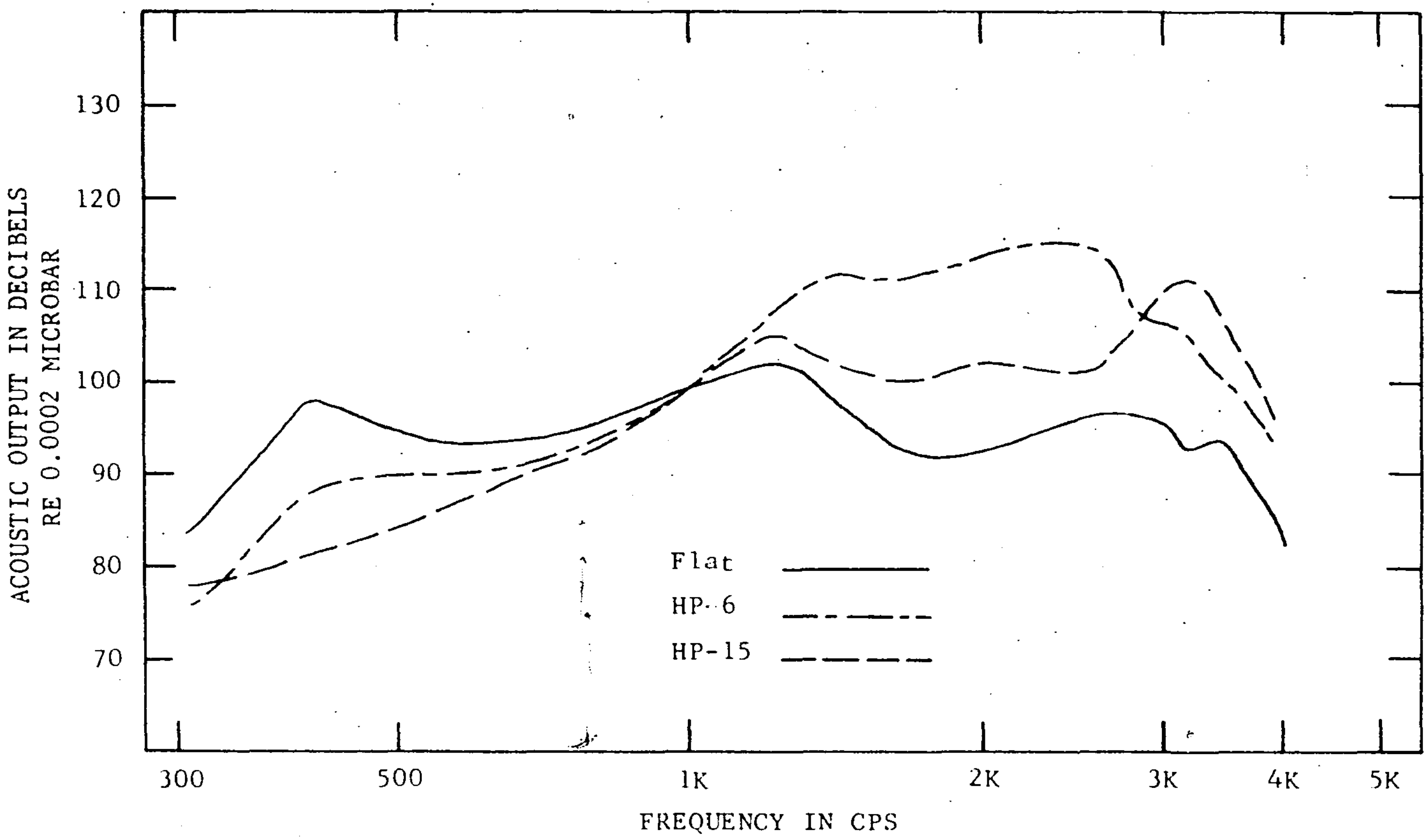

Fig. 9.--Acoustic output of the three hearing aids. Measurements made with an input of 60 db re 0.0002 microbar with the gain control of the hearing aids adjusted to give an output of 100 db at 1000 cps.

with gradually sloping sensori-neural losses.

Four specific aspects of hearing aid selection and fitting were investigated. The consistency of the present method of hearing aid volume control adjustment prior to testing was the first of these. The second was the practicability of selective amplification in hearing aids. The third was an investigation of aided noise-band threshold configuration with aids giving good speech discrimination scores. Finally, an investigation was made of the ability of the patient to select a hearing aid suited to his needs.

Preliminary Procedures

Pure tone stimuli. The preliminary testing procedures utilized with each of the experimental groups were described in the section dealing with the subject selection criteria. Briefly, the procedure for pure tone thresholds by air and bone conduction was to test the ear in which the hearing aid was normally worn. Thresholds were determined at octave intervals from 125 to 8000 cps, as well as at 3000 cps, by air conduction--and at octave intervals from 250 to 4000 cps, as well as 3000 cps, by bone conduction. All pure tone thresholds were obtained using the ascending technique described by Carhart and Jerger (12).

Speech stimuli. An unaided speech reception threshold (SRT) was determined, using spondee words from the W-1 test presented by monitored live voice. Five separate scramblings of the words were utilized. The list presented to a given subject was determined at random. The initial spondee words were presented at an intensity level approximately 15 db above the individual subject's average pure tone loss from 500 to

2000 cps. The intensity was decreased in five-db steps until the subject missed three or more of five words presented at a given level. Following this determination, the intensity was increased in one-db steps to the point where three of five words were correctly repeated. The signal was then decreased five db in intensity and the threshold again measured by increasing the intensity in one-db steps. Threshold was defined as the lowest level at which the subject could correctly repeat three of five spondee words.

The unaided speech discrimination score was determined, using the NDRC word lists (19) one through four. As with the spondee lists, the list presented to any given subject was determined at random. The words were presented by monitored live voice at an intensity level of 25 db re the individual subject's SRT. The carrier phrase, "you will say," was given prior to the presentation of each word on the test list. The percentage of the words correctly repeated was recorded as the unaided speech discrimination score.

Experimental Procedures

Unaided conditions. Thresholds for the narrow bands of noise, described in the apparatus section, were determined for the test ear under unaided conditions. As stated in the apparatus section, these narrow bands of noise served as a substitute for pure tone stimuli. This substitution was necessary to avoid the standing-waves which pure tones generate in a free field situation. Myers (55) found a high correlation between thresholds obtained for these two types of signal. His correlations were +.92 for 500 cps, +.94 for 1000 cps, +.81 for

2000 cps, and +.75 for 4000 cps. His research revealed no significant differences in variability or reliability between the two stimuli.

The procedure for the determination of threshold was the same as that utilized for pure tone testing; namely, the revised Hughson-Westlake technique (12). The narrow bands employed were nominally centered at 500, 1000, 2000 and 3000 cps and were presented in that order. In addition, a threshold for the 500-2000 cps band of thermal noise was determined under the same conditions, utilizing the same method of measurement.

Aided conditions. Two methods were utilized in adjusting the gain control of the hearing aid prior to presenting test stimuli with each instrument. One of these was labeled the "comfort setting;" the other, the "detection setting."

The comfort setting. The comfort setting was made in the following manner. The aid was placed on the baffle board and attached to the custom earmold which was placed in the subject's ear. The continuous discourse recording was then presented at a hearing level of 40 db under free field conditions. Starting from the minimum setting of the hearing aid gain control, the gain was adjusted by the examiner, at the direction of the subject, until the speech sample was received at a comfortable level. This level had been described to the subject as that point where the speech was neither too loud nor too soft, or about the level at which he would normally listen to radio or television.

The detection setting. Under the detection setting condition, speech stimulation was replaced by thermal noise band-passed with nominal cut-off frequencies of 500 and 2000 cps. This noise was used, rather than speech, for two reasons. Since the subject was asked to specify when the signal was detected, noise was considered less likely to confuse the subject. It was felt that if speech was used, some subjects might confuse the detection threshold with either the threshold of intelligibility or the threshold of perceptibility, regardless of how specific the instructions were made. In addition, since noise replaced speech, it was desirable to include the same portions of the frequency spectrum as found in a speech signal. Zarcoff's research (77) revealed the feasibility of substituting filtered thermal noise for spondee words in making an estimate of the threshold for speech.

The examiner adjusted the hearing aid gain control while the subject listened for this filtered thermal noise and instructed the examiner in the adjustment. It was felt the subject would be better able to separate the signal from any possible circuit noise or background noises, thus giving a more accurate adjustment if the signal was interrupted. The signal was, therefore, interrupted to present the noise burst once each 860 msec. with a duty cycle of 50% and a rise and decay time, for the noise signal, of 75 msec.

It was desirable that the gain control adjustment be at approximately the same level, whether set by the comfort or detection method. This, it was felt, should result in approximately the same aided speech reception thresholds, thus insuring the same amount of amplification by the instrument under each adjustment.

A formula was devised to determine intensity of the noise signal to be presented for detection by the subject. This was done on an individual basis, the noise level depending on the subject's unaided speech reception threshold (SRT) and unaided noise detection threshold (NDT).

An examination of 53 clinical hearing aid evaluation records for persons displaying a flat audiometric configuration showed the mean level of the aided SRT to be 17 db. Previous to the present research, 10 normal ears had shown the NDT to be one db lower than the SRT. Thus, for cases with flat audiograms, when the aid was adjusted to a comfort level for listening to a 40 db sample of continuous discourse, an SRT of 17 db had been obtained; and, theoretically, if the aid had been adjusted to detect a noise signal presented at a hearing level of 16 db, the same SRT (17 db) could have been expected. On the other hand, for cases displaying a sloping audiometric configuration, this relationship could not be expected to hold. Thus, the unaided thresholds for speech and noise were determined for each subject, as previously described. As was expected, the NDT was always lower than the SRT for subjects with sloping audiograms and, generally, by more than one db. The same relationship could be expected under aided conditions. Thus the formula was a simple one:

$$17 - (SRT - NDT) = NL$$

In this equation, the symbols were defined as follows:

1. 17 - the expected aided speech threshold in decibels <u>re</u> normal hearing.
2. SRT - the unaided speech threshold.
3. NDT - the unaided threshold for the 500-2000 cps band of noise.
4. NL - the noise level, in decibels, for the 500-2000 cps

band of noise to be presented for the detection setting.

Method of evaluation. The two methods of adjusting the gain control of the hearing aid, designated herein as comfort setting and detection setting, have been described. The three hearing aids were evaluated under both adjustment conditions. The combination of hearing aid (Flat, HP-6 or HP-15, as previously described) and adjustment method (comfort or detection) were randomized and all six combinations evaluated as will be described below. A 20 minute rest period was allowed each subject following these first six evaluations.

Following the rest period, the six combinations of hearing aid and adjustment method were again evaluated in random order. This procedure resulted in two sets of scores for each combination, these being designated as "test" and "retest" scores.

The evaluation of the instruments consisted of the determination of the aided speech reception threshold and the aided speech discrimination score.

Speech reception threshold. Recorded W-1 spondee words, lists A through F, were used for the determination of the aided speech reception threshold under each of the 12 test conditions. The lists were randomized separately for the six "test" conditions and the six "retest" conditions. Thus, although each list was used twice for a given subject, the time interval between the two presentations of an individual list was considerable. In addition, the recorder pickup-head was randomly placed on the recording so that even though the same lists were presented, different portions were heard, or at least a different starting point was used each time. If the end of a list was reached before the SRT had been determined, the list was presented from the beginning, a portion not previously heard.

The first word was presented at a hearing level of 40 db. If the word was correctly repeated, the intensity level was decreased five decibels for the presentation of the second word and so on, until the level was reached at which a word was missed. At the level of the first incorrect response, five words were presented. If four of the words were correctly repeated, the level was decreased five decibels and five more words were presented until the point was reached where the subject correctly repeated less than three of the words. The level was then increased in one-decibel steps until a correct response was noted on three of five words. This level was noted, the intensity decreased five decibels, and the one-decibel ascent repeated. The lowest level at which the subject could correctly repeat three of five spondee words was recorded as the speech reception threshold.

Speech discrimination score. For the determination of the speech discrimination score, the recorded Auditory Test W-22 phonetically balanced word lists were utilized. Since this test consists of six scramblings for each of four lists, a total of 24 test lists were available. The list order was partially randomized for each subject so that lists one through four appeared in a random order, this order being repeated three times during the course of the 12 determinations of the speech discrimination score. The scrambling for each list was separately randomized. The result was that the same list appeared three times to a subject, but between any two presentations, the other three lists had been presented. In addition, the word order was different during each presentation of a given list. This randomization was designed to minimize the effect of practice. During the course of the investigation, an individual recorded list was not played more than 28 times nor less than 15 times; thus any wear on the recordings could be considered negligible.

The recorded W-22 phonetically balanced (PB) word lists were presented at an intensity level 25 db above the speech reception threshold which had just been measured. To insure that no subject attained an aided discrimination score of 100%, thermal masking noise was presented with the PB words, at a level 10 decibels greater than that of the speech signal. Davis and his associates (<u>14</u>) used this method to assure that the resultant discrimination scores would not approach 100%. By increasing the difficulty of the test in this manner, the test was made more sensitive in differentiating the three hearing aids. The subject's response to each word was recorded as correct or incorrect. The number of correct responses was totalled, multiplied by two and recorded as the discrimination score in percent.

<u>Subject preference for aids</u>. At the latest point in the series of 12 evaluations where the three hearing aids were to be tested consecutively, the patient was told he would be asked to state a preference for one of the aids. It was suggested that, during the succeeding three evaluations, he note such factors as tonal quality, naturalness, general comfort, or any other aspect of hearing he thought important to him as a hearing aid wearer. He was told he would be asked to choose one of the three aids as the one he would wear if only these three instruments were

available. After testing the aids consecutively, he was asked if he preferred the first, second or third instrument. His choice was recorded.

Noise band thresholds. Under three of the 12 conditions, aided thresholds were determined for the narrow bands of filtered thermal noise nominally centered at 500, 1000, 2000 and 3000 cps. These three conditions were the comfort settings for the Flat, HP-6, and HP-15 aids under the "test" condition. The noise bands were presented free field and thresholds were determined as described earlier in the portion of the procedure dealing with tests under unaided conditions. The threshold values were appropriately recorded.

Summary

Four subject groups were utilized in the present investigation. These included persons with flat conductive, sloping conductive, flat sensori-neural and sloping sensori-neural hearing losses. Each subject underwent several tests with three commercially available transistorized hearing aids. Although identical in make and model, the aids were adjusted to present three representative frequency response patterns. The three aids were adjusted to present (a) a relatively flat response, (b) a gradually rising high frequency emphasis, and (c) a sharply rising high frequency emphasis. As stated at the outset of this chapter, the present study included four distinct but related areas of investigation. The procedure was designed to gather data relative to each of the questions posed.

One phase of the investigation dealt with the consistency of speech reception threshold measures and speech discrimination scores on test-retest. Two methods were used to adjust the gain control of each hearing aid prior to the administration of the tests. One method involved adjustment of the gain control of the instrument to a comfortable listening level for connected discourse presented at a hearing level of 40 db. For the other method, the gain control was adjusted to a point where the subject could detect the presence of a band of filtered thermal noise with nominal cut-off frequencies of 500 and 2000 cps. The level at which this signal was presented was individually determined from the unaided thresholds for speech and for the noise band. Speech reception thresholds and speech discrimination scores were obtained twice with each hearing aid, using each of the methods of setting the gain control.

A second phase of the study utilized the data gathered as outlined above. Briefly, aided speech discrimination scores were obtained with each of the three hearing aid response curves; Flat, HP-6 and HP-15. With the four experimental groups employed in the study, this data would allow a comparison of hearing loss type and audiometric configuration with the ability to discriminate speech with three hearing aid amplification patterns.

Another portion of the study included the measurement of unaided and aided thresholds for narrow bands of filtered thermal noise. The bands used were centered at 500, 1000, 2000 and 3000 cps respectively. It was intended that the aided threshold configuration with each of the three hearing aids would be compared to the aided speech reception thresholds obtained with the instruments, in an effort to answer the third question for which this investigation sought an answer: Is there a particular type of aided audiometric configuration which constitutes a good fitting as judged by the aided speech discrimination score?

The final phase of the investigation was intended to compare the aid which the subject preferred and the aid with which he had obtained his highest speech discrimination score. At the end of each testing session, the subject was asked to indicate his personal preference for one of the three test instruments. At the same time, the experimenter made note of which of the aids had given the subject the highest speech discrimination score. These choices were recorded as preferred aid and recommended aid, respectively.

CHAPTER IV

RESULTS

Introduction

The present study was designed to investigate certain aspects of the clinical evaluation and fitting of hearing aids for the hard of hearing. Four experimental groups were utilized in the study: (a) subjects with flat conductive hearing losses; (b) subjects with sloping conductive hearing losses; (c) subjects with flat sensori-neural hearing losses; and (d) subjects with sloping sensori-neural hearing losses.

Three commercially available transistorized hearing aids were used in the study. These instruments were identical, with the exception of tone settings and receivers used for each. The three aids were adjusted to give flat, HP-6, and HP-15 frequency response characteristics respectively.

The investigation sought to gather data toward the solution of four basic questions. The questions do not represent particularly new concepts, nor is this the first attempt to answer them. The present study, however, deals with these questions as they apply to the transistorized hearing aid. In addition, the methods of attacking these problems may offer ideas for further research and the possible modification of present clinical techniques.

The questions which the study sought to answer were as follows:

1. Can test-retest consistency of the speech reception threshold and speech discrimination score be improved by changing the method of adjusting the hearing aid gain control prior to the administration of these tests?
2. Does the frequency response of the hearing aid significantly affect the ability to discriminate speech?
3. Is there a particular type of aided audiometric configuration which constitutes a good fitting as judged by the aided speech discrimination score?
4. Can the patient select the type of amplification which most adequately meets his needs?

The questions will be dealt with individually in appropriate sections below.

Gain Control Adjustment

The first question to be answered was: Can test-retest consistency of the speech reception threshold and speech discrimination score be improved by changing the method of adjusting the hearing aid gain control prior to the administration of the tests?

Two methods were used to adjust the gain control of an instrument prior to the administration of the speech tests. One, hereafter called the comfort adjustment, consisted of presenting connected discourse at an intensity of 40 db (re normal threshold) and having the examiner adjust the gain control so that speech arrived at the subject's ear at a comfortable loudness level. This is the clinically accepted procedure. The other method, hereafter referred to as the detection adjustment, consisted of the examiner manipulating the gain control until the subject could barely detect an interrupted band of filtered thermal noise with nominal cut-off frequencies of 500 and 2000 cps. The intensity level of the noise signal depended on the individual subject's unaided thresholds for this signal and for spondee words. The method of deriving this level was reported in the preceding chapter.

Flat Conductive Group

The flat conductive hearing loss group showed a mean difference of 4.70 db between the two speech reception threshold (SRT) determinations when the instruments were adjusted to a comfortable listening level for connected discourse. The mean difference in SRT for all three aids, using the detection adjustment, was 2.77 db. Both means were computed from the differences between two measures, disregarding the direction of these differences. The direction of difference was ignored since it was felt that the true consistency of either method would be obscured by presenting the data where differences in one direction would tend to cancel those in the other direction.

Figure 10 shows the relationship of the mean difference between test and retest values of the SRT for each of the three hearing aids by each adjustment method. The figure shows these differences to be smaller in each case where the detection method was used.

The consistency of the speech discrimination score was judged in essentially the same manner. Again, the direction of the differences was disregarded, since absolute differences were desired. With the instrument adjusted to a comfort level, a mean difference of 7.33% was noted on test-retest of the discrimination score. Using the detection adjustment, a mean difference of 6.67% was revealed. The significance between the means was not tested for the individual experimental groups, since the data of Figure 11 showed no significant trends. Figure 11 presents the mean differences obtained with each of the hearing aids. It will be noted that the sizes of these differences did not appear to depend on the method of adjusting the hearing aid gain control prior to the test.

Sloping Conductive Group

With the hearing aid gain control adjusted by the comfort method, this group showed a mean difference of 4.23 db between the two speech thresholds. When the detection adjustment was used, this difference was 2.03 db. As can be seen in Figure 12, the direction of the differences was the same for each hearing aid.

The consistency of the discrimination scores is shown in Figure 13. It can be seen that the differences between the two methods are small and are not in the same direction for all hearing aids. The mean difference between initial and retest scores by the detection method was 7.27%, while that of the comfort method was 6.67%.

