THE DIFFERENTIATION OF LOW FIDELITY CIRCUITRY BY BEHAVIORAL TEST RESPONSE

By

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Audiologists are often called upon to recommend hearing aids for their clients. The evaluative procedures used to make these recommendations involve the clients' performance on behavioral measures designed to estimate and quantify speech intelligibility. It is documented in the research literature that electroacoustic characteristics of hearing aids can affect speech intelligibility, however, there is disagreement as to which characteristics have the most profound affect. Reasons conjectured for the disagreement include (1) behavioral measure unreliability, (2) inadequate assessment of electroacoustic interactions and (3) use of behavioral measures which are affected by different electroacoustic characteristics and/or interactions.

In order to test the validity of these conjectures forty-two discrete electroacoustic measurements were made on

each of ten hearing aids. Ten behavioral measures (C.I.D. W-22 Word Lists (CID), V.A. Discrimination Test (VAH), Modified Rhyme Test (MRT), a synthetic sentence test (SST), C.I.D. Everyday Sentences: judged intelligibility (ESJ) and write down response (ESW), a quality judgment passage (QJ) and the Intermodulation Distortion Test at three S/Ns (IMDTO, -4, -8)) were recorded through the same aids, degraded with speech spectrum noise and presented to ten normal hearing listeners.

Pearson correlation coefficients between subject test and retest performances showed good reliability ($r > .75$) for all of the behavioral measures except SST, ESW and IMDT8. Criticism of these reliable measures on the basis of instability of results, was, therefore, concluded to be unfounded in these data.

Pearson correlation, factor analysis and multiple regression calculations were performed between the electroacoustic characteristics and subject responses on the behavioral measures, in order to test the soundness of the other two conjectures.

Examination of the Pearson correlation matrix showed that many of the electroacoustic characteristics were highly correlated with one another. In these data, therefore, no characteristic was a truly independent variable, but represented the sum total of the moment-to-moment interactions with all of the other characteristics. The supposition that interaction effects require a systematic appraisal seems warranted. Assessment of solitary characteristics, apart from interactions with other characteristics, was determined to be unrealistic and, perhaps, misleading.

An obliquely rotated factor analysis was performed on the electroacoustic characteristics to permit the use of a subject-to-independent variable ratio appropriate for multiple regression procedures. Five factors were extracted from the data. The characteristic under each factor which had the highest loading was selected as the single most influential characteristic to that factor. Factor groupings , on the basis of high loadings, were labelled harmonic distortion, maximum power output, bandwidth, gain and regularity of frequency response.

Multiple regression analysis produced regression coefficients (R), the square of which indicated how much of the variance in each of the behavioral measures was accounted for by the five factors, and beta weights, which signified the relative affect of the five factors upon each measure. On the basis of this analysis, a modified cross validation and reliability coefficients, VAH, MRT, ESJ, QJ and IMDTO were determined to be stable and reliable estimates of speech intelligibility. The beta weights, however, rank ordered the influence of the five factors differently for each measure. This result was interpreted to imply that each of the investigated measures was influenced by different interactions between the electroacoustic factors.

Comparison of research results, based upon different behavioral measures, was decided to be inappropriate and, perhaps, misleading because the sensitivity of different measures to electroacoustic interactions do not appear to be equivalent.

Finally, an approach to hearing aid selection procedures was proposed which uses knowledge of differential sensitivity of behavioral measures to electroacoustic interactions, to predict speech intelligibility through a hearing aid.

CHAPTER 1
INTRODUCTION AND REVIEW OF THE LITERATURE

Statement of the Problem

Audiologists are often called upon to recommend hearing aids for their clients. The evaluative procedures used to make these recommendations involve the client's performance on behavioral measures designed to estimate and quantify the intelligibility of speech (Ross, 1972).

