A STUDY OF THE ELECTROACOUSTICAL RESPONSE-CURVE CONSISTENCY OF TRANSISTORIZED HEARING AIDS

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ABSTRACT

A STUDY OF THE ELECTROACOUSTICAL RESPONSE-CURVE CONSISTENCY OF TRANSISTORIZED HEARING AIDS

By Ronald M. Rogers

The purpose of this study was to analyze and compare the results obtained from the electroacoustical response measurements of current transistorized hearing aids so as to determine their reliability on repeated trials. The criteria employed for the desired measurements were the American Standards Association's Basic Frequency Responses and Saturation Output Responses.

Eight current clinically-used hearing aids were selected from the stock of a clinical facility under the auspices of the Michigan State University Speech and Hearing Clinic. Eight aids which matched the first selection were selected from another clinical facility under the same auspices. The measuring system employed consisted of the following: one hearing aid test box, one audio frequency spectrometer, two condenser microphones, one audio oscillator, one 2 cc coupler, one cathode follower, one cathode follower cable, and one amplifier. Each aid was evaluated by the stated criteria on three distinct trials for the frequencies of 250, 500, 1000, 2000, 3500, and 4000 cps. The response measurements of the aids, in dB coupler SPL,

were recorded for statistical analysis. The following null hypotheses were tested:

1. There is no difference in the mean coupler SPL between Hearing Aids I and II of the eight models as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses
2. The difference in coupler SPL between the first and second hearing aids of the same model do not vary as a function of auditory frequency (There is no aids-by-frequency interaction.) as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses
3. The difference in coupler SPL--taken over all frequencies--between the first and second hearing aids is the same for all models investigated (There is no aids-by-models interaction.) as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses

The results of the analyses demonstrated that the main effect and the two interactions under consideration for the basic frequency responses were statistically significant at better than the .01 level of confidence. It further demonstrated that of the one main effect and the two interactions under consideration for the saturation output responses, only one interaction (aids x frequencies) did not reveal a statistically significant F statistic below the .01 level of confidence.

The conclusions drawn from this study were that the recurrent statistically-significant results were not necessarily clinically significant.

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By

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Many clinical audiologists are engaged in the daily process of hearing aid evaluations and recommendations. The audiologist selects several instruments for evaluation on a client. The criteria for the selection of the aids for evaluation are generally the frequency response characteristics of the instrument. Information regarding the frequency response characteristics of the aid is presented in the manufacturers' specification brochures. The frequency response characteristics are based on standards established by the Hearing Aid Industry Conference (HAIC)[1] and the American Standards Association (ASA), Subcommittee S3-W-34.[2] The basic information provided in the manufacturers' specification brochures is usually adequate for the evaluation procedures. However, information regarding the reliability of the frequency responses of the aids is not published in the specification brochures. Some

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[1] S. F. Lybarger, "Standardized Hearing Aid Measurements," <u>Audecibel</u>, 10 (2), 1961, 8.

[2] "Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," <u>American Standards Association Bulletin</u>, S3.3 (1960), 7-15.

audiologists would like to have more information regarding the frequency response characteristics of the instruments they wish to evaluate on their clients.

The question that confronts the practicing audiologist is the reliability of the frequency response characteristics of current hearing aids. Will a particular hearing aid respond significantly different on different trials for the electroacoustical response characteristics of Basic Frequency Responses and Saturation Output Responses? Will the response characteristics of two different aids of the same make and model differ significantly? Are the electroacoustical characteristics of current hearing aids, with the increasing interest in miniaturization, alike enough to justify the recommendation of the purchase of a like instrument to the client? That is, will the aid the client purchases differ significantly from the instrument which performed successfully during the hearing aid evaluation?

Some practicing audiologists have advocated the procedure of having the client purchase the actual instrument that performed successfully during the aid evaluation, thereby recognizing and attempting to eliminate the problems with which this study is concerned.

A review of the literature has revealed an absence of research with current transistorized hearing aids related to the questions and problems with which this study is concerned. Therefore, there appears to be a distinct need for research findings which will attempt to answer or shed light upon the major questions of the reliability of the frequency response characteristics of current hearing aids.

Definition of Terms

For the purposes of this study the terms used are defined in the following manner.

Hearing aid evaluation.--A series of audiological tests for the purpose of determining the relative effectiveness of the available hearing aids for recommendation to a client.

Acoustic gain.--"The amount in decibels, by which the sound pressure level developed by the hearing-aid earphone in a specific coupler exceeds the sound pressure level in the free-field into which the hearing aid is introduced."[1]

Hearing Aid Industry Conference (HAIC).--A conference of hearing aid manufacturers who meet for the purposes of establishing ethics, manufacturing standards, public relations, etc., for the hearing aid industry.

American Standards Association (ASA).--"A voluntary association of manufacturers and consumers which has written standards for many branches of American industry including the field of acoustics."[2]

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[1] *Ibid.*, p. 7.

[2] Hallowell Davis and S. Richard Silverman, *Hearing and Deafness* (New York: Holt, Rinehart and Winston, Inc., 1962), p. 177.

Frequency response characteristics.--The pattern of the amplification of acoustic energy by a particular hearing aid for the stated ASA criteria.

Current hearing aids.--Hearing aid models which have been manufactured within the last three years.

ASA Basic Frequency Response.--"The frequency response for a specified input sound pressure level, maintained constant over the specified frequency range, and a specified output sound pressure level at 1000 cps that is chosen as a reference response for purposes of description."[1]

ASA Saturation Output Response.--The maximum SPL obtainable in the coupler from the earphone of the aid with the gain control of the aid at the full-on position.

Clinically-used hearing aids.--Hearing aids which have been used for the purposes of clinical evaluation on clients in the daily routine of a clinical audiology facility. These instruments have had neither excessive abuse or care.

Clinically-good operating condition.--A condition whereby the audiologist would not hesitate to use this instrument for fear of less than adequate functioning.

Randomly-selected hearing aids.--"Hearing aids with different frequency-response characteristics selected

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[1]"Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," loc. cit.

randomly from the clinic stock without regard to specific response characteristics, acoustic gain, maximum output, etc."[1]

Body-worn hearing aids.--Instruments which have been designed to be worn on the body below the shoulder line.

Ear-level hearing aids.--Instruments which are designed to be worn at the level of the ear either in eyeglasses or curving over and behind the ear.

Coupler.--"A coupler is a device for the acoustic loading of earphones. It has a specified arrangement of acoustic elements and is provided with a microphone for the measurement of the sound pressure developed in a specified portion of the device."[2]

Sound Pressure Level (SPL).--"The sound pressure level (SPL) of any sound is the ratio between its pressure and a standard reference pressure, usually 0.0002 dyne/cm^2."[3]

Coupler SPL.--The sound pressure level measured in the coupler.

Clinically significant difference.--A difference

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[1]Constance Rae Walton, "Discrimination by Normally Hearing Subjects for Filtered Speech Under Conditions of Hearing Aid Amplification" (unpublished Master's thesis, College of Communication Arts, Dept. of Speech, Michigan State University, 1964), p. 7.

[2]"Methods for Measurement of Electroacoustical Characteristics of Hearing Aids, *op. cit.*, p. 7.

[3]Hayes A. Newby, *Audiology* (New York: Appleton-Century-Crofts, Inc., 1964), p. 11.

between Aids I and II that is greater than 5 decibels.

Purpose of the Study

The purpose of this study is to analyze and compare the results obtained from the electroacoustical response measurements of current clinically-used hearing aids. The aids evaluated in this study have been used for daily routine clinical evaluations and were considered to be in clinically-good operating condition. The electroacoustical response characteristics of Basic Frequency Responses and Saturation Output Responses were obtained according to procedures recommended and outlined in the American Standards Association Bulletin S3.3 (1960).[1]

One of the purposes of the Basic Frequency Response measurement is to aid the clinical audiologist in his selection of hearing aids for evaluation on the client. This measurement provides the response characteristics of the various frequencies to a fixed input and a fixed gain adjustment on the aid. The purpose of the Saturation Output Response is as follows:

> To determine the maximum rms coupler sound pressure level that the hearing aid is capable of producing with gain control and maximum, using as much input sound pressure level as is needed to produce maximum output at each test frequency.
>
> This test gives information which is of great value when considering whether the maximum

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[1] "Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," loc. cit.

intensities available from the hearing aid may be dangerous to the ear.[1]

From this analysis it was hoped that information regarding the reliability of the electroacoustical responses of current hearing aids could be evaluated. With this goal in mind, the following null hypotheses have been formulated:

1. There is no difference in the mean coupler SPL between hearing aids I and II of the eight models as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses
2. The differences in coupler SPL between the first and second hearing aids of the same model do not vary as a function of auditory frequency (There is no aids-by-frequency interaction.) as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses
3. The differences in coupler SPL--taken over all frequencies--between the first and second hearing aids is the same for all models investigated (There is no aids-by-models interaction.) as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses

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[1] *Ibid*., p. 12.

