A NEW METHOD FOR EXPRESSING HEARING AID PERFORMANCE CHARACTERISTICS AND FOR CONDUCTING HEARING AID EVALUATIONS

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ABSTRACT

A NEW METHOD FOR EXPRESSING HEARING AID PERFORMANCE CHARACTERISTICS AND FOR CONDUCTING HEARING AID EVALUATIONS

By

Daniel R. Schumaier

This thesis was comprised of two investigations. The first sought to compare the present HAIC procedure for measuring and reporting the acoustical characteristics of hearing aids, to a new procedure developed by the present investigator. It was argued that the HAIC procedure does not accurately represent the performance of a hearing aid under normal listening conditions. The new method for evaluating and reporting hearing aid characteristics was designed to overcome the basic criticism of the HAIC procedure. The results of both methods were compared on the following specific acoustical parameters: (1) gain, (2) maximum power output, (3) frequency range and (4) frequency response curve.

The second investigation was performed in order to determine if differences could be observed between hearing aids using CNC monosyllabic speech discrimination materials. Normal hearing

subjects responded to these speech materials after they were recorded under five different listening conditions through nine different instruments. The listening conditions employed were: (1) CNCs in quiet, (2) + 10 signal-to-noise ratio, (3) + 10 signal-to-competing message ratio, (4) 0 signal-to-noise ratio, and (5) 0 signal-to-competing message ratio. The hearing aids employed were selected from three types of frequency response groups: flat, irregular and high frequency emphasis. All subjects listened to the recorded materials at a 50 dB sensation level, which was essentially equal to a normal conversational speech level (70 dB SPL). It was reasoned that if differences were seen between hearing aids, these differences could be attributed to the hearing aid's frequency response and associated acoustical distortion.

The following conclusions were drawn from the first investigation: (1) The HAIC Method tended to over-estimate actual "usable" gain by approximately 21 dB; however, because considerable variability existed between instruments, a constant correction factor could not be subtracted from the HAIC gain in order to predict the average gain derived by the new method; (2) Both methods gave approximately the same average maximum power output; (3) The frequency range derived by both methods was similar; however, the new method tended to raise the low frequency cut-off by approximately 100 Hz; (4) Both methods gave identical frequency response curves.

The following conclusions were drawn from the second experiment employing normal listeners: (1) Differences between hearing

aids could not be adequately demonstrated using CNC monosyllabic words in a quiet listening condition; (2) The + 10 secondary signals (noise and competing message) equally depressed speech discrimination scores. Moreover, these listening conditions did not demonstrate differences between hearing aids; (3) Both 0 primary-to-secondary signals resulted in substantial depression of speech discrimination scores, with the poorest scores attained by the noise condition. Also under both of these conditions differences between hearing aids were observed; (4) When hearing aids were grouped by frequency response, (flat, irregular and high frequency emphasis) differences were not found between groupings for any of the five listening conditions.

Based on the outcome of this investigation a hearing aid evaluation procedure was recommended involving the utilization of speech discrimination materials recorded through hearing aids on tape.

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By
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CHAPTER I

INTRODUCTION

At the present time many hearing clinics employ a "traditional" approach in the selection of a specific hearing aid for patients in need of amplification. With this approach the patient's performance is evaluated with several different hearing aids under "identical" listening conditions. The results are compared to determine if one hearing aid provides more benefits than others for the individual with a particular hearing loss.

In preparation for the hearing aid evaluation the audiologist examines the audiometric test results in order to select several appropriate hearing aids for trial by the patient. The level of the speech reception threshold (SRT) is used as a guide in selecting the needed gain of the hearing aid. The pure-tone audiometric configuration suggests the appropriate frequency response curve, while the threshold for discomfort dictates the maximum power output of the instruments.

In the hearing aid evaluation the patient's performance is compared on several hearing aids by obtaining such measures as aided SRT, the aided speech discrimination score, and the aided tolerance level.

The objective of such a hearing aid evaluation is to determine if one particular hearing aid and receiver combination would benefit the patient more than other hearing aids. The hearing aid and receiver combination which yields the best SRT, the highest tolerance level, and the highest speech discrimination score is generally the type of hearing aid recommended for purchase.

Several problems are inherent in this "traditional" procedure for hearing aid selection. Some of the more apparent problems are:

1. The aided SRT is usually obtained after the volume control on the instrument has been adjusted to the level where the patient "judges" it to be most comfortable, or the volume control is arbitrarily adjusted by the audiologist. This setting may or may not be the optimal setting for the particular hearing aid involved. Also this setting is not repeatable or consistent from hearing aid to hearing aid (Kasten and Lotterman, 1970).

2. Stock ear molds are generally used which many times do not form tight seals in the external ear canal, thereby, allowing acoustic

feedback to occur, which prevents setting the hearing aid for optimal gain.

3. Most clinics do not have the equipment necessary for making precise measurements of the physical performance characteristics of the individual instruments; thus, the audiologist is not always certain the aids selected are meeting the manufacturer's specifications.

4. The time factor often necessitates bringing the patient back for a separate hearing aid evaluation apart from the initial hearing evaluation. Furthermore, the time constraint usually limits the trial to three or four hearing aids.

5. Finally, the assumption is made that the manufacturer's specifications present an accurate and valid representation of how the individual instruments will perform when worn by the hearing impaired person.

With this "traditional" method of hearing aid selection many extraneous variables are left uncontrolled which lead to poor test-retest results. Better control of these variables would give a more accurate picture of the benefits of each hearing aid for the hearing impaired individual.

Purpose of the Study

The central focus of this research was to develop a new procedure for hearing aid evaluations which would:

1. Allow for identical acoustical conditions when comparing several hearing aids via aided speech audiometry.

2. Eliminate or greatly reduce the need for using stock ear molds.

3. Decrease the possibility of a trial hearing aid not operating according to specifications.

4. Allow for hearing aid evaluations to be completed in a shorter period of time.

To achieve these goals a new approach was designed for describing the acoustical performance characteristics of hearing aids which is different from that advocated by the Hearing Aid Industry Conference (HAIC) procedure (Lybarger, 1961). With this new approach the performance of the hearing aid is measured at an optimal rather than at maximal gain, since the hearing impaired person uses his hearing aid at an optimal gain setting.

It is suggested that this new procedure for describing the performance characteristics of hearing aids offers a more accurate description of how the instrument should operate while worn by the hearing impaired individual. "The HAIC Standard Method of Expressing Hearing Aid Performance" (1961) notes only physical characteristics of hearing aids. In contrast the new method considers the hearing impaired individual as an essential part of the system, expressing numerical values for range of usable gain, frequency range, and maximum power output in a more realistic manner.

Significance of the Study

The significance of this study is two-fold: First, of primary importance is the description of hearing aid performance characteristics related to the hearing impaired individual's needs. Secondly, a method for hearing aid evaluations is proposed which will enable the audiologist to better serve hearing impaired children and adults who require amplification.

CHAPTER II

BACKGROUND INFORMATION AND LITERATURE REVIEW

This chapter presents an overview of the present HAIC procedure for expressing hearing aid performance characteristics. Further, two current viewpoints regarding how hearing aid evaluations should be handled by audiologists are summarized.

Hearing Aid Response Characteristics

Attempts to describe and categorize the acoustical parameters of electronic hearing aids date back to the late 1920's (Berger, 1968). In 1942, Romanow published one of the first extensive monographs on measuring the performance characteristics of hearing aids. In 1944 Zenith standardized it's method for making measurements of acoustic gain, acoustic output and frequency response, and undoubtedly other manufacturers did likewise (Zenith publication). Later, under the auspices of the American Hearing Aid Association, Kranz (1945) published a "Tentative Code for Measurement of Performance of Hearing Aids". Although this method was proposed as a means for standardizing the measurement and expression of hearing aid performance characteristics within the industry, the procedure was not universally put into practice.

Until the early 1960's comparisons of the acoustical performance characteristics of hearing aids produced by various manufacturers were of doubtful value. Each manufacturer independently determined his own techniques for measuring hearing aid performance characteristics and for reporting these results to the consumer or the audiologist. Since a standardized method was not employed, manufacturer specifications were of little value in the hearing aid evaluation procedure.

Berger illustrated the nature of this problem by stating:

> Matters such as gain and frequency response were sometimes mentioned, with gain based on some average figures, or on the gain at 1000 Hz, or based on a peak frequency. Input, if mentioned, might be one of several levels (1970, p. 82).

In 1960 HAIC established measurement procedures and standardized expressions for hearing aid responses pertaining to acoustic gain, output, and frequency range. The technical committee, which drafted the document, was composed of representatives from the manufacturing industry. This new standardized procedure was submitted to HAIC members for ballot in November of 1960, and was accepted and initiated in 1961 (Lybarger, 1961).

The HAIC Method is primarily based on measurement procedures recommended by the United States of America Standards Institute (USASI) Standard S3.3-1960, entitled "USASI Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids". In 1967 the HAIC Standard Method, with some modification, became

USASI Standard S3.8-1967. The minor difference between the HAIC Standard Method and USASI Standard S3.8-1967 is that the latter calls for the frequency response graph to have a scale ratio of 15.05 dB per octave on the logarithmic frequency scale as opposed to the HAIC requirement of 13.5 to 15 dB per octave.

To date the majority of hearing aid manufacturers in the United States are using the HAIC standard for expressing hearing aid performance characteristics. (The entire text of the HAIC Standard Method of Expressing Hearing Aid Performance may be found in Appendix A).

In the following section details of the HAIC procedure are reviewed with discussion on acoustic gain, acoustic output, and frequency range as described by HAIC.

Gain

> The term "gain" as applied to a hearing aid shall mean the average of 500, 1000 and 2000 cps values of the full-on acoustic gain, as defined in Section 2.3 and as measured in accordance with Section 5.7 of American Standard S3.3 Unit: decibels (Lybarger, 1961, p. 17).

For the above procedure the gain control of the hearing aid is set at it's maximum-on position, and the sound-field input level is adjusted for 50 dB SPL. A frequency response curve is then obtained with this input level held constant through a wide frequency range. The output sound pressure is measured for the three frequencies 500, 1000 and 2000 Hz. The 50 dB SPL input is then subtracted from the output measurements and the three selected frequencies are averaged.

In this manner a single numerical values is obtained called the "HAIC Average Gain."

In reviewing this procedure for determining gain three important facts should be mentioned:

1. Individuals do not wear hearing aids with the volume control turned full-on.
2. The normal input for conversational speech is not 50 dB SPL.
3. The HAIC formula for reporting gain as a single numerical value (i.e., average 500, 1000, 2000 Hz) tends to distort the picture if one is considering high or low frequency emphasis hearing aids.

In essence, the gain values as figured by the HAIC Method do not represent realistic gain values for the hearing impaired individual using the hearing aid.

Davis and Silverman (1970) reported that average conversational speech at one yard averages between 65-70 dB SPL. Other investigators have reported slightly higher values for normal conversational speech ranging between 70-75 dB SPL.

It would appear that if one were interested in portraying the actual beneficial gain for speech, that the hearing aid user would receive, two important deviations should be made from the HAIC Performance Standards. First, the input level to the hearing aid should be changed to a value more accurately representing normal conversational speech intensity levels. A more realistic value of 70 dB SPL appears appropriate. Secondly, the volume control of the hearing aid should be varied from just-on to full-on in a systematic manner, thus giving a true representation of a range of gain values at various volume control settings. It is proposed that a family of gain response curves be obtained in 10 dB steps, by adjusting the hearing aid volume control while keeping the input stimulus constant.

With this procedure one would generate a family of gain curves from just-on to full-on volume control. It is felt that the gain curve selected as representative for a particular hearing aid, should be a curve that would allow for one additional 10 dB increase and still remain linear with respect to the lower gain curves. This would allow for the hearing aid user to have a residual 10 dB of gain for listening situations with less than ideal input intensities (Carhart, 1946). The values reported would be output in dB SPL minus 70 dB SPL input for 500, 1000 and 2000 Hz. The three frequency gain average would also be reported. In this fashion one could report usable average gain over a 20 dB range as "X" dB ± 10 dB. Figure 1 graphically shows an example of the proposed procedure described above applied to an individual hearing aid.

Maximum Power Output

The HAIC Standard defines output in the following manner:

> The term "output" shall mean the average of 500, 1000, 2000 cps values of the saturation sound-pressure level, as defined in Section 2.12, and as measured in accordance with Section 5.6 of American Standard S3.3 Unit: decibels re .0002 microbars (Lybarger, 1961, p. 17).

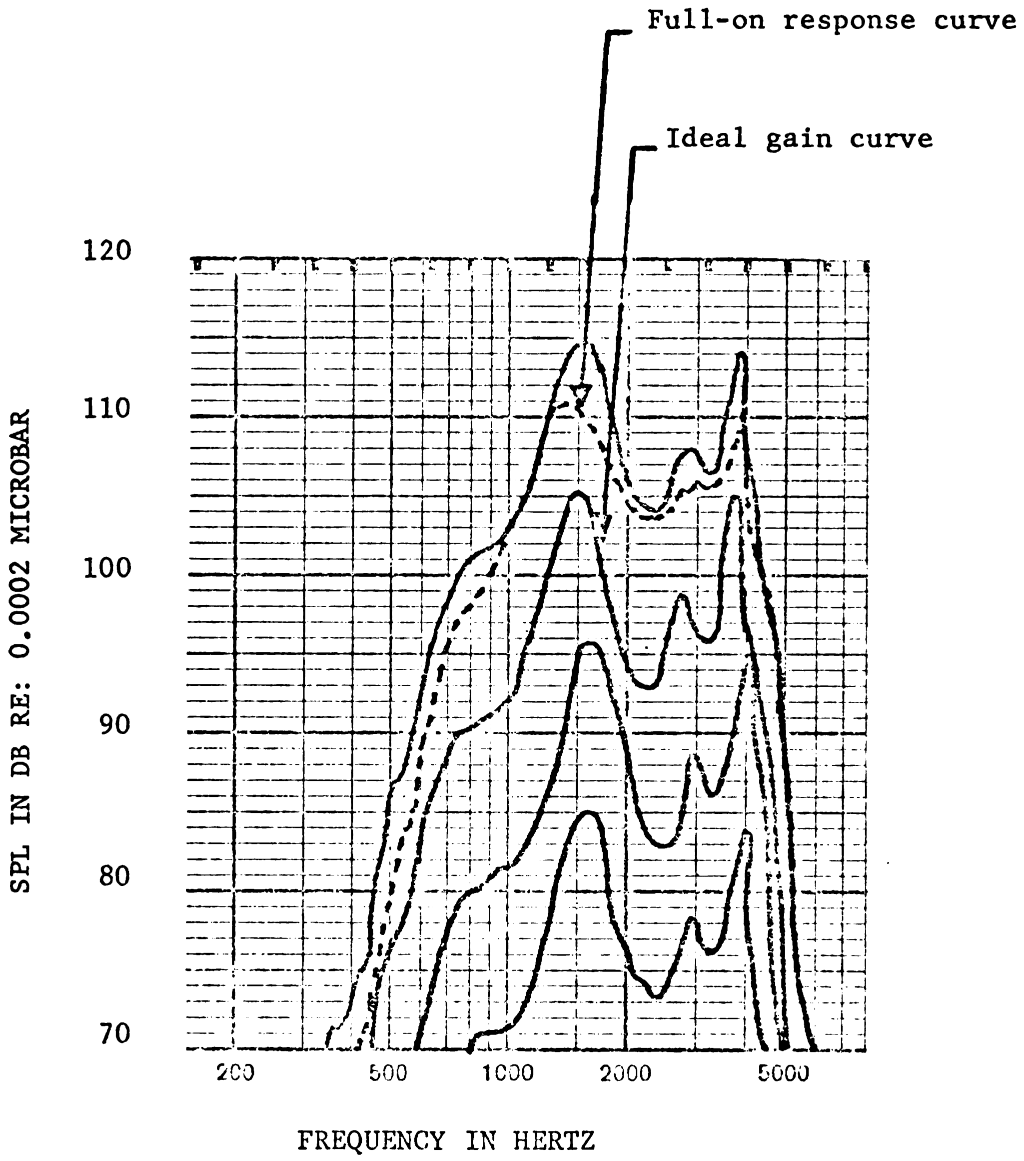

Figure 1. Family of gain curves for a specific hearing aid obtained with a different procedure than advocated by HAIC. A reducation in output is also shown for the full-on volume control adjustment.

A firm understanding of saturation output, sometimes referred to as Maximum Deliverable Pressure (MDP), Maximum Power Output (MPO) or Acoustic Output is essential for proper fitting of a hearing aid. Knowledge of this property of a hearing aid is useful and important in fitting for two reasons: first, and primarily, to minimize or prevent the amplified sound from becoming too loud or painful for the user. Secondly, to assure that the saturation output of the instrument is high enough to enable the input signal to be amplified at an adequately high sensation level above the hearing impaired individual's threshold. With the majority of hearing aids on the market, the second requirement is not a problem whereas, the first is of concern to the audiologist.

According to the HAIC procedure for measuring saturation sound pressure level, the gain control on the hearing aid is adjusted to it's maximum full-on position. The sound-field input is then increased in a systematic manner of 60, 70 and 80 dB SPL or in 10 dB steps from the basic input of 50 dB SPL. At each step a frequency response curve is obtained through a wide frequency range. In this manner a family of frequency response curves are obtained, which portray an input versus output relationship. When the output does not remain linear with respect to input, the hearing aid is considered to have reached it's saturation output level. In other words, a further increase in input does not provide a similar increase in output. When the maximum linear saturation output level is reached, the frequencies of 500, 1000 and 2000 Hz are averaged and reported as the saturation output in dB SPL.

Several basic difficulties are inherent in the HAIC procedure for determining saturation output level, particularly as applied to the hearing impaired individual using the instrument. It is felt that the MPO should not be obtained with the hearing aid volume control adjusted to the full-on position but rather adjusted to the desirable gain volume control setting for each particular instrument as described earlier. At each setting a frequency response curve should be obtained through a wide frequency range. This procedure should be continued until the output does not remain linear with respect to the input for the frequency range of 500-2000 Hz. At this point the hearing aid would be considered to have reached it's saturation output. Figure 2 illustrates this procedure.

It is believed that MPO values obtained at a "usable" volume control setting will give a more meaningful picture of maximum power output limits of the hearing aid, when worn by the hearing impaired individual. The rationale for this belief is based on the knowledge that often electroacoustic instruments lose efficiency when adjusted to a full-on position. For example, Figure 1 demonstrates a decrease in output when the hearing aid is adjusted for full-on volume control.

It is also felt that when reporting MPO, in addition to numerically expressing the three frequency average of 500, 1000 and 2000 Hz, the peak frequency saturation output level, and the MPO at 500, 1000 and 2000 Hz should also be given independently.