It is well documented in the literature that electro-acoustic characteristics of hearing aids can affect speech intelligibility (Harris et al., 1961; Jerger et al., 1966a,b; Olsen, Jabeley and Pappas, 1966; Jerger, 1967; Olsen and Carhart, 1967; Olsen and Wilbur, 1967; Bode et al., 1968; Jerger and Thelin, 1968; Bode and Kasten, 1971; Olsen, 1971a,b; Witter and Goldstein, 1971; Smaldino, 1972,1973). Results from these investigations, however, are in disagreement as to which characteristics most profoundly affect intelligibility. Among the reasons conjectured for the disagreement are in-adequate appraisal of electroacoustic interactions (Harris et al., 1961; Smaldino, 1972,1973), use of behavioral measures which are affected by different electroacoustic characteristics and/or interactions (Jerger and Thelin, 1967; Witter and Goldstein, 1971; Smaldino, 1972,1973) and behavioral measure unreliability (Shore, Bilger and Hirsh, 1960; Ross, 1972).

Review of the Literature

The electroacoustic characteristics of hearing aids which have been implicated as having an effect upon speech intelligibility include harmonic distortion, intermodulation distortion, bandwidth, irregularity of the frequency response, transient distortion and gain.

Behavioral measures which have been employed or appear to have utility in hearing aid evaluative procedures include monosyllabic word lists, rhyming monosyllables, sentence lists, quality judgments and judged intelligibility.

The literature is replete with disagreement as to which electroacoustic characteristics affect intelligibility as estimated by different behavioral measures.

Harmonic Distortion/Sentence Lists

In exploring the effects of signal-to-noise ratio, frequency range, flatness of the frequency response curve, harmonic distortion and intermodulation distortion, Harris et al. (1961) used the C.I.D. Everyday Sentences which were equated for length (6-9 words per sentence) as the behavioral measure. Harmonic distortion was found to have the highest correlation with speech intelligibility error scores. Intermodulation distortion also correlated well with intelligibility, but was highly intercorrelated with harmonic distortion, thus, was not considered a different variable from harmonic distortion. Cubic and quadratic intermodulation distortion were found not to affect intelligibility. Frequency range was slightly correlated with speech understanding, while integrated area under the frequency response curve was found to be moderate predictor of intelligibility. Transient distortion was speculated as being the best portender of intelligibility, but instrumentation for this measurement was unavailable to the investigators.

Harmonic Distortion/Sentence Lists/Monosyllabic Word Lists

Jerger, Speaks and Malmquist (1966a,b) used a multiple choice sentence intelligibility test (PAL Auditory Test, number 8, Karlin et al., 1944) and three monosyllabic word lists (C.I.D. Auditory Test, W-22, Hirsch et al., 1952; CNC Word Lists, Lehiste and Peterson, 1959; PAL PB Word Lists, Egan, 1948 which were low pass filtered at 500 Hz) to discover a behavioral task which would reliably differentiate the performance of hearing aids. Results showed that while the sentence intelligibility task, with intellective masking, rank ordered the aids in inverse proportion to harmonic distortion, "performance differences were not systematically reflected in the monosyllabic word test results" (Jerger, Speaks and Malmquist, 1966b, p. 253) presented in quiet.

Harmonic Distortion/Rhyming Monosyllables

Kruel et al. (1968) revised the Modified Rhyme Test (MRT). The response paradigm consists of fifty closed set items with six foils each. The subjects task was to draw a line through the one foil that was heard. Bode et al. (1968) using the MRT found that consonant discriminations were reduced over a range of thirteen to thirty percent with increasing harmonic distortion (five percent, fifteen percent, twenty-five percent and thirty-five percent).

Bode and Kasten (1971) using the Modified Rhyme Test mixed with noise concluded that reduced high frequency bandwidth, altered speech-to-noise ratio and harmonic distortion in hearing aids were mutually inclusive causes of reduction in consonant differentiations.

Intermodulation Distortion/Monosyllabic Word Lists/Sentence Lists

Jerger (1967) found no consistent rank ordering of a group of hearing aids when the C.I.D. W-22 Word Lists, PB Word Lists, CNC Word Lists and the PAL-8 Sentence Intelligibility Test were compared. The sentence intelligibility test did, however, show reliable differences among the aids and rank ordered the best aid first and the worst aid last. Another test, The Intermodulation Distortion Test (IDT) based upon distortion products that are generated when a 1 KHz and 1.6 KHz tone are mixed together was played through hearing aids. The subject's task in a paired comparison paradigm was to judge whether the signal passed through the hearing aid, or a reference signal made up of the same sinusoids not passed through a hearing aid was heard first. Results showed that the IDT could easily differentiate hearing aids and that it was superior to the sentence intelligibility test because it had less inter-subject variance.