Importance of the Study

This study is considered to be important in that it will provide the practicing clinical audiologist with information that will help to guide his daily decisions concerning the recommendations of hearing aids to his clients. This study will also hopefully add to the badly needed research regarding the reliability of current transistorized hearing aids. The need for clinically practical research is supported by the lack of information in the literature as evidenced in the literature review of this study.

If a client is to gain the value of the clinical findings of a hearing aid evaluation, it is important that the instrument he purchases does not differ significantly from the instrument which was determined to be helpful during the evaluation.

The primary importance of this study is to contribute up-to-date research findings which are of practical value to the practicing audiologist in the field. This study intends to provide information which would be useful to the clinical audiologist concerning the reliability of the transistorized hearing aid.

Organization of Study

Chapter One contains the statement of the problem that led to this study. An introduction to the topic and an outline of the purposes of the study are included. The terms to be used are defined. Hypotheses are stated and the importance of the study is discussed.

Chapter Two contains a review of the literature pertinent to this topic, and Chapter Three consists of a discussion of the equipment and the procedures utilized in this study. Chapter Four discusses the results of the study and Chapter Five contains the summary and conclusions.

CHAPTER II

REVIEW OF THE LITERATURE

Trend in Hearing Aid Sales

A review of the literature has revealed an ever increasing trend on the part of the consumer to purchase fewer and fewer body-worn aids in favor of ear-level instruments. With this demand by the consumer, and the interest of the manufacturer to please the consumer market, the improvements in the miniaturization of hearing aids are clearly reflected by the increased percentage of ear-level hearing aids being purchased each year.

The trend toward the smaller ear-level instruments was reported at the 1961 HAIC meeting:

> In 1959, conventional aids accounted for 27% of total sales. In 1960 this figure fell to 26% and in 1961 to approximately 23%. Eye-glass aids have dropped in this three year period from 20% of sales in 1959 to 41% in 1960 and 40% in 1961. Behind-the-ear aids have gained from 23% of sales in 1959 to 33% in 1960, and an estimated 35% in 1961.[1]

The further increase in the popularity of the smaller ear-level instruments was reported in 1962 by Bolstenin:

> A percentage comparison of types of hearing aids sold during 1961 and 1962 is given. 1962

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[1] "HAIC Meeting Notes Progress," Hearing Dealer, 11 (November, 1961), 15.

sales included conventional aids, 22%; eyeglass aids, 34.67% behind-the-ear aids, 39.33% and in-the-ear aids, 4%.[1]

In 1963 the National Hearing Aid Journal reported an estimate of the annual figures for the hearing aid industry for 1964. A still greater increase in the sales of ear-level hearing aids, and particularly behind-the-ear instruments is indicated: "It is estimated that of the aids sold, 34% will be eyeglasses, 45% behind-the-ear, 19% conventional, and 2% in-the-ear."[2]

Response Measurements of Vacuum Tube Aids

The literature has revealed a number of studies prior to 1953 which are directly concerned with the electroacoustical responses of hearing aids. Hudgins[3] and Hector et al.[4] reported studies which were concerned with the electroacoustical responses of vacuum tube hearing aids. However, these studies are obsolete as a result of the current use of transistors in hearing aids. "Transistors took the place of bulky and fragile vacuum tubes in hearing aids

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[1]M. Bolstenin, "From the Editors Desk," National Hearing Aid Journal, 16 (February, 1962), 3.

[2]"Ninth Annual Facts and Figures," National Hearing Aid Journal, 17 (January, 1963), 6.

[3]C. V. Hudgins, "Testing the Performance of Hearing Aids," Volta Review, 49 (1947), 1.

[4]G. L. Hector et al., "Recent Advances in Hearing Aids," The Journal of the Acoustical Society of America, 25 (1953), 1189-94.

in January of 1953."[1]

Indirectly Related Studies

A review of the literature has clearly indicated an absence of studies which are directly concerned with the electroacoustical response characteristics of current transistorized hearing aids.

In 1962 Goldberg reported a new electronic device which evaluates the acoustic properties of a hearing aid. The acoustic properties which can be evaluated with this device are frequency responses, maximum acoustic gain, maximum output, and harmonic distortion. The Electronic Ear is considerably different from the many components which were combined to obtain the measurements for this study. The complete device is about the size of a portable audiometer.

> The Electronic Ear consists basically of a ceramic microphone set into a six cubic centimeter coupler, and a calibrated amplifier. The coupler may be converted to two cc by inserting a miniature receiver adapter plug. Additional adapters are provided to make measurements of sub-miniature receivers and those receivers using plastic tubes.[2]

Goldberg did not report the results of any measurements with this instrument.

The following study by Shore, Bilger and Hirsh is

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[1]"Short Shorts About Hearing Aids," The Hearing Dealer, 6 (December, 1956), 18.

[2]Hyman Goldberg, "The Electronic Ear," Audecibel, 11 (May, 1962), 21.

not directly concerned with the reliability of the electroacoustical responses of hearing aids; however, they did recognize the possibility of electroacoustical fluctuation. They employed fifteen clinical patients and four popular hearing aids which they set at a variety of adjustments. Their purpose was to test the reliability of repeated measurements of gain and speech discrimination in noise and in quiet. These tests were performed on four different days. They concluded that the reliability of these measures is not sufficient to justify the investment of a large amount of clinical time in selecting hearing aids. The following statement is evidence of their awareness of possible fluctuation in the electroacoustical responses of the aids on different trials:

> This conclusion does not imply that there are no differences among conventional monaural aids; but rather it suggests that whatever differences there might be are not detectable by these three usual measures of speech audiometry.[1]

The following study by McConnell, Silber and McDonald in 1960 is again not directly concerned with the reliability of the electroacoustical responses of hearing aids. However, the results rendered might well be interpreted in the interest of this present study. They conducted a study to determine the test-retest reliability of speech audiometry

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[1]Irvin Shore, Robert C. Bilger, and Ira J. Hirsh, "Hearing Aid Evaluations: Reliability of Repeated Measurements," Journal of Speech and Hearing Disorders, 25 (1960), 112.

measures with randomly selected hearing aid users.

> Speech discrimination scores were found to have a markedly high degree of test-retest reliability even when obtained by different clinicians. Aided speech reception thresholds were less consistent on repeated measures. No significant difference was found between test results from both types of measures when the tests were administered by different clinicians.[1]

It is interesting to note that the results of the aided tests were less consistent than the unaided results. This might possibly indicate variation as a function of the electroacoustical characteristics of the hearing aids.

It is apparent from the high test-retest reliability found in this study that none of the many variables operating was sufficient to affect the results of the repeated measures. One of the variables of this study was, of course, the electroacoustical responses of the hearing aids. However, there was apparently no significant difference in the reliability of the electroacoustical responses of the instruments used in this study. If a significant difference had occurred, the test-retest reliability would have been affected.

While the "Harvard Study," reported by Davis in 1947,[2] is not primarily concerned with the reliability of

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[1]F. McConnell, E. F. Silber, and D. McDonald, "Test-Retest Consistency of Clinical Hearing Aid Tests," Journal of Speech and Hearing Disorders, 25 (1960), 112.

[2]Hallowell Davis et al., "Hearing Aids: An Experimental Study of Design Objectives" (Cambridge, Massachusetts: Harvard University Press, 1947).

the electroacoustical responses of hearing aids, it represents an awareness of the need to provide the practicing clinicians with more information than is presented by the manufacturers. It also represents an attempt to help the practicing clinician more effectively evaluate his testing procedures in light of the effectiveness of the equipment he is evaluating.