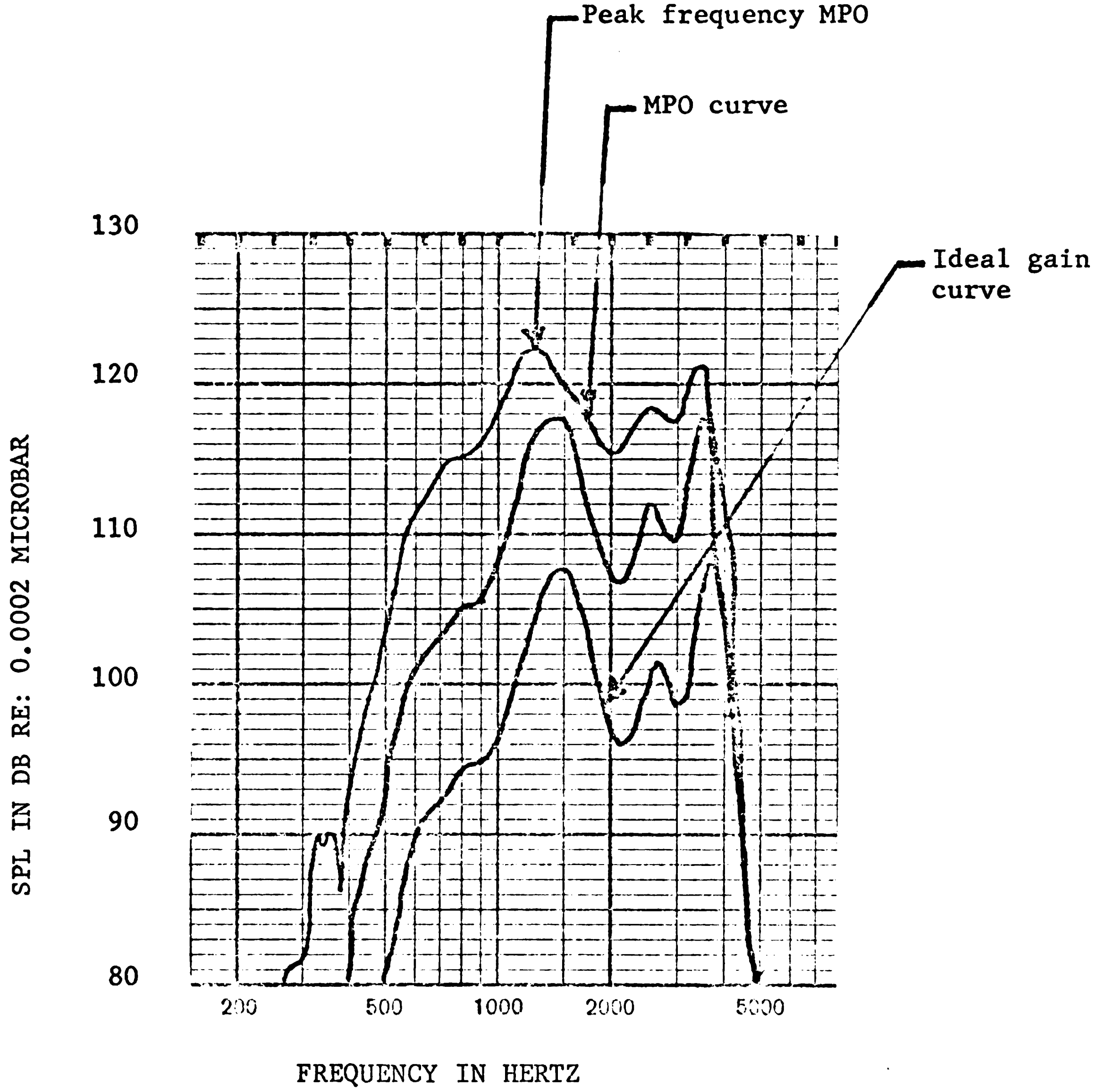

Figure 2. Illustration of the new procedure for determining the maximum power output (MPO) of a hearing aid.

Frequency Range and Frequency Response Curve

The HAIC Standard Method states the following with respect to frequency range:

> The frequency range of a hearing aid shall be expressed by two numbers, one representing the low-frequency limit of amplification in cps and the other the high frequency limit of amplification in cps . . .
>
> Determination of the frequency range shall be made using a basic frequency response curve as defined in Section 2.11 and measured per Section 5.5 of American Standard S3.3.
>
> The following procedure shall be employed to determine the lower and upper frequency limits.
>
> Determine the average of 500, 1000 and 2000 cps ordinates on the frequency response curve and plot this values on the 1000 Hz ordinate.
>
> Plot a second point on the 1000 cps ordinate 15 dB below the first point.
>
> Through the second point, draw a straight line parallel to the frequency axis.
>
> The low-frequency limit of the hearing aid is defined as the frequency where this line first intersects the frequency response curve, moving in the direction of decreasing frequency from 1000 cps . . .
>
> The high-frequency limit of the hearing aid is defined as the frequency range where this line first intersects the response curve, moving in the direction of increasing frequency from 1000 cps . . . (Lybarger, 1961, p. 33).

The HAIC Method further mentions a specific procedure to be employed, "where a single 'notch' of inconsequential effect on the hearing aid's performance may exist". (See Appendix A)

The method also mentions that the basic frequency response curve should be shown in addition to the numerical data.

It should be pointed out that the basic HAIC response curve is obtained with a 60 dB SPL input and the volume control adjusted for 40 dB gain or 100 dB SPL at 1000 Hz. (Figure 3)

It is thought that the HAIC procedure expresses results in an unrealistic manner and without concern for the individual hearing aid user. The method is unrealistic primarily because one is not assured that the response curve obtained is within the linear operating range of the hearing aid. For example, for a "low" gain instrument, with a 60 dB input it may be necessary to adjust the volume control to the full-on position in order to achieve 100 dB SPL output at 1000 Hz. Furthermore, with many low gain instruments, this desired output cannot be attained. Thus, this non-ideal setting may introduce distortion changing the true representation of the hearing aid's frequency response. In a similar fashion with high gain aids, many times the just-on position produces more than 100 dB output (e.g. 110 or 115 dB SPL) and this extremely low volume control position may also introduce distortion with respect to the frequency response curve.

A more realistic representation of the frequency response of the hearing aid might be obtained from the "ideal" gain curve as discussed earlier in the section concerned with gain.

It is proposed that the frequency range be determined by the

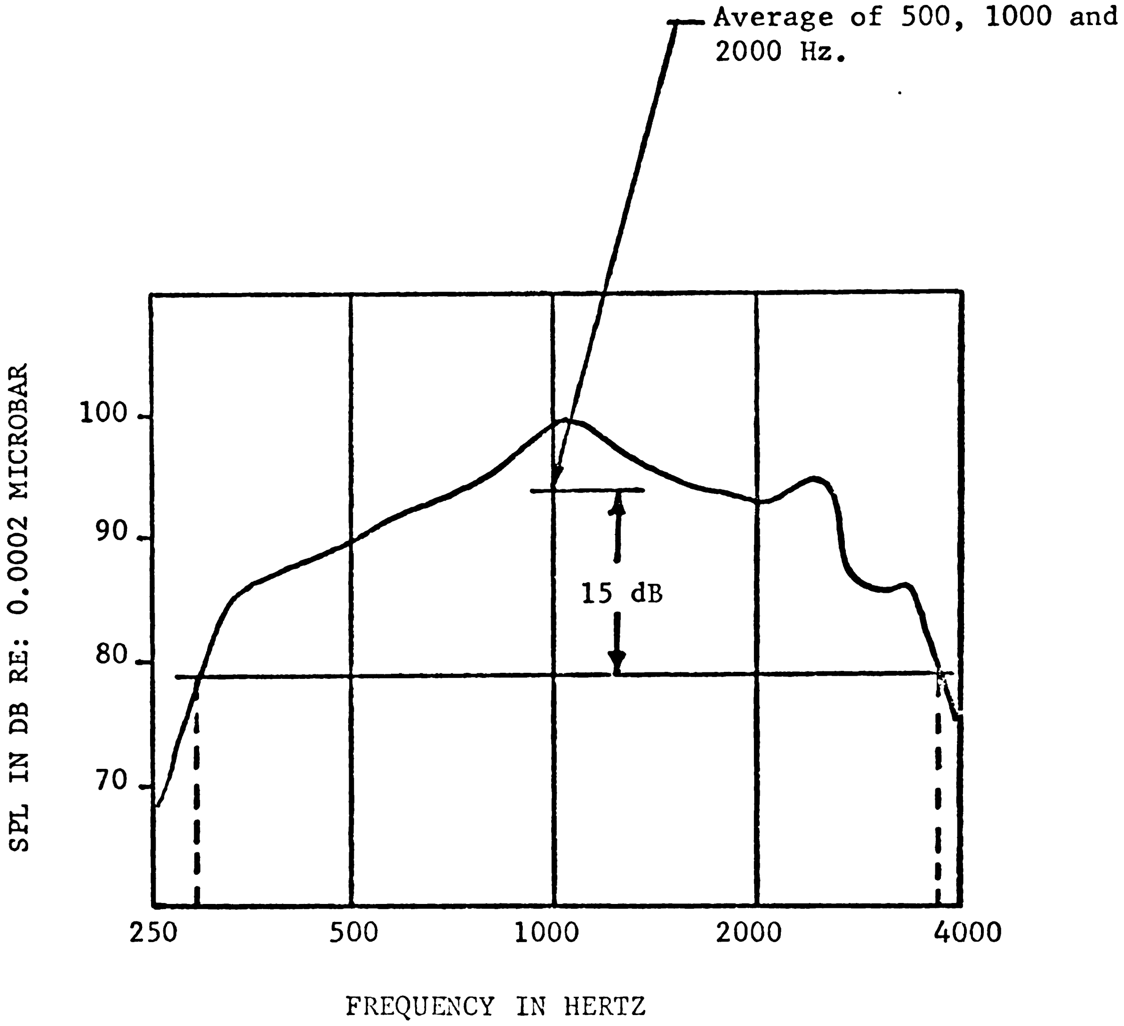

Figure 3. HAIC Method for determining the basic frequency response curve and frequency range of a hearing aid.

following method: once the ideal gain curve has been obtained, the numerical three frequency average for 500, 1000 and 2000 Hz is marked on the 1000 Hz ordinate. Ten dB is subtracted from this average and a second mark is made. A line is then drawn parallel to the abscissa. The line intersections of the low and high frequency skirts of the "ideal" gain curve defines the frequency range. This procedure produces a range which is felt to correspond to the dynamic range of ongoing speech. Previous measurements by this author of ongoing speech were found to be within a 10 dB dynamic range. The frequency range is expressed in this way by two numbers, a low and high frequency. Figure 4 graphically expresses the proposed new procedure for defining frequency range.

Credit should be given to HAIC for taking the initiative in standardizing the measuring and reporting of hearing aid performance characteristics. However, it is felt by this writer that we are now capable of describing hearing aid characteristics in a manner which also takes into account the acoustic needs of the hearing impaired individual. Thus, it is thought that hearing aid characteristics should be derived in a manner similar to how the instrument is actually used by the hearing impaired individual.

The Clinical Hearing Aid Evaluation

Evaluation Procedure

In most speech and hearing centers in the United States some form of hearing aid evaluation procedure is employed in order to

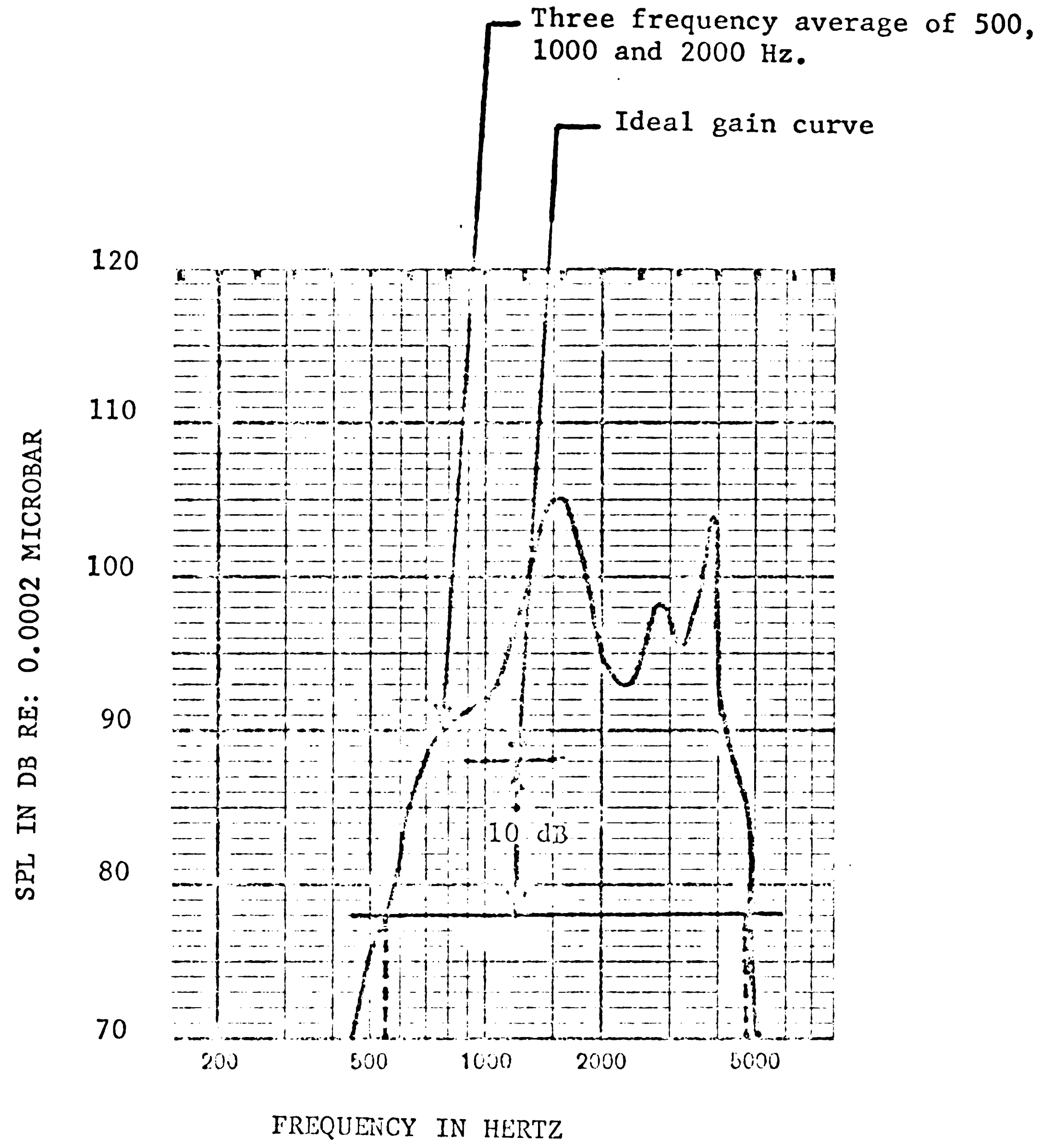

Figure 4. Illustration of proposed method for determining the frequency range of a hearing aid.

select or recommend the most appropriate hearing aid for individuals who can benefit from wearable amplification. However, considerable differences of opinion exist as to the reliability and validity of current clinical methods and materials used in the hearing aid evaluation procedure.

Most procedures that have been designed for hearing aid evaluation have sought a so called "objective" technique in an effort to determine if one particular instrument is better suited for a particular user.

At the present time it appears that there are tow general viewpoints among audiologists concerning how the hearing aid evaluation should be handled (Berger and Millin, 1971; Ross, 1972). One view is that the audiologist should be responsible for selecting the particular instrument. This procedure frequently calls for the trial of several aids whose reported characteristics appear to be suitable for the individual's hearing impairment. The goal is to select an instrument that will provide sufficient benefit for the hearing aid user. During this clinical selection procedure various comparisons among instruments are made which include measurement of a speech reception threshold, speech discrimination both in quiet and in noise, threshold of discomfort, and even subjective evaluation of quality by the hearing impaired individual.

The recommendation to the hearing aid dealer from this type of procedure may simply note the ear to be fitted, and manufacturer and model of hearing aid selected from the trial aids. The recommendation, however, may also be more specific and include various internal adjustments for a particular hearing aid.

A second viewpoint is that the hearing aid selection should be left to the hearing aid dealer. Several reasons have been given for this procedure:

1. the cost in man hours of professional time;
2. the administrative difficulties in maintaining an inventory of the hearing aids;
3. the opinion that present clinical materials do not distinguish between aids;
4. the cost to the dealer or manufacturer in assigning aids to clinics throughout the country; and
5. the belief that dealers are qualified to perform the service (1967, Conference on Hearing Aid Evaluation Procedures, p. 16).

Advocates of this viewpoint feel that if an individual's hearing is examined, and if the proper recommendations are made regarding the acoustic characteristics of the instrument, then any hearing aid meeting the patient's amplification needs will be satisfactory. It is also believed that with this method more time may be spent in counseling and providing rehabilitative services. However, the main assumption is that "identical characteristics" to the audiologist's specification will be met by the hearing aid dealer.

Perhaps the major point of controversy over the hearing aid evaluation procedure has been, "Can differences between hearing aids be demonstrated?"

Shore et.al. (1960) investigated the reliability of three measures obtained in speech audiometry that are commonly emphasized in the hearing aid evaluation. The three measures used were gain or residual hearing level for speech, speech discrimination in quiet and speech discrimination in noise.

Fifteen clinical patients with mild to moderate impairments in three diagnostic groups, conductive, sensorineural and mixed, served as subjects. Four body-type hearing aids were used in the study with each aid being evaluated under a "good" and "bad" tone control setting. Tests of hearing aid performance with all hearing aids and tone control settings were repeated on four different days.

The authors concluded that the reliability of the three measures obtained were not good enough to warrant the large investments of clinical time in obtaining them.

The above cited study served as the impetus for those who argue that the hearing aid dealer is best equipped for selection of hearing aids.

Jerger, Speaks and Malmquist (1966) and Jerger and Thelin (1969) reported that differences between hearing aids can be demonstrated. However, they also pointed-out the ineffectiveness of contemporary clinical hearing aid procedures for showing differences between aids. The opinion of these researchers appears to be that monosyllabic word lists as they are commonly used in hearing aid evaluations are incapable of demonstrating differences between hearing aids. These authors suggested that a more meaningful and discriminating test is necessary, such as a test which more closely approximates connected speech presented with a competing message.

With the above research in mind and the foregoing discussion concerning the HAIC Method for expressing hearing aid characteristics, the question might be asked: "If the hearing aid characteristics used in earlier experiments had been obtained under a different manner and if identical acoustic listening conditions were held constant for all instruments, would the same conclusions have been reached?"

A hearing aid evaluation procedure emphasizing a new method for describing the acoustical characteristics of hearing aids is proposed. This procedure incorporates taped speech materials recorded through different hearing aids. The recordings are made after the hearing aid has been carefully adjusted for its "ideal" or linear gain curve. It is felt that with this new procedure initial hearing aid evaluations could be made quickly and accurately. This method would allow for:

1. Standardized acoustical conditions.
2. Elimination of acoustic feed-back, due to ill-fitting stock earmolds.
3. Assurance that the hearing aid is delivering the proper gain.
4. Hearing aid evaluations to be made in a shorter time span.