Bandwidth/Monosyllabic Word Lists

Olsen and Carhart (1967) while investigating the usefulness of some test procedures for the evaluation of binaural hearing aids, found that speech discrimination was reduced when heard through a hearing aid, when compared with direct reception at comparable signal-to-noise ratios. This finding led the investigators to explore the effects of bandwidth, harmonic distortion and intermodulation distortion on speech intelligibility. The behavioral measures were monosyllabic words in quiet, monosyllables in the presence of competing speech (Bell Telephone Intelligibility Sentences) and Monosyllables in speech spectrum noise. They found that bandwidth was the only electroacoustic characteristic which consistently rank ordered the aids the same way as the speech discrimination scores

Olsen and Wilbur (1967) assessed bandwidth, harmonic distortion, intermodulation distortion and transient response on a group of hearing aids. The behavioral measures recorded through the aids were monosyllables in quiet and monosyllables with intellective masking (Bell Telephone Intelligibility Sentences). Conclusions drawn from the study were that bandwidth was the only physical characteristic which ranked the hearing aids in the same way as the speech discrimination scores, and that monosyllabic words with competition was the only measure which differentiated the hearing aids.

Response Irregularity/Sentence Lists

Jerger and Thelin (1968) assessed the effects of the shape of the frequency response curve, effective bandwidth, harmonic distortion, gain, signal-to-noise ratio and signal-to-hum ratio on speech understanding. The behavioral measure employed was the Synthetic Sentence Identification Test (SSI) constructed by Speaks and Jerger (1965). The test consists of a series of synthetic sentences based upon random or conditional word probabilities. The sentences were approximations to real English sentences, in that they had an appropriate linguistic pattern, but little meaning. The response paradigm of the SSI is closed set, wherein the subject merely indicates which of a group of ten sentences was heard. A high correlation was found between SSI and irregularity of frequency response. The aids which produced the highest speech scores, also had the smoothest frequency response curves. An index of Response Irregularity (IRI) was devised which was roughly proportional to the jaggedness or overall departure from smooth uniform slope in the frequency response and which showed the highest correlation with SSI scores than any other investigated characteristic. They also found that the next highest correlation with SSI scores was bandwidth below 1 KHz and that harmonic distortion was "not a significant source of degradation in speech understanding in the typical modern hearing aid" (p. 172), indeed, SSI scores tended to be higher in those aids showing the greatest distortion.

Intermodulation Distortion/Monosyllabic Word Lists

Olsen (1971a,b) found that aids having the least difference frequency intermodulation distortion (CCIF Method) and broadest bandwidth produced the highest discrimination scores (on a monosyllabic word test with intellective competing message) when persons with sensorineural hearing losses were tested. In an attempt to determine whether the effect on discrimination was due to intermodulation distortion or bandwidth, a study was conducted in which harmonic and intermodulation distortion could be varied (using a peak clipper) and where other performance characteristics could be held relatively constant. Persons with sensorineural hearing loss and excellent speech discrimination in quiet were tested with monosyllables in quiet, with competing message and in the presence of amplitude modulated white noise. Speech discrimination scores in quiet remained unchanged even with high levels of harmonic and intermodulation distortion; in the competing message condition, scores were slightly improved; a slight reduction in performance was noted in the amplitude modulated white noise condition.

Transient Distortion/Quality Judgments

Witter and Goldstein (1971) correlated preference judgments for short passages of continuous discourse recorded through five hearing aids with harmonic distortion, intermodulation distortion, frequency range and transient distortion values of the same aids. Transient distortion correlated higher with subject preferences than frequency range or harmonic distortion. Intermodulation distortion had little effect on the quality judgments. In conclusion, the authors stated that disagreement as to the important electroacoustic characteristics to speech reported in other studies, may have been caused by interaction of various characteristics. Transient response, being an indication of overall linearity (interaction effect) in an electroacoustic system, may therefore, be the most appropriate single measure of the effect a hearing aid will have on intelligibility.