This review of the literature is evidence of the need for current research directly concerned with the electroacoustical characteristics of transistorized hearing aids. This writer searched the literature extensively and was unable to find any such study.

CHAPTER III

EQUIPMENT AND TESTING PROCEDURES

Equipment

Sixteen current clinically-used hearing aids were randomly selected for this study from the hearing aid stock of two clinical audiology facilities which are under the auspices of the Michigan State University Speech and Hearing Clinic. A sample of eight aids was randomly selected from the population of aids at one of the clinical facilities, then matched with eight aids of the same make and model from the other clinical facility. The sample for this study is, therefore, composed of two aids of each make and model selected for a total of sixteen aids.

The instruments selected can be classified into two major categories with one of the categories subdivided into two types. The two major categories and two types are:

I. Body-worn instruments

II. Ear-level instruments

A. Behind-the-ear models

B. Eye-glass models

The following hearing aids and equipment were employed for the purposes of this investigation.

<u>Hearing Aids</u>:

I. Body-worn aids:

Zenith Super Extended Range, serial number 5103113, External adjustments -- "C" setting, Receiver Y-5.

Zenith Super Extended Range, serial number 5103108, External adjustments -- "C" setting, Receiver Y-5.

Sonotone 300, Serial number 302852, Internal adjustments -- all left "Normal LO-2," "Selector Switch" setting -- "Normal," Receiver 41.21.

Sonotone 300, Serial number 319065, Internal adjustments -- all left "Normal LO-2," "Selector Switch" setting -- "Normal," Receiver 41.21.

II. Ear-level instruments:

A. Behind-the-ear instruments:

Beltone Jubilee, Serial number 809556, Internal adjustments -- "clear dot setting," Acoustic tubing #16 gauge.

Beltone Jubilee, Serial number 812567, Internal adjustments -- "clear dot setting," Acoustic tubing #16 gauge.

Zenith Delegate B, Serial number B4170, Internal adjustments -- None, Acoustic tubing #16 gauge.

Zenith Delegate B, Serial number B4164, Internal adjustments -- None, Acoustic tubing #16 gauge.

Radioear 891, Serial number IRA98, Internal adjustments -- Normal, Acoustic tubing #16 gauge.

Radioear 891, Serial number IVD94, Internal adjustments -- Normal, Acoustic tubing #16 gauge.

Sonotone 55, Serial number 77351, Internal adjustments -- None, Acoustic tubing #16 gauge.

Sonotone 55, Serial number 89752, Internal adjustments -- None, Acoustic tubing #16 gauge.

B. Eye-glass instruments:

Sonotone 75, Serial number 704212, Internal adjustments -- None, Acoustic tubing #16 gauge.

Sonotone 75, Serial number 704194, Internal adjustments -- None, Acoustic tubing #16 gauge.

Zenith Z-20, Serial number 7203217, Internal adjustments -- None, Acoustic tubing #16 gauge.

Zenith Z-20, Serial number 7202928, Internal adjustments -- None, Acoustic tubing #16 gauge.

Equipment:

Hearing aid test box, Bruel and Kjaer (type 4214).

Precision sound level meter, Bruel and Kjaer (type 2203).

Audio frequency spectrometer, Bruel and Kjaer (type 2112).

Pistonphone, Bruel and Kjaer (type 4220).

Low frequency audio oscillator, Hewlett-Packard (type 202C).

Condenser microphone, one inch/pressure, Bruel and Kjaer (type 4132).

Condenser microphone, one inch/pressure, Bruel and Kjaer (type 4132).

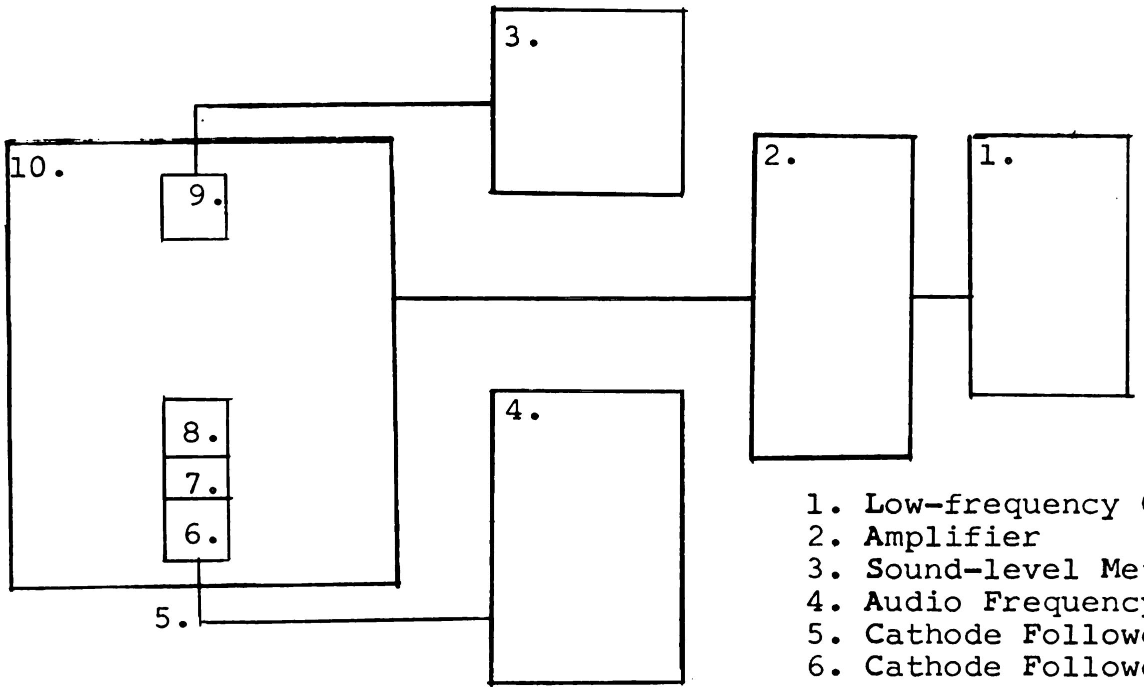
Cathode follower, Bruel and Kjaer (type 2613).

Cathode follower cable, Bruel and Kjaer (type AO-0033).

Acoustic coupler, 2cc., Bruel and Kjaer (type DB-0138).

Amplifier, Ampex (model 620).

See Figure 1 for a block diagram of the equipment arrangement.



1. Low-frequency Oscillator
2. Amplifier
3. Sound-level Meter
4. Audio Frequency Spectrometer
5. Cathode Follower Cable
6. Cathode Follower
7. Condenser Microphone
8. 2 cc Coupler
9. Condenser Microphone (sound-field monitor)
10. Hearing Aid Test Box

Figure 1.--Block diagram arrangement for Aid Response Evaluation.

Procedures

Response Test Procedures:

The procedures followed for obtaining the Basic Frequency Responses and Saturation Output Responses for hearing aids are those outlined by the American Standards Association.[1]

Placement of Aid in Test Box:

The reference point for the hearing aids was at the center of the microphone grill area. The hearing aid was placed with the reference point located toward the sound source so that the direction of the incident sound was perpendicular to the surface of the reference point.

The instruments were placed in the same location within the test box. The microphone of the aid being tested was on the same plane as the sound-field monitoring microphone at a distance of one inch apart.

Standardization of Test Procedures:

All test procedures were standardized so that the replication of events would occur under the same conditions. Each instrument was evaluated on three distinct different trials for the desired data. The different trials occurred on different days.

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[1] "American Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," *American Standards Association Bulletin*, S3.3 (1960), 10-13.

Batteries:

The batteries were tested to be certain of the desired power before each aid was evaluated. The batteries used in the various aids were those recommended by the manufacturer.

Acoustic Tubing:

The gauge of the acoustic tubing used on all ear-level instruments was that recommended by the manufacturer for maximum gain and frequency response range. In all cases, for the aids used in this study, number sixteen gauge tubing was used. The length of the acoustic tubing was standardized to 2 inches.

Internal and External Aid Adjustments:

On those instruments which had either internal or external adjustments which controlled the range of frequencies or gain responses, the adjustments were made that would produce maximum gain and maximum frequency response range according to the manufacturers' specification brochures. In all cases the particular adjustments or settings have been stated.