However, before this new procedure could be employed in a clinical setting this investigator sought to evaluate five stimuli conditions recorded through several hearing aids. This was done in order to find the most demanding and discriminatory listening condition for showing differences between hearing aids with normal hearing subjects. For this reason a second investigation was conducted.

Specific Questions Asked

In summary two studies were performed. In the first the HAIC Method for determining and reporting hearing aid characteristics was compared with a new method designed by this author. The specific questions asked were:

1. Do both methods yield comparable gain values?
2. Do both methods yield comparable MPO values?
3. Do both methods yield comparable frequency response curves?
4. Do both methods yield comparable frequency ranges?

The second investigation sought to answer the following questions relative to the performance of normal hearing subjects under the following listening conditions:

1. Can differences be shown between hearing aids when monosyllabic words (N.U. Auditory Test No. 6) are recorded through them under a variety of listening conditions, and played to normal hearing subjects at the same sensation level?
2. Which listening condition(s) is best for showing differences between hearing aids using normal listeners?

3. Can differences be shown between hearing aids with different frequency response characteristics when monosyllabic words (N.U. Auditory Test No. 6) are recorded through them under a variety of listening conditions and played to normal hearing subjects at the same sensation level?

4. Which listening condition(s) is best for normal listeners in showing differences between hearing aids with different frequency response characteristics?

CHAPTER III

EXPERIMENTAL DESIGN

This chapter has been divided into three sections. The first section describes the new procedure used for specifying and reporting hearing aid characteristics. The second section explains the speech stimuli and the procedure used for recording these materials through each instrument. The final section describes the testing design for evaluating the speech materials recorded through each hearing aid.

Procedure for Describing Hearing Aid Characteristics

Selection of Hearing Aids

The hearing aids used for this study were selected from the stock of new hearing aids in the Hearing Clinic at Michigan State University. Since a large selection of body style hearing aids were not available, only ear level instruments were chosen for inclusion in this research.

Three categories of gain as determined by the HAIC Method, were selected as being representative of mild, moderate and high gain ear-level hearing aids. The numerical gain values were: 0-40 dB, 41-49 dB and 50-60 dB respectively. In order to have hearing aids which were equally representative of this range, an equal number of instruments were selected for each gain category.

To insure that the hearing aids selected were in good working condition and meeting the manufacturer's specifications, all hearing aids underwent spectral analysis according to the HAIC Standard Method of Expressing Hearing Aid Performance.

Only those hearing aids that were within ± 6 dB of the manufacturer's specified HAIC average gain, within ± 70 Hz and ± 300 Hz of the manufacturer's low and high frequency limits respectively, and whose maximum power outputs were within ± 10 dB were included. Table 1 shows the manufacturer's HAIC specifications and the HAIC characteristics obtained at Michigan State University for the hearing aids used in this research.

The above stated criteria for inclusion of hearing aids was made arbitrarily since specific information is not provided in the HAIC Standard as to allowable variations from the manufacturer's reported specifications. In fact, the HAIC Standard Method simply says:

> Sampling procedures should be adequate to insure that the published performance data will be, to the best of the manufacturer's knowledge, representative of the average product being offered for sale (Lybarger, 1961, p. 33).

Using these criteria six hearing aids were selected for each gain category mentioned above. A total of eighteen hearing aids were chosen representing eight manufacturers. All of these aids were felt to be within the manufacturer's specifications according to HAIC.

Table 1. Manufacturers' HAIC specifications and HAIC specifications obtained at Michigan State University Audiology Research Laboratory.

Hearing Aid	Gain (dB)	Gain M.S.U. (dB)	MPO (dB)	MPO M.S.U. (dB)	Frequency Range (Hz)	Frequency Range M.S.U. (Hz)
Mild Gain Group						
Oticon UX	40	40	118	112	300-4000	180-3800
Zenith Westwood B	30	35	106	103	550-4100	500-4500
Siemens 380	32	37	116	114	450-4500	500-5000
Zenith Moderator A	43	37	109	107	400-4500	450-4300
Radioear 1000	42	40	121	118	270-4400	190-4800
Sonotone 37	38	40	117	114	470-4300	450-4500
Moderate Gain Group						
Beltone Overture YY	42	42	115	114	380-4200	380-4200
Beltone Overture R	46	44	120	119	480-3900	480-3900
Audiotone A-19	48	45	116	113	520-4500	520-4500
Audiotone A-20	47	46	123	121	350-5200	280-4900
Beltone Overture Y	50	49	115	115	490-4500	380-4200
Zenith Newport	44	49	122	123	420-4100	480-4400
High Gain Group						
Siemens 382	54	50	125	121	450-4500	400-4900
Sonotone 77	48	50	124	124	390-3800	320-3800
Siemens 383	53	50	124	115	450-4500	390-4600
Audiotone A 21 II	49	51	127	127	450-4200	450-5200
Norelco 6730	56	51	---	128	--------	400-4500
Radioear 990	54	53	127	129	400-5100	370-4800

Equipment Used For Analysis of Hearing Aids

Figure 5 shows a block diagram of the equipment used for acoustical analysis of the hearing aids involved in this study. Prior to making all measurements, this system was calibrated with a piston microphone (Bruel and Kjaer, Type 4220) employing a 250 Hz tone at 124 dB SPL re 0.0002 microbar. Each hearing aid was coupled to the artificial ear using a one inch piece of number thirteen tubing.

New Procedure Used For Obtaining and Reporting Hearing Aid Characteristics

These eighteen hearing aids were then analyzed utilizing the new procedure. The same equipment and strict precautions used earlier were employed to assure that the equipment was in proper calibration.

The new procedure used for determining the acoustical characteristics of each hearing aid consisted of the following steps:

1. The hearing aid was coupled to the $2cm^3$ artificial ear (Bruel and Kjaer, Type DB 0138) using a one inch length of number 13 tubing. The volume control of the hearing aid was rotated to the just-on position or the lowest volume control setting.

2. A narrow band of noise produced by the sine-random generator (Bruel and Kjaer,

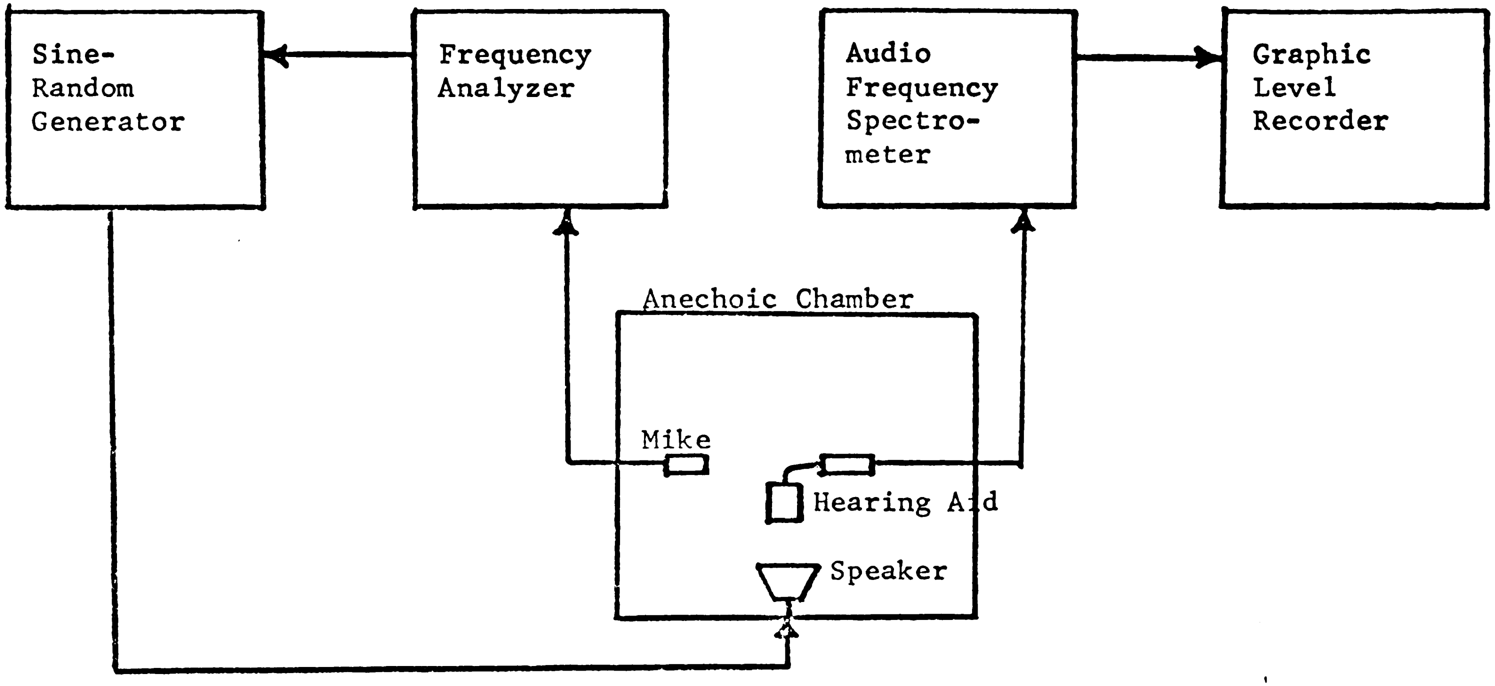

Figure 5. Simplified block diagram of hearing aid measurement system: Sine-Random Generator (Bruel and Kjaer, Type 1124); Anechoic Chamber (Bruel and Kjaer, Type 4212); Frequency Analyzer (Bruel and Kjaer, Type 2107); Audio Frequency Spectrometer (Bruel and Kjaer, Type 2112); Graphic Level Recorder (Bruel and Kjaer, Type 2305).

Type 1124) and centered at 2000 Hz with a bandwidth of 100 cycles was introduced into the anechoic chamber at a level of 70 dB SPL.

3. A frequency response curve was then obtained at this volume control setting through the frequency range of 20-20,000 Hz. The input level of 70 dB SPL was held constant for all frequencies.

4. The sine-random generator was readjusted to produce the narrow band of noise as mentioned under step two. The volume control of the hearing aid was again rotated until a 10 dB increase in output was obtained from the initial volume control setting. A new frequency response curve was obtained at this volume control adjustment.

5. Steps two through four were repeated until the volume control was rotated to the full-on or maximum-on position.

With the procedure described above a family of gain versus frequency response curves were obtained with a constant input level of 70 dB SPL for all frequencies.

The frequency of 2000 Hz was arbitrarily selected for the adjustment input since many hearing aids have resonant peaks around this region, and also because this frequency is important for speech intelligibility.

A comparison between the narrow band of noise centered at 2000 Hz and a pure-tone of 2000 Hz was made for each instrument to determine if the gain values were the same. Identical gain values were found for both inputs for all hearing aids.

New Frequency Response Curve and Gain Values

Once the family of gain versus frequency response curves were obtained, the "ideal" gain versus frequency response curve, or volume control setting, was selected using the following criteria: a frequency response curve which allows for a volume control adjustment (gain setting) of an additional 10 dB and, still remains linear with respect to the lower curve within the speech frequency range of 500 to 2000 Hz.

From the "ideal curve" the discrete gain values for 500, 1000 and 2000 Hz were obtained by subtracting the 70 dB input from the output. The average gain was derived by averaging the gain for the above three frequencies.

New Frequency Range

The frequency range of each instrument was also determined by using the "ideal" gain or frequency response curve. The frequency range was obtained by plotting the numerical value of the three frequency average (500, 1000 and 2000 Hz) gain on the 1000 Hz ordinate; a line was then drawn parallel to the abscissa at a level 10 dB lower than the average gain. The points where the line crossed the lower and higher "ideal" frequency response curve skirts defined the frequency range for the instrument. Figure 4 shows an example of this procedure.

New Maximum Power Output

The maximum power output for each instrument was also determined by adjusting the hearing aid for it's "ideal" gain versus frequency response curve and then obtaining separate frequency response curves for each 10 dB increase in the input signal (i.e. 70, 80 and 90 dB SPL). With this procedure a new family of curves was obtained. Saturation output was defined as a frequency response curve where a further increase in input did not produce a further linear increase in output for the frequency range of 500-2000 Hz. From this curve the MPO for the discrete frequencies 500, 1000 and 2000 Hz was obtained in dB SPL. The three frequency average MPO for the above frequencies was also obtained. In addition the peak MPO for each aid was also noted in dB SPL from this curve.

This new procedure for describing the performance characteristics of hearing aids was used on all eighteen hearing aids under investigation.

Speech Stimuli and Recording Procedure

In order to evaluate different speech stimuli conditions for future use in hearing aid evaluations, five speech stimuli conditions were recorded through nine of the original eighteen hearing aids. The speech conditions, recording procedures and hearing aids used are described within this section.

Stimulus Materials Recorded

Speech discrimination material under various signal-to-noise and signal-to-competing message ratios was recorded through each of the nine hearing aids.

The speech material selected for use was the Northwestern University Auditory Test No. 6, Form B (Tillman and Carhart, 1966), which was locally recorded by a male talker (William F. Rintelmann, f_o 95 Hz) with a predominately General American dialect. This test (Appendix B) has four lists of 50 monosyllabic consonant-nucleus-consonant (CNC)[1] words derived from lists originally developed by Lehiste and Peterson (1959) and Peterson and Lehiste (1962). Each word was preceded by the carrier phrase, "You will say _____." In a study at Michigan State University Rintelmann and Schumaier (1972) found the four lists of the locally recorded test to be highly equivalent, with the variability between lists no greater than the variability found within lists.

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[1] CNC refers to monosyllabic words comprised of an initial and final consonant and a vowel nucleus.

Five speech stimuli conditions were used, recording one list of N.U. Auditory Test No. 6, for each condition. It was necessary to repeat one list for each hearing aid; however, care was taken in recording to assure three lists always intervened before any list was repeated.

Primary and Secondary Signals

The Northwestern University Auditory Test No. 6 materials was introduced in the sound-field at a level of 70 dB SPL for all recording conditions. For the signal-to-noise conditions, continuous broad band white noise, generated by a Maico 24 clinical audiometer was used. For the signal-to-competing message conditions a disk recording of Fulton Lewis Jr. (f_o 105 Hz) describing a housing development in Michigan was employed. This recording was selected as the competing message due to it's fairly constant intensity level.[1]

Both of the secondary signals were adjusted to give the appropriate signal-to-noise or signal-to-competing message ratios. The clinical audiometer was used to mix and present the stimuli at the appropriate level through it's associated single speaker in the sound-field.

Listening Conditions

Following is a list of the stimulus conditions which were tape recorded through each hearing aid:

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[1] This recording is commercially available from Technisonic Studios, St. Louis, Missouri.

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1. N.U. Auditory Test No. 6 in quiet
2. N.U. Auditory Test No. 6 signal-to-noise + 10 dB
3. N.U. Auditory Test No. 6 signal-to-noise 0 dB
4. N.U. Auditory Test No. 6 signal-to-competing message + 10 dB
5. N.U. Auditory Test No. 6 signal-to-competing message 0 dB

In addition a calibration signal consisting of a narrow band of noise with a center frequency of 2000 Hz and a 100 Hz bandwidth was recorded at a level of 70 dB SPL.

The intention in selecting these primary-to-secondary ratios was to have listening conditions which were relatively easy (+ 10) and listening conditions which were relatively hard (0). Previous studies concerned with speech discrimination in noise or in a competing message context have used a variety of primary-to-secondary ratios, because the difficulty of the listening task is dependent upon a number of factors such as size of the response set, type of primary signal, type of subjects and method of presentation (Miller, Heise and Lichten, 1951).

Selection of Hearing Aids

Analysis of the "ideal" frequency response curves of the initial eighteen hearing aids was accomplished by referencing the intensities for the frequencies 500, 1000, 2000 and 4000 Hz to the intensity level of the center frequency of 2000 Hz. A visual inspection of these curves revealed three categories of frequency responses: (1) relatively flat response from 500-3000 Hz; (2) high frequency emphasis 500-3000 Hz; and (3) irregular frequency response 500-3000 Hz. Based on this classification system, and by visual inspection, three hearing aids with similar frequency responses were selected from each frequency response category. Figures 6, 7 and 8 show the frequency response curves for the three individual hearing aids in each frequency response category (flat, high frequency emphasis and irregular response). Figure 9 shows the mean frequency response for each of the three groupings. Only the five speech conditions as recorded through these nine hearing aids were evaluated in this phase of the research.

Additionally, it should be pointed-out that gain was not a criterion for selecting the nine hearing aids employed in this phase of the study because all listening conditions were accomplished at a single sensation level. This will be explained further below.

Recording Equipment

Figure 10 shows a block diagram of the equipment used for recording. All recordings were made in a double walled pre-fabricated IAC sound-treated room (Series, 1200). The ambient noise in the room was less than 45 dB on the C scale of a sound level meter (Bruel and Kjaer, Type 2230).

Before the recordings were made, the sound level meter was calibrated with a piston microphone (Bruel and Kjaer, Type 4220) employing a 250 Hz tone at 124 dB SPL re 0.0002 microbar.

A clinical audiometer (Maico, MA 24) with it's associated

Figure 6. Individual frequency response curves of three hearing aids with relatively flat frequency response characteristics between 500 and 3000 Hz.