Gain, Bandwidth, IRI, Transient Distortion/Sentence Lists

Smaldino (1972,1973) correlated thirty-one performance characteristics of sixteen hearing aids with behavioral scores on a multiple choice key word in sentences discrimination test (Kent State University Discrimination Test, Berger, 1969). Results showed that fifty-nine percent of the variance in the discrimination test scores could be accounted for by the combination of (in order of strength of effect) white noise gain, bandwidth below 1 KHz, bandwidth above 1 KHz, shape of the frequency response curve and transient distortion. Conclusions included the hypothesis that interactive effects of performance characteristics may dictate the moment to moment effect of the characteristics upon speech understanding.

Quality Judgments, Judged Intelligibility and Revised Monosyllabic Word Lists

Jeffers (1960) constructed eight, one minute selections of continuous discourse and played them through five hearing aids which represented a range of relative flatness of the frequency response curve and gain. Subjects made paired comparisons of the hearing aids, making a preference judgment for the aid that sounded best to them. Results showed that the electroacoustic characteristic differences represented by these hearing aids did affect the quality of speech passed through them and that subjects were excellent judges of the differences.

Zerlin (1962) used a paired comparison technique with six hearing aids. Subjects heard a thirty second long passage of continuous discourse in a background of cafeteria noise. Their task was to decide which passage of the pair was most intelligible, or if equal, which was the most comfortable to listen to. C.I.D. W-22 half lists were recorded through the same aids. Results showed that discrimination scores derived from the W-22 half lists did not differentiate the hearing aids, whereas, the preference judgments yielded clear-cut and reliable differences for five of the six hearing aids.

Speaks et al. (1972) suggested a scaling of intelligibility based upon a decision by the listener as to how well continuous discourse is understood. While the procedure has not been used to differentiate hearing aids, the decisions reached by the listeners correspond well with actual intelligibility scores.

Campbell et al. (1973) revised the C.I.D. W-22 Word Lists. "About seventy percent of the original words were replaced by words more suitable in familiarity and difficulty" (p. 449). The revised lists have not been used to differentiate hearing aids, although the presumed improvement of distribution of difficulty over the original words suggest that they might be useful in hearing aid selection procedures.

In summary, various electroacoustic characteristics of hearing aids have been correlated with a variety of behavioral measures designed to estimate and quantify speech intelligibility. Research results are not in agreement as to which electroacoustic characteristics are most degrading to speech nor is there agreement as to which behavioral measure to use to estimate and quantify speech understanding.

For the purpose of this study measures of harmonic distortion, intermodulation distortion, bandwidth, irregularity of the frequency response, maximum power output and gain were employed. Behavioral measures included monosyllabic word lists, rhyming monosyllables, sentence lists, quality judgments and judged intelligibility.

Purpose of the Study

Results from investigations relating electroacoustic characteristics of hearing aids to behavioral measures designed to estimate and quantify speech intelligibility are in disagreement. Among the reasons conjectured for the disagreement are inadequate appraisal of electroacoustic interactions, use of behavioral measures sensitive to different electroacoustic characteristics and/or interactions, and behavioral measure unreliability.

The purpose of this study was to explore the validity of the reasons conjectured for the disagreement in research results by investigating the effects of various electroacoustic characteristics on several behavioral measures.

The specific questions asked were:

What is the relationship between the electroacoustic characteristics and the behavioral measures?

What is the relationship between the electroacoustic characteristics?

What is the relationship between the behavioral measures?

Which electroacoustic characteristics are influential in affecting the score derived from each behavioral measure and what is the relative weight of the influence of each characteristic?

What is the coefficient of reliability for each of the behavioral measures?

CHAPTER 2
MATERIALS AND PROCEDURES

Ten used hearing aids of several different brands and types were assembled for this investigation. Measurements of frequency response, saturation output, gain, regularity of the frequency response, bandwidth, harmonic distortion and intermodulation distortion were made on each hearing aid. The C.I.D. Auditory Test W-22, the Miami Veterans Administration Discrimination Test, the Modified Rhyme Test, a synthetic sentence measure, a judged intelligibility test using the C.I.D. Everyday Sentences, the C.I.D. Everyday Sentence Test, the Intermodulation Distortion Test and quality judgment material were all recorded through each of the hearing aids and constituted the behavioral test battery. Subjects' responses to these behavioral tests were correlated with the electroacoustic measurements.