Basic Frequency Response Procedures:

The basic frequency response characteristics for each of the sixteen aids were obtained on three distinct trials for each of the six frequencies. The desired data were obtained in the following manner:

The free field sound pressure level in the hearing aid test box was adjusted to read 60 dB $\pm$ 1 dB at the frequency of 1000 cps. The gain control of the instrument under evaluation was then adjusted so as to give a sound pressure level in the coupler of 100 dB $\pm$ 2 dB at 1000 cps. The aids which did not have sufficient gain to permit this adjustment were set at maximum gain with the volume control in the full-on position. All of the ear-level instruments used in this study were set at maximum gain.

The frequencies of the sound source used were: 250, 500, 1000, 2000, 3500, and 4000 cps. Following the 100 dB $\pm$ 2 dB coupler SPL measurement at 1000 cps., the output in dB coupler SPL of the other five frequencies were also measured and recorded on each of the three distinct trials.

<u>Saturation Output Responses</u>:

The saturation output responses for each of the sixteen aids were measured in dB coupler SPL on three distinct trials for each of the six frequencies in the following manner:

The gain control was turned to the full-on position. The saturation output measurements were recorded for the selected six frequencies of 250, 500, 1000, 2000, 3500, and 4000 cps. This was done by increasing the coupler sound pressure level until the instrument reached its maximum pressure, a point at which the maximum reading fell with a further increase of input sound pressure. The maximum reading was recorded as the saturation output response for that particular frequency.

Summary

In order to study the Basic Frequency Response and Saturation Output Response Characteristics of sixteen clinically-used hearing aids, the following procedures were employed.

Eight hearing aids were randomly selected and matched with eight more aids of the same make, model, and setting. Therefore, two aids of each make and model of the original selection made up the sample. The Basic Frequency Responses and Saturation Output Responses were measured in dB coupler SPL on three distinct trials for each of the six following frequencies: 250, 500, 1000, 2000, 3500, and 4000 cps. All procedures were standardized according to standards set forth by the American Standards Association.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The data for this study were obtained by measuring the electroacoustical response characteristics of sixteen current hearing aids for Basic Frequency Responses and Saturation Output Responses as prescribed by American Standards Association Bulletin S3.3 (1960).[1] The null hypotheses under consideration are:

1. There is no difference in the mean coupler SPL between Hearing Aids I and II of the eight models as measured by the following criteria:
   (a) ASA Basic Frequency Responses
   (b) ASA Saturation Output Responses
2. The differences in coupler SPL between the first and second hearing aids of the same model do not vary as a function of auditory frequency (There is no aids-by-frequency interaction.) as measured by the following criteria:
   (a) ASA Basic Frequency Responses

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[1] "Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," American Standards Association Bulletin S3.3 (1960), p. 7.

(b) ASA Saturation Output Responses

3. The differences in coupler SPL--taken over all frequencies--between the first and second hearing aids is the same for all models investigated (There is no aids-by-models interaction.) as measured by the following criteria:

(a) ASA Basic Frequency Responses

(b) ASA Saturation Output Responses

Appendix A contains the raw data obtained from the Basic Frequency Response measurements of the hearing aids. Appendix B contains the raw data obtained from the Saturation Output Response measurements of the hearing aids. Since it was the desire of this investigator to determine if any significant difference and/or interaction existed between the aids, models, and frequencies, a 2 x 8 x 6 factorial analysis of variance was employed. The design employed is described by Edwards.[1] The statistical analyses of this study were computed by the CDC 3600 computer at the Michigan State University Computer Laboratory. The computer routine employed for the analysis was the Option 2 of FACREP.[2]

The statistical analysis of the results of the

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[1]Allen L. Edwards, Experimental Design in Psychological Research (New York: Rinehart and Company, Inc., 1960), pp. 201-205.

[2]D. F. Kiel, A. F. Kenworthy, and W. L. Rubel, "Analysis of Variance Routines" (East Lansing: Michigan State University, September 30, 1963), p. 23.

Basic Frequency Response measurements is summarized in Table I. The statistical analysis of the results of the Saturation Output Response measurements is summarized in Table II.

There is a significant difference in the mean coupler SPL between Hearing Aids I and II of the eight models as measured by ASA Basic Frequency Responses at the .01 level of confidence. The F attained by this analysis was 19.8. This indicates that part (a) of the first hypothesis can be rejected at better than the .01 level of confidence.

There is a significant difference in the mean coupler SPL between Hearing Aids I and II of the eight models as measured by ASA Saturation Output Responses at the .01 level of confidence. The F attained by this analysis was 36.79. This indicates that part (b) of the first hypothesis can be rejected at better than the .01 level of confidence.

The second null hypothesis states that the difference in coupler SPL between the first and second hearing aids of the same model do not vary as a function of auditory frequency (There is no aids-by-frequency interaction.) as measured by ASA Basic Frequency Responses. An examination of Table I indicates that part (a) of the second hypothesis can be rejected at better than the .01 level of confidence. The F attained by this analysis was 4.88.

An examination of Table II indicates that part (b) of the second hypothesis was not rejected at the .01 level

TABLE I

SUMMARY OF ANALYSIS OF VARIANCE
FOR
BASIC FREQUENCY RESPONSES

Sources of Variance	Sum of Squares	df	Mean Square	F
Aids (A)	63.28	1	63.28	19.80*
Models (B)	6899.41	7	985.63	-
A x B	202.52	7	28.93	9.05*
Frequencies (C)	25686.72	5	5137.34	-
A x C	77.94	5	15.58	4.88*
B x C	11847.19	35	338.49	-
A x B x C	1002.07	35	28.63	-
Error (Within Treatments)	613.33	192	3.19	
Total	46392.49	287		

*Significant below the .01 level of confidence.

TABLE II

SUMMARY OF ANALYSIS OF VARIANCE
FOR
SATURATION OUTPUT RESPONSES

Sources of Variance	Sum of Squares	df	Mean Square	F
Aids (A)	96.83	1	96.83	36.79*
Models (B)	20492.10	7	2927.44	-
A x B	1498.02	7	214.00	81.31*
Frequencies (C)	7239.22	5	1447.84	-
A x C	15.05	5	3.01	1.14
B x C	3014.07	35	86.11	-
A x B x C	127.57	35	3.64	-
Error (Within Treatments)	505.33	192	2.63	
Total	32988.24	287		

*Significant below the .01 level of confidence.

of confidence. The F attained by this analysis was 1.14. This indicates that no significant difference in the coupler SPL was demonstrated between the first and second hearing aids of the same model as a function of auditory frequency as measured by ASA Saturation Output Responses.

The third hypothesis states that the differences in coupler SPL--taken over all frequencies--between the first and second hearing aids is the same for all models investigated (There is no aids-by-models interaction.) as measured by (a) ASA Basic Frequency Responses and (b) ASA Saturation Output Responses.

An examination of Table I indicates that there is a significant difference in the third hypothesis as measured by part (a) at the .01 level of confidence. The F attained by this analysis was 9.05. This indicates that there is a significant aids-by-models interaction as measured by ASA Basic Frequency Responses.

An examination of Table II indicates that there is a significant aids-by-models interaction as measured by ASA Saturation Output Responses. The F attained by this analysis was 81.31. This indicates that part (b) of the third hypothesis can be rejected at better than the .01 level of confidence.

Discussion

The analysis of the data has shown that parts (a) and (b) of the first hypothesis were rejected. This hypothesis concerned the reliability of the mean coupler SPL between Aids I and II of the eight models as measured by ASA Basic Frequency Responses (part (a) of the first hypothesis). Although the study has shown statistical significance, as evidenced in Table I, observation of Figure 2 reveals that the mean coupler SPL difference between Aids I and II is only 1 dB. The 1 dB difference, while statistically significant, is not significant in its practical or clinical application. The fact that 1 dB is not significant in its practical or clinical application is supported by <u>ASA Bulletin</u> S3.3,[1] a ± 1 dB for error in the free-field sound pressure level, and a ± 2 dB error in the gain adjustment of hearing aids as stated in the procedures for the electroacoustical measurements of hearing aids. Therefore, the ASA allowed error could exceed the 1 dB difference observed in the results of part (a) of the first hypothesis.