Flat Sensori-Neural Group

Use of the comfort adjustment of the gain control resulted in a mean SRT difference of 4.07 db. Using the detection method, the mean difference between test and retest values was 2.20 db. The average

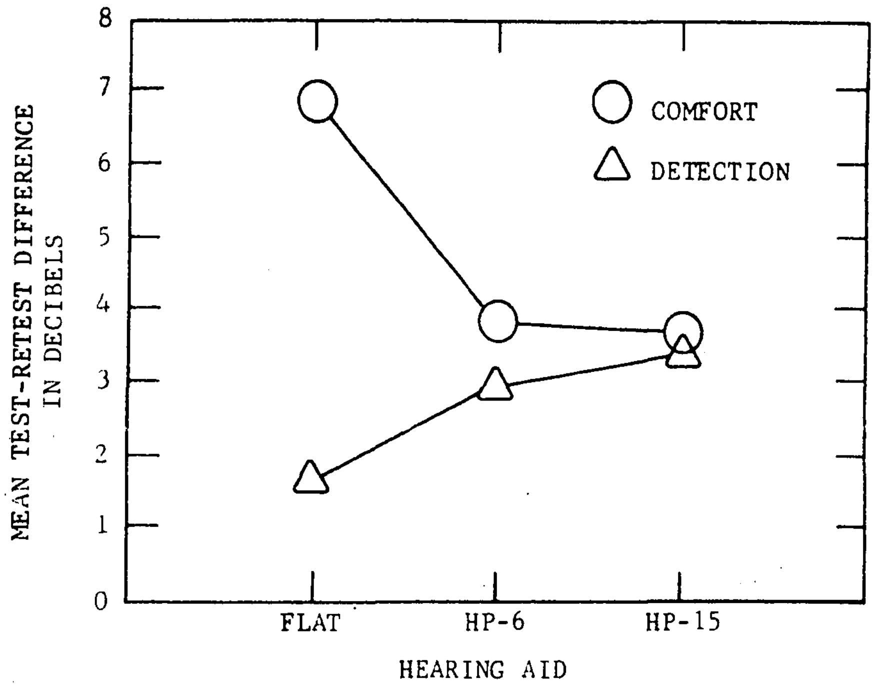

Fig. 10.--The mean difference, in decibels, between speech reception thresholds for two tests on each hearing aid for the flat conductive group.

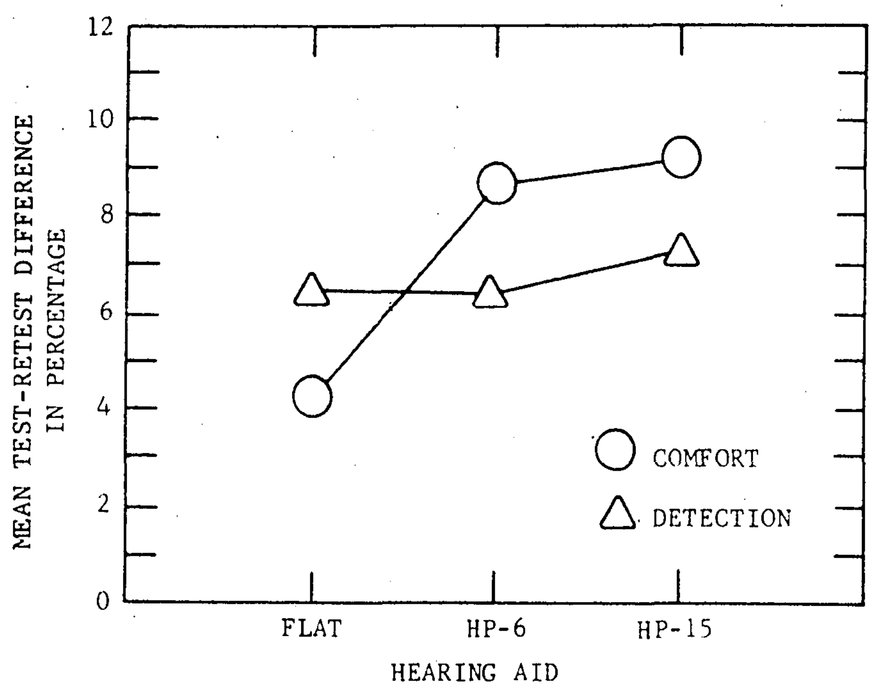

Fig. 11.--The mean difference, in percentage, between discrimination scores for two tests on each hearing aid for the flat conductive group.

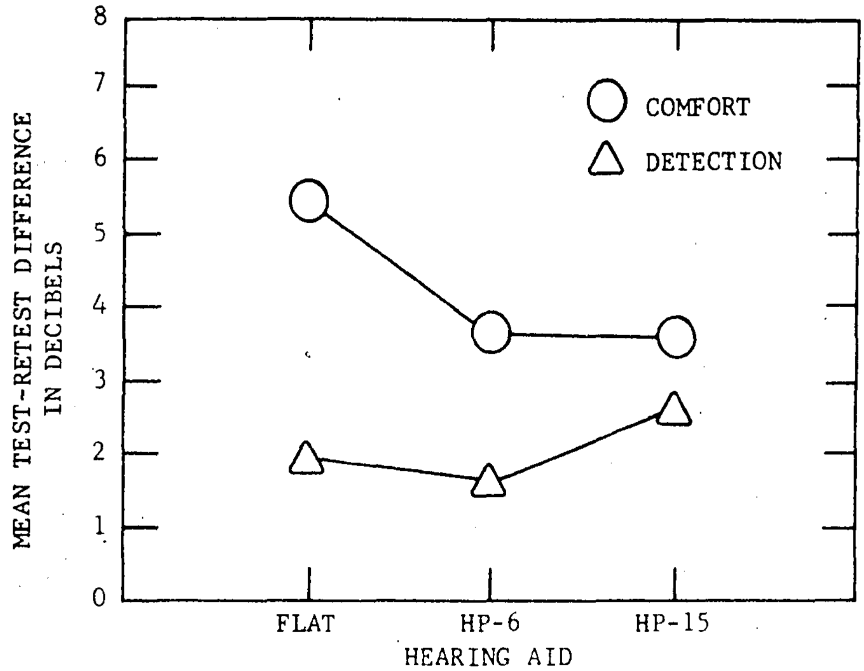

Fig. 12.--The mean difference, in decibels, between speech reception scores for two tests on each hearing aid for the sloping conductive group.

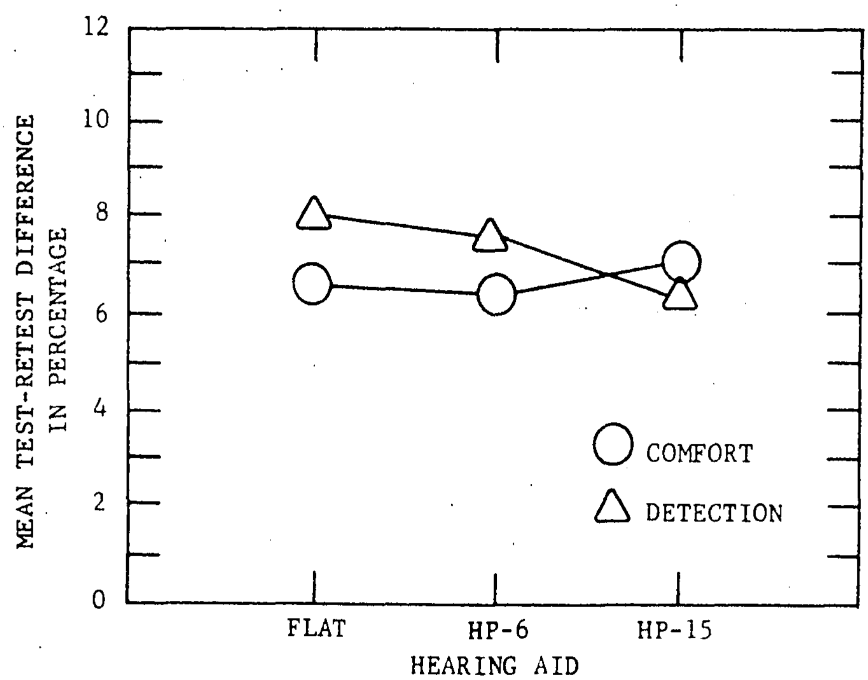

Fig. 13.--The mean difference, in percentage, between discrimination scores for two tests on each hearing aid for the sloping conductive group.

difference value for each of the hearing aids can be found in Figure 14. It can be seen that the detection adjustment tended to result in greater consistency when using each of the three hearing aids.

Figure 15 gives a representation of the consistency of the discrimination score by each of the methods under investigation. As with the groups previously reported, considerable variation is shown. With the Flat aid the comfort method appears to result in more consistent scores; with the HP-6 aid the detection method seems most consistent; and with the HP-15 instrument a negligible difference is found. These findings reflect the inconsistencies found in the measured discrimination score using either method of gain control adjustment. Grouping the data, the mean differences found between discrimination scores on the two tests were 6.33%, using the comfort method, and 5.67%, using the detection method.

Sloping Sensori-Neural Group

This experimental group showed a mean difference between initial and retested speech thresholds of 5.10 db by the comfort method and 2.07 db by the detection method. These differences were also computed for each of the individual hearing aids. These data are presented in Figure 16. In each case, the speech thresholds obtained, with the gain control adjusted to a detection threshold, tended to be more consistent than those measured with the aid adjusted to a comfort level.

Figure 17 represents the consistency of the speech discrimination scores when determined under the two experimental conditions. Although smaller differences are noted for the comfort adjustment in each

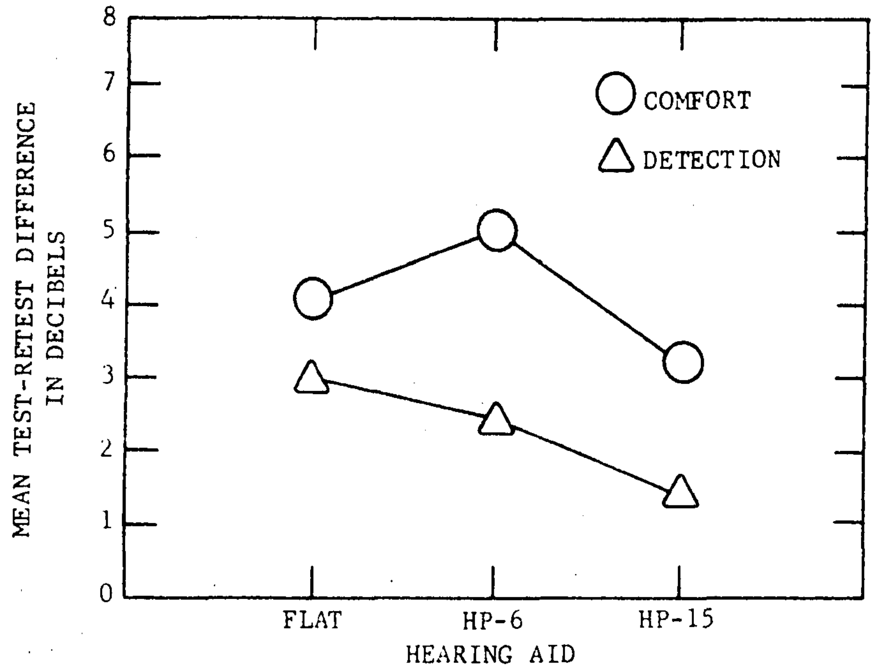

Fig. 14.--The mean difference, in decibels, between speech reception thresholds for two tests on each hearing aid for the flat sensori-neural group.

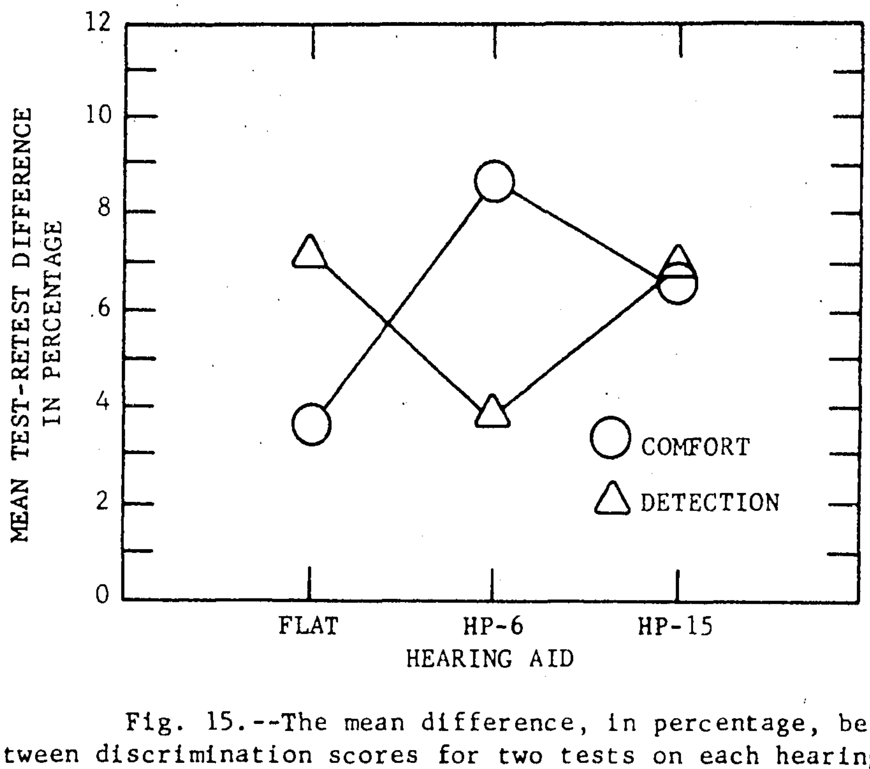

Fig. 15.--The mean difference, in percentage, between discrimination scores for two tests on each hearing aid for the flat sensori-neural group.

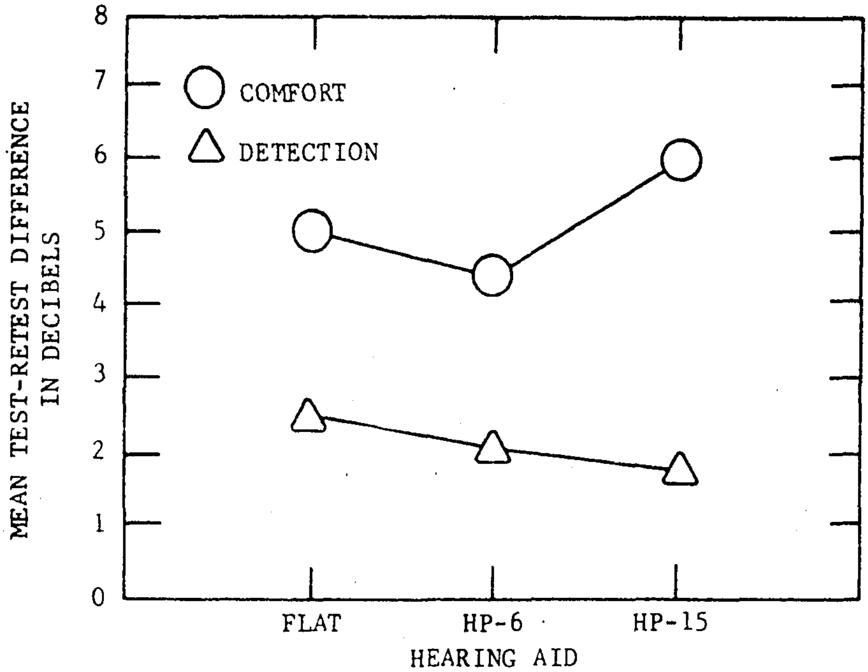

Fig. 16.--The mean difference, in decibels, between speech reception thresholds for two tests on each hearing aid for the sloping sensori-neural group.

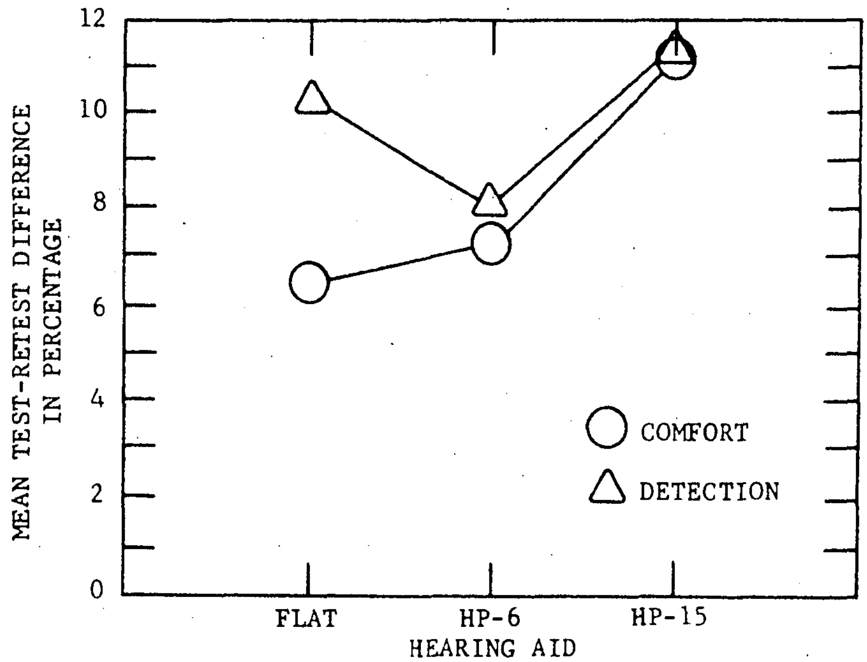

Fig. 17.--The mean difference, in percentage, between discrimination scores for two tests on each hearing aid for the sloping sensori-neural group.

case, the difference between the methods is negligible for the HP-6 and HP-15 instruments. Disregarding the individual hearing aids, the mean difference between the two sets of scores was 8.20% when the aid was adjusted to a comfort level and 9.87% when adjusted to detect the noise signal.

All Subjects Combined

Since there was no reason to suspect that the type of audiometric configuration and/or the type of hearing loss should affect the consistency with which gain control adjustment was made, it seemed reasonable to discuss the four experimental groups as one.

The mean difference between speech reception thresholds for the combined group was 4.53 db when the aid was adjusted by the comfort method. Use of the detection method resulted in a mean difference of 2.27 db. The differences obtained with each of the hearing aids are presented in Figure 18. Inspection of the figure shows the consistency with which smaller differences were obtained when adjusting the aids by the detection method.

The discrimination scores are treated in a similar manner in Figure 19. It appears obvious that there was no general superiority of one adjustment method over the other when the consistency of the discrimination score is considered. The mean difference for all aids grouped, using the comfort method, was 7.13%. When the detection method was utilized, the mean difference for all aids was 7.37%.

Statistical Treatment

The significance of this phase of the study was tested, using

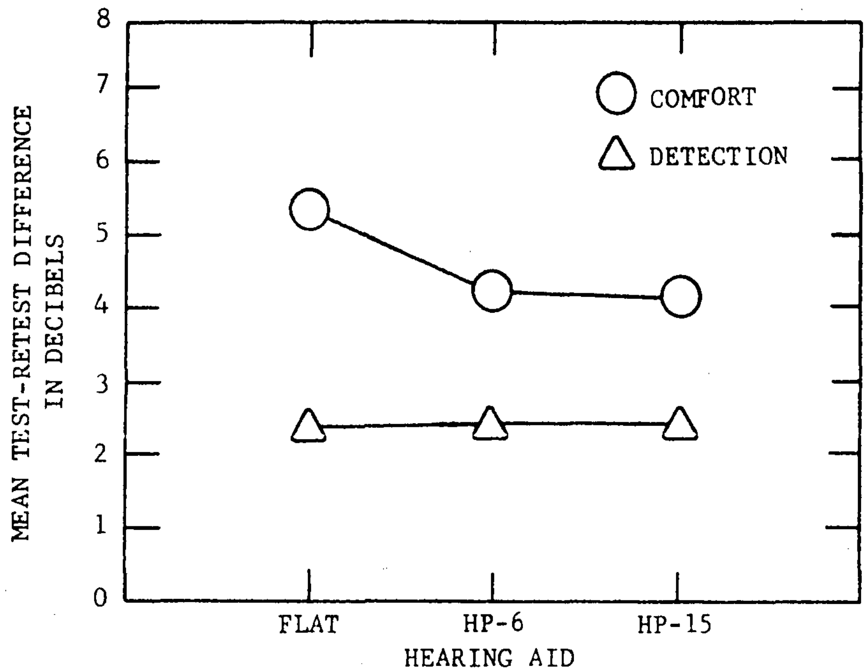

Fig. 18.--The mean difference, in decibels, between speech reception thresholds for two tests on each hearing aid for all subjects.

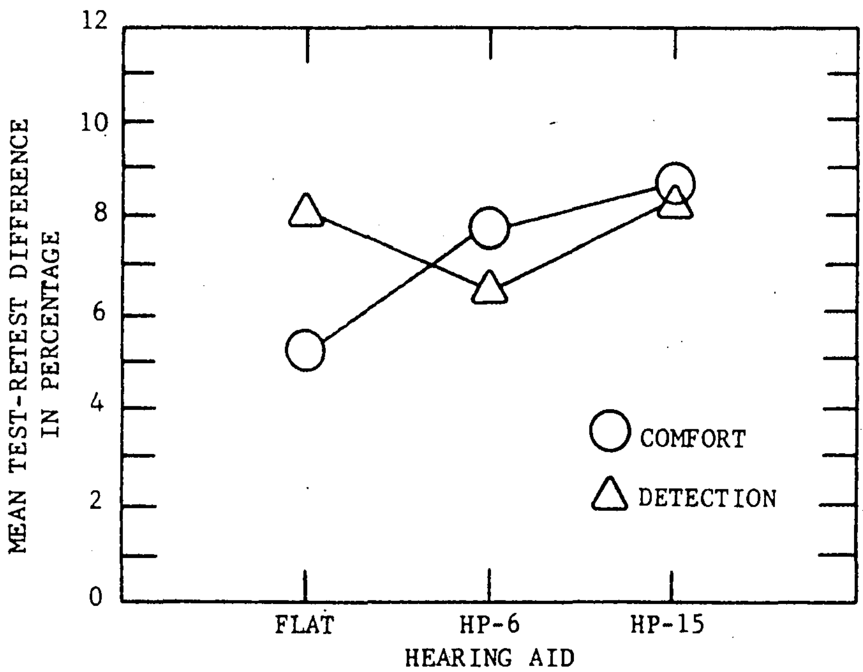

Fig. 19.--The mean difference, in percentage, between discrimination scores for two tests on each hearing aid for all subjects.

an analysis of variance technique with a randomized complete block design which incorporated a factorial arrangement of fixed treatments and a random arrangement of subjects. The model for the design is given in Appendix G.