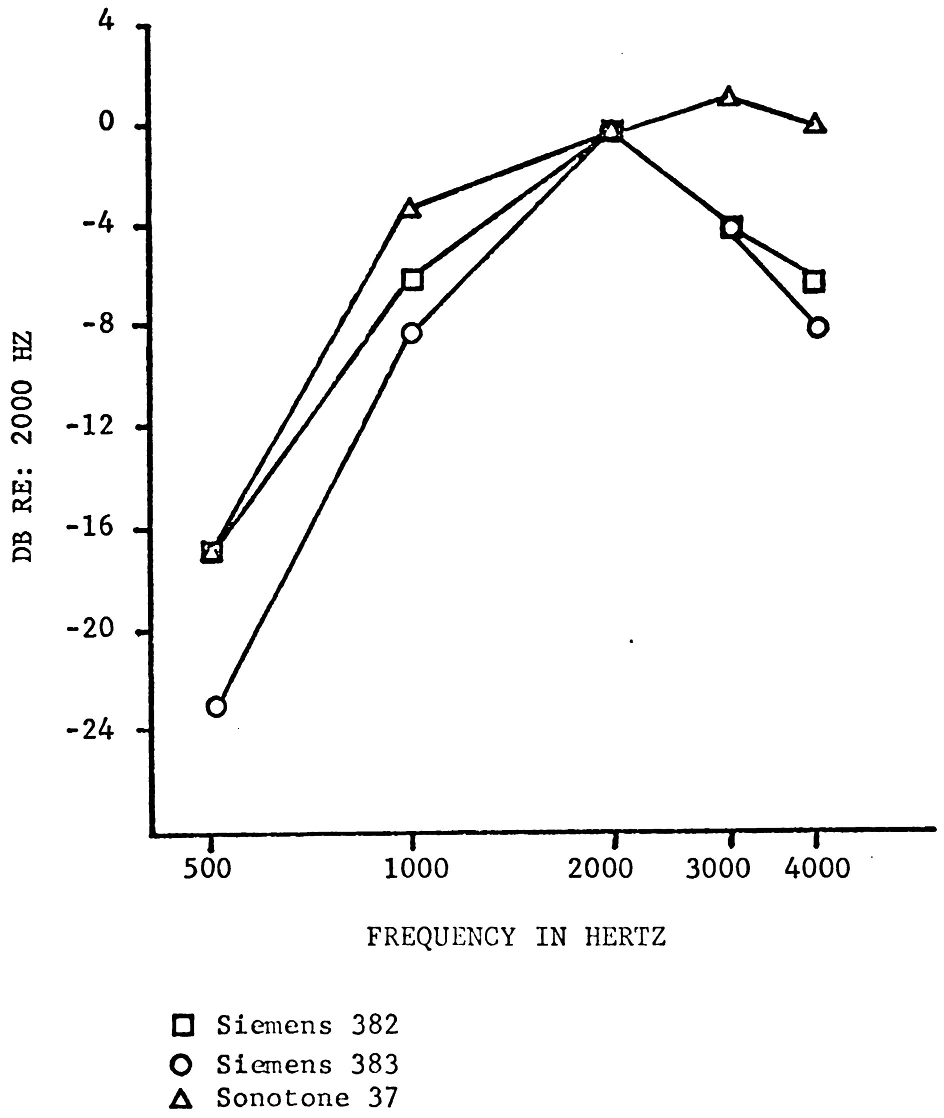
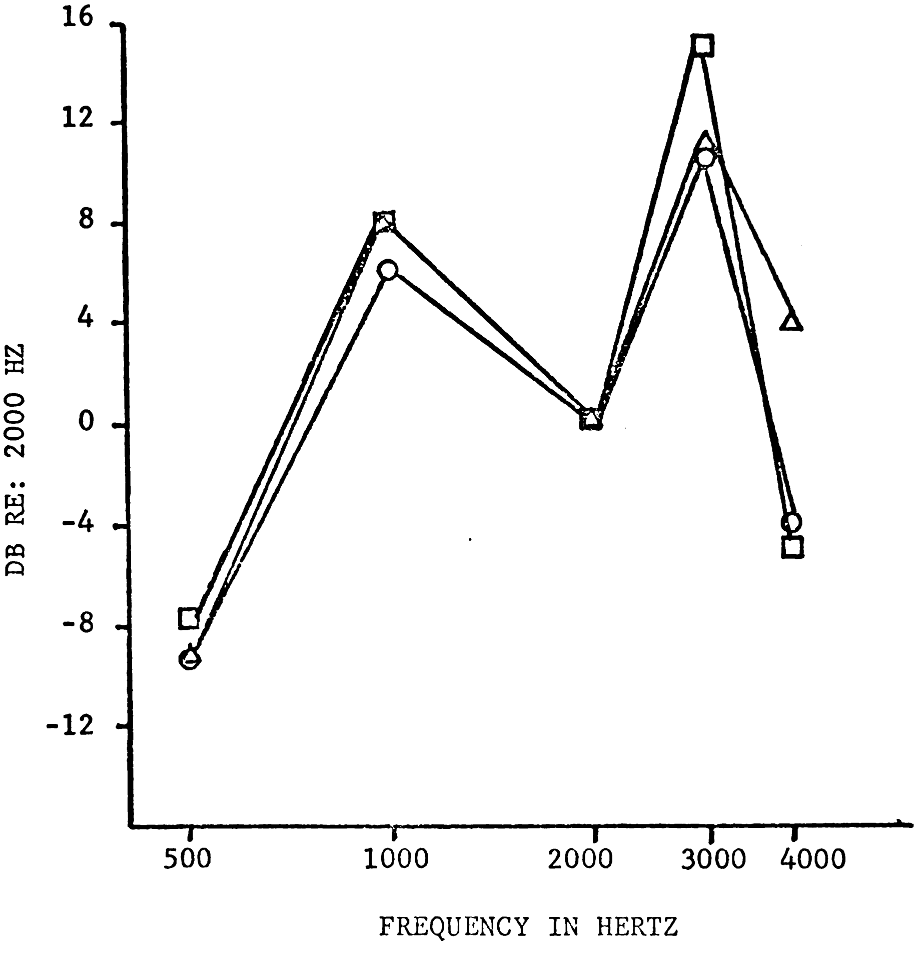


Figure 7. Individual frequency response curves for three hearing aids with high frequency emphasis between 500 and 3000 Hz.



○ Radioear 990
□ Beltone Overture R
△ Beltone Overture YY

Figure 8. Individual frequency response curves for three hearing aids with irregular frequency response between 500 and 3000 Hz.

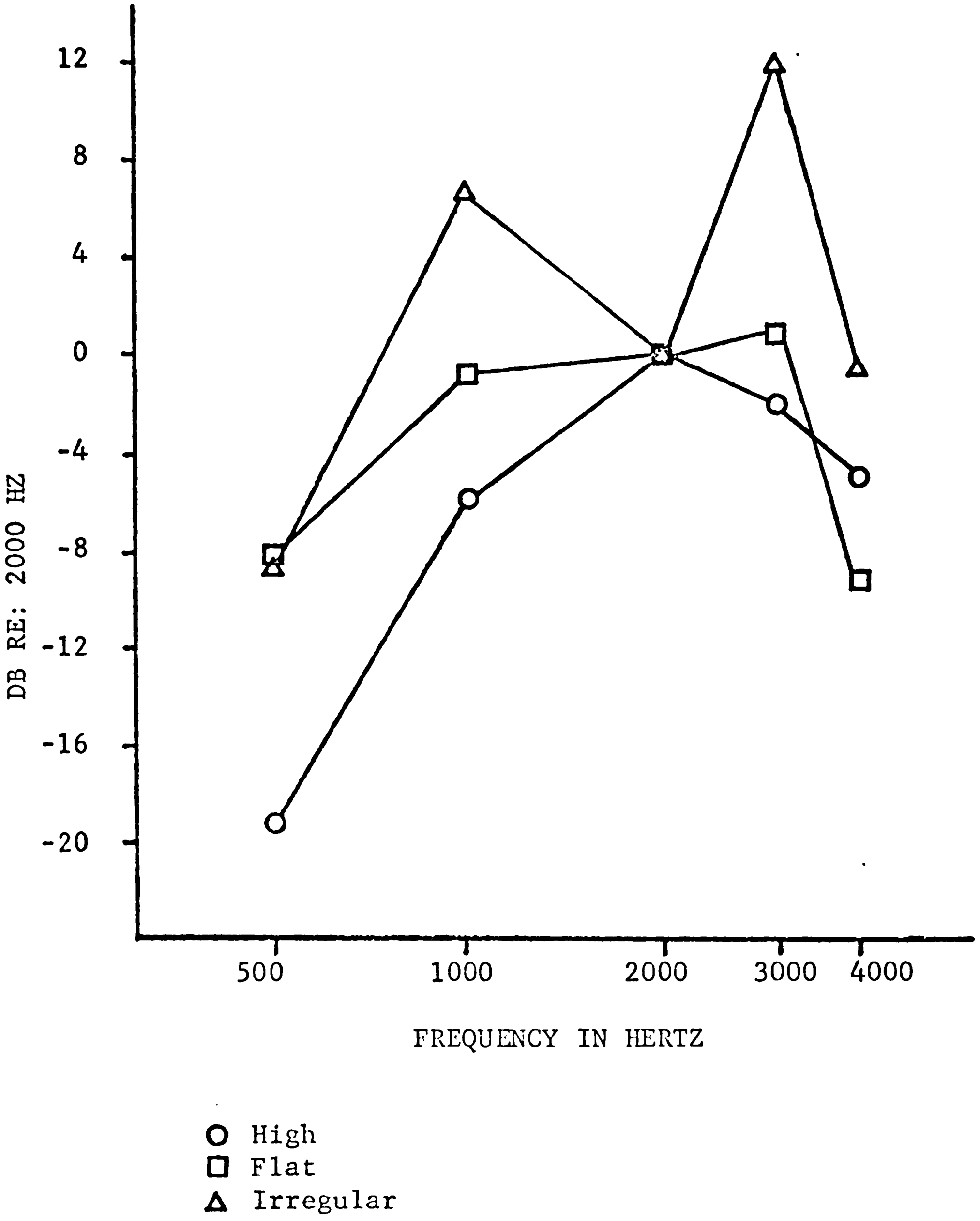


Figure 9. Mean frequency response curves from 500 to 4000 Hz for the three frequency response groups: high frequency emphasis, flat and irregular.

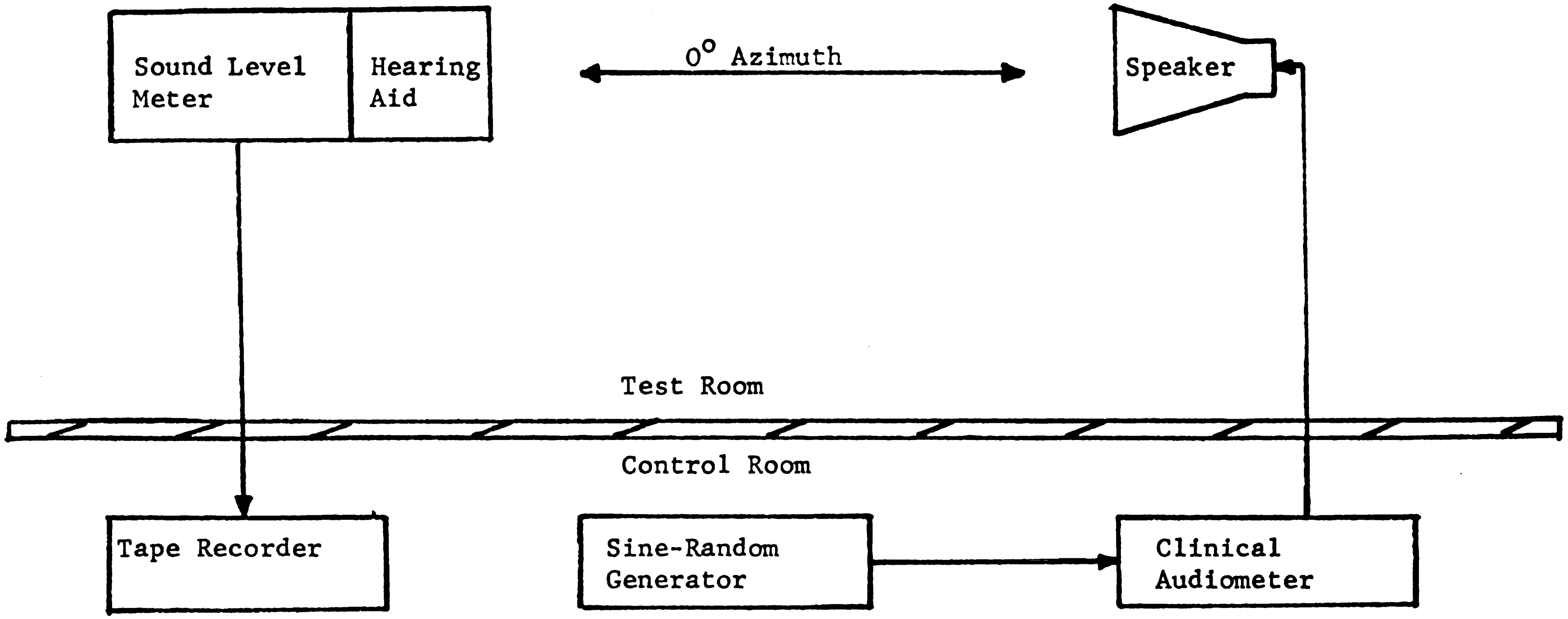


Figure 10. Simplified block diagram of equipment used for recording speech materials through hearing aids: Sound Level Meter (Bruel and Kjaer, Type 2204); Tape Recorder (Ampex, AG 600); Sine-Random Generator (Bruel and Kjaer, Type 1024); Clinical Audiometer (Maico 24) with it's associated tape deck, speaker and turn table.

tape deck (Viking, Model 442) was used to present the stimulus material in the sound-field. Prior to recording, the output signal level for a narrow band of noise centered at 2000 Hz with a 100 Hz bandwidth was calibrated, for 70 dB SPL at the position of the hearing aid within the sound room. A sound level meter (Bruel and Kjaer, Type 2204) with it's associated octave band filter set (Bruel and Kjaer, Type 1613) employing a sound field condensor microphone (Bruel and Kjaer, Type 4145) was used for calibration.

Procedure Used For Recording

Each hearing aid was coupled to the $2cm^3$ artificial ear (Bruel and Kjaer, Type DB 0138) using one inch of number 13 tubing. The hearing aid microphone was positioned for a zero degree azimuth in relation to the speaker. Using the sine-random generator (Bruel and Kjaer, Type 1024) a narrow band of noise 100 Hz wide, with a center frequency of 2000 Hz, was introduced in the sound-field at an intensity level of 70 dB SPL. The volume control on the hearing aid was then adjusted until it's "ideal" gain value for 2000 Hz was obtained on the sound level meter. In this manner one was assured the hearing aid was adjusted for the correct frequency response curve as ascertained earlier from the new calibration procedure. The sound level meter was then switched to the record mode and used as a microphone amplifier. With this instrumentation, the speech stimuli were introduced in the sound-field and recorded through each hearing aid. The speech signal at the output of the hearing aid was recorded with an Ampex tape recorder (AG 600) using Scotch (201) magnetic tape.

Experimental Design

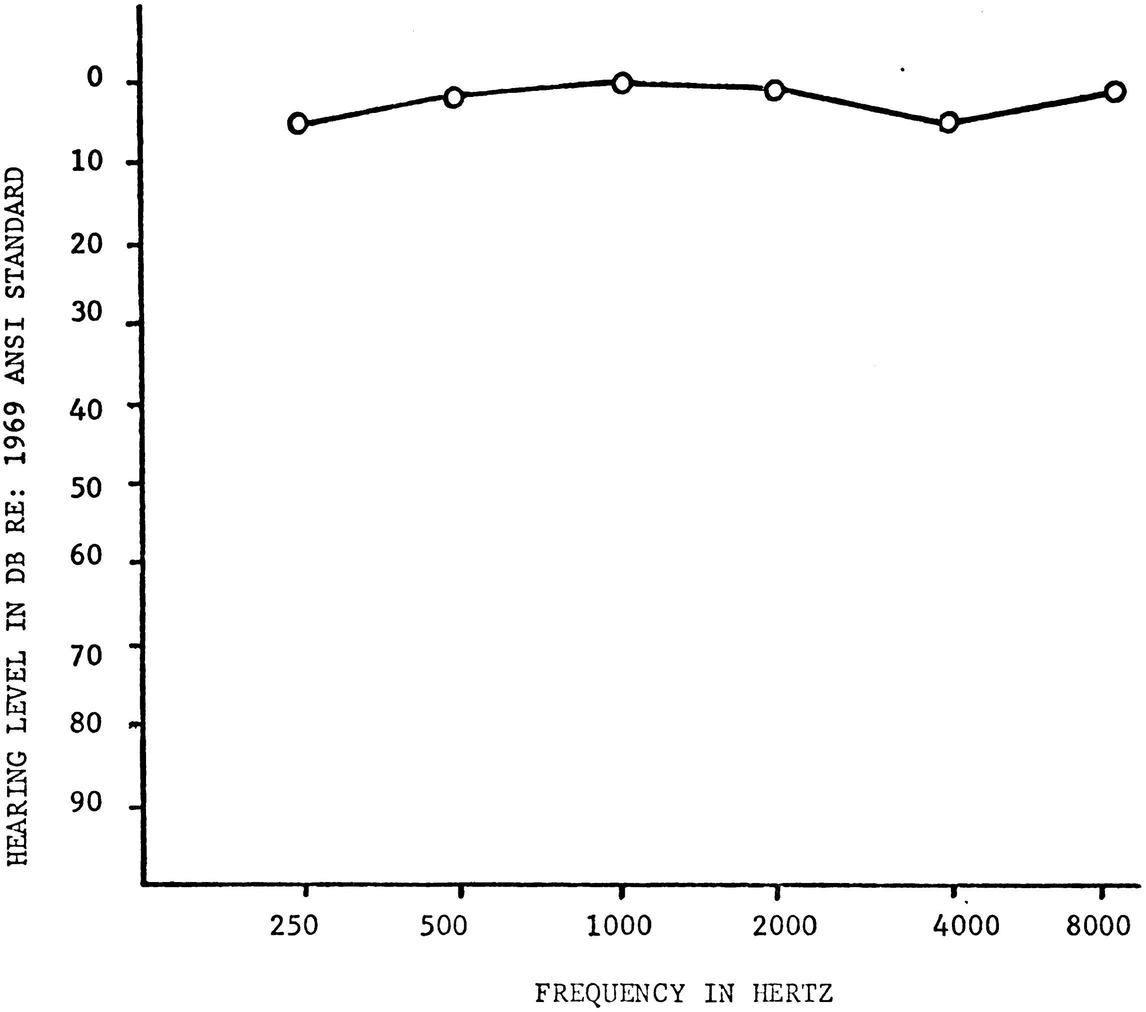
This experiment was performed in order to evaluate the five speech conditions recorded through the nine hearing aids. An attempt was made to discover if certain recorded speech conditions using monosyllabic words were more discriminatory than others between hearing aids with different and similar frequency response characteristics. Since all recordings were made through each hearing aid at the same intensity level, this investigation was actually evaluating the frequency response of each aid and it's distortion against the five recorded speech conditions.

Subjects

The subjects selected were ninety normal hearing young adult untrained listeners. The subjects ranged in age from 18.6 to 30.0 years with a mean age of 23.7 years. All subjects had hearing threshold levels within 20 dB of audiometric zero re ANSI 1969 Standard for pure-tone audiometers. Only the better ear, as determined by the SRT and pure-tone thresholds, served as the test ear. Figure 11 shows the mean audiogram, speech reception threshold and pure-tone average for the ninety subjects.

Testing Equipment

All testing was conducted in a two-room testing suite with the experimenter in the control room and the subject in a double-walled sound-treated test booth (IAC, Series 1200). The ambient noise level in the test room was 42 dB on the C scale of a sound level meter (Bruel and Kjaer, Type 2203).



Pure-tone Average 500-2000 Hz = 2.4 dB HL
Speech Reception Threshold = 1.6 dB HL

Figure 11. Mean audiogram, speech reception threshold, and pure-tone average for ninety normal listeners.

Pure-tone air-conduction thresholds were measured with a commercial audiometer (Beltone, Model 15C) with TDH-39 earphones mounted in MX 41/AR cushions.

For all speech testing, a commercially available speech audiometer (Grason-Stadler, Model 162) was used to amplify and attenuate the electrical output of the tape recorder (Ampex, Model 601) used to present the tape recorded material. The output from the speech audiometer drove a single TDH-39 earphone housed in a MX 41/AR cushion.