Part (b) of the first hypothesis was also shown to be statistically significant. This would indicate that there is a significant difference in the reliability of the mean coupler SPL between hearing aids I and II of the eight models as measured by ASA Saturation Output Responses. An observation of Table II will confirm the significant F. However, an observation of Figure 3 reveals a mean coupler SPL difference between Aids I and II of only 1 dB. Although

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[1] "Methods for Measurement of Electroacoustical Characteristics of Hearing Aids," <u>op. cit</u>., p. 12.

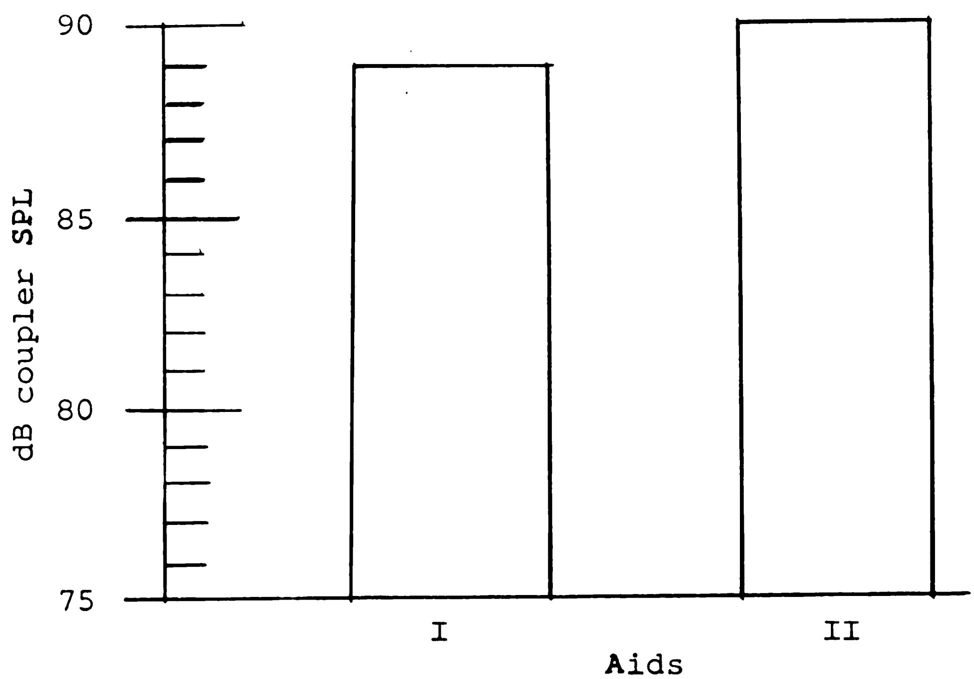


Figure 2.--Mean coupler SPL of Aids I and II for the frequencies of 250, 500, 1000, 2000, 3500, and 4000 cps, as measured by ASA Basic Frequency Responses.

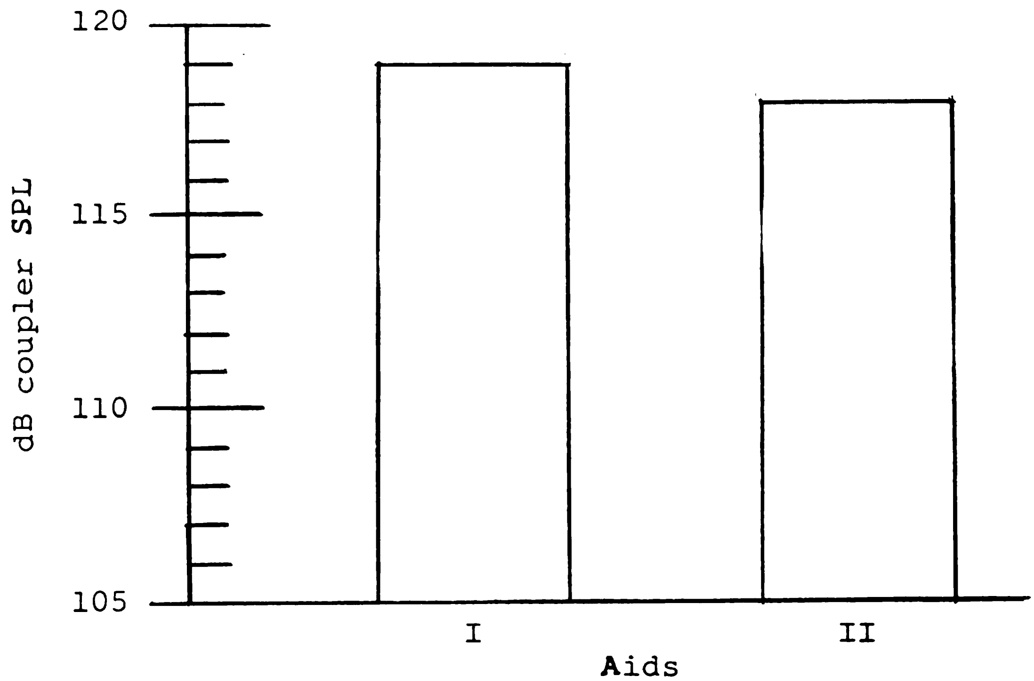


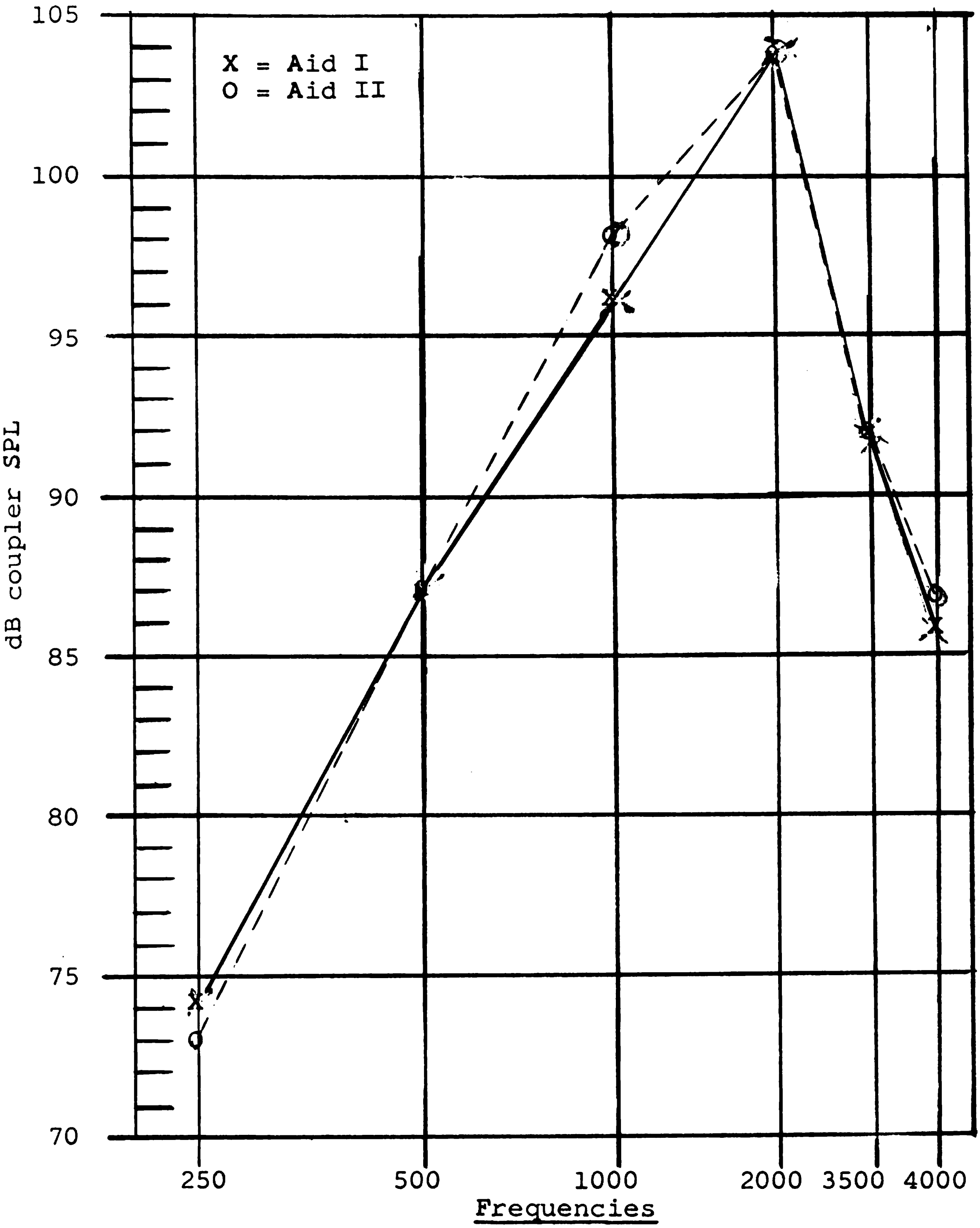
Figure 3.--Mean coupler SPL of Aids I and II for the frequencies of 250, 500, 1000, 2000, 3500, and 4000 cps, as measured by ASA Saturation Output Responses.

the mean coupler SPL difference between Aids I and II reveals a statistical significance, there would seem to be no significant difference with regard for the practical or clinical application.