The same design was used to test the consistency of the speech reception threshold and the speech discrimination score respectively.

The analysis of variance testing the consistency of the speech thresholds obtained by the two methods of adjusting the hearing aid gain control is shown in Table 2.

TABLE 2.--Summary of analysis of variance for evaluation of SRT consistency for all subjects under two conditions of gain control adjustment

Source	df	ms	F
Subject Group (G)	3	5.74	0.78
Adjustment Method (A)	1	306.00	41.50*
Hearing Aid (R)	2	8.65	1.17
GA	3	4.32	0.59
GR	6	4.44	0.60
AR	2	8.50	1.15
GAR	6	13.77	1.87
Total	23		

*Significant at the .01 level.

Since none of the interactions of the analysis approached significance, it was assumed they were a part of the error and could, therefore, be pooled (5). The result is shown in Table 3.

TABLE 3.--Summary of analysis of variance for evaluation of SRT consistency with the interactions pooled to become a part of the error term

Source	df	ms	F
Subject Group	3	5.74	0.77
Adjustment Method	1	306.00	41.11*
Hearing Aid	2	8.65	1.16
Total	6		

*Significant at the .01 level.

The method of adjusting the gain control of the instrument was shown to have been significant at the .01 level while none of the other variables were significant. The statement may then be made that the total variability related to the speech reception threshold, in the instance of this experiment, lies solely in the method of setting the gain control of the hearing aid prior to testing.

As stated above, the same statistical design and model were used to determine the superiority of the one adjustment method over the other in increasing the consistency of the speech discrimination score. A summary of the analysis of variance is presented in Table 4.

The analysis of variance revealed that none of the variables or interactions approached significant values. It can be stated that, under the conditions of this experiment, a superiority could not be demonstrated for either of the methods of gain control adjustment by measuring the speech discrimination score. In other words, the consistency of test-retest measurement of the speech discrimination score was as good when using the comfort adjustment as when using the detection adjustment. There was clearly no advantage to be gained by adjusting the gain control to detect a noise signal. The reasons for the inconsistency of the speech discrimination score obviously lie elsewhere.

TABLE 4.--Summary of analysis of variance for evaluation of the consistency of the speech discrimination score for all subjects under two conditions of gain control adjustment

Source	df	ms	F
Subject Group (G)	3	97.71	2.00
Adjustment Method (A)	1	3.27	0.01
Hearing Aid (R)	2	53.60	1.10
GA	3	19.04	0.39
GR	6	25.38	0.52
AR	2	93.07	1.90
GAR	6	16.98	0.35
Total	23		

Hearing Aid Response

The second question to be investigated by the present study was: Does the frequency response output of the hearing aid significantly affect the ability to discriminate speech?

Briefly, aided speech discrimination scores were obtained for each experimental group using the Flat, HP-6, and HP-15 hearing aids. The scores were measured by presently accepted clinical procedures; i.e., using recorded PB word lists presented at a sensation level of 25 db in the presence of a background of thermal noise.

In addition to treating each experimental group in an independent analysis, the groups were pooled in four combinations for further analysis. These combinations were: (a) all flat configuration losses, (b) all sloping configuration losses, (c) all conductive losses, and (d) all sensori-neural losses. By the use of this type of grouping, it was felt that the variables of audiometric configuration and type of hearing loss could be isolated, thus making it possible to determine which, if either, of these variables was important in the determination of the type of amplification to be applied to a given hearing loss. The results of this phase of the study are discussed below for each experimental group and for each combination of groups. It should be remembered that all discrimination tests were made more difficult by the presence of a background of thermal noise, thus accounting for the low mean speech discrimination scores reported in the discussion of results.

Flat Conductive Group

This group obtained a mean discrimination score of 71.00% while wearing the Flat aid, 66.00% with the HP-6 instrument, and 62.80% with the HP-15 instrument. The significance of these differences was tested, using an analysis of variance with a randomized complete block design having a factorial arrangement of fixed treatments and a random arrangement of subjects. The model for this analysis can be found in Appendix G. The analysis is summarized in Table 5.

The analysis showed that a significant difference existed among the discrimination scores obtained with the three instruments. Although the F-test revealed significant differences, it could not show how each mean related to the others. It was desirable to discover how each of the means differed from the others (66). Therefore, analysis was made by subjecting the data to the multiple range test (18). The results, as given in Appendix G, showed that the mean discrimination score obtained with the Flat aid was significantly better than that obtained with the HP-15 instrument. This difference was evidenced at the .05 level. The mean score obtained with the HP-6 instrument did not differ significantly from those obtained with either the Flat or the HP-15 aids. Thus, subjects displaying flat conductive hearing losses obtained significantly superior aided speech discrimination scores with the Flat response aid than they did with the HP-15 instrument.

TABLE 5.--Summary of analysis of variance for evaluation of discrimination scores obtained by the flat conductive loss group with the three hearing aids

Source	df	ms	F
Subjects	9	110.36	
Hearing Aids	2	170.80	4.91*
Total	11		

*Significant at the .05 level.

Sloping Conductive Group

This experimental group showed mean aided speech discrimination scores as follows: Flat aid, 68.80%; HP-6 aid, 68.40%; HP-15 aid, 63.60%. An analysis of variance technique, identical to that described above, was employed with the data obtained with this subject group. This analysis is summarized in Table 6.

The analysis of variance revealed no evidence of significance among the discrimination scores obtained with the three hearing aids. Thus, this experimental group seemed to understand speech about as well with one aid as with the others.

TABLE 6.--Summary of analysis of variance for evaluation of discrimination scores obtained by the sloping conductive group with the three hearing aids

Source	df	ms	F
Subjects	9	80.36	
Hearing Aids	2	83.73	1.74
Total	11		

Flat Sensori-Neural Group

The subjects displaying flat sensori-neural hearing losses showed mean discrimination scores of 61.20% with the HP-6 aid, 56.20% with the HP-15 aid and 53.00% with the Flat aid. The analysis of variance is summarized in Table 7.

TABLE 7.--Summary of analysis of variance for evaluation of discrimination scores obtained by the flat sensori-neural group with the three hearing aids

Source	df	ms	F
Subjects	9	684.09	
Hearing Aids	2	170.80	3.65*
Total	11		

*Significant at the .05 level.

The analysis revealed a significant difference among aided speech discrimination scores for the three hearing aids. In order to determine which of the aids could be differentiated, the multiple range test was employed. The results of this technique, shown in Appendix G, revealed that the HP-6 hearing aid was superior to the Flat aid but not significantly different from the HP-15 aid. It can be stated, therefore, that discrimination scores obtained by the flat sensori-neural group were better with the HP-6 instrument than with the Flat instrument.

Sloping Sensori-Neural Group

The mean aided speech discrimination scores for the sloping sensori-neural loss group were 61.00% with the HP-15 aid, 58.20% with the HP-6 aid and 51.60% with the Flat aid. The summary of the analysis is shown in Table 8.

TABLE 8.--Summary of analysis of variance for evaluation of discrimination scores obtained by the sloping sensori-neural group with the three hearing aids

Source	df	ms	F
Subjects	9	212.21	
Hearing Aids	2	232.93	2.70
Total	11		

The analysis of variance gave no evidence of a superiority of any one aid over either of the other instruments in delivering intelligible speech to the listener possessing a sloping sensori-neural hearing loss.

Flat Audiometric Configuration

As a group, subjects displaying flat audiometric configurations, whether a conductive or sensori-neural loss, showed a mean aided discrimination score of 63.60% with the HP-6 aid, 62.00% with the Flat aid and 59.50% with the HP-15 aid. An analysis of variance, similar to those used for each individual experimental group, was utilized in testing the results. The only manner in which this analysis differed from those above was the sample size, the flat conductive group and the flat sensori-neural group having been pooled and treated as one sample. The summary of the analysis is shown in Table 9.

TABLE 9.--Summary of analysis of variance for evaluation of discrimination scores obtained by subjects with flat audiometric configurations with the three hearing aids

Source	df	ms	F
Subjects	19	452.14	
Hearing Aids	2	85.40	1.64
Total	21		

The analysis of variance revealed no significant differences among the speech discrimination scores obtained with the three hearing aids. Thus, those subjects displaying relatively flat audiometric configurations, when treated as one group, seemed to understand speech equally well with any of the three hearing aids. This statement must be considered with caution, however. It must be noted that the flat conductive loss cases obtained significantly better scores with the Flat aid than they did with the HP-15 instrument, while the sloping conductive loss group scored significantly better with the HP-6 hearing aid than they did with the Flat aid. Thus, when the two groups were pooled for the above analysis, the scores obtained by the two classes of hearing loss tended to cancel each other.

Sloping Audiometric Configuration

When all subjects with sloping losses, both conductive and sensori-neural, were treated as a group, the mean aided discrimination scores were 63.30% with the HP-6 hearing aid, 62.30% with the HP-15 aid and 60.20% with the Flat aid. The analysis of variance is shown in Table 10.

TABLE 10.--Summary of analysis of variance for evaluation of discrimination scores obtained by subjects with sloping audiometric configurations with the three hearing aids

Source	df	ms	F
Subjects	19	217.53	
Hearing Aids	2	50.07	0.64
Total	21		

As can be seen by reference to Table 10, the differences among the hearing aids were not significant. The subjects with sloping losses appeared to understand speech about as well with one aid as with the others.

Conductive Loss

In the attempt to discover whether the type of hearing loss could be a determining factor for the type of amplification to be used, the experimental subjects were pooled into conductive and sensori-neural groups. The conductive loss group consisted of all conductive loss subjects regardless of the displayed audiometric configuration. The mean aided speech discrimination scores for the group were 69.90% with the Flat aid, 67.20% with the HP-6 aid and 63.20% with the HP-15 aid.

The analysis of variance described above was applied to the data. This analysis is summarized in Table 11.

TABLE 11.--Summary of analysis of variance for evaluation of discrimination scores obtained by subjects with conductive hearing losses with the three hearing aids

Source	df	ms	F
Subjects	19	90.42	
Hearing Aids	2	227.27	5.58*
Total	21		

*Significant at the .01 level.

The analysis of variance gave evidence of a significant difference among the scores obtained with the three hearing aids. To determine the nature of the differences, the multiple range test was again utilized. The results of this statistical treatment revealed that the Flat hearing aid yielded significantly superior discrimination scores when compared to those obtained with the HP-15 hearing aid. The HP-6 aid could not be significantly differentiated from either the Flat or HP-15 instruments. The analysis suggests that the patient displaying a conductive hearing loss will be better able to discriminate speech with a flat response hearing aid than he will with a sharply peaked high frequency response hearing aid.

Sensori-Neural Loss

For the purposes of this analysis, the flat sensori-neural and sloping sensori-neural groups were combined. The combined group showed mean aided discrimination scores of 61.00% with the HP-15 aid, 58.20% with the HP-6 aid and 51.60% with the Flat aid. The data were analyzed by the analysis of variance technique which is summarized in Table 12.

TABLE 12.--Summary of analysis of variance for evaluation of discrimination scores obtained by subjects with sensori-neural hearing losses with the three hearing aids

Source	df	ms	F
Subjects	19	424.55	
Hearing Aids	2	318.87	4.73*
Total	21		

*Significant at the .05 level.

The analysis revealed significant differences among the speech discrimination scores obtained with the three hearing aids. To determine where these significant differences occurred, the multiple range test was employed. The test results, given in Appendix G, showed the scores obtained with both the HP-6 and HP-15 hearing aids to be significantly superior to those obtained with the Flat instrument--the former two aids being undifferentiated by the analysis. In summary then, subjects with sensori-neural hearing losses appeared to understand speech better with either the HP-6 or HP-15 instruments than they did with the Flat hearing aid.

Aided Audiometric Configuration

A third phase of the present study dealt with aided noise band threshold configurations and their relationship to the aided speech discrimination score. Thresholds were measured for four narrow bands of filtered thermal noise centered at 500, 1000, 2000 and 3000 cps respectively. In the following discussion, the center frequency of the band will be used to designate each band of filtered thermal noise. These measures, as well as speech discrimination scores, were obtained under unaided conditions and under aided conditions with each of the three hearing aids. The experimental subjects were treated separately in their four categories: (a) flat conductive loss, (b) sloping conductive loss, (c) flat sensori-neural loss, and (d) sloping sensori-neural loss.

Mean noise band thresholds were computed for six separate conditions. The first of these was the mean unaided thresholds for the noise bands. Three of the conditions were the mean thresholds obtained with the three individual hearing aids; Flat, HP-6 and HP-15. A fifth condition was the mean thresholds obtained with the aid which would have been recommended for each subject. In other words, for each subject, the aids were rated by the investigator on the basis of the aided speech threshold and the discrimination score, as is done clinically. The aid giving the best discrimination score--or where two aids were similar in this respect--the aid giving the lowest threshold for speech was selected for each subject.[4] Mean noise band thresholds were computed for this group of hearing aids and designated as the mean thresholds for the recommended instrument. For the sixth and final condition, mean thresholds were derived for the aids designated as being preferred

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[4]In two cases the speech discrimination score was the same for two aids, and selection of a recommended aid was made on the basis of the SRT.

by each subject. In summary, mean noise band thresholds were obtained for: unaided conditions, the Flat aid, the HP-6 aid, the HP-15 aid, the recommended aid and the preferred aid.

Flat Conductive Group

The mean thresholds for narrow bands of noise obtained by the flat conductive loss group with each of the three hearing aids are shown in Figure 20. As might have been predicted, the Flat aid resulted in more acute hearing in the low frequency range and less acute hearing for the higher frequency noise bands than did the other two hearing aids. With the Flat aid, the mean speech discrimination score for this group was 71.00%. The HP-6 instrument gave slightly better hearing for the high frequencies, while providing less emphasis in the low frequency range, and resulted in a mean discrimination score of 66.00%. The thresholds obtained with the HP-15 hearing aid closely approximated those of the HP-6 aid, except for a more acute threshold for the band centered at 2000 cps. The mean discrimination score measured with the HP-15 aid was 62.80%.

The mean thresholds for the recommended instrument revealed a fairly flat configuration with a slight decrease in acuity for the band centered at 3000 cps. With this set of thresholds, the mean discrimination score was 73.20%. This set of thresholds closely approximated those obtained with the Flat instrument for this group. This finding was what would have been expected, since, for eight of the 10 subjects in the flat conductive loss group, the Flat instrument would have been recommended on the basis of the speech tests.

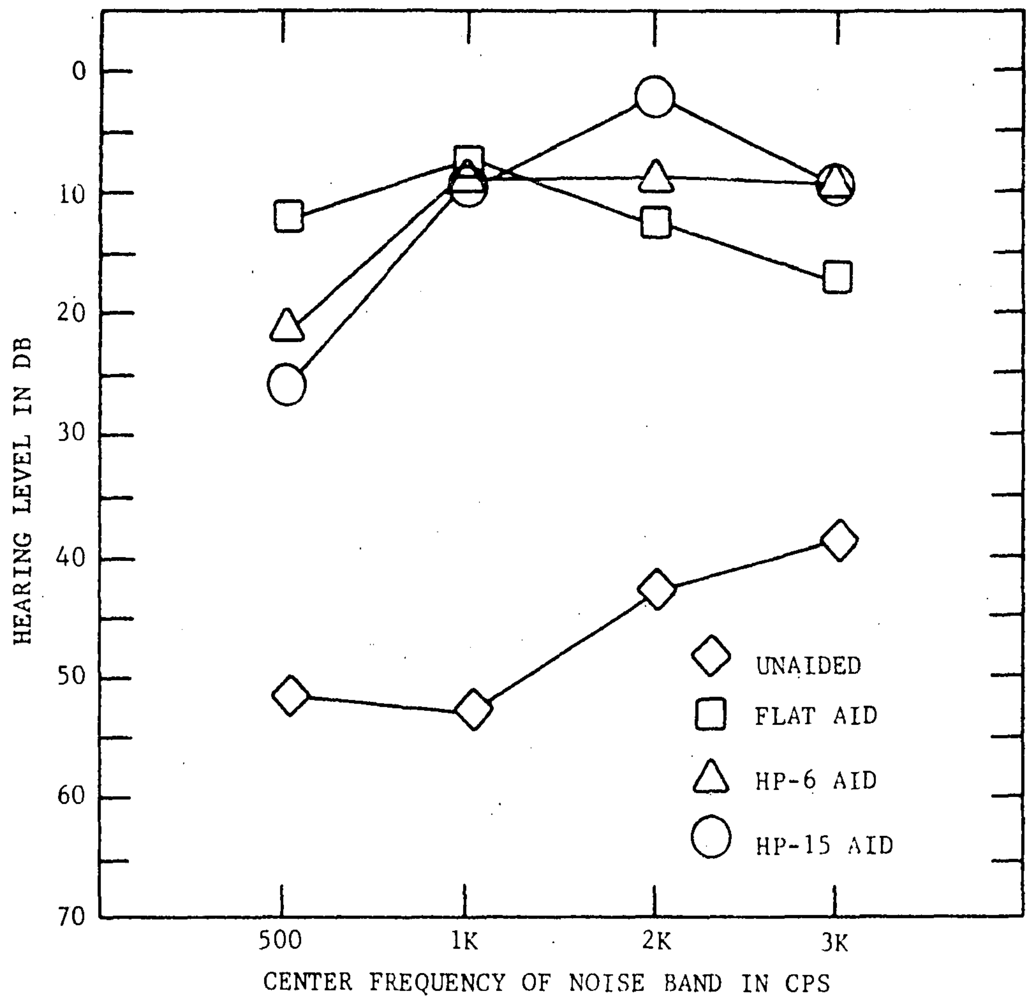

Fig. 20.--Mean hearing level, in decibels *re* normal threshold, for four bands of noise under aided conditions with each of the three hearing aids for the flat conductive group.

The mean noise band thresholds computed for the preferred instrument showed the same general pattern, with the exception of a slightly poorer threshold for the band centered at 500 cps and a slightly better threshold at 3000 cps. A mean discrimination score of 67.80% was computed from the scores each subject obtained with the aid for which he stated a preference. This configuration could almost be superimposed on the pattern of threshold obtained with the HP-6 instrument. The HP-6 aid was preferred by five of the ten subjects in this group.

The thresholds for the recommended and preferred instruments are presented in Figure 21. The recommended instrument showed a flat threshold pattern from 500 through 2000 cps with a slight decrease in acuity at 3000 cps. The preferred instrument, on the other hand, gave a flat configuration from 1000 through 3000 cps, with less acute hearing at 500 cps.

Sloping Conductive Group

The HP-6 and HP-15 instruments gave similar threshold values--except at 500 cps where the threshold was more acute with the HP-15 instrument. The mean discrimination scores with these instruments were 68.40% and 63.60%, respectively, for the sloping conductive group. The Flat hearing aid presented a pattern of thresholds that were more acute at 500 cps and less acute at 2000 and 3000 cps than those obtained with the other two instruments. A mean discrimination score of 68.80% was obtained with the Flat instrument. All three instruments gave the same approximate gain at 1000 cps. The thresholds are shown in Figure 22.