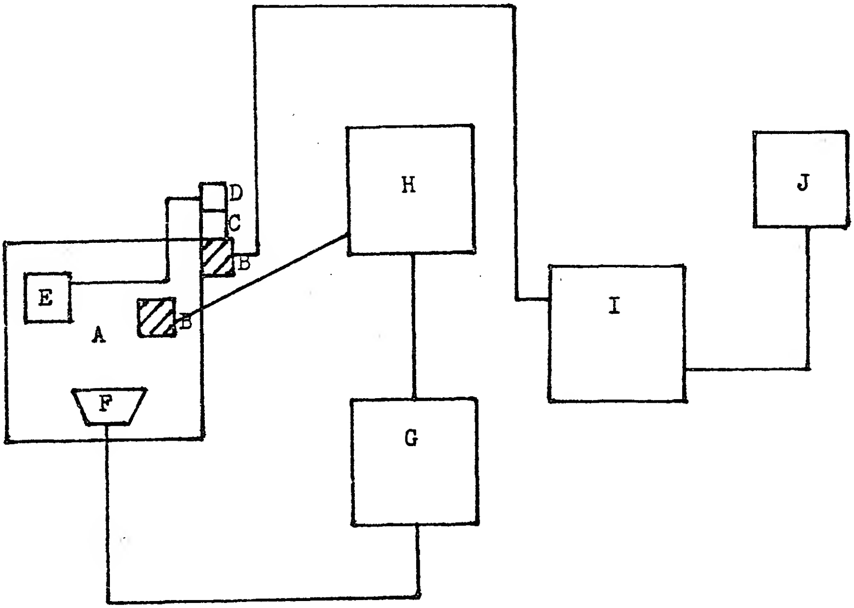
Electroacoustic Measurements

Frequency Response

The electroacoustic characteristics of the microphone, amplifier and receiver of a hearing aid interact so that the gain across frequencies is not linear. Some frequencies are, therefore, amplified to a greater extent than other frequencies. A quantification of this frequency response is a graphic plot

FIGURE 1

BLOCK DIAGRAM OF THE EQUIPMENT USED
FOR OBTAINING FREQUENCY RESPONSE OF
THE HEARING AIDS UNDER INVESTIGATION



A - B&K Type 4212 Hearing Aid Test Chamber
B - B&K Type Condenser Microphone
C - 2cc Coupler
D - Hearing Aid Receiver
E - Hearing Aid Body
F - Speaker
G - B&K Type 1022 Beat Frequency Oscillator
H - B&K Type 2603 Microphone Amplifier
I - B&K Type 2107 Audio Frequency Spectrometer
J - B&K Type 3205 Graphic Level Recorder