The analysis of the data has shown significance in part (a) of the second hypothesis and a lack of significance in part (b) of the second hypothesis. The results of part (a) indicate a significant difference in the mean coupler SPL between the first and second hearing aids of the same model as a function of auditory frequency (an aids-by-frequencies interaction) as measured by ASA Basic Frequency Responses. An inspection of Table I will confirm the significant F of 4.88. Figure 4 graphically demonstrates the aids by frequencies interaction of part (a) of this hypothesis. The higher frequency range of 2000 through 4000 cps seems to be more reliable in Basic Frequency Responses than the lower frequency range of 250 through 1000 cps.

Although the statistical analysis of those data clearly demonstrates significance, there appears to be no significance in terms of the clinical application of the results. The greatest aids by frequency interaction is at the frequency of 1000 cps. As Figure 4 indicates, this difference is only 2 dB between the mean coupler SPL of Aids I and II.

Reference to Table II will indicate a lack of

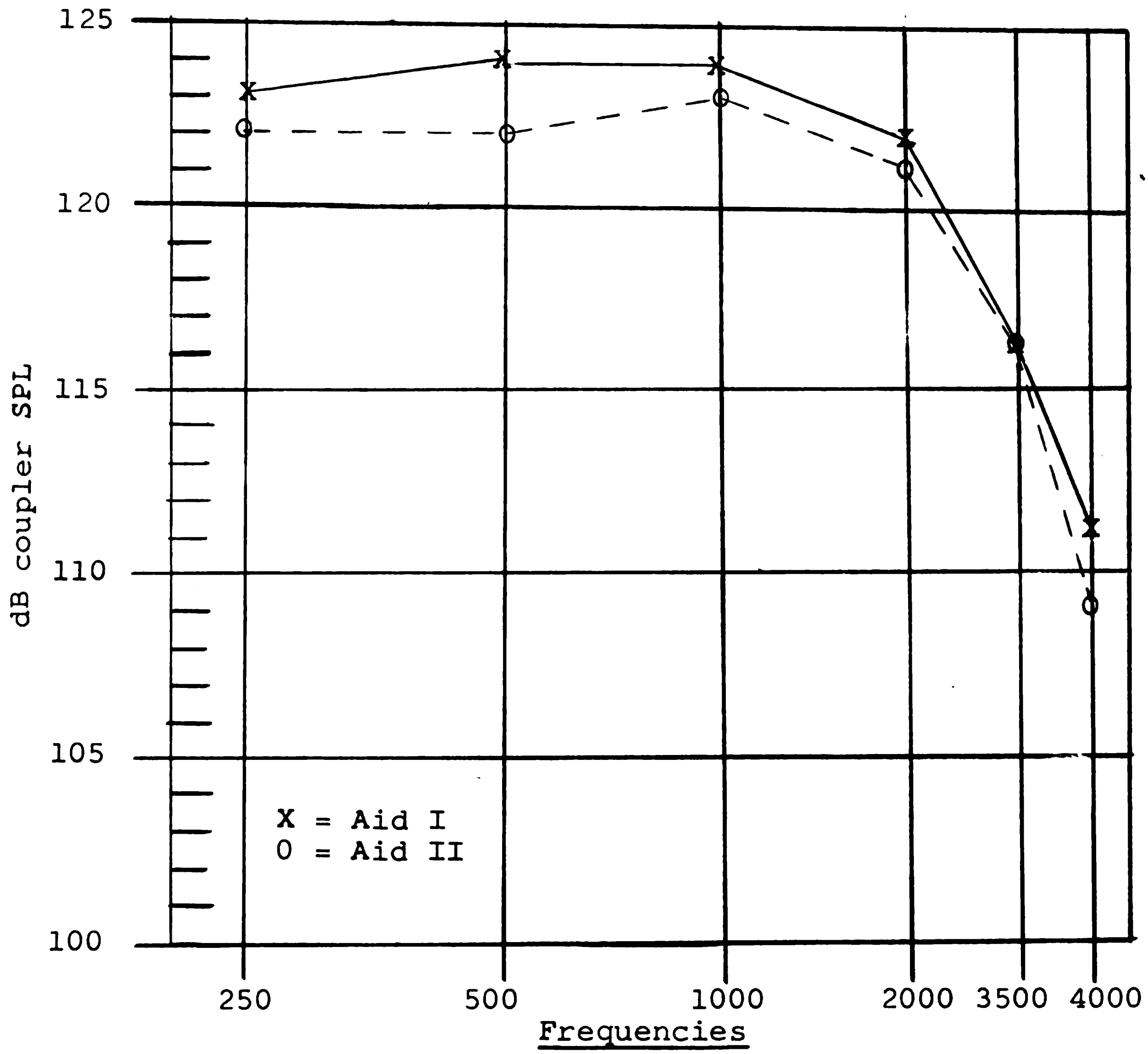


Aids x Frequencies Interaction

Figure 4.--Mean frequency responses for Aids I and II of each model for Basic Frequency Responses.

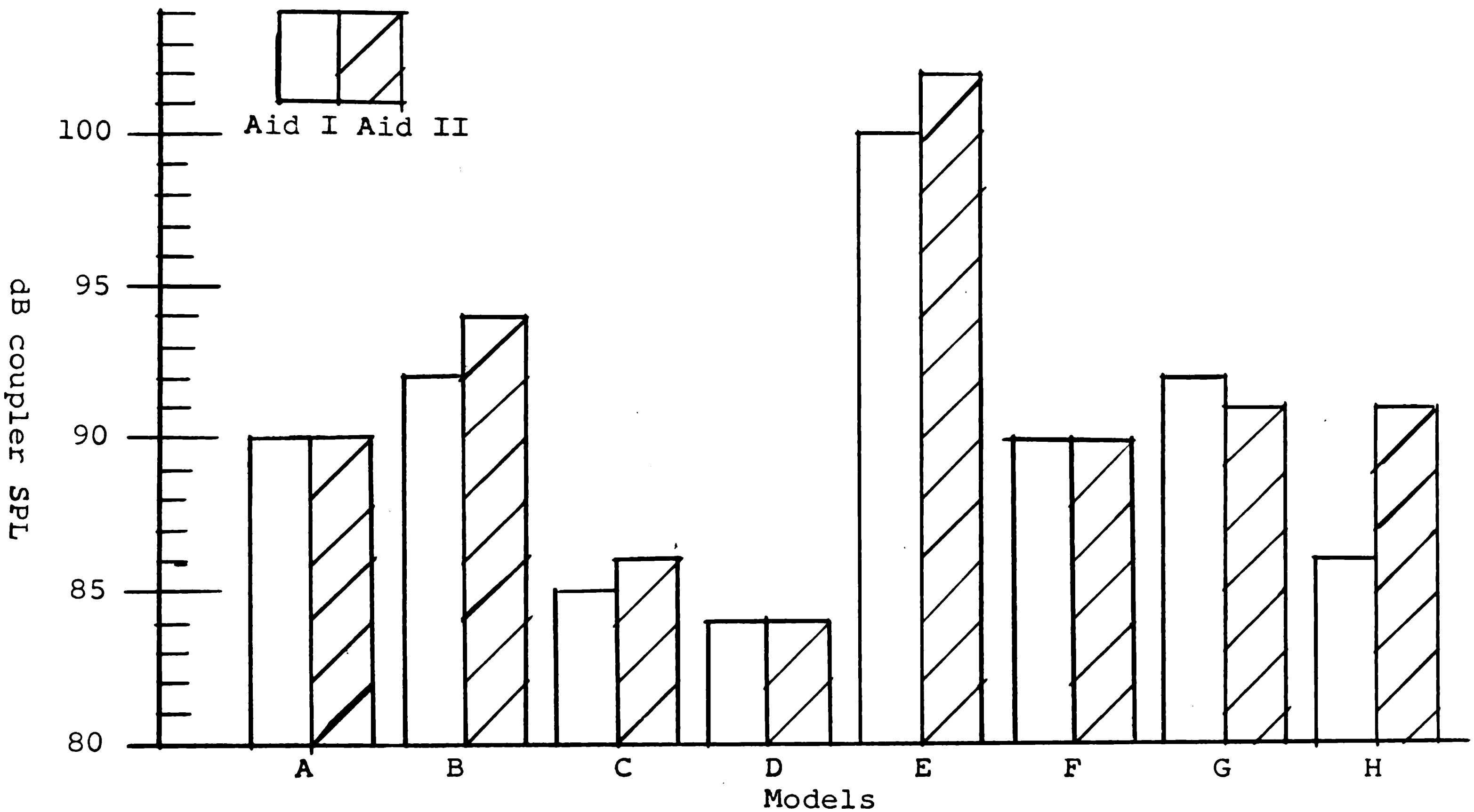
significance in part (b) of the second hypothesis for the aids by frequencies interaction, as measured by ASA Saturation Output Responses, with an F of 1.14. Therefore, on the basis of this statistical analysis, it cannot be said that there is an aids-by-frequency interaction as measured by ASA Saturation Output Responses. The results of these measurements are graphically presented in Figure 5.