The sloping conductive hearing loss group showed almost no

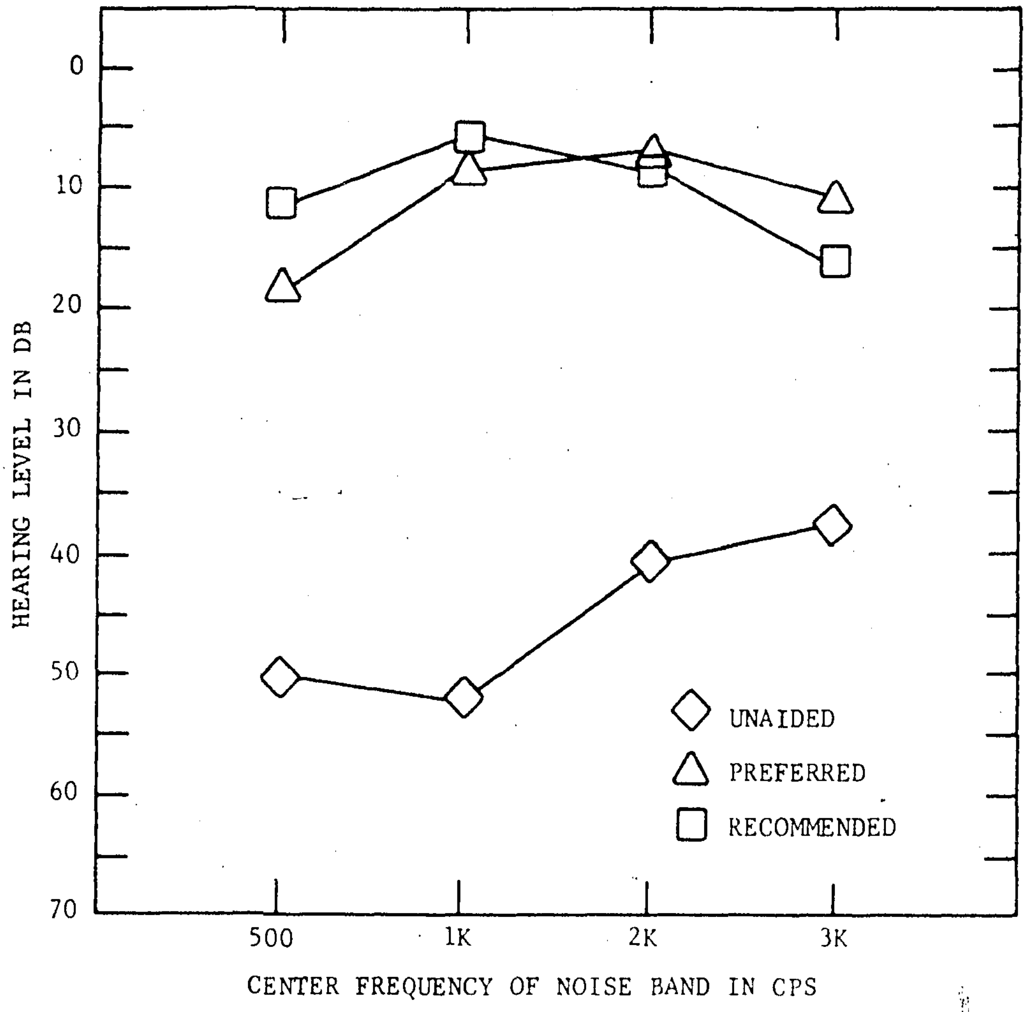

Fig. 21.--Mean hearing level, in decibels *re* normal threshold, for four bands of noise under aided conditions with the recommended and preferred hearing aids for the flat conductive group.

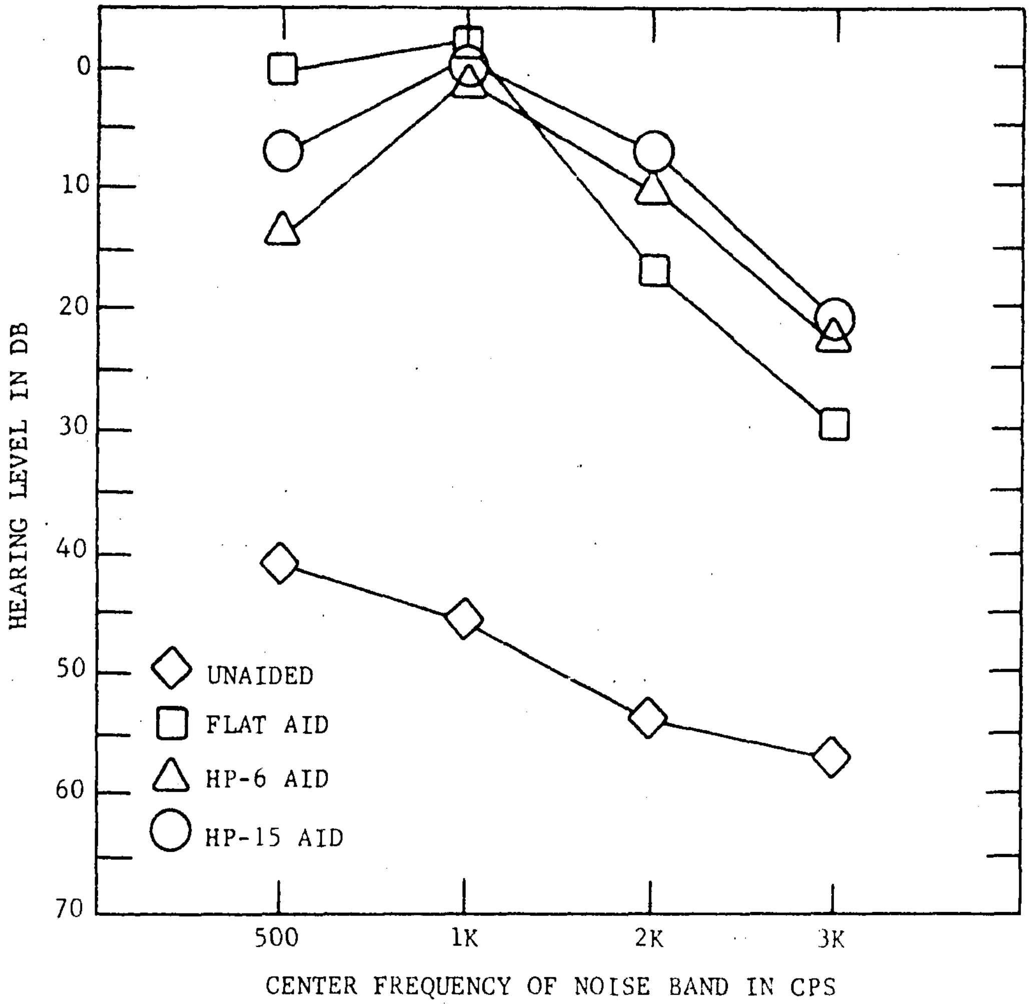

Fig. 22.--Mean hearing level, in decibels re normal threshold, for four bands of noise under aided conditions with each of the three hearing aids for the sloping conductive group.

difference between mean thresholds obtained with the preferred and recommended instruments. The configurations were nearly identical--with those thresholds obtained with the preferred hearing aid being approximately one db more acute for each noise band. The thresholds of the preferred instrument most nearly approached those obtained with the HP-15 hearing aid. The two patterns showed the threshold at 500 cps to be about seven db poorer than that at 1000 cps. In addition, there was an almost linear 12 db per octave drop in acuity from 1000 through 3000 cps.

The thresholds obtained with the preferred and recommended instruments are shown in Figure 23. Although these patterns approximated the thresholds of the HP-15 aid, the HP-6 instrument was most frequently recommended and most frequently preferred by this experimental group. In computing mean discrimination scores for the recommended and preferred instruments, a score of 72.60% was noted for the former and 64.60% for the latter.

Flat Sensori-Neural Group

As in the case of the two groups discussed above, the Flat hearing aid resulted in the best threshold at 500 cps and the poorest thresholds at 2000 and 3000 cps. This configuration resulted in a mean discrimination score of 53.00%. The HP-6 aid gave a slightly poorer threshold at 500 cps and slightly better hearing at 2000 and 3000 cps, and the HP-15 instrument showed a further drop in acuity at 500 cps. The HP-6 instrument gave a mean discrimination score of 61.20%, while a mean score of 56.20% was obtained with the HP-15 aid. All three

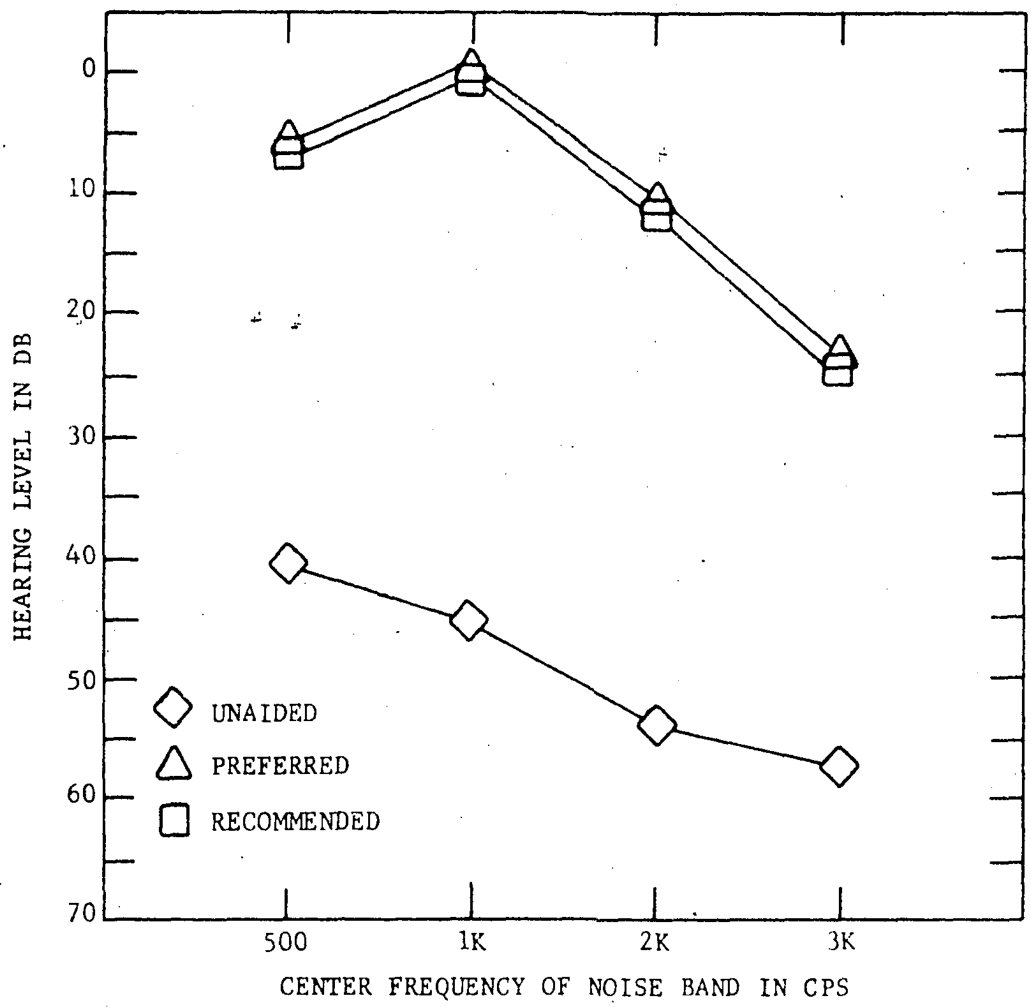

Fig. 23.--Mean hearing level, in decibels re normal threshold, for four bands of noise under aided conditions with the recommended and preferred hearing aids for the sloping conductive group.

instruments furnished about the same amount of amplification at 1000 cps. These thresholds are presented in Figure 24.

The thresholds obtained with the recommended hearing aid revealed a configuration not unlike that obtained with the HP-15 instrument and gave a mean discrimination score of 62.40%. This instrument was recommended for the majority of the subjects in the flat sensori-neural hearing loss group. The pattern showed nearly equal amplification at 1000 and 2000 cps with slightly less output at 500 and 3000 cps.

The pattern of noise band thresholds with the preferred instrument was only slightly divergent from that of the recommended instrument. The mean discrimination score computed from the aid preferred by each subject was 59.00%. The preferred pattern was nearly identical with that of the HP-6 aid which was preferred by six of the subjects in this group. Except at 500 cps, the thresholds obtained with the preferred and HP-6 instruments were less than a decibel apart.

The preferred and recommended patterns are shown in Figure 25. In comparing the two sets of threshold measurements, it can be seen that the subjects tended to prefer slightly less high frequency amplification than would have been recommended for them.

Sloping Sensori-Neural Group

Those subjects displaying sensori-neural hearing losses, with increased loss in the high frequencies, showed aided threshold patterns which were similar to their unaided threshold configurations, but at a lower intensity level. As in the other three subject groups, the thresholds were nearly the same for all three instruments at 1000 cps.

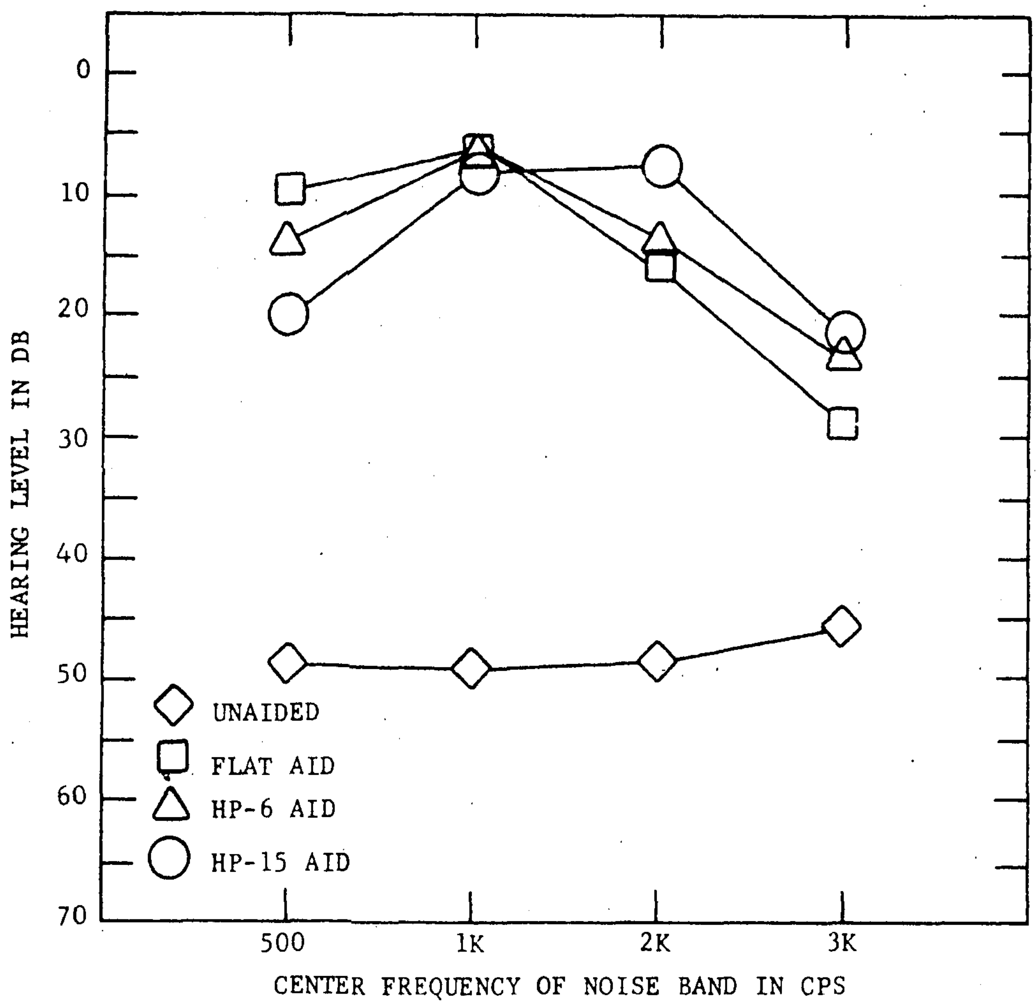

Fig. 24.--Mean hearing level, in decibels re normal threshold, for four bands of noise under aided conditions with each of the three hearing aids for the flat sensori-neural group.

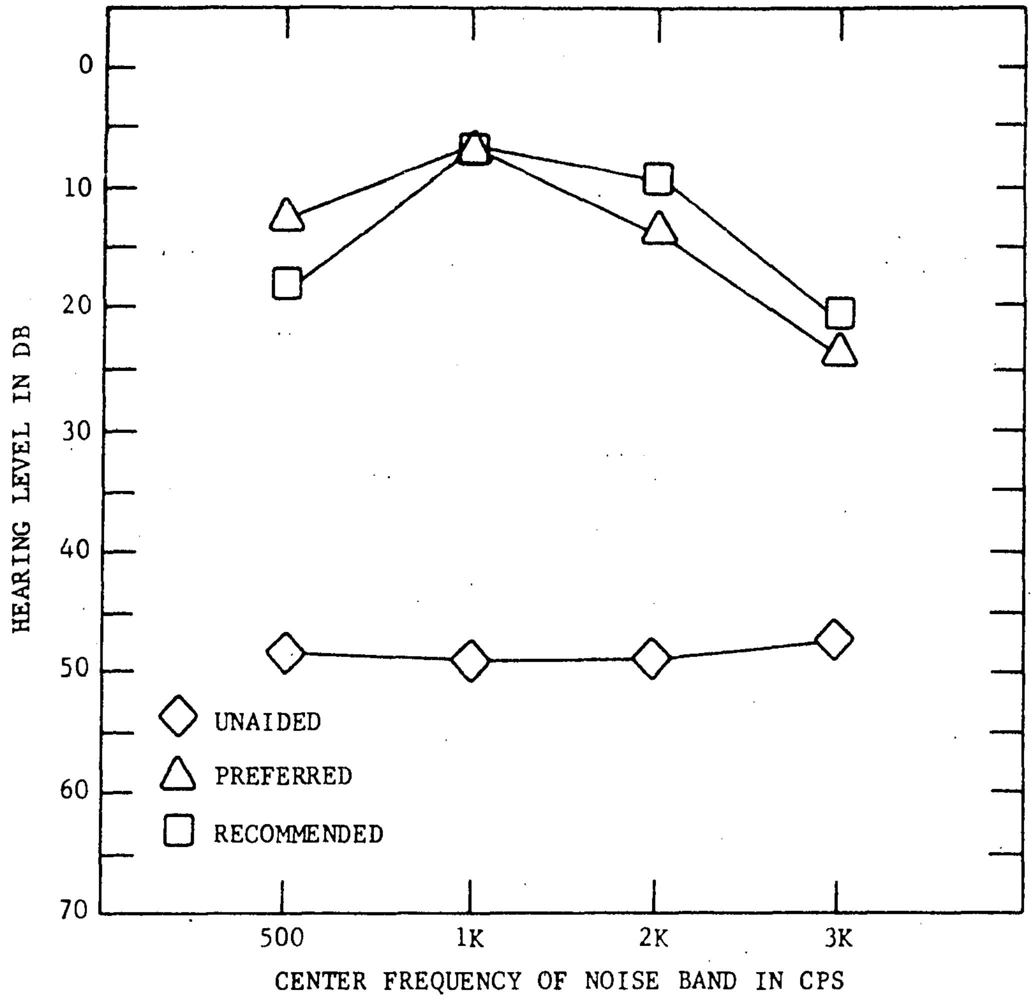

Fig. 25.--Mean hearing level, in decibels re normal threshold, for four bands of noise under aided conditions with the recommended and preferred hearing aids for the flat sensori-neural group.

Below this point, the Flat aid provided the greatest amplification, the HP-6 aid less, and the HP-15 aid still less. Above 1000 cps this trend reversed; i.e., the Flat aid provided least amplification, etc. Mean discrimination scores for each aid were 51.60% with the Flat aid, 58.20% with the HP-6 aid, and 61.00% with the HP-15 instrument. These patterns are given in Figure 26.

The amplified threshold patterns of the recommended and preferred aids are shown in Figure 27. Mean discrimination scores were 65.40% with the recommended aid but only 53.60% with the preferred aid. Both sets of data approximated the pattern obtained with the HP-6 hearing aid, with the preferred pattern showing slightly less acuity at 500 cps, while the recommended pattern gives slightly more acute hearing at this point. At 1000 cps and above, the preferred and recommended patterns were nearly the same, both showing the same general configuration as the unaided thresholds. The sloping sensori-neural group seemed to prefer slightly more low frequency emphasis than would have been recommended. It is interesting to note that, while the HP-6 and HP-15 instruments were each recommended for five of the subjects, the aid preferred by the majority of the group was the Flat instrument.

In summarizing this portion of the study, there does not appear to be a particular aided audiometric configuration which constitutes a best fitting as judged by the aided speech discrimination score. Any attempt to make such a determination seems doomed, due to the small differences among mean thresholds provided by the three instruments and the great variability among subjects.