Calibration checks of the pure-tone and speech audiometric system were made prior to and after the completion of the experiment. Appendix C details the calibration procedures and findings for the speech audiometric system.

Testing Procedures

Normal hearing bilaterally was first ascertained for each subject prior to the experiment through pure-tone air-conduction threshold testing for the octave frequencies from 250-8000 Hz. All pure-tone thresholds were determined by the Hughson-Westlake technique as described by Carhart and Jerger (1959).

Speech reception thresholds were then obtained bilaterally with tape-recorded spondee word lists, recorded by the same talker (William F. Rintelmann) who recorded the CNC monosyllables. The spondees were the same words used in CID Auditory Test W-1 (Hirsh et. al., 1952). Each subject was first familiarized with the spondee test vocabulary in a manner previously described by Tillman and Jerger (1959).

SRT's were then established in the following manner: The words were initially presented at a 20 dB HL by earphones. Two words were presented at this level and if both words were repeated correctly the level of the signal was attenuated 10 dB. This was continued until the subject missed both words. The level of the signal was then increased 10 dB and attenuated now in 2 dB steps. The criterion for starting was that five out of six words must be correctly repeated. If they were, the descent was continued. If not, the examiner increased the level by 10 dB and began again. The 2 dB descent, with presenting two words at each level, was continued until the subject missed five out of six words. The speech reception threshold was defined as the lowest level where the subject received both words correctly minus 1 dB for those words responded to correctly thereafter. Since the speech audiometric attenuator was calibrated in 2 dB steps, for all odd-integer spondee thresholds, the SRT was increased by 1 dB.

Only the better ear, as determined by the SRT and the pure-tone threshold, served as the test ear.

Each subject then listened to all five speech conditions as recorded through one of the nine hearing aids. The speech stimuli were presented at a 50 dB sensation level re the subject's SRT for the test ear. Since the group mean SRT was 1.6 dB HL, the average level for presenting the speech material was equal to a normal conversational speech level (71.6 dB SPL). Each subject responded to the speech material by writing his or her responses to each test word.

To avoid fatigue all subjects were given a five minute rest period between the second and third list of recorded material.

All word responses were graded by one observer; thus, any bias in the acceptance of orthographic errors was systematic.

Using the above procedure 90 normal hearing subjects participated in the experiment. Each subject was randomly assigned to one of the nine hearing aids; thus, 10 subjects responded to the material recorded through each hearing aid. The order of presentation of the stimulus material (five listening conditions) was counterbalanced for each hearing aid thereby reducing the possibility of order effects.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter has been divided into three sections. The first section contains the data obtained from the first investigation, and a discussion of its significance. This study compared the HAIC Standard Method for determining and reporting hearing aid characteristics versus a new method. The second section contains the data from the second investigation and a discussion of its significance. This experiment sought to evaluate five stimulus conditions, using CNC monosyllabic words, in an effort to find the best stimulus condition(s) for use in future hearing aid evaluations. The final section concerns the clinical implications of both investigations.

Hearing Aid Response Characteristics

The following four specific questions were asked regarding a comparison between the HAIC Method and the new method for determining and expressing hearing aid performance characteristics:

1. Do both methods yield comparable gain values?
2. Do both methods yield comparable MPO values?
3. Do both methods yield comparable frequency ranges?

4. Do both methods yield comparable response curves?

In this section each of the above questions is answered and discussed.

Gain

Recall that the primary difference between the HAIC Method and the new method for determining gain dealt with input intensity level and volume control adjustment. The HAIC procedure required that each instrument be adjusted for full-on volume control and use a 50 dB SPL input, whereas the new method used a 70 dB SPL input and varied the volume control from just-on to full-on in 10 dB steps. Further, the new method selected a gain versus frequency response curve which allowed for a reserve linear gain of 10 dB.

Table 2 shows, for all eighteen hearing aids, a comparison of the three frequency (500, 1000 and 2000 Hz) average gain obtained with both methods. In addition, the difference in gain between the two methods is shown for each hearing aid. The hearing aids have also been divided into the three original gain categories (mild, moderate and high) as determined from the HAIC characteristics.

Inspection of this table reveals that for each hearing aid the average gain values obtained with the HAIC procedure were substantially greater than the average gain values obtained with the new method. It can also be seen that the rank ordering of hearing aids, by gain categories, is not maintained with the new method.

Table 3 shows for each gain category and the total sample, the mean differences, standard deviations (SDs) and the range of

Table 2. Comparison of gain values obtained with HAIC Method for determining gain and the new method for determining gain. The difference in gain between the two methods for each hearing aid is also shown.

Hearing Aid	HAIC Gain in dB*	New Method Gain in dB	Difference in dB: HAIC - New Method
Mild Gain Group			
Oticon UX	40	18	22
Zenith Westwood B	35	11	24
Siemens 380	37	18	19
Zenith Moderator A	37	25	12
Radioear 1000	40	24	16
Sonotone 37	40	18	22
Moderate Gain Group			
Beltone Overture YY	42	19	23
Beltone Overture R	44	25	19
Audiotone A-19	45	22	23
Audiotone A-20	46	18	28
Beltone Overture Y	49	22	27
Zenith Newport	49	21	28
High Gain Group			
Siemens 382	50	23	27
Sonotone 77	50	36	14
Siemens 383	50	23	27
Audiotone A 21 II	51	38	13
Norelco 6730	51	36	15
Radioear 990	53	36	17

*The HAIC values were obtained on each hearing aid at Michigan State University Audiology Research Laboratory and do not represent manufacturers' published HAIC specifications.

Table 3. Mean differences, standards deviations and range of differences in dB between the HAIC Method and the new method for determining gain. Values are given by the three original gain categories and for the total sample of eighteen hearing aids.

Gain Grouping	Mean Difference	Standard Deviation	Range of Gain Differences
Mild	19.16	4.48	12-14
Moderate	24.66	3.61	19-28
High	18.83	6.46	13-27
Total Sample	20.88	5.44	13-28

differences between the HAIC Method and the new method for determining average gain. This table indicates that the mean differences, SDs and the range of gain differences are similar for all three gain groups. Also, the mean difference between both methods varies from 19 to 25 dB. Differences between the two methods for the total sample were found to be statistically significant ($t= 16.31$; $df= 17$; $p\ 0.01 = 2.567$).

In comparing the results from Tables 2 and 3, it is obvious that a constant correction factor may not be applied to the HAIC gain values in order to derive gain characteristics according to the new method. Therefore, it appears that the two measurement procedures for gain do not yield directly comparable results. Thus, the average gain obtained by the HAIC Method cannot be corrected to accurately predict the average gain of the new method.

The differences in average gain found between the two methods can perhaps account, at least partially, for the inability to achieve expected gain often encountered in routine hearing aid evaluations. To explain, a 50 dB HAIC "average" gain hearing aid will not improve a 50 dB HL SRT to 0 dB HL.

Thus, it is thought that the new method for measuring and reporting hearing aid gain characteristics gives the audiologist a more accurate picture of how a particular hearing aid will operate on the hearing impaired individual with normal input intensities for speech. The new method also reports the gain for 500, 1000 and 2000 Hz independently (Appendix D). This information would be helpful to the audiologist, especially for hearing aid evaluations on hypoacusic subjects with sloping audiograms.

Maximum Power Output

Several differences exist between the HAIC Standard Method and the new method for determining and reporting maximum power output. The HAIC procedure requires the hearing aid to be adjusted for full-on volume control and the input intensities are increased in 10 dB steps from the basic input of 50 dB SPL. At each input level a frequency response curve is obtained through a wide frequency range. When the output does not remain linear with respect to the input, the discrete frequencies 500, 1000 and 2000 Hz are averaged and reported as the saturation output level in dB SPL.

In contrast, by the new method, each hearing aid's volume control is first carefully adjusted for it's "ideal" gain versus frequency response curve. Input intensities are then increased in 10 dB increments from the basic input level of 70 dB SPL. At each input level a frequency response curve is obtained through a wide frequency range. When the output does not remain linear with respect to the input, the hearing aid is considered to have reached it's saturation output level. The discrete speech frequencies (500, 1000 and 2000 Hz) are then averaged and reported as the average maximum power output. In addition, the new method also reports the MPO for 500, 1000 and 2000 Hz independently, and the frequency and intensity of the peak maximum power output in dB SPL.

Table 4 shows a comparison between the average MPO values

Table 4. Comparison of maximum power output (MPO) obtained with the HAIC Method and the new method. Values represent the three frequency average of 500, 1000 and 2000 Hz. The difference between the two methods is given for each hearing aid. Also, the peak frequency MPO obtained with the new method is shown.

Hearing Aid	HAIC MPO in dB SPL	New Method Average MPO in dB SPL	Difference in dB: HAIC - New Method	New Method	
				Peak Frequency	MPO in dB SPL
Mild Gain Group					
Oticon UX	112	108	4	800 Hz	112
Zenith Westwood	103	96	7	2500	103
Siemens 380	114	110	4	2000	121
Zenith Moderator A	107	110	-3	1000	119
Radioear 1000	118	116	2	900	121
Sonotone	114	113	1	1200	122
Moderate Gain Group					
Beltone Overture YY	114	104	10	2500	125
Beltone Overture R	119	119	0	900	125
Audiotone A-19	113	108	5	200	120
Audiotone A-20	121	122	-1	900	127
Beltone Overture Y	115	111	4	900	119
Zenith Newport	123	113	10	1000	121
High Gain Group					
Siemens 382	121	111	10	3500	116
Sonotone 77	124	122	2	1000	124
Siemens 383	115	115	0	3500	123
Audiotone A 21 II	127	124	3	1000	129
Norelco 6730	128	123	5	800	131
Radioear 990	129	127	2	900	133

obtained with the HAIC Method and the new method for each of the eighteen hearing aids. The difference in dB between both methods is also indicated. Inspection of these data shows that both methods yielded results which were within a 10 dB range of one another, with the average difference between the two methods being 3.6 dB. It is also apparent that with all but two hearing aids, the HAIC Method resulted in higher MPO values. One can also note that with the higher gain instruments, the MPO levels were higher. However, this finding is to be expected.

Table 4 also shows a comparison of the peak frequency MPO by the HAIC (average) MPO with the new method average MPO. It is of interest to note that in all instances, except two, the peak MPO intensities obtained with the new method are equal to or exceed the HAIC maximum power output values. Also, as expected, in every instance the peak MPO intensity was considerably higher than the new method average MPO. In fact, the average difference between the two was 8 dB with differences as great as 21 dB.

Considering the data from Table 4, and the measurement procedures for both methods, the following conclusions appear warranted. First, although both methods do not yield identical average MPO values, they are very similar, with the new method tending to give values approximately 4 dB lower. Secondly, and most importantly, peak MPO intensities are often considerably higher than the average MPO values.

The new method also reports independently the MPO values for 500, 1000 and 2000 Hz. This data has not been included in this section, but may be seen for each hearing aid in Appendix D.

Frequency Range

The procedure of the new method for determining frequency range differs from that used by HAIC. The HAIC procedure uses the basic frequency response curve (60 dB SPL input at 1000 Hz with 100 dB SPL output) and then plots the average of 500, 1000 and 2000 Hz on the 1000 Hz ordinate; 15 dB below this point a line is drawn parallel to the frequency axis. The intersection of this line with the skirts of the frequency response curve marks the high and low frequency limits.

The new procedure uses the "ideal" gain versus frequency response curve, plots the average gain of 500, 1000 and 2000 Hz on the 1000 Hz ordinate; 10 dB below this point a line is drawn parallel to the frequency axis. In both methods the results are expressed by a high and low frequency cut-off and not in terms of frequency range in Hertz.

Table 5 shows by gain groups the high and low cut-off frequencies obtained with both methods for all eighteen hearing aids. The difference in Hertz between the two methods is also shown. Inspection of this table shows that irrespective of gain grouping the new method tends to raise the low frequency values while the high frequency cut-offs remain the same. The average difference between both methods for determining the low frequency cut-off was found to be 91 Hz. This is understandable since by the new method one does not mark the frequency cut-offs as far down on the response curve skirts. Hence, the low frequency cut-off is affected by the new method.

Table 5. High and low cut-off frequencies obtained with HAIC Method and the new method for determining frequency range. The difference in Hertz between both methods is also shown.

Hearing Aid	HAIC Low Frequency*	New Method Low Frequency	Difference in Hz	HAIC High Frequency	New Method High Frequency	Difference in Hz
Mild Gain Group						
Oticon UX	180	150	30	3800	3800	0
Zenith Westwood B	500	550	-50	4500	4500	0
Siemens 380	480	600	-120	5000	5000	0
Zenith Moderator A	450	540	-90	4300	4300	0
Radioear 1000	190	340	-150	4800	4600	200
Sonotone 37	450	550	-100	4500	4500	0
Moderate Gain Group						
Beltone Overture YY	380	550	-170	4200	4200	0
Beltone Overture R	350	450	-100	4300	4300	0
Audiotone A-19	460	580	-120	3600	3600	0
Audiotone A-20	280	450	-170	4900	4600	300
Beltone Overture Y	380	380	0	4200	4200	0
Zenith Newport	480	650	-170	4400	4400	0
High Gain Group						
Siemens 382	400	500	-100	4900	4900	0
Sonotone 77	320	400	-80	3800	3800	0
Siemens 383	390	380	10	4600	4600	0
Audiotone A 21 II	450	550	-100	5200	4500	700
Norelco 6730	400	450	-50	4500	4500	0
Radioear 990	370	480	-110	4800	4800	0

*HAIC values were obtained for each aid at Michigan State University Audiology Research Laboratory and do not represent manufacturers' published HAIC specification.

However, both methods result in similar high frequency cut-off values. The reason for this is that the slope of the high frequency end of the response curve is so steep that a small (approximately 5 dB) difference in marking the high frequency skirt does not alter the high frequency cut-off point. An example is illustrated in Figure 12.

In considering this data it appears that both methods tend to give similar frequency range characteristics. However, the new method tends to shift upward (higher) the low frequency cut-off by about 100 Hz, thus slightly decreasing the absolute width of the frequency range.

Frequency Response Curve

Several differences exist between the new method and the HAIC Method for determining the frequency response curve of a hearing aid. The HAIC Method uses an input intensity of 60 dB SPL and adjusts the volume control for a specific gain of 40 dB at 1000 Hz. With this adjustment the frequency response curve is then obtained through a wide frequency range. The new method uses a 70 dB SPL input intensity and a gain versus frequency response curve is selected which allows for an additional 10 dB increase in gain so that the frequency response curve remains linear with respect to the lower curves.

The frequency response curves obtained with both methods, for all hearing aids, were evaluated by superimposing one another on an illuminated table. The results of this procedure showed that both

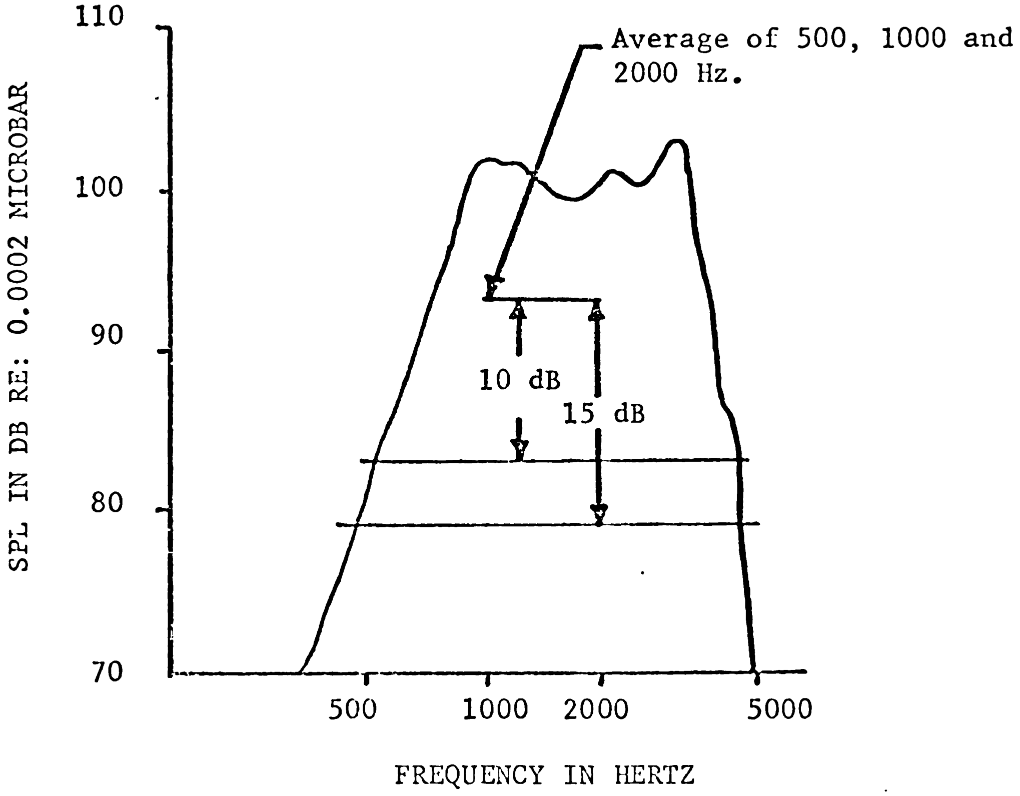


Figure 12. Illustration of frequency range as measured by the HAIC Method and the new method. The frequency response curves obtained from both methods have been superimposed for this illustration.

methods gave similar frequency response curves. Figure 13 shows a comparison of the frequency response curves obtained with both procedures for the hearing aid exhibiting the smallest difference and the hearing aid with the largest difference. The deviation between the two methods when comparing frequency response curves for the remaining hearing aids fell between these two extremes.

Speech Materials For Hearing Aid Evaluations

In the second study the investigator sought to evaluate the performance of normal hearing subjects on five stimulus conditions (inquiet, signal-to-noise + 10 dB, signal-to-noise 0, signal-to-competing message + 10 dB, and signal-to-competing message 0) recorded through nine different hearing aids. The recordings were made with each hearing aid adjusted for it's "ideal" frequency response curve. Each subject responded to all five conditions for one hearing aid at a 50 dB sensation level above his speech reception threshold. A total of ten subjects listened to the stimulus materials recorded through each of the nine hearing aids.

The questions asked at the start of this experiment were:

1. Can differences be shown between hearing aids when monosyllabic words (N.U. Auditory Test No. 6) are recorded through them under a variety of listening conditions, and played to normal hearing subjects at the same sensation level?