The analysis of the data for the third hypothesis has shown statistical significance for parts (a) and (b) of this hypothesis; thereby rejecting the hypothesis that there is no aids-by-models interaction as measured by: (a) ASA Basic Frequency Responses and (b) ASA Saturation Output Responses. An inspection of Table I will reveal a significant F of 9.05 for part (a) of this hypothesis. Although statistical significance has been demonstrated, there again appears to be no significant difference with regard to the clinical application of these data. Figure 6 graphically presents the aids-by-models interaction. Model H, which shows a 5 dB difference between Aids I and II, is the only model which comes near demonstrating a clinically-significant aids-by-models interaction. An inspection of Table II will reveal a statistically significant F of 81.31 for the aids-by-models interaction as measured by ASA Saturation Output Responses. The graphic presentation of the data in Figure 7 reveals the aids-by-models interaction. It can be seen that Models A, C, D,



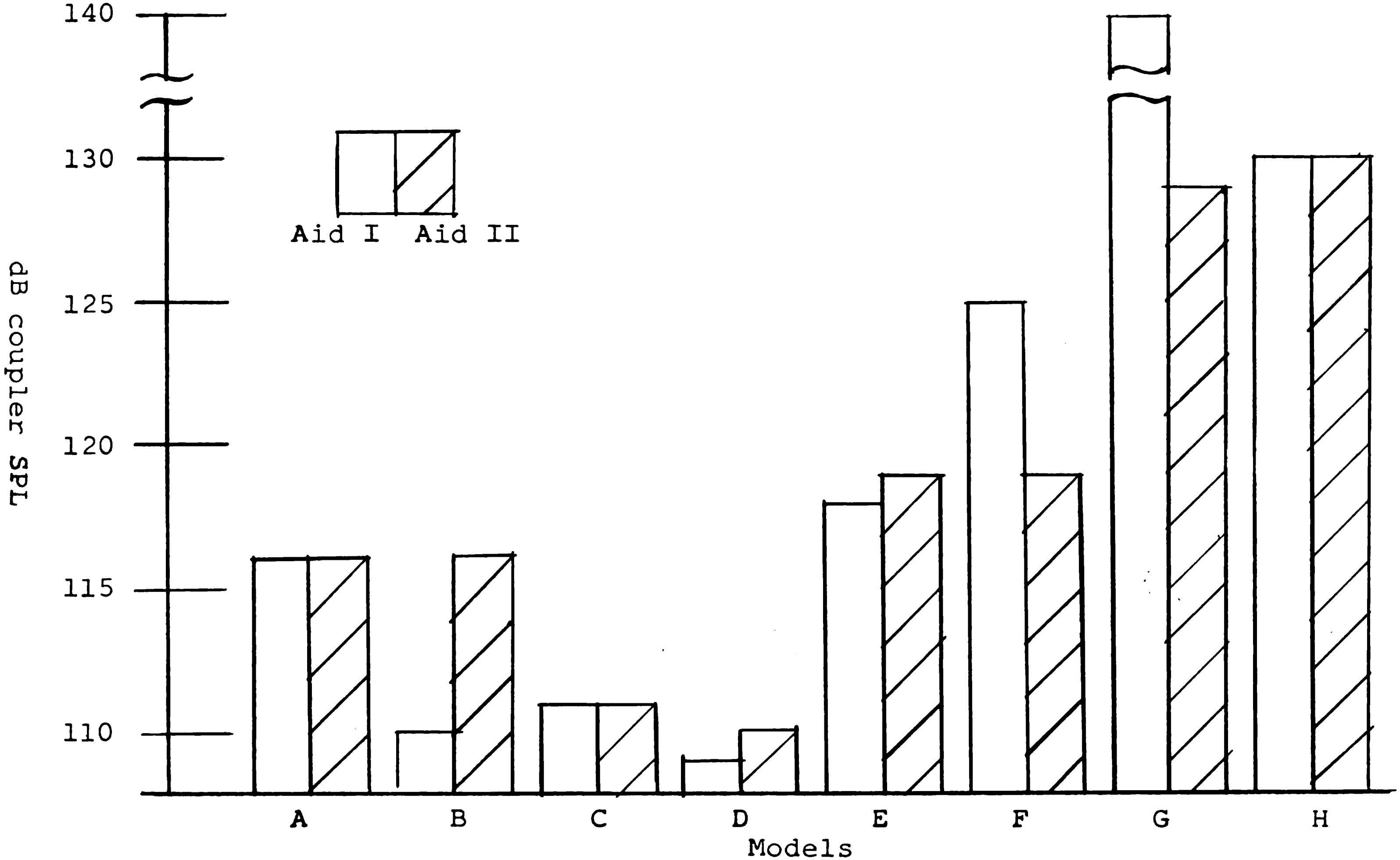
Aids x Frequencies Interaction

Figure 5.--Mean frequency responses for Aids I and II of each model for Saturation Output Responses.



Aids x Models Interaction

Figure 6.--Mean coupler SPL of Aids I and II over all frequencies for each of the eight models as measured by ASA Basic Frequency Responses.



Aids x Models Interaction

Figure 7.--Mean coupler SPL of Aids I and II over all frequencies for each of the eight models as measured by ASA Saturation Output Responses.

E, and H, while having contributed to the significant statistical interaction, have not individually demonstrated an interaction which has clinical significance. That is, Aids I and II of these five models do not demonstrate a clinically-significant aids-by-models interaction. It can also be seen that Aids I and II of Model B differ by 6 dB. Aids I and II of Model G show the greatest aids-by-models interaction with a mean coupler SPL difference of 10 dB.

The 10 dB difference observed, if not compensated for by the audiologist, could conceivably be sufficient to cause undue discomfort, pain, or damage to a client. Therefore, it is important that the practicing clinical audiologist be aware of the possible fluctuation of the electroacoustical response characteristics of hearing aids.

It is interesting to note that while statistical significance has been clearly demonstrated for four of the sources of variability tested, only one of the sources has also demonstrated clinical significance. The demonstration of statistical significance without clinical significance can be accounted for by the measuring system that was employed. The measuring system employed was more precise and repeatable than the instruments being measured. The data would seem to support the view that the precision of the instruments being measured was, in the main, adequate for clinical use.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

During recent years the increased technological and scientific advances in amplification systems, and particularly the advent of the transistor replacing the vacuum tube, has led to the continuing miniaturization of wearable hearing aids. "Transistors took the place of bulky and fragile vacuum tubes in hearing aids in January of 1953."[1] The continuing miniaturization has created questions with regard for the reliability of the electroacoustical responses of the aids. A review of the literature has revealed literally no studies which are directly concerned with the reliability of the electroacoustical response characteristics of transistorized hearing aids. Hudgins (1947)[2] and Hector *et al*. (1953)[3] reported data they had collected on the electroacoustical response characteristics of vacuum tube hearing aids. However, this information is presently

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[1]"Short Shorts About Hearing Aids," *The Hearing Dealer*, 6 (December, 1956), 18.