FIGURE 2

FREQUENCY RESPONSE CURVE OF AID NUMBER ONE
USING THE 2 CC COUPLER

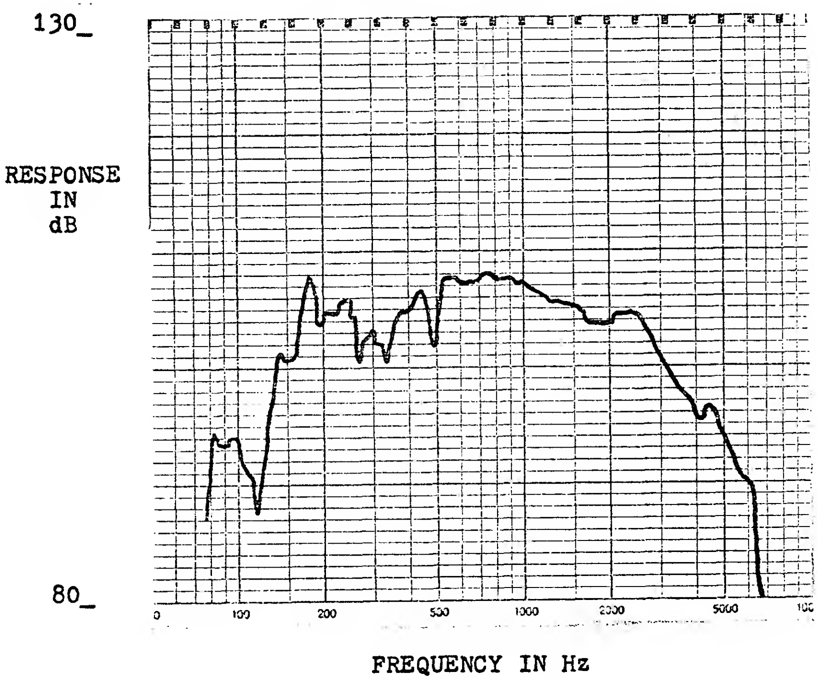
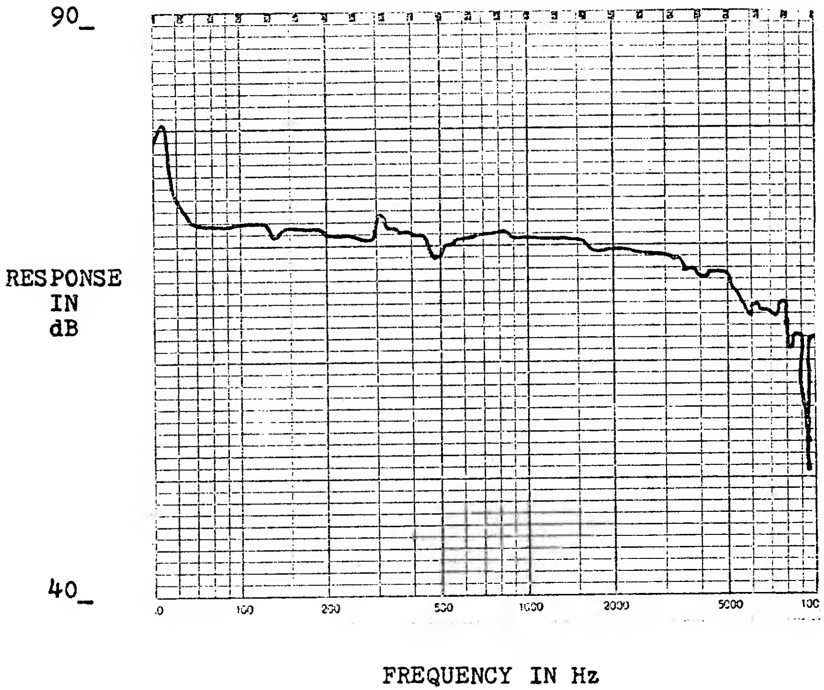


FIGURE 3

FREQUENCY RESPONSE CURVE OF
HEARING AID TEST CHAMBER



with the gain in decibels (dB) on the ordinate and frequency in Hertz (Hz) on the abscissa.

The procedure involves placing the hearing aid under test in a Bruel and Kjaer (B&K) type 4212 hearing aid test chamber (Figure 1). A 1 KHz tone was generated by a B&K type 1022 beat frequency oscillator and introduced into the test chamber by a speaker. The receiver of the hearing aid was coupled to a B&K pressure condenser microphone by a USASI standard 2 cubic centimeter coupler. The output of the coupler was read in dB on a B&K type 2107 audio frequency spectrometer. The voltage of the oscillator was set so that the free field level of a 1 KHz tone in the test chamber was 70 dB SPL. A second B&K condenser microphone, adjacent to the hearing aid microphone acted as the monitor of a compression circuit made up of a B&K type 2603 microphone amplifier and the oscillator. The function of this cybernetic system was to keep the free field sound level constant at 70 dB SPL at the face of the hearing aid microphone. The gain control of the test aid was set to a level 6 dB below its saturation output level, re: the 70 dB, 1 KHz reference tone. The oscillator was automatically swept through the frequency range 10 Hz-10 KHz and the relative gain of the aid for each frequency recorded in dB versus Hz on a B&K type 3205 graphic level recorder. This plot was called the frequency response curve for each test aid (Figure 2 and Appendix A).

Figure 3 shows the response of the B&K 4212 test chamber with a 70 dB input, and is included to provide a baseline response of the system through which the hearing aid response curves were obtained.

Saturation Output (Maximum Power Output)

"At any frequency a hearing aid has a limit to the maximum sound pressure level that it can produce in the test coupler, regardless of the input sound pressure at that frequency. This maximum sound pressure level is called the saturation output" (Berger, 1970, p.85).

The procedure for measurement includes placing the test aid in the chamber and attaching it to a 2 cc coupler as in the measurement of frequency response. The voltage output of the oscillator was increased until, with the aid's gain control set full on, the output of the hearing aid did not increase with a further increment in voltage. This point was obtained for each aid and coupler at 500 Hz, 1 KHz and 2 KHz. The average of these three frequencies was termed the saturation output of each aid.