2. Which listening condition(s) is best for showing differences between hearing aids using normal listeners?

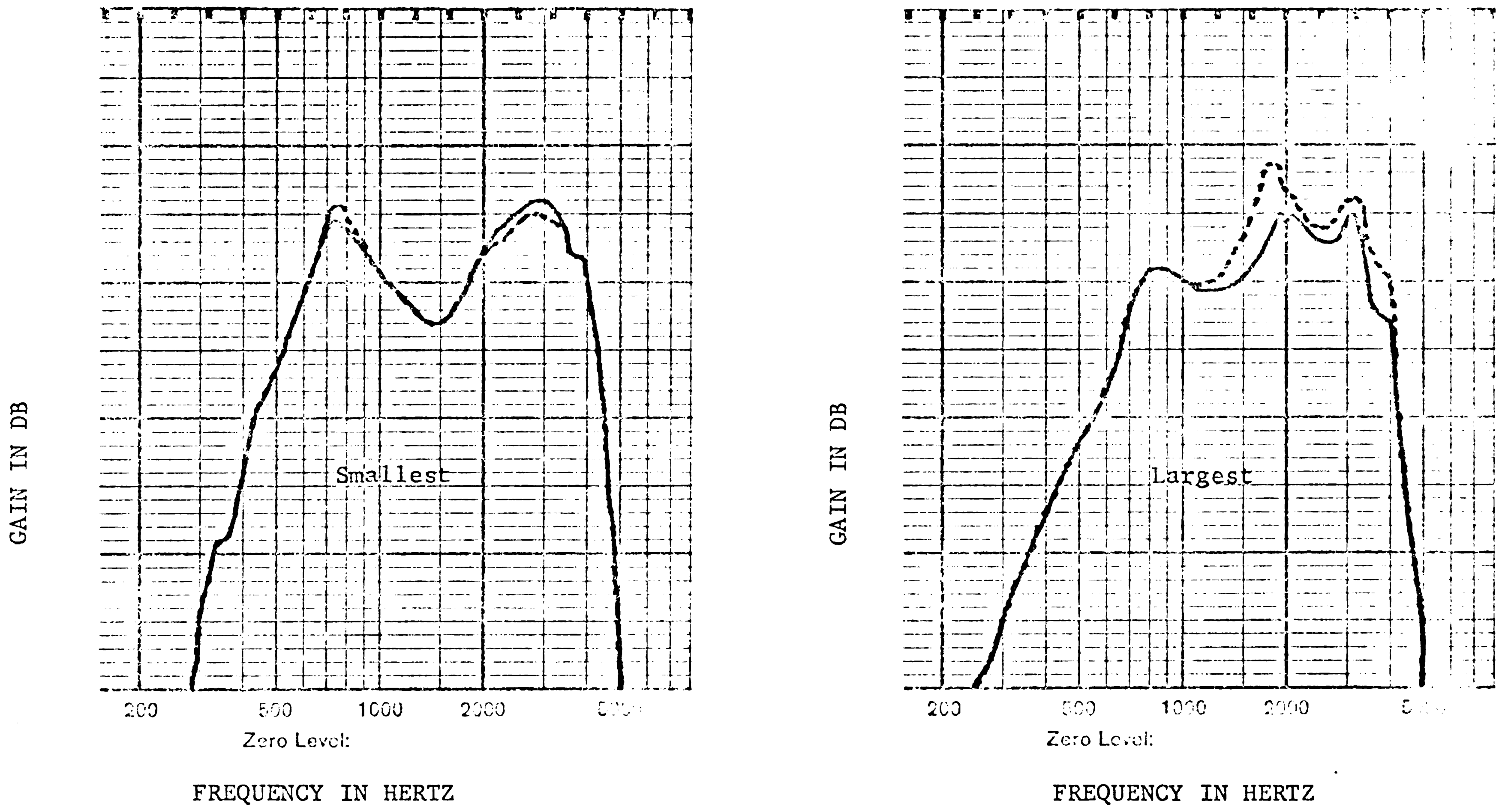


Figure 13. Comparison of the frequency response curves obtained with both procedures for the hearing aid exhibiting the smallest difference and the hearing aid with the largest difference. The dashed frequency response curve represents the new procedure.

3. Can differences be shown between hearing aids with different frequency response characteristics when monosyllabic words (N.U. Auditory Test No. 6) are recorded through them under a variety of listening conditions and played to normal hearing subjects at the same sensation level?

4. Which listening condition(s) is best for normal listeners in showing differences between hearing aids with different frequency response characteristics?

Results of the analysis of variance for the nine hearing aids and five listening conditions are summarized in Table 6. A significant main effect at greater than the 0.0005 level was found for listening conditions (F of 1324.2) and hearing aids (F of 4.9). Also, a significant interaction was found between hearing aids and listening conditions at greater than the 0.0005 level (F of 10.5).

Table 7 shows the mean discrimination scores (in percent correct) for each of the nine hearing aids for all five listening conditions and the mean for each listening condition across all nine hearing aids is also shown. In addition, the standard deviation, and range of scores obtained for each listening condition for all hearing aids is presented. Figure 14 presents a graphic display of the mean discrimination scores for all nine hearing aids under each of the five listening conditions.

Listening Conditions

Inspection of Table 7 and Figure 14 reveals that for all nine hearing aids the in quiet listening condition always gave the highest mean discrimination score. Also, this condition gave the smallest

Table 6. Summary of analysis of variance for hearing aids and listening conditions.

Source of Variance	SS	dF	MS	F ratio	Probability of statistic
WITHIN					
Listening Conditions(A)	218871.4	4	54717.9	1324.2	0.0005
A x Ear(B)	342.1	4	85.5	2.1	0.085
A x Hearing Aid (C)	13823.1	32	432.0	10.5	0.0005
A x B x C	1560.7	32	48.8	1.2	0.238
Within Error	11900.2	288	41.3		
BETWEEN					
A	94.3	1	94.3	0.9	0.338
C	3993.1	8	499.1	4.9	0.0005
B x C	876.8	8	109.6	1.1	0.385
Between Error	7288.6	72	101.2		

Table 7. Mean discrimination scores (in percent correct) for each of nine hearing aids for five listening conditions. Means for each hearing aid across all listening conditions and the means for each listening condition across all hearing aids is also shown. In addition, standard deviations (SDs) for listening conditions are presented.

Hearing Aid	Listening Conditions					
	In Quiet	S/N+10	S/N 0	S/CM+10	S/CM 0	Mean of 5 Conditions
Flat Frequency Response						
1. Radioear 1000	97.2	78.2	49.4	78.8	61.0	72.9
2. Oticon UX Greendot	99.2	71.8	30.6	81.6	62.8	69.2
3. Norelco 6730	97.2	84.6	26.0	80.8	63.8	70.5
Irregular Frequency Response						
4. Radioear 990	98.6	83.6	21.8	76.8	44.6	64.7
5. Beltone Overture R	98.0	76.7	45.0	80.6	64.4	72.9
6. Beltone Overture YY	95.6	78.0	36.2	88.8	56.6	71.0
High Frequency Response						
7. Siemens 383	98.2	83.0	33.2	83.4	62.6	72.1
8. Siemens 382	96.8	79.6	36.4	74.4	36.0	64.6
9. Sonotone 37	97.6	83.8	25.6	80.6	64.6	70.4
Mean of Nine Aids	97.4	79.9	33.8	80.6	57.4	
SD	1.0	4.2	9.1	4.0	10.2	
Range of Scores	3.6	12.8	27.6	14.4	28.6	

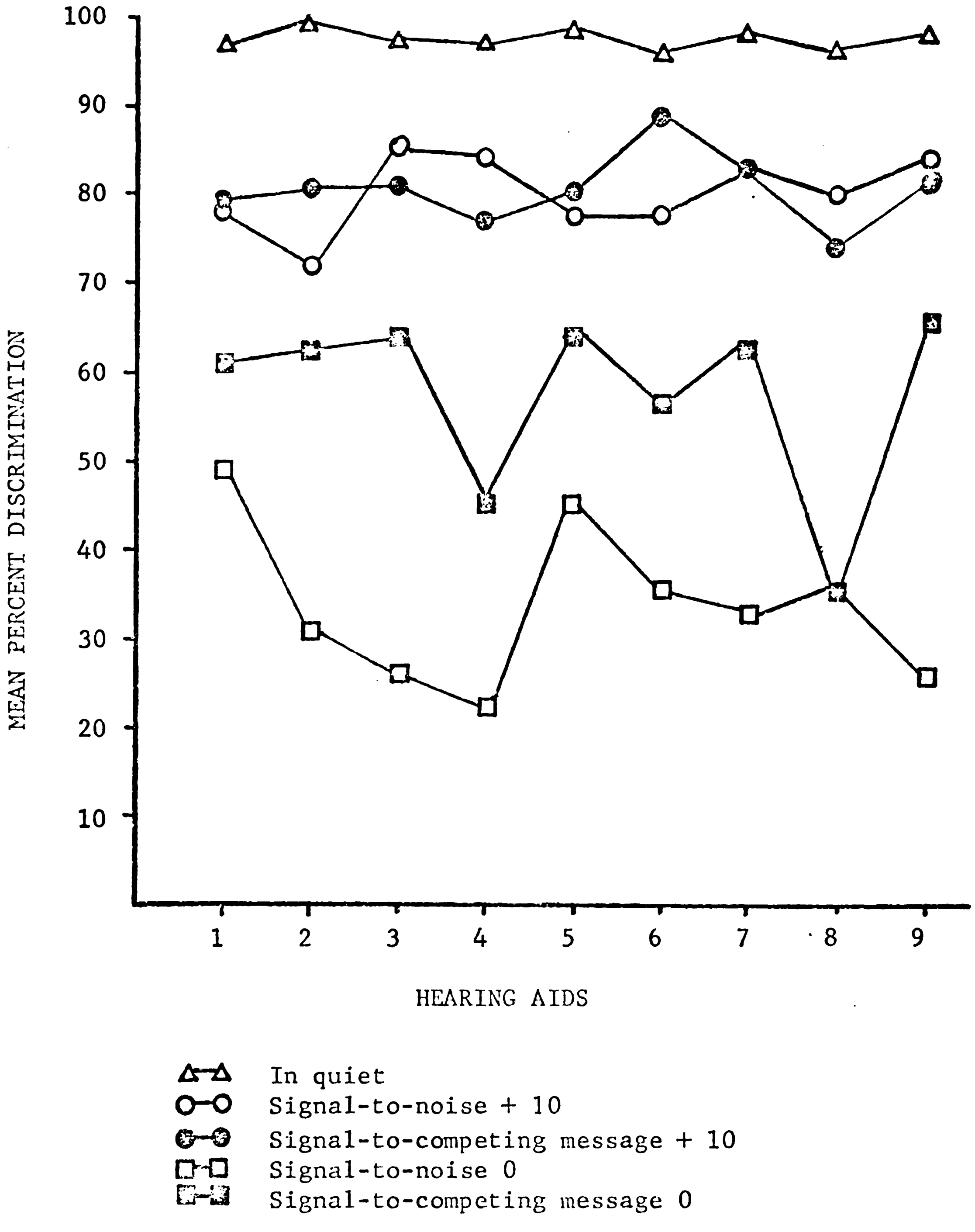


Figure 14. Mean discrimination scores from each hearing aid for all five listening conditions.

standard deviation (1.0%), and range of scores (3.6%).

In contrast, for all nine hearing aids, the less favorable signal-to-noise and signal-to-competing message listening conditions always gave lower discrimination scores when compared to the three more favorable listening conditions. These two listening conditions also have the largest standard deviations (9.1% and 10.2%) and range of scores (27.6% and 28.6%).

When comparing the + 10 signal-to-competing message and + 10 signal-to-noise conditions across hearing aids, both conditions gave similar means (80.6% and 79.9%), standard deviations (4.0% and 4.2%) and range of scores (14.4% and 12.8%). Inspection of Table 7 and Figure 14 shows that for four hearing aids the signal-to-noise conditions gave the highest discrimination scores; with three aids the signal-to-competing message resulted in the best scores and for two aids the two conditions were equal in difficulty. Hence, for a sample of several hearing aids, both broad band white noise and the competing message appear to be essentially equal in difficulty at a + 10 signal-to-noise ratio. However, when comparing the 0 signal-to-competing message listening condition to the 0 signal-to-noise listening condition across hearing aids both conditions did not give similar means (57.4% and 33.8%). With eight hearing aids the signal-to-noise listening condition gave the lowest discrimination scores, and for the other (ninth) hearing aid both scores were equal. Thus, it appears that at less favorable signal-to-noise and signal-to-competing message listening situations the two secondary signals have differential effects upon speech intelligibility, with the noise producing the poorest scores. One can also readily observe that as the listening conditions become more difficult, the variability in normal listener performance found between hearing aids is substantially increased.

Hearing Aids

When considering individual hearing aids across all five listening conditions Table 7 shows that hearing aids one and five achieved the highest and identical discrimination scores (72.9%), while hearing aids four and eight received the lowest scores (64.7% and 64.6% respectively). The five remaining hearing aids achieved very similar scores, within a small range of 2.9%. The range for the nine hearing aids across all conditions was also small being only 8.3%. It is also apparent from Table 7 that both hearing aids (one and five) producing the highest scores and both hearing aids (four and eight) giving the lowest scores across all conditions are not from the same frequency response groups.

Listening Conditions By Frequency Response Grouping

Results of the analysis of variance between hearing aids grouped by frequency response and listening conditions are summarized in Table 8. This analysis shows a significant main effect beyond the 0.0005 level (F 723.5) for listening conditions. A significant interaction between frequency response and listening conditions was also found ($P < 0.01$, F 2.5). However, a significant main effect was not

Table 8. Summary of analysis of variance for frequency response and listening conditions.

Source of Variance	SS	dF	MS	F ratio	Probability of Statistic
WITHIN					
Listening Conditions(A)	218871.4	4	54717.9	723.5	0.0005
Frequency Response (B) x A	1516.1	8	189.5	2.5	0.012
Within Error	26318.1	348	75.6		
BETWEEN					
B	262.6	2	131.3	1.0	0.383
Between Error	11782.3	87	135.4		

found for hearing aids grouped by frequency response.

Table 9 presents the means for the three frequency response groupings (flat, irregular and high frequency) for all five listening conditions. The means for all listening conditions across the three frequency response groups and the means for each frequency response group across listening conditions are also given. Figure 15 displays the mean discrimination scores achieved by each frequency response group for all five listening conditions.

Inspection of Table 9 and Figure 15 reveals that with one exception the three frequency response groups resulted in highly similar discrimination scores at each of the five listening conditions. However, for the 0 signal-to-competing message condition the flat frequency response group gave the highest mean discrimination score by approximately 7%. With this one exception it appears that hearing aid frequency response per se did not affect the normal listeners performance under any of the listening tasks.

Discussion

In light of the above findings and in answer to the first experimental question, it appears that with CNC monosyllabic words differences can be shown between hearing aids with normal hearing listeners. However, in this study, the differences that were shown across all listening conditions for each hearing aid were rather small (range 8.3%). Therefore, since differences can be seen the important question appears to be: "What listening condition(s) shows the

Table 9. Mean discrimination scores (in percent correct) by frequency response groupings (flat, irregular and high frequency) for the five listening conditions. The mean for each of the three groups across all five conditions is also shown.

Frequency Response Groups	In Quiet	S/N + 10	S/N 0	S/CM + 10	S/CM 0	Mean of Five Conditions
Flat	97.9	78.2	35.3	80.4	62.5	70.9
Irregular	96.8	79.4	34.3	82.1	55.2	69.6
High	97.5	82.1	31.7	79.5	54.4	69.1

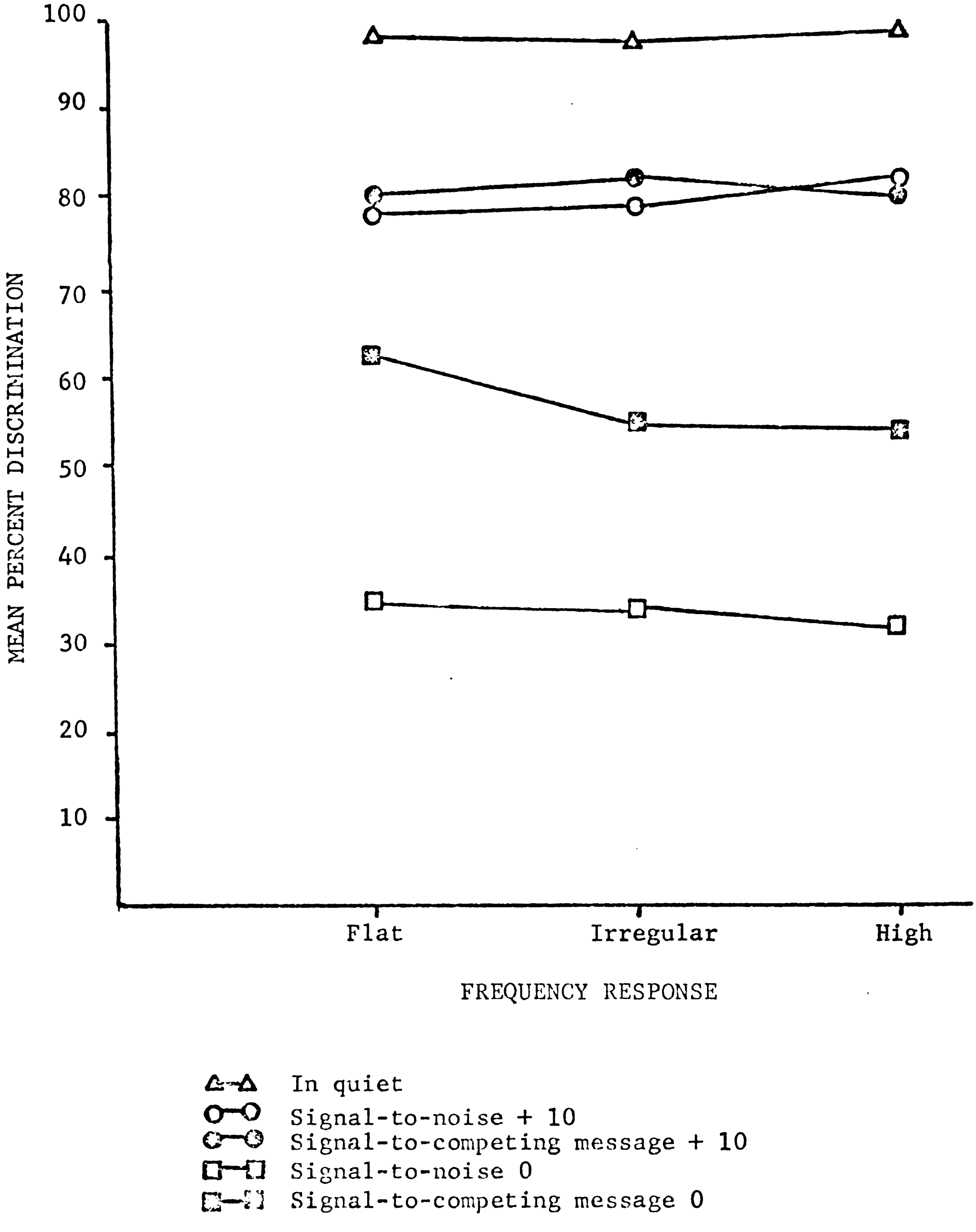


Figure 15. Mean discrimination scores for the three frequency response groupings for all five listening conditions.

greatest difference(s) between hearing aids?"