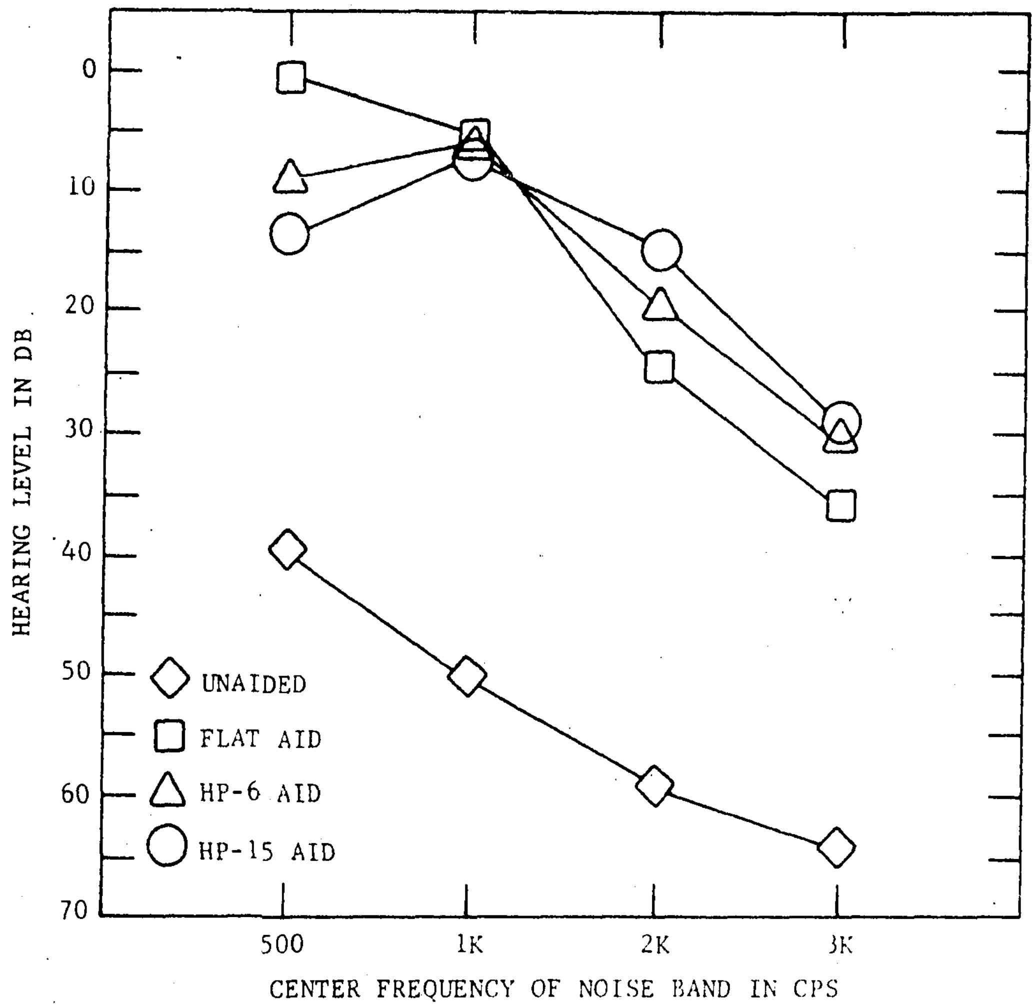

Fig. 26.--Mean hearing level, in decibels *re* normal threshold, for four bands of noise under aided conditions with each of the three hearing aids for the sloping sensori-neural group.

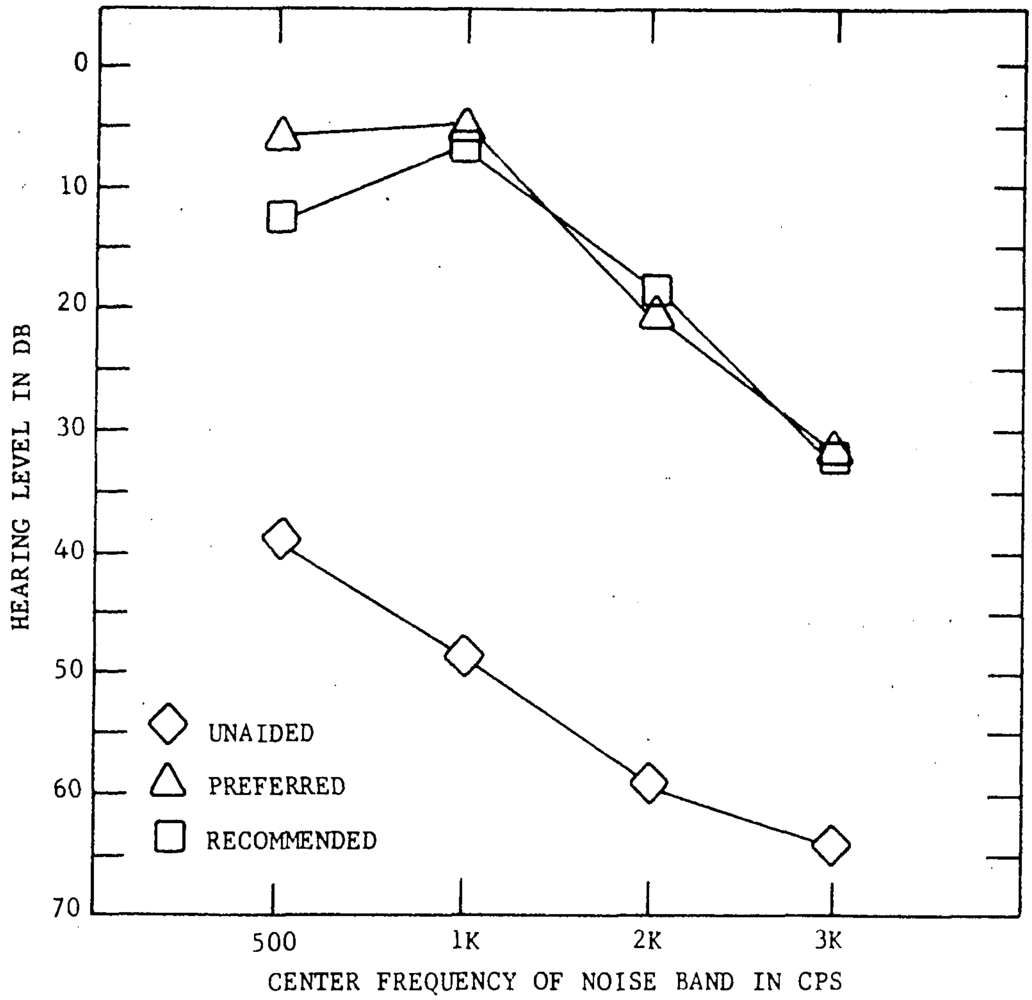

Fig. 27.--Mean hearing level, in decibels re normal threshold, for four bands of noise under aided conditions with the recommended and preferred hearing aids for the sloping sensori-neural group.

Subject Judgment

The final question for which the investigation sought an answer was: Can the patient adequately select the type of amplification which most adequately meets his needs?

For the answer to this question, a comparison was made between the aid preferred by the subject and the aid with which his hearing for speech was most adequate. The determination of the recommended instrument was based on the aided speech results obtained with each of the three hearing aids. The selection was based primarily on the speech discrimination score; however, in two cases where two aids gave similar scores, the selection was based on the better speech reception threshold. The preferred fitting was determined by asking the subject to choose among the aids, as described in the previous chapter.

The comparison of recommended and preferred fittings are made below for each of the experimental groups. The results for each individual subject are given in Appendix F.

Flat Conductive Group

For the 10 subjects displaying flat conductive hearing losses, the Flat hearing aid would have been recommended for eight subjects, the HP-6 aid for one, and the HP-15 for the other subject. Of the eight subjects for whom the Flat aid was recommended, only three preferred this fitting, while three picked the HP-6 aid and two, the HP-15 aid. The two subjects who performed best with the HP-6 and HP-15 instruments both preferred the HP-6 aid. Thus, of the 10 subjects in this group, only four preferred the instrument which would have been recommended for them on the basis of the test results.

Two statistical treatments of the data were indicated for this phase of the study. First, it was desirable to observe how the choice of aid made by the subject compared to the aid with which he obtained his best discrimination of speech. This comparison was made by computation of the cosine-pi formula as an estimate of the tetrachoric correlation, as discussed in Guilford (27). The method of computing this factor is shown in Appendix G. The correlation obtained for the flat conductive group was +0.613.

The second statistical procedure was designed to determine whether significant differences actually existed between discrimination scores obtained with the recommended and preferred instruments. If the two scores did not differ significantly, there would be no reason to expect correlation of the preferred aid with the aid with which the subject heard best. The Student's *t* test was used for matched pairs of scores to determine significance between discrimination scores obtained with the recommended and preferred aids. This test can also be found in Appendix G. In the case of the flat conductive group, a *t* of 3.195 was computed, indicating significance at the .05 level.

As a group then, the subjects with flat conductive hearing losses showed a real difference between the discrimination scores obtained with the recommended and preferred instruments. As judges, their ability to select the aid which most adequately met their needs was only fair.

Sloping Conductive Group

Three of the subjects in this group performed best with the Flat aid, five with the HP-6 aid, and two with the HP-15 aid. Of the three subjects for whom the Flat aid was best, none preferred this fitting. Two of them selected the HP-6 instrument, the other the HP-15 instrument. While five subjects performed best with the HP-6 aid, only two preferred its response--while one picked the Flat aid and two the HP-15 aid. Both subjects who heard best with the HP-15 instrument actually preferred the characteristics of the Flat instrument. From the total group of 10 subjects, only two preferred the overall response of the instrument which was judged to be best for them.

The estimate of the tetrachoric correlation between the aid chosen by the subject and that giving the best discrimination of speech was 0.000 for the sloping conductive group. Thus, the group displayed no ability to select an aid considered suitable for their needs. This occurred in spite of a significant difference between the scores obtained with the two instruments. The computed $\underline{t}$ was 3.750, showing significance at the .01 level of confidence.

Flat Sensori-Neural Group

Of this group, the Flat aid was recommended for one subject, the HP-6 aid for four subjects, and the HP-15 aid for the remaining five subjects. The subject who performed best with the Flat aid preferred the response of the HP-6 instrument. Of the four for whom the HP-6 instrument was recommended, one preferred the Flat aid, two the HP-6, and one the HP-15. One subject who heard best with the HP-15 aid chose the Flat aid, three chose the HP-6 aid, and only one the HP-15 instrument. Only three subjects from the flat sensori-neural group preferred the aid with which they heard speech best.

The estimate of the tetrachoric correlation between recommended and preferred aids for the flat sensori-neural group was -0.347. This would indicate that the group tended to prefer a frequency response different from that which gave them the best discrimination of speech. However, the *t* test revealed that the discrimination scores obtained on the two aids, recommended and preferred, were not significantly different.

Sloping Sensori-Neural Group

None of the subjects in this group performed best with the Flat hearing aid. The HP-6 and HP-15 instruments were each recommended for five subjects. Of those who heard best with the HP-6 instrument, three preferred the Flat aid, one preferred the HP-6 and one the HP-15 instrument. Two of the subjects who understood best with the HP-15 hearing aid preferred it--while two others preferred the Flat aid, one the HP-15 aid. From this group of 10 subjects, only two showed a preference for the aid with which they had the best understanding of speech.

The cosine-pi approximation of the tetrachoric correlation between recommended and preferred instruments was -0.198 for the sloping sensori-neural group. The *t* test of differences between the scores obtained with the two aids resulted in a *t* of 2.752 which was significant at the .05 level. Thus, although the discrimination scores obtained with the recommended and preferred hearing aids were significantly different, the subjects in this group did not show a preference for the aid which gave them the best hearing as judged by their aided discrimination scores.

All Subjects Combined

When the data for all subjects were combined, it was found that only 11 of the 40 subjects stated a personal preference for the aid with which they obtained their best speech discrimination score. The estimate of the tetrachoric correlation between the two hearing aids was -0.206. That there was a real difference between the performance yielded by the two instruments is shown by a t of 2.545 which indicates significance at the .05 level of confidence.

In summary, the subjects of this experiment, when treated as a group, obtained significantly poorer discrimination scores with the aid each preferred than they did with the aid considered best for them. In addition, although the aids differed significantly, the subjects did not often indicate a preference for the aid yielding the higher discrimination score.

Summary

Consistency of Scores

The results of this study emphasize the lack of consistency of speech threshold and discrimination tests as presently employed in the clinical evaluation of hearing aids. The experimental method; i.e., adjusting the hearing aid gain control to allow the subject to detect a 500 - 2000 cps band of filtered thermal noise, significantly reduced the inconsistency inherent in the measurement of the speech reception threshold. The use of this method did not increase the consistency of speech discrimination scores, however. These findings were the same with each of the four experimental groups.

Hearing Aid Response

For the flat conductive loss group, the Flat hearing aid gave better discrimination of speech than did the HP-6. Subjects with flat sensori-neural losses understood speech better with the HP-6 aid than with the Flat instrument. No significant differences were revealed among performances with the three hearing aids when worn by the sloping conductive or sloping sensori-neural hearing loss groups.

Perhaps of greater interest were the findings when the individual hearing loss groups were combined. Four pooled groups were evaluated: flat configuration, sloping configuration, conductive hearing loss, sensori-neural hearing loss. No significant differences were revealed among performances with the Flat, HP-6 and HP-15 hearing aids for either the flat or sloping hearing loss groups. On the other hand, subjects displaying conductive hearing losses showed significantly better understanding of speech with the Flat aid than they did with the HP-15 aid. In addition, subjects with sensori-neural losses had significantly better discrimination for speech with either the HP-6 or HP-15 hearing aids than they did with the Flat aid. The possible significance of this finding will be discussed in the next chapter.

Aided Threshold Configuration

Aided noise band thresholds with the three hearing aids showed the same general result for all four experimental groups. In each instance, the Flat aid resulted in the best threshold at 500 cps and in the poorest thresholds at 2000 and 3000 cps. The HP-15 instrument had just the reverse effect, giving the best thresholds at 2000 and 3000 cps and the poorest threshold at 500 cps. The thresholds obtained with the HP-6 hearing aid fell between those of the Flat and HP-15 instruments at all three of these frequencies. The fulcrum of the aided configuration was at 1000 cps for each experimental group. Here the thresholds were nearly identical for all three hearing aids. In comparing the aided threshold configuration which was preferred by the subjects to that which resulted in the best speech discrimination, no great discrepancy was noted. The subjective differences, as reported by the subjects, were more apparent than those which were revealed by psychophysical measurement. The flat conductive group tended to prefer less low frequency emphasis and slightly more high frequency emphasis than would have been recommended. The preferred and recommended aided threshold patterns for the sloping conductive loss group were nearly identical to each other. For both the flat and sloping sensori-neural loss groups there tended to be a preference for slightly more amplification at 500 cps than that obtained with the instrument giving the best hearing for speech.

Subject Judgment

Four subjects in the flat conductive group preferred the aid with which they obtained their best speech discrimination score. In the sloping conductive group, two subjects preferred the recommended aid; in the flat sensori-neural group, three preferred it; in the sloping sensori-neural group, two preferred the recommended instrument. A total of 11 subjects indicated a preference for the aid with which they discriminated speech best, while 29 preferred one of the other hearing aids.

Estimates of the tetrachoric correlation between the aid giving the best discrimination score and the aid preferred by each subject revealed that only the flat conductive group approached any degree of preference for the aid with which the best performance was obtained. It must be assumed that, due to the size of the sample, the most reliable estimate of the correlation will be gained by pooling all of the subjects. In this case the correlation was -0.206.

The significance of the discrimination scores obtained with the recommended and preferred aids was tested by using the Student's _t_ for differences between matched pairs. The significance of these differences was tested to see if real differences existed between the performance on the two aids. If differences did not exist, the subject's preference would have to be considered as valid a criterion of selection as the test results. The differences were significant for all but the flat sensori-neural group. With all subjects combined, the differences were significant at the .05 level of confidence.

CHAPTER V

DISCUSSION

Consistency of Scores

The first question which the present study sought to answer was: Can test-retest consistency of the speech reception threshold and speech discrimination score be improved by changing the method of adjusting the hearing aid gain control prior to the administration of these tests?

The results of this investigation clearly indicate that the consistency of the speech reception threshold can be improved, while the consistency of the speech discrimination score cannot be improved, by the use of the experimental method described herein; i.e., by adjusting the gain control of the hearing aid to detect a noise signal.

Speech Reception Threshold

Mean absolute differences between initial and retested speech reception thresholds were computed, disregarding the direction of the difference so that differences in one direction would not cancel those in the other direction. These differences, using the conventional method of adjusting the gain control to a comfort level, were 4.70 db, 4.23 db, 4.07 db and 5.10, respectively, for subjects with flat conductive, sloping conductive, flat sensori-neural and sloping sensori-neural hearing losses. The same subject groups showed mean absolute differences of 2.77 db, 2.03 db, 2.20 db and 2.07 db, respectively, when the gain control of the hearing aid was adjusted to detect the noise signal.

Since there was no reason to suspect that the consistency of setting the gain control of a hearing aid was dependent upon the type or configuration of the hearing loss, the significance of the differences, as obtained by the two methods, was tested for the subject group as a whole. The mean difference between thresholds by the classical method of gain control adjustment was 4.53 db. When the gain control was set to detect a noise signal, this difference between two determinations of the speech threshold was 2.27 db. The detection setting method significantly improved the consistency of speech reception threshold measurement, as evidenced by statistical significance beyond the .01 level.

Speech Discrimination Score

The consistency of the speech discrimination score was determined in an identical manner, using the comfort and detection methods of adjusting the hearing aid gain control prior to the administration of the tests. Mean absolute differences between initial and second test scores were computed for each subject group. These mean differences, using the comfort setting, were 7.33%, 6.67%, 6.33% and 8.20%, respectively, for subjects with flat conductive, sloping conductive, flat sensori-neural and sloping sensori-neural hearing losses. The mean differences for these same groups were 6.67%, 7.27%, 5.67% and 9.87% when the detection setting was utilized. When all subjects were pooled and treated as one experimental group, a mean difference of 7.13% was obtained when setting the gain control to a comfort level--while a difference of 7.37% was found when adjusting the gain control to detect a noise signal. The consistency of the speech discrimination score did not differ significantly between the two methods of making the gain control adjustment.

Implications

The inconsistency of the speech reception threshold, when adjusting the gain control of the hearing aid to a comfortable listening level, was greater with the present experimental group than previous research had shown. Whereas Carhart (11) reported a mean difference of 2.67 db, the present study revealed a mean difference of 4.53 db. The incompatability of the two studies may be due to the subject groups utilized. Carhart's study was performed in a military hospital with patients participating in a program of intensive aural rehabilitation; and, as such, his subjects were in the process of auditory training. Thus, it seems likely that they possessed greater ability in making loudness and comfort judgments than would most hard of hearing persons. Subjects for the present study were all experienced hearing aid wearers, but none had undergone extensive auditory training of the type available in the military setting. These subjects probably more nearly represent the types of clinical cases seen in most speech and hearing clinics.

Regardless of this difference, the present investigation reveals a significant improvement in the consistency with which speech reception threshold values can be repeated. The resultant reduction of clinical error provides far greater precision in this measure and, by doing so, increases the ability of this particular clinical test to differentiate among hearing aids. The increased precision offered by such a method should recommend its serious consideration as a clinical procedure.

The experimental results may further serve to supply the data for which Shore, Bilger and Hirsh (66) stressed a need; i.e., the determination of the reliability of speech reception thresholds obtained with recorded spondee words so as to determine when differences between scores obtained on two hearing aids are significant.

The experimental method was not superior to the clinical method in obtaining greater consistency for the speech discrimination score. It seems doubtful that the gain control setting of the hearing aid has an effect on the ability to discriminate speech in the clinical evaluation procedure, particularly since this test is always presented at the same level above threshold. The only instance where this statement would not be true, would be at amplification levels where distortion of the signal by the aid itself prevented optimal intelligibility of the signal.

In summary, the consistency with which the speech reception threshold can be repeated by the experimental method makes it possible to discriminate among hearing aids for this particular measure. As Davis and his associates (16) have suggested, the adjustment of a hearing aid to a comfortable listening level appears to be one of the greatest weaknesses in the present evaluation procedure. The detection threshold is clearly more stable and would be recommended by the present investigation.

Hearing Aid Response

The second question investigated was: Does the frequency response output of the hearing aid significantly affect the ability to discriminate speech?

Three hearing aid frequency response curves were evaluated in this study; a flat response aid, an aid with an output which emphasized the higher frequencies at the rate of six decibels per octave (HP-6), and an instrument which had an increased output in the high frequencies of 15 db per octave (HP-15).

Subjects displaying flat conductive hearing losses obtained significantly better discrimination scores with the flat response hearing aid than they did with the HP-15 instrument. Those subjects with conductive hearing losses, having a sloping audiometric configuration, showed no significant superiority in the ability to discriminate speech with any of the three hearing aids. Significantly better speech discrimination scores were obtained by subjects with flat sensori-neural hearing losses when tested with the HP-6 aid than when tested wearing the flat response instrument. No significant differences among hearing aid response curves were found by speech discrimination testing for persons with sloping sensori-neural hearing losses.

The four subject groups used for this investigation constituted combinations of two types of hearing loss and two types of audiometric configuration. The groups were analyzed to detect what effect these factors would have on discrimination ability.

When persons displaying flat audiometric configurations were grouped and the data were analyzed, significant differences were not apparent among the discrimination scores obtained with the three hearing aids. This finding, however, is perhaps misleading. As noted above, persons in this configuration category whose hearing losses were conductive in nature showed significant superiority of the Flat aid over the HP-15 aid. On the other hand, persons with flat audiograms and sensori-neural hearing losses revealed significantly better scores with the HP-6 aid than those obtained with the flat response instrument. Thus, where the Flat aid rated best for half of the subjects with flat audiometric configurations, it rated poorest with the other half. When the groups were pooled, the high and low scores tended to cancel each other, thus obscuring the true picture.

In treating all sloping configuration hearing losses as a group, discrimination scores obtained with the three hearing aids were not significantly different.

A second dichotomy was made, which placed all subjects, regardless of audiometric configuration, into conductive hearing loss and sensori-neural hearing loss groups. Those persons whose losses were conductive in type revealed significantly superior speech discrimination scores with the Flat aid when compared to scores obtained with the HP-15 aid. Conversely, subjects with sensori-neural hearing losses scored significantly better with either the HP-6 or HP-15 aids than they did with the Flat instrument.