Gain

Hearing aid amplification systems are not linear and thus do not amplify different frequencies to the same extent. The gain of a hearing aid is defined, under certain conditions, as how much the hearing aid increases the output sound pressure over the input sound pressure when the gain control is set at maximum.

The procedure for measuring gain employed two different input levels. The hearing aid under test was placed in the B&K equipment as described under frequency response. The gain of the hearing aid was set at maximum. The input level for a 500 Hz, 1 KHz and 2 KHz was introduced and monitored at the face of the hearing aid microphone at 50 dB SPL and then 70 dB SPL. The difference between the input level and the output level for each of the three frequencies was termed the gain of the test aid. The average gain of each aid at each level was the average of the gain at the three frequencies.

Index of Response Irregularity (IRI)

The IRI was measured as described by Jerger and Thelin (1968) from the frequency response curve of each test instrument. It is a quantification of the jaggedness or overall departure from smooth uniform slope in an aid's frequency response.

The procedure involved drawing a reference line parallel to the frequency axis at the lowest reversal of the response curve of more than 2.5 dB. Parallel lines were then drawn at 3.0 dB intervals above this reference. The number of crossings of these parallel lines with the response curve, above the reference, was counted and termed the index of response irregularity for that aid.

Bandwidth

Bandwidth is the range of frequencies over which a hearing aid amplification system provides effective amplification. It is specified by a low and high frequency limit of amplification by several methods (Halpike, 1934; Lybarger, 1961 a,b,c; Burnett and Priestley, 1964; USASI, 1960; Berger, 1970).

Hearing Aid Industry Conference (H.A.I.C.) Procedure. H.A.I.C. bandwidth was obtained from the graph of the frequency response curve (Berger, 1970; Lybarger, 1961 a,b,c). The ordinate values, in dB, for 500 Hz, 1 KHz and 2 KHz were averaged and plotted on the 1 KHz ordinate, 15 dB below the first. A straight line was then drawn through this point parallel to the frequency axis. The low and high frequency limits of amplification for that aid were the frequencies where this line first intersected the frequency response curve, moving in the direction of decreasing and increasing frequency, respectively, from 1 KHz.

Houston Speech and Hearing Center (H.S.H.C.) Procedure. H.S.H.C. bandwidth was obtained from the frequency response of each hearing aid (Jerger and Thelin, 1968). A line was drawn "parallel to the frequency axis at 10 dB below the highest point on the response curve" (p.170). The low and high frequency limit of amplification of the test aid was defined as the frequency where the parallel line first intersected the response curve, moving in the direction of decreasing and increasing frequency, respectively, from 1 KHz.

Bandwidth calculations for both the H.A.I.C. and H.S.H.C. procedures were expressed below 1 KHz, above 1 KHz and total.

Harmonic Distortion

If a pure tone of frequency f_0 is passed through a linear electroacoustic system, the output will contain only the f_0, with perhaps, phase and amplitude differences (Davis and Silverman, 1970). If the electroacoustic system is nonlinear, as are most hearing aids, harmonics of the input pure tone frequency, ie., $2f_0$, $3f_0$,...Nf_0 will also be present in the output. Since the frequency range of a hearing aid defines the high and low frequency limits of amplification and acts as an effective filter, low fundamental frequencies will generate more measurable harmonics than high frequencies, because it is probable that more of the former are within the effective handwidth of the hearing aid. The presence of harmonic components of the f_0 within the limits of amplification of a hearing aid is termed harmonic distortion.