It seems reasonable to assume that the listening condition which exhibits the largest standard deviation in discrimination scores across hearing aids would be the most likely condition for showing differences between hearing aids. As was seen in Table 7 and Figure 14, the quiet listening condition gave almost identical speech discrimination scores for all hearing aids. This was exhibited by the small standard deviation (1.0%) and the narrow range of scores (3.6%). It was also found that the less favorable, (0), signal-to-competing message and signal-to-noise conditions gave the largest standard deviations (10.2% and 9.1%) and range of speech discrimination scores (28.6% and 23.9%). Thus, it is felt that these listening conditions tax the listener and hearing aid the most and, therefore, are best for showing differences between hearing aids.

From Table 7 it was also observed that the more favorable (+ 10) signal-to-noise and signal-to-competing message ratios gave similar means across hearing aids (79.9% and 80.6% respectively). However, the same close agreement between means (38.8% and 57.4%) across hearing aids was not found for the less favorable (0) signal-to-noise and signal-to-competing message conditions. A possible explanation for this discrepancy is that at the more favorable conditions (+ 10) neither of the competing signals are sufficiently interfering with the primary message so as to demonstrate which is a more effective competing signal. However, under the less favorable listening situations, the competing signals are sufficiently high so as to interfere substantially with the speech signal. The higher scores found for the signal-to-competing message condition may be due to the small fluctuations in intensity or the short pauses in the secondary signal; whereas, the broad band white noise has a flat continuous spectrum.

A finding similar to that reported above was obtained by Carhart et al. (1968) when comparing the masking effect of an unmodulated white noise with a white noise which was modulated four times per second to a "depth" of 10 dB with a 50% duty cycle. Spondee thresholds were improved by approximately 4 dB with the modulated masker. Related to their findings the authors stated:

> . . . it is reasonable to expect that the presence of modulation in a masker, whether it be artificially induced or be the normal modulation of connected speech, should furnish acoustic "windows," which the listener utilizes to advantage (Carhart, Tillman and Greetis, 1968, p. 695).

Thus, in the present investigation the better speech discrimination scores obtained by the normal listener for the 0 signal-to-competing message listening condition are perhaps attributable to what Carhart et al. describe as the "window effect."

The important finding appears to be that all hearing aids are not equally affected by the same type of secondary signal (noise or competing message). If they were equally affected, all hearing aids would give similar depressions in speech discrimination scores, since without a secondary signal (quiet condition) they appear very similar.

In view of these findings, hearing aid evaluations employing monosyllabic speech discrimination material in "noise-free" environments or under favorable listening conditions, may not accurately assess how the instrument will operate under the less favorable signal-to-noise condition in which we live.

These findings appear to be in direct conflict with the results of Shore et al. (1960). The study found no significant differences attributable to hearing aids for speech discrimination in noise at a signal-to-noise ratio of zero dB. They also found larger differences between hearing aids for discrimination in quiet. However, in their study they used only four hearing aids, each with two tone control settings. In an appendix to the study the authors remarked that the possibility remained that since they only used four good hearing aids, the restricted sample eliminated any bad aids.

The interaction found between hearing aids and listening conditions for the favorable (+ 10) signal-to-noise and signal-to-competing message ratio's are not surprising since both listening conditions gave approximately the same results. Also, when comparing the less favorable (0) signal-to-noise and signal-to-competing message conditions (Figure 14) an interaction was found for only one of the nine hearing aids.

The data from this experiment also tends to indicate that when hearing aids are grouped by frequency response (flat, irregular and high frequency) and monosyllabic speech materials are presented under five different listening conditions, differences in speech discrimination scores among normal listeners are typically not seen due to frequency response. The results also showed that each listening condition equally affected the three frequency response groups (See Figure 15). This would tend to suggest that differences seen between individual hearing aids are due to something other than frequency response characteristics.

It is felt that at the present time these results should be interpreted with caution, however, since only the scores for three hearing aids were averaged for each frequency response group and there was some variability within groups under the least favorable (0) signal-to-noise and signal-to-competing message listening condition. Thus, perhaps a larger sample of hearing aids under each category are necessary before group differences between types of frequency response can be shown. The above findings await further verification.

Other acoustical parameters of hearing aids such as harmonic distortion and rise and decay times should be investigated. In this experiment a retrospective comparison between the average harmonic distortion (500, 700 and 900 Hz) measured according to A.S.A. S3.3-1960 and the discrimination scores obtained under each listening condition and across all listening conditions was attempted. No trends were noted. In fact, under the input and gain conditions employed the average distortion for all nine hearing aids was small (2.9%) and within a range of 3.9%.

Clinical Implications

The results from the first study have shown that large differences exist between the HAIC Method versus the new method for determining gain. Both methods give similar results for average maximum power output; however, the new method also indicates a hearing aid's peak maximum power output intensity which may be considerably higher than the average. Similar frequency ranges are obtained with both methods, with the new method tending to increase (make higher) the low frequency cut-off by approximately 100 Hz. Both methods yield very similar frequency response curves.

The rationale was developed earlier that the new method attempts to measure a hearing aid's acoustical parameter in a manner similar to how the hearing impaired patient wears the instrument. The important finding from this study appears to be the discrepancy found between gain with the two methods.

With the traditional clinical hearing aid evaluation procedure several hearing aids are generally selected for trial whose characteristics are dependent upon the results from the hearing evaluation test battery. These hearing aids are individually tried by the patient. The volume control of each instrument is first adjusted to a level where the patient "feels" it is most comfortable. Generally stock ear molds are used with this procedure which often do not form tight seals of the external ear canal, causing feedback, which limits adjustment of the instrument for higher gain. Once the hearing aid is adjusted, speech discrimination material is introduced into the sound-field at a level of normal conversational speech (approximately 70 dB SPL).

With this procedure each trial hearing aid is evaluated. The instrument giving the best speech discrimination score is usually recommended for purchase. Critiques of this procedure (Shore, Bilger and Hirsh, 1960; Zerlin, 1962; and Jerger, Malmquist and Speaks, 1966) generally contend that it is not sufficiently reliable for showing differences between hearing aids. This criticism is understandable since many variables are left uncontrolled in the typical hearing aid evaluation.

The second study demonstrated that by attempting to control all variables except frequency response and associated hearing aid distortion, differences could be observed between instruments. This experiment also showed that monosyllabic speech materials presented in quiet were not as effective in demonstrating differences between hearing aids. However, the same material in a difficult signal-to-noise or signal-to-competing message context showed wide differences between the same group of aids.

In view of the results from both studies it appears that accurate and reliable clinical hearing aid evaluations may be performed with the use of tape recorded materials. This would be accomplished by first ascertaining the acoustical characteristics of hearing aids according to the new procedure advocated in the present investigation. Speech discrimination material in an unfavorable signal-to-noise or signal-to-competing message context would then be recorded through each hearing aid while adjusted for it's "ideal" frequency response curve as described in chapter three.

These recordings would be classified according to the frequency response and gain characteristics of the instruments. Thus, one tape could contain high frequency emphasis, mild gain instruments etc.

After the initial hearing evaluation is completed, the audiologist would select a tape containing discrimination material recorded through instruments with the generally desired acoustical characteristics. The speech material recorded through each hearing aid would be played to the individual at a level equal to the amount of gain the instrument would deliver. Thus, for a hearing aid with 30 dB of gain the discrimination material would be presented at 80 dB HL. With this procedure each subject could respond to a number of hearing aids, and the hearing aid giving the highest discrimination score would normally be recommended for trial or purchase.

Since this procedure presents all materials through earphones the problem of feedback would be eliminated. Gain would also be held constant. Further, individual hearing aid adjustments would not be necessary thus saving a considerable amount of time, thereby allowing for a larger number of hearing aids to be evaluated.

If a procedure similar to this would be adopted in a large number of clinics, it is conceivable that hearing aid manufacturers could furnish clinics with individual recordings of their instruments rather than several actual hearing aids. This has obvious advantages over a clinic "library" of hearing aids for both the manufacturer and the audiologist.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Two procedures for hearing aid evaluations are currently being employed in the majority of hearing clinics. A traditional procedure seeks to evaluate individual hearing aids with the hearing impaired subject. Measures such as aided speech reception thresholds and aided speech discrimination scores are obtained in an effort to recommend a specific instrument for purchase or trial.

The other procedure is founded on the basis that reliable differences cannot be shown between hearing aids with the usual measures in speech audiometry. Using this procedure, evaluations of specific hearing aids are completely eliminated and no particular hearing aid is recommended. Instead, the hearing impaired patient is given recommendations as to the type of hearing aid which should be purchased.

With both of these procedures the audiologist must rely on the manufacturer's HAIC specifications for accurately representing the acoustical characteristics of the different hearing aids.

This thesis consisted of two investigations. The first sought to evaluate the HAIC procedure for measuring and reporting the acoustical characteristics of hearing aids, as opposed to a new procedure developed by this writer. The argument was made that the HAIC procedure does not accurately represent the performance of a hearing aid under normal listening conditions. The new method for evaluating and reporting hearing aid characteristics was designed to overcome the basic criticism of the HAIC procedure. The results of both methods were compared on the following specific acoustical parameters: (1) gain, (2) maximum power output, (3) frequency range, and (4) frequency response curve.

The second investigation was performed in order to determine if differences could be observed between hearing aids, using CNC monosyllabic speech discrimination materials. Normal hearing subjects responded to these speech materials after they were recorded under five different listening conditions through nine different instruments. The listening conditions employed were: (1) CNCs in quiet, (2) + 10 signal-to-noise ratio, (3) + 10 signal-to-competing message ratio, (4) 0 signal-to-noise ratio, and (5) 0 signal-to-competing message ratio. The hearing aids employed were selected from three types of frequency response groups: flat, irregular and high frequency emphasis. All subjects listened to the recorded materials at the same sensation level. It was reasoned that if differences were seen between hearing aids, these differences could be attributed to the hearing aid's frequency response and associated acoustical distortion.

Conclusions

Several conclusions appear warranted from the first investigation:

1. The HAIC procedure for measuring and describing the acoustical parameters of hearing aids does not give an accurate description of how these instruments function under normal listening conditions.

2. When comparing the HAIC Method and the new method for determining gain, the HAIC Method tends to over-estimate actual usable gain by approximately 21 dB; however, because considerable variability exists between instruments, a constant correction factor cannot be subtracted from the HAIC gain in order to predict the average gain which would be derived by the new method.

3. Both methods tend to give approximately the same average (500, 1000 and 2000 Hz) maximum power output; however, the peak MPO can be considerably higher than the average.

4. The frequency range found with both methods are similar; however, the new method tends to raise the low frequency cut-off by

approximately 100 Hz, thereby reducing slightly the reported frequency range.

5. Both methods give identical frequency response curves.

The following conclusions appear warranted from the second experiment employing normal listeners:

1. Differences between hearing aids cannot be adequately demonstrated when using CNC monosyllabic speech discrimination material in a quiet listening condition.

2. When noise or a competing message was simultaneously presented with the primary speech signal at a + 10 signal to noise (competing message) ratio, speech discrimination scores of normal listeners were essentially equally depressed with both secondary signals. However, this condition did not demonstrate differences between hearing aids.

3. In order to show differences between hearing aids, the discrimination material must be in a difficult listening situation. The 0 signal-to-noise and 0 signal-to-competing message listening conditions showed the

largest differences between hearing aids.

4. In general, when the hearing aids were grouped by frequency response, (flat, irregular and high frequency emphasis) differences were not seen between groupings for any of the five listening conditions.

Recommendations

In the present investigation differences observed between hearing aids were obtained with normal hearing listeners. It is clinically important to determine whether these or other differences can be observed with hypoacusic subjects.

The second experiment also revealed that the undistorted monosyllabic words when presented in quiet were incapable of showing differences between hearing aids. It would be of interest to see if these same findings hold true for hypoacusic subjects under conditions of the present study.

When the hearing aids in the second investigation were grouped by frequency response, differences were not observed. It was suggested that the small sample of hearing aids in each group accounted for this finding. However, this assumption needs to be verified.

Since differences can exist between competing messages employed as secondary signals, future work should consider the use of modulated white noise. The employment of this type of secondary signal would allow for exact duplication of stimuli used in different research and clinical settings.

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APPENDICES

APPENDIX A

HAIC STANDARD METHOD OF EXPRESSING HEARING AID PERFORMANCE

HAIC Standard

1. General:

The purpose of this Standard is to provide a uniform method of numerically and graphically expressing certain fundamental performance characteristics of hearing aids in a simple manner, so that those using such data can be assured of its meaning.

2. Method of Measurement:

All quantities to be specified in this Standard shall be based on measurements made in accordance with American Standard S3.3, entitled "American Standard Methods for Measurement of the Electro-Acoustical Characteristics of Hearing Aids," or a succeeding Standard approved by the American Standards Assn. The above Standard is published by the American Standards Assn., Inc., 10 East 40 St., New York 16, N.Y.

3. Definitions:

Simple numerical expression of the terms gain, output and frequency range shall be defined as follows:

3.1 Gain

The term "gain" as applied to a hearing aid shall mean the average of the 500, 1000 and 2000 cps values of the full-on acoustic gain, as defined in Section 2.3, and as measured in accordance with Section 5.7, of American Standard S3.3. Unit: decibels.

3.2 Output

The term "output" shall mean the average of the 500, 1000 and 2000 cps values of the saturation sound-pressure level, as defined in Section 2.12, and as measured in accordance with Section 5.6, of American Standard S3.3. Unit: decibels re .0002 microbars.

3.3 Frequency Range

3.3.1 The frequency range of a hearing aid shall be expressed by two numbers, one representing the low-frequency limit of amplification in cps, and the other the high-frequency limit of amplification in cps, both as defined below. (Note: The frequency range of a hearing aid shall not be expressed as the number of cycles per second between the low and high-frequency limits, because of the distorted impression this method can give.)

3.3.2 Determination of the frequency range shall be made using a basic frequency-response curve as defined in Section 2.11, and as measured per Section 5.5 of American Standard S3.3.

3.3.3 The following procedure shall be employed to determine the lower and upper-frequency limits.

3.3.3.1 Determine the average of the 500, 1000 and 2000 cps ordinates on the frequency-response curve and plot this value on the 1000 cps ordinate.

3.3.3.2 Plot a second point on the 1000 cps ordinate 15 dB below the first point.

3.3.3.3 Through the second point draw a straight line parallel to the frequency axis.

3.3.3.4 The low-frequency limit of the hearing aid is defined as the frequency where this line first intersects the response curve, moving in the direction of decreasing frequency from 1000 cps. (Note: In the event the curve dips below the 15 dB line and returns above it, the second downward crossing of the line may be considered the low-frequency limit provided: (a) that the band width of the dip does not exceed 15 percent of the frequency of the first downward crossing, and (b) that the band width of the following rise above the 15 dB line is 15 perdent or more of the frequency of the first upward crossing. The purpose of this exception is to avoid penalty where a single "notch" of inconsequential effect on the hearing aid's performance may exist.)

3.3.3.5 The high-frequency limit of the hearing aid is defined as the frequency where this line first intersects the response curve, moving in the direction of increasing frequency from 1000 cps. (Note: In the event the curve dips below the 15 dB line and returns above it, the second downward crossing of the line may be considered the high-frequency limit provided: (a) that the band width of the dip does not exceed 15 percent of the frequency of the first downward crossing and (b) that the band width of the following rise above the 15 dB line is 15 percent or more of the frequency of the first upward crossing. The purpose of this exception is to avoid penalty where a single "notch" of inconsequential effect on the hearing aid's performance may exist.)

4. Frequency Response:

A frequency-response curve of the hearing aid shall be known in addition to specifying numerical data. This curve shall be the "basic frequency response" as defined in Section 2.11, and as measured in Section 5.5, of American Standard S3.3. The curve shall be plotted on a grid having a linear decibel ordinate scale and a logarithmic frequency scale. One octave's length on the logarithmic scale shall equal between 13.5 and 15 decibels' length on the decibel scale.

5. Supplementary Information:

At least the following data shall be presented with the corresponding numerical and graphical data:

5.1 Manufacturer's model number.
5.2 External earphone type (if applicable)
5.3 Control settings.
5.4 Nominal battery voltage.
5.5 If applicable, earphone-tubing dimensions L and D, per Figs. 2 or 4 of American Standard S3.3 (For conventional insert earphones, it is assumed that the HA-2 coupler, shown in Fig 3 of A.S.A. S3.3, will be used.)

6. Sampling:

Sampling procedures should be adequate to insure that the published performance data will be, to the best of the manufacturer's knowledge, representative of the average product being offered for sale.

7. Identification:

It is recommended that data presented in conformity with this standard method carry the statement:

"Data are expressed using Standard HAIC method." (Lybarger, 1961, p. 17, p. 33)

APPENDIX B

NORTHWESTERN UNIVERSITY AUDITORY TEST
NUMBER SIX, FORM B, LISTS I-IV

FORM B

List I

burn
lot
sub
home
dime
which
keen
yes
boat
sure
hurl
door
kite
sell
nag
take
fall
week
death
love
tough
gap
moon
choice
king
size
pool
vine
chalk
laud
goose
shout
fat
puff
jar
reach
rag
mode
tip
page
raid
raise
bean
hash
limb
third
jail
knock
whip
met

List II

live
voice
ton
learn
match
chair
deep
pike
room
read (reed)
calm
book
dab
loaf
goal
shack
far
witch (which)
rot
pick
fail
said
wag
haze
white
hush
dead
pad
mill
merge
juice
keg
gin
nice
numb
chief
gaze
young
keep
tool
soap
hate
turn
rain
shawl
bought
thought
bite
lower
(lore)
south

List III

sheep
cause
rat
bar
mouse
talk
hire
search
luck
cab
rush
five
team
pearl
soup
half
chat
road
pole
phone
life
pain
base
mop
mess
germ
thin
name
ditch
tell
cool
seize
dodge
youth
hit
light
jug
wire
walk
date
when
ring
check*
note
gun
beg
void
shall
lid
good

* In recording N.U. Auditory Test No. 6 at Michigan State University Audiology Research Laboratory, the word check was substituted for cheek accidently.

List IV

rose
dog
time
such
have
mob
bone
sail
rough
dip
join
check
wheat
thumb
near
lease
yearn
kick
get
lose
kill
fit
judge
should
pass
back
hall
bath
tire
peg
perch
chain
make
long
wash
food
mood
neat
tape
ripe
hole
gas
came
vote
lean
red
doll
shirt
sour
wife

APPENDIX C

CALIBRATION OF EQUIPMENT

Prior to and after the experiment the total speech audiometric system was checked for calibration. Periodically during the experiment the equipment was monitored for correct intensity calibration. The method used for monitoring and checking the calibration of the equipment is described below.

Acoustic Output of the Grason-Stadler 162 Speech Audiometer

The acoustic output of the speech audiometer was measured before the experiment, weekly during the experiment and after the termination of the experiment. The speech audiometer was calibrated so that audiometric zero was defined as being 20 dB above 0.0002 dynes/cm^2. For all speech materials the level of the narrow band calibration noise recorded on the tape was adjusted to 0 VU.