Implications

Numerous early studies stressed the need for selective amplification; i.e., the amplification of each area of the audible spectrum only to the degree to which the individual patient displayed a deficiency of hearing in that area. A few writers suggested this idea could be carried to a point where the fitting of hearing aids would be as precise as the fitting of eyeglasses in returning the defective organ to normal perception. The Harvard Report (14) seemed to refute these concepts with finality.

Many audiologists are still prone to evaluate hearing aids having a high frequency emphasis on persons whose greatest loss is in the higher frequencies and, as would be expected, to use uniform amplification with patients whose losses are uniform or whose greatest deficiency is for low frequency sounds. The findings of the present investigation are essentially in accordance with those of the Harvard Report. The results of this study most closely support the first rule of fitting specified by the Harvard Report; viz, the use of an HP-6 frequency response hearing aid for all persons. Although some individual cases will not be best served by this recommendation, the fitting of this response should not be highly inadvisable for any type of hearing loss. In no instance in the present investigation did the Flat or HP-15 response instruments yield significantly better discrimination scores than the HP-6 hearing aid.

An interesting finding, considered worthy of further mention, was the fact that the Flat aid was superior to the HP-15 aid for conductive hearing losses; whereas, the HP-6 and HP-15 instruments were both superior to the Flat aid for sensori-neural hearing losses. This finding would indicate that perhaps those seeking cues from the audiogram, to assist in the proper fitting of a hearing aid, have been looking at the wrong aspect of the hearing loss. It might be worthwhile to look at the type of hearing loss in seeking these cues. The present investigation would indicate the use of a flat or slightly rising frequency response for a patient displaying a conductive hearing loss but a slightly rising or sharply rising frequency response for those with sensori-neural hearing losses. This aspect of the fitting of hearing aids seems worthy of further investigation.

Aided Audiometric Configuration

A third question which the present study considered was: Is there a particular type of aided audiometric configuration which constitutes a good fitting as judged by the aided speech discrimination threshold?

Aided noise band thresholds--determined for narrow bands of noise centered at 500, 1000, 2000 and 3000 cps--were computed for the three hearing aid responses, as well as for the aids preferred by the subjects, and for the aids with which the best speech discrimination scores were obtained. There appeared to be no consistent pattern of aided thresholds which accompanied optimal ability to discriminate speech. An approach to the normal threshold curve seemed to result in no better scores than did other, seemingly less desirable, patterns. The ability to approach the normal threshold curve was, of course, limited by the response and gain of the hearing aids and the configuration and degree of loss of each individual subject. As it turned out, none of the 40 subjects approached normal threshold levels for all four of the test stimuli under aided conditions.

The mean threshold values for each group revealed no consistent response pattern resulting in good or poor discrimination scores. The differences among mean threshold values for the five patterns, computed for each subject group, were quite small. In addition, variation among subjects was so great as to obscure any possible meaningful data which might have been sought.

Implications

From the discussion given above, it seems reasonable to conclude that, at least under these experimental conditions and with this type of stimulus, there is no aided audiometric configuration which is typical of a hearing aid that can be expected to deliver intelligible speech to the deficient hearing organ. The possibility of using non-speech stimuli to predict an adequate hearing aid fitting is not evident in these test results. The concept of using aided audiograms in an attempt to select an aid which would return the threshold of hearing for discrete frequency stimuli to the normal level does not seem either realistic or possible at this time.

Subject Judgment

The final question which the present investigation sought to answer was: Can the patient adequately select the type of amplification which most adequately meets his needs?

The reader is referred to Table 18 for a general summary of this phase of the study. Nearly all subjects with flat conductive hearing losses performed best with the Flat hearing aid, while nearly all chose an aid with a high frequency emphasis as the one they would prefer to wear. Persons with sloping conductive losses most often preferred the HP-6 aid, while the majority performed best with this same instrument. The majority of the flat sensori-neural group also preferred the HP-6 instrument, but the HP-15 aid most often resulted in best performance. For those subjects with sloping sensori-neural hearing losses, the choice was most often the Flat aid, while all of the subjects in this group performed best with either the HP-6 or HP-15 instruments.

Although there were individual exceptions, for the experimental group as a whole the discrimination scores obtained with the recommended and preferred instruments were significantly different, those with the preferred instrument being lower, since this score formed the basis for selecting the recommended hearing aid. Whereas the instruments showed significant differences, there was a slight negative correlation between the aid which the examiner designated as best and that which the subjects designated as being preferred by them.

Implications

The conclusion to be drawn from this set of data is that the hard-of-hearing person cannot, or does not, select from a group of aids the hearing aid which gives him the best hearing as judged by the speech discrimination score. The patient's choice seems to be affected by subjective preferences for tonal quality. Previous studies have suggested that the patient prefers a hearing aid response which merely amplifies sound but does not alter his threshold configuration. If this had been true in this investigation, it would be reasonable to assume that most persons would have selected an instrument with a flat frequency response; i.e., uniform amplification of all areas of the frequency range. Only seven of the 20 subjects who showed sloping audiometric configurations preferred the Flat aid, while the other 13 chose an aid which gave its greatest amplification in the high frequencies, the area of hearing most deficient for these subjects.

In summary, the present study indicates that, by whatever criteria he judges, the patient is a poor judge of the type of hearing aid he should wear. Critics of the present methods of clinical selection of a hearing aid for an individual hard-of-hearing patient should agree that, although these procedures have weaknesses, the clinical recommendation of a hearing aid provides the hearing defective person with better hearing than he could obtain by using his own criteria of judgment.

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APPENDIX A

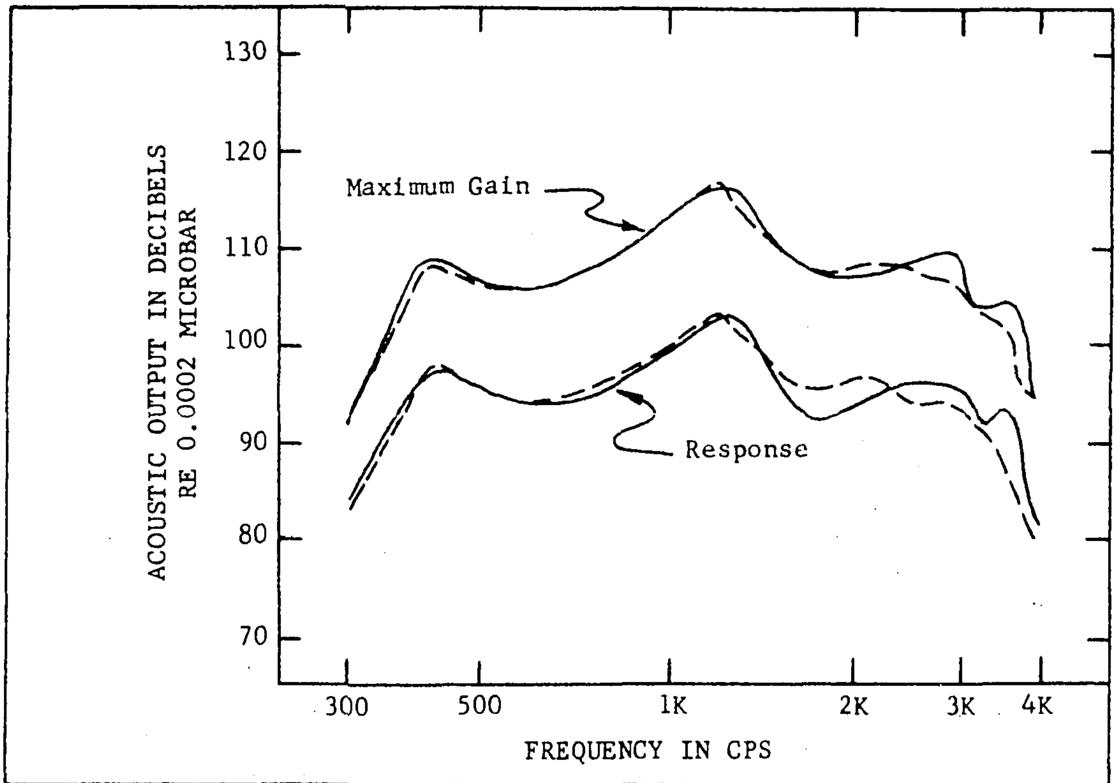
SUBJECT IDENTIFICATION

TABLE 13.--Identifying information for subjects in the four experimental groups

Group	Subject Number	Age	Sex	Test Ear	Duration of Loss in Years	Years of Hearing Aid Use
Flat Conductive	1	39	M	R	16	7
	2	54	F	L	11	1
	3	64	F	R	15	7
	4	41	M	R	18	16
	5	20	F	L	3	1
	6	46	F	R	22	16
	7	39	F	R	15	11
	8	47	M	L	41	8
	9	50	F	L	46	4
	10	41	M	L	15	9
Sloping Conductive	1	53	F	L	30	5
	2	42	M	L	17	9
	3	28	M	R	8	3
	4	34	M	R	15	7
	5	35	M	L	14	12
	6	56	F	R	24	20
	7	63	M	R	26	15
	8	50	F	L	32	24
	9	24	M	L	10	1
	10	39	M	R	16	12
Flat Sensori-neural	1	43	F	L	9	4
	2	52	M	R	15	10
	3	38	M	R	11	4
	4	36	M	R	4	1
	5	44	M	R	16	6
	6	65	F	L	21	14
	7	56	F	L	50	3
	8	45	M	R	16	11
	9	65	F	L	18	11
	10	41	M	R	18	1
Sloping Sensori-neural	1	42	M	L	17	13
	2	50	M	L	17	3
	3	56	M	R	7	4
	4	33	M	R	16	9
	5	51	M	L	17	4
	6	43	M	L	18	14
	7	53	F	R	40	4
	8	51	M	L	27	18
	9	53	F	L	16	2
	10	60	M	R	17	16

APPENDIX B

HEARING AIDS



RADIOEAR HEARING AID, Model 850, S.N. 108P4

Test Conditions:

1. Battery - RM401, 1.3 volts
2. Receiver - M-75
3. External adjustment - Screw in #3 position
4. Internal adjustment - S.O. - position "A" H.F. - position "Cut"
5. Microphone - L.F. tube "open"
6. Temperature - September 14, 1959 - 82° F. May 3, 1960 - 75° F.

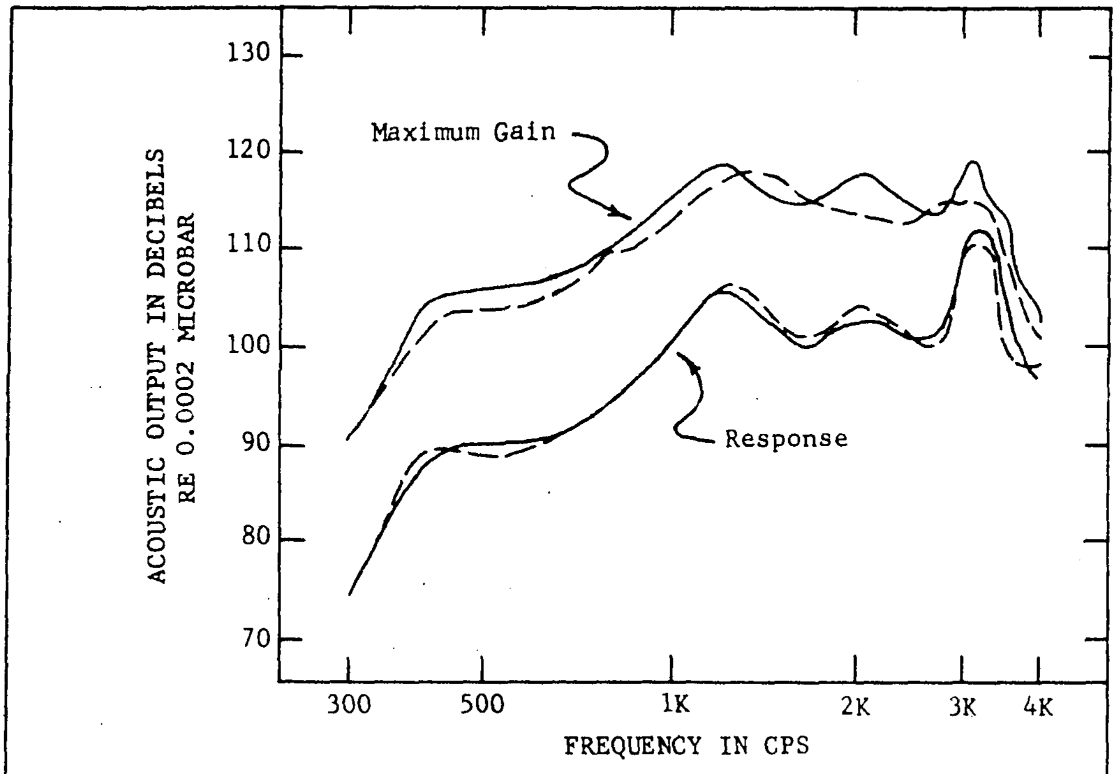
Test Methods:

1. Max. Gain - Volume control full on, input SPL = 50 db
2. Response - Volume control adjusted to give 100 db output at 1000 cycles with input SPL = 60 db

Tests by:

E. A. Myers and Sons, Inc.

Fig. 28.--Frequency response and maximum gain of the Flat hearing aid, measured previous to (solid lines) and following (dotted lines) the period of the research.



RADIOEAR HEARING AID, Model 850, S.N. 113N1

Test Conditions:

1. Battery - RM401, 1.3 volts
2. Receiver - M-70
3. External adjustment - Screw in #3 position
4. Internal adjustment - S.O. - position "B" H.F. - position "N"
5. Microphone - L.F. tube "open"
6. Temperature - September 14, 1959 - 82° F. May 3, 1960 - 75° F.

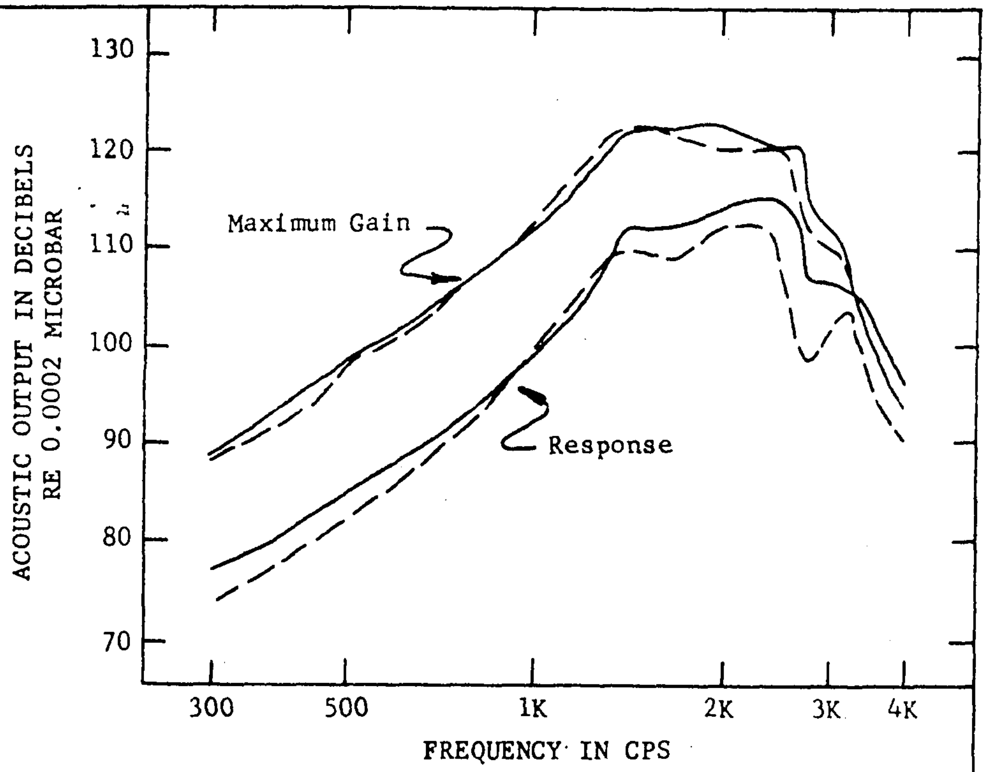
Test Methods:

1. Max. Gain - Volume control full on, input SPL = 50 db
2. Response - Volume control adjusted to give 100 db output at 1000 cycles with input SPL = 60 db

Tests by:

E. A. Myers and Sons, Inc.

Fig. 29.--Frequency response and maximum gain of the HP-6 hearing aid, measured previous to (solid lines) and following (dotted lines) the period of the research.



RADIOEAR HEARING AID, Model 850, S.N. 101V1

Test Conditions:

1. Battery - RM40i, 1.3 volts
2. Receiver - M-74
3. External adjustment - Screw in #3 position
4. Internal adjustment - S.O. - position "B" H.F. - position "N"
5. Microphone - L.F. tube "closed"
6. Temperature - September 14, 1959 - 82° F. May 3, 1960 - 75° F.

Test Methods:

1. Max. Gain - Volume control full on, input SPL = 50 db
2. Response - Volume control adjusted to give 100 db output at 1000 cycles with input SPL = 60 db

Tests by:

E. A. Myers and Sons, Inc.

Fig. 30.--Frequency response and maximum gain of the HP-15 hearing aid, measured previous to (solid lines) and following (dotted lines) the period of the research.

APPENDIX C

SPEECH TESTS

Spondee words from CID Test W-1 used for the determination of unaided speech reception thresholds by live voice

List A	List A--Continued	List B	List B--Continued	List C	List C--Continued
daybreak	padlock	duckpond	grandson	stairway	headlight
greyhound	mushroom	hotdog	farewell	doormat	greyhound
oatmeal	armchair	pancake	mousetrap	iceberg	cowboy
playground	pancake	sunset	airplane	oatmeal	toothbrush
birthday	duckpond	toothbrush	armchair	hotdog	mousetrap
baseball	whitewash	workshop	playground	padlock	sunset
hotdog	grandson	padlock	oatmeal	workshop	baseball
airplane	workshop	drawbridge	baseball	horseshoe	eardrum
headlight	doormat	eardrum	greyhound	mushroom	airplane
iceberg	northwest	hothouse	woodwork	farewell	inkwell
toothbrush	hothouse	iceberg	whitewash	hardware	schoolboy
woodwork	farewell	mushroom	stairway	railroad	daybreak
sidewalk	inkwell	headlight	birthday	armchair	drawbridge
horseshoe	mousetrap	cowboy	schoolboy	sidewalk	birthday
railroad	drawbridge	horseshoe	daybreak	playground	whitewash
hardware	cowboy	inkwell	railroad	woodwork	pancake
sunset	schoolboy	doormat	sidewalk	grandson	northwest
stairway	eardrum	hardware	northwest	duckpond	hothouse

Spondee words from CID Test W-1 used for the determination of unaided speech reception thresholds by live voice

List D	List D--Continued	List E	List E--Continued	List F	List F--Continued
grandson	whitewash	duckpond	drawbridge	woodwork	baseball
airplane	hotdog	hotdog	woodwork	sidewalk	horseshoe
birthday	iceberg	grandson	oatmeal	birthday	padlock
greyhound	daybreak	cowboy	schoolboy	headlight	schoolboy
playground	northwest	sunset	mousetrap	playground	eardrum
stairway	schoolboy	whitewash	iceberg	duckpond	stairway
pancake	mushroom	stairway	padlock	doormat	mousetrap
railroad	workshop	toothbrush	eardrum	pancake	hotdog
headlight	eardrum	railroad	farewell	iceberg	armchair
mousetrap	woodwork	northwest	pancake	railroad	workshop
hardware	sidewalk	hardware	daybreak	mushroom	airplane
armchair	drawbridge	sidewalk	greyhound	toothbrush	sunset
inkwell	cowboy	inkwell	horseshoe	inkwell	greyhound
sunset	hothouse	armchair	birthday	hardware	drawbridge
baseball	horseshoe	playground	workshop	daybreak	grandson
oatmeal	duckpond	headlight	mushroom	northwest	farewell
padlock	doormat	airplane	doormat	cowboy	oatmeal
farewell	toothbrush	baseball	hothouse	whitewash	hothouse

Phonetically balanced words from the NDRC lists used for the determination of unaided speech discrimination scores by live voice

List 1	List 1--*Continued*	List 2	List 2--*Continued*
are	bad	pit	mute
folk	plush	gill	hit
crash	feast	cloud	scythe
dish	no	bean	sludge
hid	creed	fate	dab
strife	hunt	job	vamp
then	rat	wish	bought
ford	smile	else	need
clove	not	log	rib
heap	fuss	pick	hock
pest	pile	tan	ways
dike	hive	tang	earl
death	rag	charge	shoe
cleanse	nook	nab	start
fraud	there	our	niece
pan	wheat	gloss	five
slip	rise	blush	bud
cane	grove	nut	hire
rub	ride	moose	awe
bask	such	them	trash
end	mange	bait	perk
bar	toe	rap	suck
is	yews	bounce	frog
deed	box	quart	vast
fern	pants	snuff	corpse

Phonetically balanced words from the NDRC lists used for the determination of unaided speech discrimination scores by live voice