[2]C. V. Hudgins, "Testing the Performance of Hearing Aids," *Volta Review*, 49 (1947), 1.

[3]G. L. Hector *et al*., "Recent Advances in Hearing Aids," *The Journal of the Acoustical Society of America*, 25 (1953), 1189-94.

obsolete as a result of the current use of transistors.

The following questions are a result of the increasing miniaturization of wearable hearing aids. Are these very small amplification systems reliable from model to model and trial to trial? Will the response characteristics of two different aids of the same make and model differ significantly? In other words, will the instrument the client purchases differ significantly from the instrument which performed successfully during the hearing aid evaluation?

The purpose of this study was to analyze and compare the results obtained from the electroacoustical response measurements of sixteen clinically-used hearing aids so as to determine their reliability on repeated trials. The criteria employed for these response measurements was the ASA Basic Frequency Responses, and the ASA Saturation Output Responses.

The instrumentation for this study consisted of: one Bruel and Kjaer hearing aid test box, one Bruel and Kjaer sound-level meter, one Bruel and Kjaer audio frequency spectrometer, two Bruel and Kjaer one-inch condenser microphones, one Bruel and Kjaer cathode follower, one Bruel and Kjaer 2 cc acoustic coupler, one Hewlett-Packard low-frequency audio oscillator, and one Ampex amplifier.

All test procedures, including the placement of the hearing aids in the sound-field, the sound-field pressure level in the test box, the gain adjustment of the aids, etc., were performed in accordance with procedures outlined in the American Standards Association Bulletin S3.3.[1] Each aid was subjected to six trials at each of the six frequencies: three trials for the basic frequency response measurements and three trials for saturation output response measurements. The data, in the form of dB coupler SPL, were recorded for statistical analyses. For the analyses of this study a 2 x 8 x 6 factorial analysis of variance procedure was employed. The analyses were computed by the CDC 3600 computer at the Michigan State University Computer Laboratory. The results of the analyses demonstrated that the main effect and the two interactions under consideration for the basic frequency responses were statistically significant below the .01 level of confidence. It further demonstrated that of the one main effect and the two interactions under consideration for the saturation output responses, only one interaction (aids x frequencies) did not reveal a statistically-significant F statistic below the .01 level of confidence.

Conclusions

Statistically-significant results were obtained for the main effect (aids) and the two interactions (aids x models and aids x frequencies), for the ASA Basic Frequency

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[1]"Methods for Measurements of Electroacoustical Characteristics of Hearing Aids," op. cit., p. 7.

Response criteria. Although the F statistics attained clearly indicate rejection of the null hypotheses at better than the .01 level of confidence, there appear to be no clinically-significant differences as defined in this study between Aids I and II for the stated criteria.

Statistically-significant differences between Aids I and II were also attained for the main effect (aids) and the interaction (aids x models) for the ASA Saturation Output Response criteria. The second interaction (aids x frequencies) did not reveal statistically-significant differences at the .01 level of confidence. While the main effect (aids) and the interaction (aids x models) have clearly demonstrated statistically-significant F ratios, only two models (F and G) of the interaction (aids x models) have indicated differences between Aids I and II which have clinical significance as defined in this study.

The recurrent demonstration of statistical significance without clinical significance can be accounted for by the measuring system that was employed. The measuring system employed was more precise and repeatable than the instruments being measured. This condition existed despite the fact that the instruments being measured appeared to be highly consistent from a clinical point of view.

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APPENDICES

APPENDIX A

RAW DATA: BASIC FREQUENCY RESPONSES

Models	Trials	250 Aids I	250 Aids II	500 Aids I	500 Aids II	1000 Aids I	1000 Aids II	2000 Aids I	2000 Aids II	3500 Aids I	3500 Aids II	4000 Aids I	4000 Aids II
A:	1	78	65	86	84	98	100	100	101	93	95	88	89
	2	72	67	85	84	101	102	98	101	92	94	88	88
	3	68	69	86	84	102	102	99	102	94	95	88	89
B:	1	68	64	88	87	96	94	106	105	100	102	101	104
	2	63	65	83	86	93	97	104	110	102	106	92	94
	3	76	70	86	86	94	100	106	112	100	109	101	96
C:	1	63	62	72	74	92	94	107	107	89	92	83	90
	2	63	60	74	72	92	92	106	103	89	93	86	85
	3	63	63	74	73	92	94	106	105	89	92	88	89
D:	1	74	61	78	80	86	89	103	100	84	84	81	88
	2	78	62	77	80	84	90	100	100	80	84	84	89
	3	76	60	78	82	86	89	102	100	80	82	82	87
E:	1	82	84	105	104	101	101	108	110	106	110	101	101
	2	83	84	104	104	100	101	106	109	106	110	101	101
	3	78	84	103	103	100	102	108	109	105	109	102	101
F:	1	70	76	78	87	92	100	110	106	101	94	88	86
	2	70	67	78	85	92	98	110	104	100	94	88	87
	3	70	66	78	86	92	100	110	105	100	94	87	87
G:	1	80	80	98	99	100	100	102	102	90	91	78	78
	2	80	82	98	98	100	100	103	100	90	89	80	76
	3	81	83	99	98	100	100	103	100	92	88	80	76
H:	1	81	96	88	94	100	102	102	105	72	74	67	70
	2	81	96	89	94	100	102	102	105	72	75	69	70
	3	83	97	91	96	101	102	102	105	73	76	69	71

Frequencies; values in dB coupler SPL

The make, model, and serial number of Models A through H listed above can be found in Appendix C.

APPENDIX B

RAW DATA: SATURATION OUTPUT RESPONSES

Models	Trials	250 Aids I	250 Aids II	500 Aids I	500 Aids II	1000 Aids I	1000 Aids II	2000 Aids I	2000 Aids II	3500 Aids I	3500 Aids II	4000 Aids I	4000 Aids II
A:	1	116	115	118	118	119	120	116	117	112	116	107	108
	2	115	116	119	120	122	122	116	118	114	116	108	109
	3	115	115	120	120	123	122	117	118	114	116	108	109
B:	1	115	117	112	118	114	117	111	115	113	116	107	113
	2	109	117	107	116	110	118	108	118	113	120	106	103
	3	115	118	112	116	112	121	111	120	112	120	106	103
C:	1	112	112	112	112	116	116	118	118	104	106	102	103
	2	111	112	112	112	116	116	118	116	105	109	101	100
	3	113	112	112	112	116	116	118	118	104	107	102	103
D:	1	114	116	116	116	113	114	112	112	100	90	116	101
	2	112	116	116	116	112	114	112	112	99	99	100	101
	3	113	117	116	116	113	114	112	112	98	100	100	101
E:	1	120	120	123	123	120	120	116	116	118	120	113	114
	2	120	121	123	124	120	121	116	116	117	120	114	114
	3	121	120	123	123	120	121	116	116	117	120	113	114
F:	1	125	120	124	120	130	123	129	122	124	120	116	110
	2	125	121	124	120	129	124	129	122	125	120	115	110
	3	125	120	125	120	130	125	129	122	124	120	115	111
G:	1	147	133	146	133	144	133	144	130	136	126	126	116
	2	147	134	146	134	143	134	143	133	136	127	125	116
	3	146	134	146	134	144	133	142	132	135	126	125	116
H:	1	138	138	138	138	138	138	131	131	120	120	112	112
	2	138	138	138	138	138	139	132	131	121	120	113	112
	3	138	138	139	138	139	139	132	131	121	120	113	112

dB coupler SPL

The make, model, and serial number of Models A through H listed above can be found in Appendix C.

APPENDIX C

HEARING AIDS EMPLOYED

	MODELS	AIDS I	AIDS II
A:	Sonotone 75	#704212	#704194
B:	Beltone Jubilee	#809556	#812567
C:	Zenith Delegate B	#B4170	#B4164
D:	Zenith Z-20	#7203217	#7202928
E:	Radioear 891	#IRA98	#IVD94
F:	Sonotone 55	#77351	#89752
G:	Zenith Super Extended Range	#5103113	#5103108
H:	Sonotone 300	#302852	#319065