The speech audiometer system including the left earphone (TDH-39) with the associated cushion (MX-41/AR) was calibrated with an artificial ear assembly (Bruel and Kjaer, Type 4152) using a condenser microphone (Bruel and Kjaer, Type 4144), a sound level meter (Bruel and Kjaer, Type 2203) with it's associated octave band filter network (Bruel and Kjaer, Type 1613). "Speech Spectrum Noise" was used for calibration of the earphone system of the speech audiometer according to a procedure described by Tillman, Johnson and Olsen (1966). The input level of the noise, at a given attenuator setting, was adjusted until it produced a deflection to zero on the speech audiometer VU meter. The resultant acoustic output of the system was then measured. This value was accepted as the intensity of the spondee words at the same attenuator setting under the condition in which the peaks of the words produced a deflection to zero on the VU meter. For example, with the speech audiometer attenuator set to 60 dB HL, the output of the artificial ear would be 80 dB SPL re 0.0002 dynes/cm^2. All measurements made during the course of the investigation were within ± 1 dB.

Tape Recorder

The tape recorder (Ampex, Model 601) heads and contacts were cleaned daily during the course of the investigation.

Earphone Frequency Response

Prior to and after the experiment the frequency response of the left earphone (TDH-39) with it's associated cushion (MX-41/AR) was independently obtained with an artificial ear assembly (Bruel and Kjaer, Type 4152) and a condenser microphone (Bruel and Kjaer, Type 4144). A sine-random generator (Bruel and Kjaer, Type 1024) was used to drive the earphone. The output from the artificial ear assembly was connected to a microphone amplifier (Bruel and Kjaer, Type 2603) which in turn was coupled to a power level recorder (Bruel and Kjaer, Type 2305). No changes in the frequency response of the earphone were noted for these two measurements. Figure 16 shows the final frequency response of the earphone obtained at the end of the experiment.

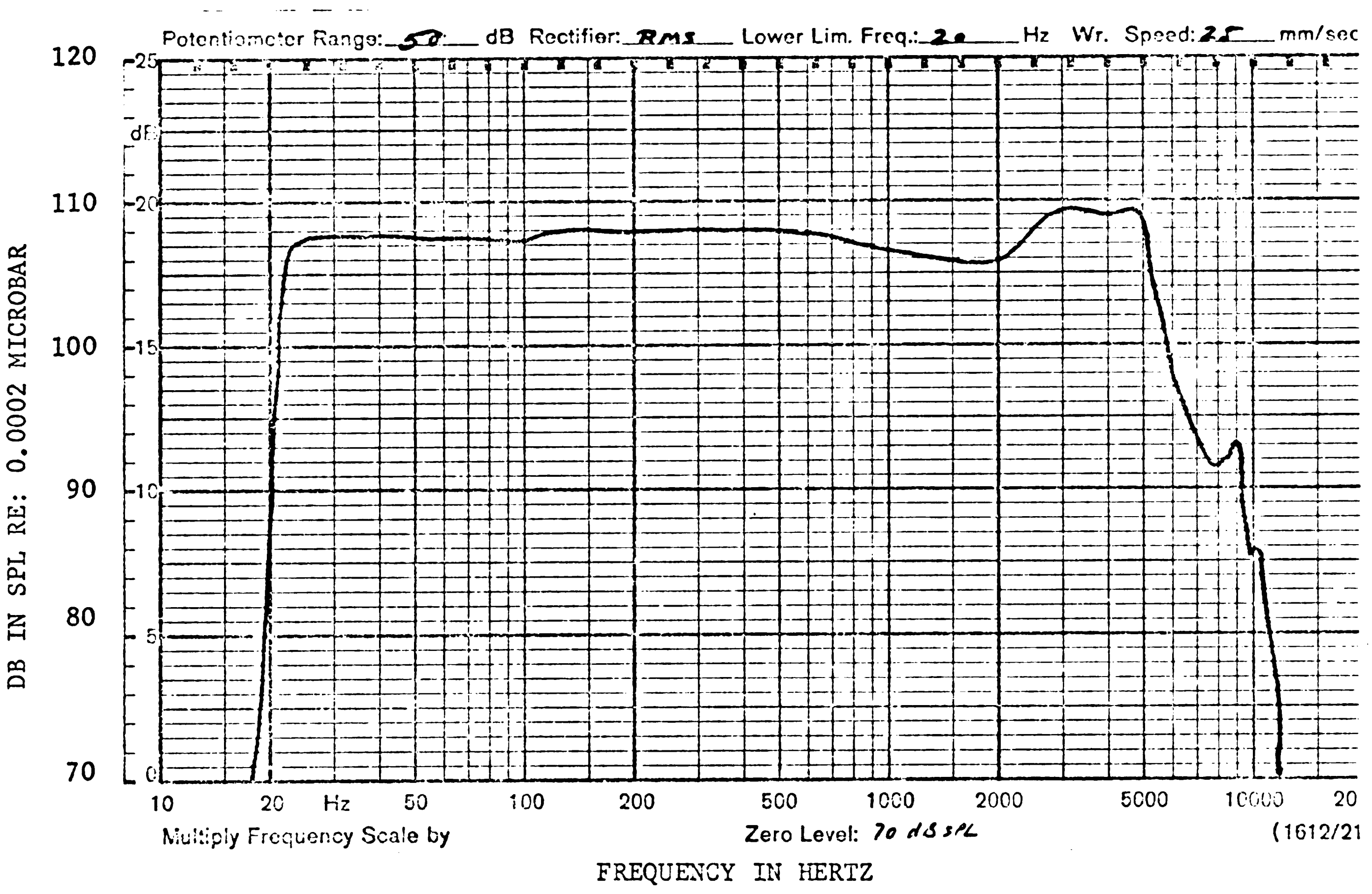

Figure 16. Frequency response of left earphone on Grason-Stadler 162 speech audiometer. Pre and post experimental frequency response curves were identical.

Frequency Response of the Entire System

The frequency response of the entire system (tape recorder, speech audiometer and earphone) was also checked prior to and after the completion of the experiment. This was accomplished by using a frequency test tape (Ampex, No. 01-31321-01). The output from the earphone was measured using an artificial ear and sound level meter. The descrete frequencies 12KHz, 10KHz, 7.5KHz, 5KHz, 2.5KHz, 1KHz, 500 Hz, 250 Hz, 100 Hz, 50 Hz and 30 Hz were measured. The results showed that the frequency response of the system was identical to the frequency response of the earphone. Thus, the frequency response of the entire system was limited by the frequency response of the test earphone (TDH-39) and cushion (MX-41/AR). This system did not change in it's characteristics during the experiment.

APPENDIX D

NEW METHOD AND HAIC DATA FOR ALL EIGHTEEN HEARING AIDS

Hearing Aid: Oticon UX
Model: Greendot
Serial Number: 684107

New Method Data	HAIC Data
Gain	Gain
Average 18 dB ± 10 dB	40 dB
500 Hz 15 dB	
1000 Hz 19 dB	
2000 Hz 20 dB	
Maximum Power Output	Maximum Power Output
Average 108 dB SPL	112 dB SPL
500 Hz 106 dB SPL	
1000 Hz 109 dB SPL	
2000 Hz 109 dB SPL	
Peak 112 dB, 800 Hz	
Frequency Range	Frequency Range
Low Frequency 150 Hz	Low Frequency 180 Hz
High Frequency 3800 Hz	High Frequency 3800 Hz

Hearing Aid: Zenith
Model: Westwood B
Serial Number: B 21768

New Method Data	HAIC Data
Gain	Gain
Average 11 dB ± 10 dB	35 dB
500 Hz 1 dB	
1000 Hz 17 dB	
2000 Hz 16 dB	
Maximum Power Output	Maximum Power Output
Average 96 dB SPL	103 dB SPL
500 Hz 85 dB SPL	
1000 Hz 103 dB SPL	
2000 Hz 100 dB SPL	
Peak 103 dB, 2500 Hz	
Frequency Range	Frequency Range
Low Frequency 550 Hz	Low Frequency 500 Hz
High Frequency 4500 Hz	High Frequency 4500 Hz

Hearing Aid: Siemens
Model: 380
Serial Number: 511

New Method Data	HAIC Data
Gain	Gain
Average 18 dB ± 10 dB	37 dB
500 Hz 4 dB	
1000 Hz 20 dB	
2000 Hz 31 dB	
Maximum Power Output	Maximum Power Output
Average 110 dB SPL	114 dB SPL
500 Hz 96 dB SPL	
1000 Hz 113 dB SPL	
2000 Hz 121 dB SPL	
Peak 121 dB, 2000 Hz	
Frequency Range	Frequency Range
Low Frequency 600 Hz	Low Frequency 480 Hz
High Frequency 5000 Hz	High Frequency 5000 Hz

Hearing Aid: Zenith
Model: Moderator A
Serial Number: DW 681

New Method Data	HAIC Data
Gain	Gain
Average 14 dB ± 10 dB	37 dB
500 Hz 14 dB	
1000 Hz 30 dB	
2000 Hz 37 dB	
Maximum Power Output	Maximum Power Output
Average 110 dB SPL	107 dB SPL
500 Hz 96 dB SPL	
1000 Hz 119 dB SPL	
2000 Hz 116 dB SPL	
Peak 119 dB, 1000 Hz	
Frequency Range	Frequency Range
Low Frequency 540 Hz	Low Frequency 450 Hz
High Frequency 4300 Hz	High Frequency 4300 Hz

Hearing Aid: Radioear
Model: 1000
Serial Number: FH 083

New Method Data	HAIC Data
Gain	Gain
Average 24 dB ± 10 dB	40 dB
500 Hz 18 dB	
1000 Hz 25 dB	
2000 Hz 28 dB	
Maximum Power Output	Maximum Power Output
Average 116 dB SPL	118 dB SPL
500 Hz 110 dB SPL	
1000 Hz 120 dB SPL	
2000 Hz 117 dB SPL	
Peak 121 dB, 900 Hz	
Frequency Range	Frequency Range
Low Frequency 340 Hz	Low Frequency 190 Hz
High Frequency 4600 Hz	High Frequency 4800 Hz

Hearing Aid: Sonotone
Model: 37
Serial Number: 62367

New Method Data	HAIC Data
Gain	Gain
Average 18 dB ± 10 dB	40 dB
500 Hz 6 dB	
1000 Hz 23 dB	
2000 Hz 25 dB	
Maximum Power Output	Maximum Power Output
Average 113 dB SPL	114 dB SPL
500 Hz 105 dB SPL	
1000 Hz 119 dB SPL	
2000 Hz 115 dB SPL	
Peak 122 dB, 1200 Hz	
Frequency Range	Frequency Range
Low Frequency 550 Hz	Low Frequency 450 Hz
High Frequency 4500 Hz	High Frequency 4500 Hz

Hearing Aid: Beltone
Model: Overture YY
Serial Number: W 25604

New Method Data	HAIC Data
Gain	Gain
Average 19 dB ± 10 dB	42 dB
500 Hz 17 dB	
1000 Hz 24 dB	
2000 Hz 17 dB	
Maximum Power Output	Maximum Power Output
Average 104 dB SPL	114 dB SPL
500 Hz 91 dB SPL	
1000 Hz 117 dB SPL	
2000 Hz 103 dB SPL	
Peak 125 dB, 2500 Hz	
Frequency Range	Frequency Range
Low Frequency 550 Hz	Low Frequency 380 Hz
High Frequency 4200 Hz	High Frequency 4200 Hz

Hearing Aid: Beltone
Model: Overture R
Serial Number: W 27153

New Method Data	HAIC Data
Gain	**Gain**
Average 25 dB ± 10 dB	44 dB
500 Hz 17 dB	
1000 Hz 33 dB	
2000 Hz 25 dB	
Maximum Power Output	Maximum Power Output
Average 119 dB SPL	119 dB SPL
500 Hz 116 dB SPL	
1000 Hz 122 dB SPL	
2000 Hz 118 dB SPL	
Peak 125 dB, 900 Hz	
Frequency Range	Frequency Range
Low Frequency 450 Hz	Low Frequency 350 Hz
High Frequency 4300 Hz	High Frequency 4300 Hz

Hearing Aid: Audiotone
Model: A-19
Serial Number: 1641

New Method Data	HAIC Data
Gain	Gain
Average 22 dB ± 10 dB	45 dB
500 Hz 5 dB	
1000 Hz 27 dB	
2000 Hz 33 dB	
Maximum Power Output	Maximum Power Output
Average 108 dB SPL	113 dB SPL
500 Hz 90 dB SPL	
1000 Hz 115 dB SPL	
2000 Hz 120 dB SPL	
Peak 120 dB, 2000 Hz	
Frequency Range	Frequency Range
Low Frequency 580 Hz	Low Frequency 460 Hz
High Frequency 3600 Hz	High Frequency 3600 Hz

Hearing Aid: Audiotone
Model: A-20
Serial Number: 5142

New Method Data	HAIC Data
Gain	Gain
Average 18 dB ± 10 dB	46 dB
500 Hz 11 dB	
1000 Hz 23 dB	
2000 Hz 20 dB	
Maximum Power Output	Maximum Power Output
Average 122 dB SPL	121 dB SPL
500 Hz 120 dB SPL	
1000 Hz 126 dB SPL	
2000 Hz 120 dB SPL	
Peak 127 dB, 900 Hz	
Frequency Range	Frequency Range
Low Frequency 450 Hz	Low Frequency 280 Hz
High Frequency 4600 Hz	High Frequency 4900 Hz

Hearing Aid: Beltone
Model: Overture Yellow
Serial Number: W 34395

New Method Data	HAIC Data
Gain	Gain
Average 22 dB ± 10 dB	49 dB
500 Hz 13 dB	
1000 Hz 29 dB	
2000 Hz 25 dB	
Maximum Power Output	Maximum Power Output
Average 111 dB SPL	115 dB SPL
500 Hz 105 dB SPL	
1000 Hz 116 dB SPL	
2000 Hz 113 dB SPL	
Peak 119 dB, 900 Hz	
Frequency Range	Frequency Range
Low Frequency 380 Hz	Low Frequency 380 Hz
High Frequency 4200 Hz	High Frequency 4200 Hz

Hearing Aid: Zenith
Model: Newport
Serial Number: NB 667

New Method Data	HAIC Data
Gain	Gain
Average 21 dB ± 10 dB	49 dB
500 Hz 5 dB	
1000 Hz 29 dB	
2000 Hz 28 dB	
Maximum Power Output	Maximum Power Output
Average 113 dB SPL	123 dB SPL
500 Hz 100 dB SPL	
1000 Hz 121 dB SPL	
2000 Hz 191 dB SPL	
Peak 121 dB, 1000 Hz	
Frequency Range	Frequency Range
Low Frequency 650 Hz	Low Frequency 480 Hz
High Frequency 4400 Hz	High Frequency 4400 Hz

Hearing Aid: Siemens
Model: 382
Serial Number: 10649

New Method Data	HAIC Data
Gain	Gain
Average 23 dB ± 10 dB	50 dB
500 Hz 14 dB	
1000 Hz 24 dB	
2000 Hz 30 dB	
Maximum Power Output	Maximum Power Output
Average 111 dB SPL	121 dB SPL
500 Hz 105 dB SPL	
1000 Hz 113 dB SPL	
2000 Hz 115 dB SPL	
Peak 116 dB, 3500 Hz	
Frequency Range	Frequency Range
Low Frequency 500 Hz	Low Frequency 400 Hz
High Frequency 4900 Hz	High Frequency 4900 Hz

Hearing Aid: Sonotone
Model: 77S
Serial Number: 2563S

New Method Data	HAIC Data
Gain	Gain
Average 36 dB ± 10 dB	50 dB
500 Hz 29 dB	
1000 Hz 38 dB	
2000 Hz 40 dB	
Maximum Power Output	Maximum Power Output
Average 122 dB SPL	124 dB SPL
500 Hz 118 dB SPL	
1000 Hz 124 dB SPL	
2000 Hz 124 dB SPL	
Peak 124 dB, 1000 Hz	
Frequency Range	Frequency Range
Low Frequency 400 Hz	Low Frequency 320 Hz
High Frequency 3800 Hz	High Frequency 3800 Hz

Hearing Aid: Siemens
Model: 383
Serial Number: 9610

New Method Data	HAIC Data
Gain	Gain
Average 23 dB ± 10 dB	50 dB
500 Hz 10 dB	
1000 Hz 26 dB	
2000 Hz 33 dB	
Maximum Power Output	Maximum Power Output
Average 115 dB SPL	115 dB SPL
500 Hz 104 dB SPL	
1000 Hz 119 dB SPL	
2000 Hz 121 dB SPL	
Peak 123 dB, 3500 Hz	
Frequency Range	Frequency Range
Low Frequency 380 Hz	Low Frequency 390 Hz
High Frequency 4600 Hz	High Frequency 4600 Hz

Hearing Aid: Audiotone
Model: A 21 II
Serial Number: 1913

New Method Data	HAIC Data
Gain	Gain
Average 38 dB ± 10 dB	51 dB
500 Hz 27 dB	
1000 Hz 42 dB	
2000 Hz 46 dB	
Maximum Power Output	Maximum Power Output
Average 124 dB SPL	127 dB SPL
500 Hz 118 dB SPL	
1000 Hz 129 dB SPL	
2000 Hz 124 dB SPL	
Peak 129 dB, 1000 Hz	
Frequency Range	Frequency Range
Low Frequency 550 Hz	Low Frequency 450 Hz
High Frequency 4500 Hz	High Frequency 5200 Hz

Hearing Aid: Norelco
Model: 6730
Serial Number: 85132

New Method Data	HAIC Data
Gain	Gain
Average 35 dB ± 10 dB	51 dB
500 Hz 29 dB	
1000 Hz 39 dB	
2000 Hz 39 dB	
Maximum Power Output	Maximum Power Output
Average 123 dB SPL	128 dB SPL
500 Hz 122 dB SPL	
1000 Hz 126 dB SPL	
2000 Hz 122 dB SPL	
Peak 131 dB, 800 Hz	
Frequency Range	Frequency Range
Low Frequency 450 Hz	Low Frequency 400 Hz
High Frequency 4500 Hz	High Frequency 4500 Hz

Hearing Aid: Radioear
Model: 990
Serial Number: 2L6 906

New Method Data	HAIC Data
Gain	Gain
Average 36 dB ± 10 dB	53 dB
500 Hz 28 dB	
1000 Hz 43 dB	
2000 Hz 37 dB	
Maximum Power Output	Maximum Power Output
Average 127 dB SPL	129 dB SPL
500 Hz 125 dB SPL	
1000 Hz 129 dB SPL	
2000 Hz 126 dB SPL	
Peak 133 dB, 900 Hz	
Frequency Range	Frequency Range
Low Frequency 480 Hz	Low Frequency 370 Hz
High Frequency 4800 Hz	High Frequency 4800 Hz