List 3	List 3--Continued	List 4	List 4--Continued
air	who	peck	neat
class	toil	pod	hiss
path	check	bath	kite
bead	fame	merge	sage
hurl	muck	touch	float
drop	neck	heed	hatch
balk	sob	race	earn
crime	turf	strap	rut
vow	jam	how	raw
nest	shout	sour	tick
why	rate	beast	sketch
law	leave	shin	court
lush	deck	bush	rack
please	size	dupe	starve
wedge	cast	pinch	or
stag	oak	slap	bee
dill	fig	cloak	hot
crave	far	new	scab
rouse	wharf	oils	course
dig	ache	move	shed
trip	barb	frown	bus
sped	pulse	test	dodge
trash	gnaw	eel	fin
take	sit	rave	pert
cape	flush	blonde	budge

CID test W-1 (recorded) used to determine aided speech reception thresholds

List A	List A--Continued	List B	List B--Continued	List C	List C--Continued
greyhound	baseball	playground	toothbrush	birthday	farewell
schoolboy	stairway	grandson	mushroom	hothouse	mousetrap
inkwell	cowboy	daybreak	farewell	toothbrush	armchair
whitewash	iceberg	doormat	horseshoe	horseshoe	drawbridge
pancake	northwest	woodwork	pancake	airplane	mushroom
mousetrap	railroad	armchair	inkwell	northwest	baseball
eardrum	playground	stairway	mousetrap	whitewash	grandson
headlight	airplane	cowboy	airplane	hotdog	padlock
birthday	woodwork	oatmeal	sidewalk	hardware	greyhound
duckpond	oatmeal	railroad	eardrum	woodwork	sunset
sidewalk	toothbrush	baseball	greyhound	stairway	cowboy
hotdog	farewell	padlock	birthday	daybreak	duckpond
padlock	grandson	hardware	hothouse	sidewalk	playground
mushroom	drawbridge	whitewash	iceberg	railroad	inkwell
hardware	doormat	hotdog	schoolboy	oatmeal	eardrum
workshop	hothouse	sunset	duckpond	headlight	workshop
horseshoe	daybreak	headlight	workshop	pancake	schoolboy
armchair	sunset	drawbridge	northwest	doormat	iceberg

CID test W-1 (recorded) used to determine aided speech reception thresholds

List D	List D--Continued	List E	List E--Continued	List F	List F--Continued
hothouse	playground	northwest	headlight	padlock	mousetrap
padlock	oatmeal	doormat	airplane	daybreak	workshop
eardrum	northwest	railroad	inkwell	sunset	eardrum
sidewalk	woodwork	woodwork	grandson	farewell	greyhound
cowboy	stairway	hardware	workshop	northwest	doormat
mushroom	hotdog	stairway	hotdog	airplane	horseshoe
farewell	headlight	sidewalk	oatmeal	playground	stairway
horseshoe	pancake	birthday	sunset	iceberg	cowboy
workshop	birthday	farewell	pancake	drawbridge	sidewalk
duckpond	greyhound	greyhound	eardrum	baseball	mushroom
baseball	mousetrap	cowboy	mushroom	woodwork	armchair
railroad	schoolboy	daybreak	whitewash	inkwell	whitewash
hardware	whitewash	drawbridge	hothouse	pancake	hotdog
toothbrush	inkwell	duckpond	toothbrush	toothbrush	schoolboy
airplane	doormat	horseshoe	playground	hardware	headlight
iceberg	daybreak	armchair	baseball	railroad	duckpond
armchair	drawbridge	padlock	iceberg	oatmeal	birthday
grandson	sunset	mousetrap	schoolboy	grandson	hothouse

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 1A	List 1A--Continued	List 1B	List 1B--Continued	List 1C	List 1C--Continued
an	you	carve	dad	felt	yard
yard	as	wire	stove	bells	thing
carve	wet	felt	ache	owl	ran
us	chew	thing	us	jam	law
day	see	knees	him	what	high
toe	deaf	poor	not	them	chew
felt	them	owl	me	isle	me
stove	give	law	it	bathe	ace
hunt	true	there	see	none	see
ran	isle	give	earn	it	mew
knees	or	what	true	up	him
not	law	chew	bathe	stove	day
mew	me	as	you	an	ache
low	none	twins	wet	not	hunt
owl	jam	isle	could	skin	you
it	poor	ace	them	us	she
she	him	deaf	high	earn	dad
high	skin	she	or	deaf	true
there	east	none	low	wet	could
earn	thing	mew	jam	as	give
twins	dad	skin	ran	or	low
could	up	hunt	east	there	poor
what	bells	up	toe	east	twins
bathe	wire	day	bells	knees	wire
ace	ache	an	yard	carve	tow

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 1D	List 1D--Continued	List 1E	List 1E--Continued	List 1F	List 1F--Continued
owl	toe	them	owl	isle	it
wire	jam	give	up	ace	could
isle	low	it	twins	east	yard
give	bathe	ace	poor	hunt	dad
up	dad	deaf	him	earn	us
she	stove	law	thing	what	you
wet	ache	yard	ran	jam	none
ace	us	earn	chew	ache	felt
skin	see	see	as	him	carve
day	as	an	true	bells	up
east	high	dad	stove	owl	wire
law	knees	what	felt	twins	she
thing	yard	toe	low	as	chew
carve	ran	jam	bathe	there	thing
mew	there	none	skin	not	day
earn	you	ache	us	ran	skin
chew	deaf	or	hunt	high	true
or	him	high	knees	stove	or
hunt	not	carve	mew	low	bathe
an	me	there	you	poor	toe
true	it	day	east	an	knees
none	twins	not	me	mew	see
poor	bells	she	wet	law	me
what	could	bells	could	wet	deaf
felt	them	wire	isle	give	them

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 2A	List 2A--Continued	List 2B	List 2B--Continued	List 2C	List 2C--Continued
yore	and	way	ail	smart	bin
bin	young	by	chest	well	eat
way	cars	smart	thin	jaw	ice
chest	tree	eat	gave	off	oak
then	dumb	odd	rooms	cap	send
ease	that	ill	knee	does	tree
smart	die	jaw	send	that	and
gave	show	oak	one	with	flat
pew	hurt	else	hurt	live	hurt
ice	own	show	tare	one	move
odd	key	cap	dumb	die	rooms
knee	oak	tree	with	gave	then
move	new	young	and	chest	ail
now	live	air	cars	yore	thin
jaw	off	that	too	knee	pew
one	ill	does	flat	ham	own
hit	rooms	own	new	tare	hit
send	ham	hit	key	new	dumb
else	star	live	now	cars	air
tare	eat	move	off	young	too
does	thin	ham	ice	key	show
too	flat	pew	star	else	now
cap	well	die	ease	star	ill
with	by	then	well	odd	ease
air	ail	yore	bin	way	by

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 2D	List 2D--Continued	List 2E	List 2E--Continued	List 2F	List 2F--Continued
jaw	chest	that	well	knee	ease
ease	off	ill	die	flat	pew
that	show	knee	one	tree	does
die	too	pew	then	else	odd
new	hit	star	own	smart	tare
with	well	and	bin	ail	with
knee	ail	tree	key	gave	chest
then	ham	odd	oak	by	now
cars	young	dumb	young	ice	young
does	send	ham	live	oak	eat
star	hurt	smart	hit	air	own
oak	odd	with	by	then	new
eat	bin	off	chest	die	well
way	ice	thin	show	jaw	one
tree	else	gave	cap	bin	cars
and	key	now	ail	rooms	key
move	own	send	tare	live	move
tare	rooms	move	hurt	send	hit
dumb	yore	ice	way	thin	show
live	pew	eat	else	off	cap
now	one	rooms	does	hurt	ham
cap	air	cars	yore	dumb	way
smart	flat	air	too	yore	and
by	ill	new	flat	star	too
thin	gave	jaw	ease	that	ill

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 3A	List 3A--Continued	List 3B	List 3B--Continued	List 3C	List 3C--Continued
bill	aim	year	west	though	three
add	when	cute	ate	bill	hand
west	book	though	tan	may	glove
cute	tie	hand	dull	nest	pie
start	do	raw	out	do	owes
ears	hand	lie	if	use	wool
tan	end	may	king	tie	end
nest	shove	pie	no	done	jar
say	have	have	farm	oil	farm
is	owes	this	shove	no	is
out	jar	do	camp	ears	out
lie	no	wool	tie	dull	we
three	may	aim	when	ate	west
oil	knit	book	are	if	tan
king	on	use	ten	start	on
pie	if	end	done	add	king
he	raw	smooth	owes	shove	when
smooth	glove	jar	he	are	camp
farm	ten	oil	knit	he	book
this	dull	is	nest	raw	ten
done	though	start	glove	smooth	knit
use	chair	on	say	year	this
camp	we	ears	chair	aim	lie
wool	ate	we	bill	have	chair
are	year	add	three	say	cute

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 3D	List 3D--Continued	List 3E	List 3E--Continued	List 3F	List 3F--Continued
may	cute	add	three	west	ears
chair	nest	we	bill	start	ate
tie	knit	ears	chair	farm	jar
ears	done	start	say	cut	if
king	jar	is	glove	book	use
ten	dull	on	nest	when	shove
start	west	jar	farm	this	do
we	he	oil	he	oil	are
add	farm	smooth	owes	lie	may
when	raw	end	done	owes	he
aim	owes	use	ten	glove	though
pie	have	book	are	cute	say
hand	three	aim	when	three	bill
say	glove	wool	tie	chair	year
wool	year	do	camp	hand	nest
smooth	end	this	shove	knit	raw
is	are	have	knit	pie	done
shove	out	pie	no	ten	have
tan	if	may	king	wool	tie
ate	on	lie	if	camp	aim
camp	no	raw	out	end	no
oil	book	hand	dull	king	smooth
this	use	though	tan	on	dull
do	lie	cute	ate	tan	is
though	bill	year	west	we	add

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 4A	List 4A--Continued	List 4B	List 4B--Continued	List 4C	List 4C--Continued
all	darn	chin	wood	wood	chin
wood	art	all	bee	bee	all
at	will	who	they	they	who
where	dust	few	dust	dust	few
chin	toy	stiff	ought	ought	stiff
they	aid	my	jump	jump	my
dolls	than	nuts	leave	leave	nuts
so	eyes	save	in	in	save
nuts	shoe	his	ear	ear	his
ought	his	tin	than	than	tin
in	our	aid	bread	bread	go
net	men	yet	will	will	yet
my	near	art	eyes	darn	art
leave	few	so	arm	of	can
of	jump	why	toy	toy	why
hang	pale	darn	cook	cook	eyes
save	go	tea	shoe	shoe	tea
ear	stiff	men	hang	hang	men
tea	can	of	near	near	arm
cook	through	pale	go	go	pale
tin	clothes	our	can	aid	our
bread	who	through	net	net	through
why	bee	dolls	clothes	clothes	dolls
arm	yes	yes	where	where	yes
yet	am	at	am	am	at

CID Auditory Test W-22 (recorded) used to determine aided speech discrimination scores

List 4D	List 4D--Continued	List 4E	List 4E--Continued	List 4F	List 4F--Continued
they	at	ought	be	our	wood
yes	dust	wood	dolls	art	in
leave	our	through	jump	darn	men
pale	in	ear	of	ought	cook
bread	tea	men	then	stiff	tin
eyes	will	darn	why	am	where
toy	art	can	arm	go	all
yet	cook	shoe	hang	few	hang
near	his	tin	nuts	arm	near
save	go	so	aid	yet	why
clothes	stiff	my	net	jump	bread
few	where	am	who	pale	dolls
all	chin	few	chin	yes	they
my	who	all	where	bee	leave
so	net	clothes	stiff	eyes	of
am	hang	save	go	than	aid
tin	aid	near	his	save	nuts
shoe	nuts	yet	cook	toy	clothes
can	arm	toy	art	my	who
darn	why	eyes	will	chin	so
men	than	bread	tea	shoe	net
ear	of	pale	in	his	can
through	jump	leave	our	ear	will
ought	dolls	yes	dust	tea	through
wood	bee	they	at	at	dust

APPENDIX D

INSTRUCTIONS

Pure Tone Thresholds:

"During this first portion of the test, you will be listening for tones, just as when you have had your hearing tested on previous occasions. I would like to have you raise your hand each time you can detect anything other than silence in the earphone, even though the tone may not be clear to you. Are there any questions?"

Speech Reception Threshold, Unaided:

"I will be saying a group of two syllable words to you through the earphone. If you can tell what the word is, please repeat it after me, even if you are not positive of the word. We are looking for the faintest speech you can understand. Are there any questions?"

Speech Discrimination Score, Unaided:

"You will hear a list of 50 words which will be loud enough for you to hear comfortably. I would like you to repeat the word after me each time. It is important on this test that you respond to each word, so if you are not sure of the word, tell me whatever it sounded like to you. Any questions?"

Noise Band Thresholds:

"Now you will hear some noises which will sound very much like a steam pipe, or like water running. When you can detect the presence of the sounds, no matter how faint, please raise your hand as you did for the tone test, then put your hand down when the noise goes off, and listen for the next noise. Are there any questions?"

Speech Discrimination Score, Aided:

"Here again, you will hear a list of 50 words at a comfortable listening level. Please repeat the words to me as before. This time there will be a 'hissing' noise in the background, which will make the words more difficult for you to hear, but try to ignore this noise and repeat as many of the words as you can. Any questions?"

Comfort Level Setting:

"You will now hear a recording of a man's voice. While you listen to this recording, I will adjust the loudness of your hearing aid, as you tell me to make it louder or softer. We are looking for the point where this speech is most comfortable for you, like the level at which you would listen to the radio or television. When we reach this comfortable level, let me know. Be sure to find the most comfortable loudness for you; take your time and be sure."

Detection Level Setting:

"You will now hear a faint sound like a steam pipe. This noise will be going on and off fairly rapidly, to make it easier for you to hear. I will adjust the loudness of the hearing aid to the point where you can just barely detect this noise. Remember, we don't want it at a comfortable level, but at a level where you can just barely tell the noise is there. You stop me when we reach this point. You may try it several times if necessary. Take your time so you can be sure."

APPENDIX E

DATA SHEETS

DATA SHEET

GROUP__________ SUBJECT__________ AGE______ SEX______

YEARS HAD LOSS______ YEARS WORN HEARING AID______ EAR______

PRELIMINARY MEASUREMENTS:

Pure Tones: Noise Bands:

	125	250	500	1K	2K	3K	4K	8K	500	1K	2K	3K
Air	___	___	___	___	___	___	___	___	___	___	___	___
Bone		___	___	___	___	___	___					

AIDED NOISE BANDS:

	500	1K	2K	3K
Flat	___	___	___	___
HP-6	___	___	___	___
HP-15	___	___	___	___

INITIAL TEST:

Flat, Comfort: SRT ____ PB ____

HP-6, Comfort: SRT ____ PB ____

HP-15, Comfort: SRT ____ PB ____

Flat, Detection: SRT ____ PB ____

HP-6, Detection: SRT ____ PB ____

HP-15, Detection: SRT ____ PB ____

RETEST:

Flat, Comfort: SRT ____ PB ____

HP-6, Comfort: SRT ____ PB ____

HP-15, Comfort: SRT ____ PB ____

Flat, Detection: SRT ____ PB ____

HP-6, Detection: SRT ____ PB ____

HP-15, Detection: SRT ____ PB ____

Recommended Aid: __________ Preferred Aid: __________

SUMMARY SHEET

GROUP_______________ SUBJECT__________________ AGE________ SEX___________

YEARS HAD LOSS________ YEARS WORN HEARING AID_________ EAR______________

THRESHOLD:

	COMFORT			DETECTION		
	FLAT	HP-6	HP-15	FLAT	HP-6	HP-15
TEST	____	____	____	____	____	____
RETEST	____	____	____	____	____	____
DIFF.	____	____	____	____	____	____

DISCRIMINATION:

	COMFORT			DETECTION		
	FLAT	HP-6	HP-15	FLAT	HP-6	HP-15
TEST	____	____	____	____	____	____
RETEST	____	____	____	____	____	____
DIFF.	____	____	____	____	____	____

INITIAL TEST, COMFORT ADJUSTMENT:

	FLAT	HP-6	HP-15
SRT	____	____	____
PB%	____	____	____

Recommended:______________ Preferred:________________

NOISE BANDS, AIDED THRESHOLDS:

	500	1K	2K	3K
FLAT AID	___	___	___	___
HP-6 AID	___	___	___	___
HP-15 AID	___	___	___	___
Recommend.	___	___	___	___
Preferred	___	___	___	___

APPENDIX F

INDIVIDUAL SUBJECT DATA

TABLE 14.--Individual pure tone thresholds by air and bone conduction in db re USPHS norms for the four experimental groups

Group	Subject Number	Air Conduction 125	250	500	1K	2K	3K	4K	8K	Bone Conduction 250	500	1K	2K	3K	4K
		Frequency in CPS													
Flat Conductive	1	45	50	55	55	40	40	45	45	10	10	10	25	20	10
	2	55	55	45	45	50	40	55	40	5	0	5	25	15	25
	3	60	55	65	65	55	60	60	NR*	5	10	15	10	25	25
	4	50	45	40	45	45	45	40	50	5	5	5	5	15	10
	5	50	55	50	50	50	55	55	55	10	15	15	5	5	5
	6	55	50	40	45	45	40	45	60	10	10	0	20	25	15
	7	40	35	40	35	30	35	45	35	5	0	10	15	15	5
	8	45	35	40	35	35	35	25	25	5	5	10	10	20	15
	9	55	45	50	55	50	55	65	55	10	5	15	25	25	15
	10	50	45	50	60	50	45	45	35	-5	-10	0	10	20	5
Sloping Conductive	1	40	35	30	40	50	50	65	55	5	10	15	35	50	45
	2	60	60	55	65	80	80	95	NR	10	15	25	50	NR	NR
	3	25	25	25	35	45	70	75	65	5	0	10	25	40	40
	4	60	55	35	45	60	70	80	50	0	-10	5	35	45	30
	5	55	40	35	45	55	55	70	75	0	5	15	25	20	25
	6	50	40	40	60	70	75	90	NR	10	15	25	40	NR	NR
	7	30	20	25	40	55	65	70	70	5	10	25	35	45	45
	8	65	55	40	50	60	75	70	60	5	0	10	30	50	50
	9	45	35	35	50	60	70	75	NR	15	10	25	50	NR	NR
	10	45	40	25	35	45	45	60	45	5	5	15	30	40	30

TABLE 14--Continued

Group	Subject Number	Air Conduction 125	250	500	1K	2K	3K	4K	8K	Bone Conduction 250	500	1K	2K	3K	4K
		Frequency in CPS													
Flat Sensori-neural	1	35	25	40	50	50	50	50	60	20	35	45	NR	NR	NR
	2	65	70	75	80	75	80	90	NR	NR	NR	NR	NR	NR	NR
	3	40	30	40	45	50	55	55	70	NR	35	50	NR	NR	NR
	4	35	35	35	40	30	20	45	45	NR	40	45	15	20	40
	5	45	45	55	55	55	55	60	60	NR*	NR	NR	NR	NR	50
	6	45	45	45	50	55	50	65	65	NR	45	40	45	50	NR
	7	45	45	40	50	55	60	60	60	NR	35	40	40	NR	NR
	8	65	65	65	65	60	50	65	55	NR	NR	NR	NR	NR	NR
	9	40	45	45	40	45	50	45	60	NR	45	50	50	45	45
	10	20	25	30	35	45	55	55	55	NR	40	35	45	NR	NR
Sloping Sensori-neural	1	45	45	45	55	65	70	75	70	NR	40	45	NR	NR	NR
	2	30	25	35	50	60	75	75	NR	NR	40	45	NR	NR	NR
	3	30	20	25	45	55	65	70	75	15	25	40	NR	NR	NR
	4	60	45	55	65	80	90	90	60	NR	45	NR	NR	NR	NR
	5	55	55	55	75	85	NR	95	65	NR	45	NR	NR	NR	NR
	6	25	20	25	45	60	70	70	65	20	25	35	NR	NR	NR
	7	45	40	25	40	50	50	60	NR	NR	20	30	50	50	NR
	8	50	50	45	55	65	65	75	65	NR	40	45	NR	NR	NR
	9	20	20	25	35	50	45	60	45	25	35	35	45	NR	NR
	10	40	35	35	50	60	70	75	NR	NR	40	45	NR	NR	NR

*NR indicates no response at the maximum output of the equipment. These levels were as follows: air conduction; 125 cps, 70 db; 250 cps, 80 db; 500 cps through 4000 cps, 100 db; 8000 cps, 80 db; bone conduction; 250 cps, 30 db; 500 cps through 4000 cps, 50 db.

TABLE 15.--Unaided thresholds for noise bands and spondee words (in db re normal hearing level) and speech discrimination scores (in percent correct)

Group	Subject Number	Noise Bands 500	1K	2K	3K	500-2K	SRT	PB Score
Flat Conductive	1	62	52	39	42	44	46	100
	2	45	45	42	37	32	41	100
	3	70	64	50	50	47	59	100
	4	48	60	57	50	36	39	100
	5	54	53	45	49	45	48	100
	6	38	50	29	20	33	38	96
	7	38	38	28	28	25	32	98
	8	43	44	31	25	31	33	100
	9	53	53	46	51	46	49	96
	10	55	63	51	37	38	44	100
Sloping Conductive	1	40	35	41	39	34	33	94
	2	57	59	76	76	60	61	92
	3	31	37	41	53	27	30	92
	4	47	48	51	49	41	42	96
	5	35	42	52	55	28	38	98
	6	44	57	67	71	47	55	90
	7	31	41	54	61	34	34	90
	8	48	56	59	67	50	53	94
	9	49	50	49	51	44	47	92
	10	26	34	51	52	36	38	100
Flat Sensori-neural	1	37	48	48	41	39	41	96
	2	75	79	77	70	67	72	58
	3	35	57	49	50	41	44	84
	4	35	26	23	15	17	33	86
	5	61	51	49	45	45	50	92
	6	53	51	47	44	40	47	82
	7	45	41	53	57	33	47	88
	8	66	66	56	57	53	54	84
	9	42	41	43	42	38	39	80
	10	33	33	43	47	28	31	88
Sloping Sensori-neural	1	44	53	61	60	51	43	64
	2	36	50	54	71	36	36	68
	3	34	44	53	62	41	46	78
	4	59	58	68	86	50	63	78
	5	50	68	89	95	56	70	80
	6	28	45	60	62	35	40	82
	7	25	39	46	44	28	27	82
	8	50	53	56	51	44	49	84
	9	23	28	46	50	25	27	68
	10	45	59	61	62	44	56	72

TABLE 16.--Aided speech reception thresholds and speech discrimination scores for individual subjects on initial test (a) and on retest (b) by comfort and detection setting of the hearing aid gain control for the three hearing aids

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
Flat Conductive	1	Comfort	Flat	8	14	82	80
			HP-6	11	10	74	76
			HP-15	10	7	72	68
		Detection	Flat	9	8	68	82
			HP-6	4	10	76	84
			HP-15	6	8	78	58
	2	Comfort	Flat	26	11	84	90
			HP-6	23	11	78	76
			HP-15	15	23	64	90
		Detection	Flat	6	1	76	84
			HP-6	9	1	76	70
			HP-15	1	3	72	78
	3	Comfort	Flat	26	10	56	66
			HP-6	19	18	68	66
			HP-15	18	17	52	62
		Detection	Flat	1	3	66	74
			HP-6	8	3	62	68
			HP-15	8	5	62	50
	4	Comfort	Flat	10	16	74	74
			HP-6	6	9	66	84
			HP-15	4	3	64	66
		Detection	Flat	13	11	82	76
			HP-6	8	5	66	78
			HP-15	14	6	62	60
	5	Comfort	Flat	6	9	70	74
			HP-6	5	8	68	68
			HP-15	10	4	64	70
		Detection	Flat	7	7	72	66
			HP-6	5	7	80	76
			HP-15	8	6	68	74
	6	Comfort	Flat	15	19	68	68
			HP-6	15	17	56	72
			HP-15	14	20	62	72
		Detection	Flat	7	5	66	74
			HP-6	12	12	70	70
			HP-15	10	12	64	66

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
	7	Comfort	Flat	10	13	68	78
			HP-6	12	16	64	72
			HP-15	16	13	78	70
		Detection	Flat	3	5	78	76
			HP-6	8	9	70	78
			HP-15	11	7	68	66
	8	Comfort	Flat	15	12	76	78
			HP-6	16	8	66	60
			HP-15	13	9	58	62
		Detection	Flat	13	15	74	78
			HP-6	12	13	60	70
			HP-15	13	10	60	58
	9	Comfort	Flat	15	11	62	58
			HP-6	12	14	56	70
			HP-15	13	14	60	48
		Detection	Flat	8	10	62	70
			HP-6	9	13	64	66
			HP-15	14	10	50	62
	10	Comfort	Flat	21	14	70	74
			HP-6	17	15	64	82
			HP-15	18	15	54	64
		Detection	Flat	10	10	70	70
			HP-6	11	11	74	66
			HP-15	12	17	42	50
Sloping Conductive	1	Comfort	Flat	16	8	58	70
			HP-6	11	12	52	46
			HP-15	18	16	66	58
		Detection	Flat	11	13	58	76
			HP-6	13	15	72	66
			HP-15	14	9	62	64
	2	Comfort	Flat	20	22	72	70
			HP-6	24	21	58	54
			HP-15	20	14	62	66
		Detection	Flat	14	15	68	62
			HP-6	21	20	50	44
			HP-15	14	17	76	74
	3	Comfort	Flat	3	-1	72	74
			HP-6	3	-2	64	72
			HP-15	4	3	60	70
		Detection	Flat	5	6	70	78

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
			HP-6	6	7	52	70
			HP-15	4	5	58	64
	4	Comfort	Flat	18	17	78	78
			HP-6	13	16	82	86
			HP-15	13	10	66	68
		Detection	Flat	7	5	70	82
			HP-6	11	10	84	78
			HP-15	14	5	82	90
	5	Comfort	Flat	13	4	78	86
			HP-6	11	8	76	78
			HP-15	8	4	66	60
		Detection	Flat	3	3	82	78
			HP-6	8	7	72	84
			HP-15	5	3	56	62
	6	Comfort	Flat	15	11	62	66
			HP-6	12	8	68	60
			HP-15	11	7	64	68
		Detection	Flat	10	8	58	64
			HP-6	6	8	66	72
			HP-15	6	6	58	66
	7	Comfort	Flat	19	10	54	68
			HP-6	20	15	64	62
			HP-15	18	11	68	60
		Detection	Flat	7	6	62	58
			HP-6	18	17	70	60
			HP-15	16	19	70	64
	8	Comfort	Flat	20	11	78	70
			HP-6	12	10	76	70
			HP-15	13	11	58	62
		Detection	Flat	8	9	62	78
			HP-6	10	9	62	58
			HP-15	13	10	66	62
	9	Comfort	Flat	15	11	66	58
			HP-6	13	12	72	58
			HP-15	15	9	70	64
		Detection	Flat	11	13	60	62
			HP-6	11	10	64	72
			HP-15	11	11	72	60

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
	10	Comfort	Flat	19	15	70	78
			HP-6	21	11	72	82
			HP-15	15	14	56	74
		Detection	Flat	11	4	78	74
			HP-6	13	8	78	78
			HP-15	8	8	66	58
Flat Sensori-neural	1	Comfort	Flat	11	13	66	68
			HP-6	13	7	64	66
			HP-15	13	13	58	66
		Detection	Flat	11	8	60	68
			HP-6	10	13	58	68
			HP-15	16	12	64	68
	2	Comfort	Flat	28	19	18	10
			HP-6	30	19	20	24
			HP-15	20	18	20	20
		Detection	Flat	24	17	16	12
			HP-6	22	16	20	18
			HP-15	18	18	20	18
	3	Comfort	Flat	13	17	44	42
			HP-6	16	11	52	44
			HP-15	11	7	52	46
		Detection	Flat	11	9	46	42
			HP-6	9	11	48	52
			HP-15	14	15	58	56
	4	Comfort	Flat	16	9	62	54
			HP-6	18	13	58	74
			HP-15	11	13	66	74
		Detection	Flat	11	10	64	62
			HP-6	11	11	66	66
			HP-15	9	12	56	76
	5	Comfort	Flat	13	20	66	66
			HP-6	16	21	72	70
			HP-15	16	18	74	70
		Detection	Flat	9	8	72	74
			HP-6	11	11	70	66
			HP-15	11	9	72	72
	6	Comfort	Flat	21	19	50	54
			HP-6	20	18	80	60
			HP-15	16	18	66	82

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
		Detection	Flat	13	10	46	44
			HP-6	14	16	66	66
			HP-15	16	18	62	74
	7	Comfort	Flat	17	19	58	58
			HP-6	19	21	66	68
			HP-15	23	17	44	42
		Detection	Flat	17	16	56	58
			HP-6	25	20	68	72
			HP-15	18	18	58	48
	8	Comfort	Flat	20	20	48	46
			HP-6	16	19	60	32
			HP-15	18	17	42	46
		Detection	Flat	20	14	30	58
			HP-6	11	13	42	38
			HP-15	16	16	44	28
	9	Comfort	Flat	16	12	56	58
			HP-6	13	9	64	66
			HP-15	13	8	66	58
		Detection	Flat	12	11	54	66
			HP-6	10	11	58	64
			HP-15	11	11	60	60
	10	Comfort	Flat	11	14	62	54
			HP-6	20	13	76	74
			HP-15	14	6	74	62
		Detection	Flat	6	2	62	68
			HP-6	9	7	88	76
			HP-15	4	6	72	70
Sloping Sensori-neural	1	Comfort	Flat	11	6	44	50
			HP-6	8	13	44	62
			HP-15	11	15	42	48
		Detection	Flat	3	11	56	50
			HP-6	6	8	42	42
			HP-15	13	10	48	50
	2	Comfort	Flat	13	9	32	30
			HP-6	14	15	46	46
			HP-15	19	11	78	44
		Detection	Flat	9	5	52	46
			HP-6	13	10	68	58
			HP-15	7	7	72	56

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
	3	Comfort	Flat	16	11	42	32
			HP-6	8	7	48	44
			HP-15	9	13	52	56
		Detection	Flat	16	17	50	42
			HP-6	13	11	54	52
			HP-15	8	11	50	60
	4	Comfort	Flat	16	13	58	70
			HP-6	20	14	66	70
			HP-15	13	17	54	80
		Detection	Flat	12	11	68	58
			HP-6	13	14	62	70
			HP-15	14	12	70	74
	5	Comfort	Flat	21	11	58	72
			HP-6	18	11	66	66
			HP-15	26	11	74	72
		Detection	Flat	20	22	60	80
			HP-6	14	15	58	76
			HP-15	18	19	66	78
	6	Comfort	Flat	8	9	62	64
			HP-6	6	11	56	72
			HP-15	8	9	72	74
		Detection	Flat	6	5	62	82
			HP-6	8	5	62	66
			HP-15	2	6	64	70
	7	Comfort	Flat	6	0	62	62
			HP-6	8	13	68	78
			HP-15	12	3	80	80
		Detection	Flat	6	6	54	74
			HP-6	13	11	78	76
			HP-15	14	14	84	78
	8	Comfort	Flat	15	21	46	50
			HP-6	8	17	56	72
			HP-15	13	9	58	48
		Detection	Flat	9	13	50	54
			HP-6	13	14	66	64
			HP-15	6	9	52	62
	9	Comfort	Flat	14	21	58	52
			HP-6	19	19	70	80
			HP-15	15	23	54	64

TABLE 16--Continued

Group	Subject Number	Adjustment Method	Hearing Aid	SRT a	SRT b	PB Score a	PB Score b
		Detection	Flat	9	6	58	66
			HP-6	4	7	62	80
			HP-15	9	9	66	74
	10	Comfort	Flat	18	21	54	46
			HP-6	24	19	62	58
			HP-15	18	16	46	62
		Detection	Flat	14	15	42	42
			HP-6	12	14	50	66
			HP-15	13	12	26	66

TABLE 17.--Aided thresholds for narrow bands of noise with the three hearing aids

Group	Subject Number	Hearing Aid	Noise Bands 500	1K	2K	3K
Flat Conductive	1	Flat	0	-9	0	5
		HP-6	16	-2	0	-3
		HP-15	29	4	-2	4
	2	Flat	22	21	27	27
		HP-6	30	20	28	17
		HP-15	21	8	8	13
	3	Flat	27	21	19	28
		HP-6	20	3	-7	23
		HP-15	37	21	1	17
	4	Flat	9	2	7	14
		HP-6	22	2	3	8
		HP-15	25	4	-6	5
	5	Flat	4	-9	1	5
		HP-6	16	-2	3	3
		HP-15	28	1	0	0
	6	Flat	2	11	14	8
		HP-6	16	14	11	6
		HP-15	17	13	4	5
	7	Flat	7	1	10	17
		HP-6	20	9	9	6
		HP-15	20	7	0	15
	8	Flat	19	6	12	17
		HP-6	31	10	12	13
		HP-15	27	4	1	8
	9	Flat	14	12	13	32
		HP-6	18	13	5	22
		HP-15	29	10	10	26
	10	Flat	16	21	25	15
		HP-6	17	18	20	4
		HP-15	28	19	15	5

TABLE 17--Continued

Group	Subject Number	Hearing Aid	Noise Bands 500	1K	2K	3K
Sloping Conductive	1	Flat	11	-1	19	25
		HP-6	23	4	19	20
		HP-15	32	7	14	24
	2	Flat	-10	4	11	32
		HP-6	-7	9	6	30
		HP-15	1	3	5	25
	3	Flat	-2	-10	11	31
		HP-6	2	-7	1	20
		HP-15	12	-8	-3	21
	4	Flat	24	9	26	30
		HP-6	24	5	14	19
		HP-15	31	7	10	14
	5	Flat	-2	4	25	25
		HP-6	4	-1	14	17
		HP-15	6	-4	7	15
	6	Flat	-16	-10	5	30
		HP-6	-8	6	0	24
		HP-15	-2	-3	-1	15
	7	Flat	1	4	24	39
		HP-6	7	5	17	32
		HP-15	14	6	14	31
	8	Flat	8	1	17	36
		HP-6	13	1	10	27
		HP-15	14	-4	1	21
	9	Flat	18	3	16	32
		HP-6	25	6	12	21
		HP-15	29	8	8	16
	10	Flat	-19	-7	19	28
		HP-6	-9	-10	13	24
		HP-15	0	-7	12	25

TABLE 17--Continued

Group	Subject Number	Hearing Aid	Noise Bands 500	1K	2K	3K
Flat Sensori-neural	1	Flat	5	6	5	22
		HP-6	5	0	5	19
		HP-15	15	6	3	22
	2	Flat	7	9	24	42
		HP-6	11	5	17	37
		HP-15	16	-1	1	24
	3	Flat	3	16	4	34
		HP-6	2	11	5	30
		HP-15	12	12	1	27
	4	Flat	35	10	25	23
		HP-6	43	16	22	18
		HP-15	41	13	12	14
	5	Flat	16	2	14	17
		HP-6	27	10	19	13
		HP-15	29	10	8	13
	6	Flat	18	22	21	32
		HP-6	25	22	21	32
		HP-15	17	21	13	29
	7	Flat	-4	-11	17	29
		HP-6	-3	-11	11	21
		HP-15	15	-5	9	26
	8	Flat	16	10	15	18
		HP-6	21	8	9	8
		HP-15	35	16	10	19
	9	Flat	4	-4	8	28
		HP-6	6	-2	4	22
		HP-15	16	4	3	13
	10	Flat	1	12	32	47
		HP-6	11	13	27	45
		HP-15	13	9	20	39

TABLE 17--Continued

Group	Subject Number	Hearing Aid	Noise Bands 500	1K	2K	3K
Sloping Sensori-neural	1	Flat	-5	-3	14	25
		HP-6	8	9	18	25
		HP-15	13	12	15	27
	2	Flat	-1	16	33	50
		HP-6	18	16	18	47
		HP-15	16	17	22	51
	3	Flat	-12	0	4	26
		HP-6	-2	2	9	27
		HP-15	3	2	3	30
	4	Flat	14	9	31	36
		HP-6	22	12	32	30
		HP-15	23	10	20	26
	5	Flat	13	16	40	55
		HP-6	-1	-2	15	38
		HP-15	18	8	23	50
	6	Flat	-5	6	37	49
		HP-6	1	6	28	35
		HP-15	5	6	19	33
	7	Flat	-2	3	13	14
		HP-6	5	3	18	9
		HP-15	14	3	19	15
	8	Flat	11	-2	14	20
		HP-6	16	-4	7	11
		HP-15	20	2	3	11
	9	Flat	3	2	34	48
		HP-6	18	6	34	49
		HP-15	19	2	22	30
	10	Flat	-1	10	24	35
		HP-6	4	13	18	28
		HP-15	3	8	4	16

TABLE 18.--Comparison of the aid which would have been recommended on the basis of clinical criteria and the aid preferred by each subject

Group	Subject Number	Recommended Hearing Aid	Preferred Hearing Aid
Flat Conductive	1	Flat	HP-15
	2	Flat	Flat
	3	HP-6	HP-6
	4	Flat	Flat
	5	Flat	HP-15
	6	Flat	HP-6
	7	HP-15	HP-6
	8	Flat	Flat
	9	Flat	HP-6
	10	Flat	HP-6
Sloping Conductive	1	HP-15	Flat
	2	Flat	HP-15
	3	Flat	HP-6
	4	HP-6	Flat
	5	Flat	HP-6
	6	HP-6	HP-6
	7	HP-15	Flat
	8	HP-6	HP-15
	9	HP-6	HP-6
	10	HP-6	HP-15
Flat Sensori-neural	1	Flat	HP-6
	2	HP-15	Flat
	3	HP-15	HP-6
	4	HP-15	HP-15
	5	HP-15	HP-6
	6	HP-6	HP-15
	7	HP-6	HP-6
	8	HP-6	HP-6
	9	HP-15	HP-6
	10	HP-15	Flat
Sloping Sensori-neural	1	HP-6	Flat
	2	HP-15	Flat
	3	HP-15	HP-6
	4	HP-6	Flat
	5	HP-15	HP-15
	6	HP-15	HP-6
	7	HP-15	Flat
	8	HP-6	Flat
	9	HP-6	HP-15
	10	HP-6	HP-6

APPENDIX G

STATISTICAL NOTES

I. TEST-RETEST RELIABILITY

An analysis of variance using a randomized complete block design with a factorial arrangement of fixed treatments and a random arrangement of subjects was used to determine the reliability of both the speech reception threshold and the speech discrimination score in separate analyses.

The model for these analyses was:

$$Y = \mu + G_i + S_{ij} + A_k + R_l + (AR)_{kl} + (GA)_{il} + (GAR)_{ikl} + \epsilon_{jkl(i)}$$

Where; G = hearing loss group
S = subjects within groups
A = adjustment method
R = hearing aid

And; i = 1, 2, 3, 4
j = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
k = 1, 2
l = 1, 2, 3

An analysis was completed for each group of data to determine the feasibility of using the analysis of variance technique described above. The Bartlett test of homogeneity of variance was employed. The formula for this test was:

$$X^2 = \frac{(\log_e 10)\ (n - 1)\ (a \log s^{-2} - \sum \log s^2)}{1 + \frac{a + 1}{3a\ (n - 1)}}$$

II. HEARING AID RESPONSE

The analysis was made for each individual hearing loss group to determine the effect of the hearing aid frequency response on the aided speech discrimination score. A randomized complete block design analysis of variance was used.

The model was:

$$Y = \mu + S_i + R_j + \epsilon_{ij}$$

Where; S = subjects within the group
R = hearing aid response

And; i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
j = 1, 2, 3

The Duncan multiple range test was used to locate the significant differences which were detected by the analysis of variance. The test results for each significant group are shown below.

Flat Conductive Loss Group:

(a) Standard error of the mean: 1.87; $n_2 = 18$

(b) Shortest significant ranges:

p:	(2)	(3)
R_p:	5.55	5.93

(c) Results:

Hearing aid:	HP-15	HP-6	FLAT
Means:	62.8	66.0	71.0

Note: Any two means not underscored by the same line are significantly different at the .05 level.

Flat Sensori-Neural Group:

(a) Standard error of the mean: 2.16; $n_2 = 18$

(b) Shortest significant ranges:

p:	(2)	(3)
R_p:	6.42	6.74

(c) Results:

Hearing aid:	FLAT	HP-15	HP-6
Means:	53.0	56.2	61.2

Note: Any two means not underscored by the same line are significantly different at the .05 level.

All Conductive Loss Subjects

(a) Standard error of the mean: 1.43; $n_2 = 38$

(b) Shortest significant ranges:

p:	(2)	(3)
R_p:	4.09	4.30

(c) Results:

Hearing aid:	HP-15	HP-6	FLAT
Means:	63.2	67.2	69.9

Note: Any two means not underscored by the same line are significantly different at the .05 level.

All Sensori-Neural Loss Subjects

(a) Standard error of the mean: 1.84; $n_2 = 38$

(b) Shortest significant ranges:

p:	(2)	(3)
R_p:	5.26	5.54

(c) Results:

Hearing aid:	FLAT	HP-15	HP-6
Means:	52.3	58.6	59.7

Note: Any two means not underscored by the same line are significantly different at the .05 level.

III. SUBJECT JUDGMENT

In correlating the recommended and preferred hearing aids, the cosine-pi formula was utilized to approximate the tetrachoric r. Two dichotomies were made to facilitate this statistic: aided speech discrimination scores were dichotomized at the mean, and; hearing aids were dichotomized by whether the preferred aid agreed or disagreed with the recommended hearing aid.

The table thus became:

	agreed	disagreed
above mean	a	b
below mean	c	d

The formula was:

$$r_{cos-pi} = \cos\left(\pi \frac{\sqrt{bc}}{\sqrt{ad} + \sqrt{bc}}\right)$$

The Student's t test, used to determine significant differences between the discrimination scores obtained with the recommended hearing aid and those obtained with the preferred hearing aid, was computed using the following formula:

$$t = \frac{\sum D}{\sqrt{\frac{N\sum D^2 - (\sum D)^2}{N - 1}}}$$

Where: D = the difference between matched pairs of scores.