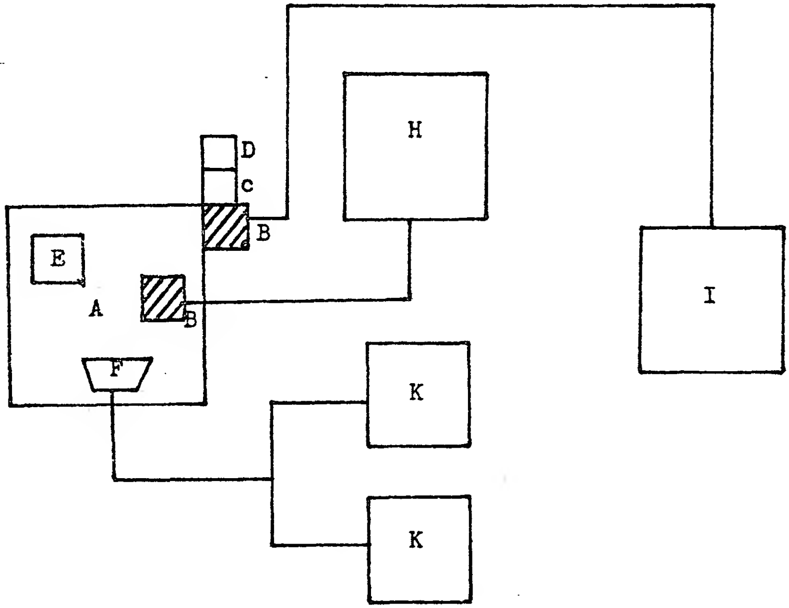
The measurement procedure requires the same instrumentation described for procurement of the frequency response curve (Figure 1). The gain of each hearing aid was set to 6 dB below its saturation output and the input signal was always 70 dB SPL. The filter set on the B&K 2107 audio frequency spectrometer was set to approximate one thire octave. According to the International Electrotechnical Commission Procedure (Berger, 1970) fundamental frequencies of 400 Hz, 1 KHz and 1.5 KHz were used as input signals. The third octave filters were centered on the first through third harmonics of each of the fundamentals, ie., 400 Hz: 800 Hz, 1.2 KHz, 1.6 KHz; 1 KHz: 2 KHz, 3 KHz, 4 KHz; 115 KHz: 3 KHz, 4.5 KHz, 6 KHz and the energy present in dB recorded and termed the harmonic distortion.

Difference Frequency Intermodulation Distortion

The instrumentation shown in the block diagram (Figure 4) was used to generate and measure second (quadratic) and third (cubic) order intermodulation distortion components. The second order (quadratic) component was obtained using the International Telephonic Consultation Committee (C.C.I.F.) Method (C.C.I.F., 1937; Peterson, 1951). Two sinsoidal test

FIGURE 4

BLOCK DIAGRAM OF EQUIPMENT USED FOR OBTAINING QUADRATIC AND CUBIC INTERMODULATION COMPONENTS



A - B&K Type 4212 Hearing Aid Test Chamber
B - B&K Type Condenser Microphone
C - 2cc or Zwislocki Coupler
D - Hearing Aid Receiver
E - Hearing Aid Body
F - Speaker
H - B&K Type 2603 Microphone Amplifier
I - B&K Type 2107 Audio Frequency Spectrometer
K - Hewlet Packard Oscillators

signals (f_1 and $f_1 + \Delta f = f_2$) of equal amplitude (70 dB SPL) were generated by two oscillators and mixed together. The difference in frequency between the two oscillators was kept constant at 400 Hz (Δf). The mixed signal was applied to the speakers in the hearing aid test chamber, where its amplitude was monitored at 70 dB SPL by a B&K condenser microphone and type 2603 microphone amplifier. The output of the hearing aid, located in the test chamber was applied to a B&K type 2107 audio frequency spectrometer and analyzed by a one third octave band accept filter tuned to the difference frequency Δf (400 Hz). f_1 took the values of .5, 1 and 2 KHz for each aid investigated and correspondingly f_2 took the values of .9, 1.4 and 2.4 KHz. The energy, in dB, observed in the 400 Hz band was designated the quadratic difference frequency intermodulation distortion.

The cubic intermodulation measurements were carried out as above, except that the difference frequency measured at the spectrometer was of the form $2f_2 - f_1$. So that when f_1 took on the values .5, 1 and 2 KHz and f_2 took on the values .9, 114 and 2.4 KHz, $2f_2$ was then 1.8, 2.8 and 4.8 KHz and the difference frequencies were 1.3, 1.8 and 2.8 KHz. The dB output of the filters for these difference frequencies was termed the cubic difference frequency intermodulation distortion.

Behavioral Measures

Description of Measures

The following is a brief description of each of the behavioral measures used in this study. Appendix B contains the actual stimulus materials, Appendix C the instructions given to the subjects prior to the presentation of each measure and Appendix D is composed of sample subject response forms.

Central Institute for the Deaf (C.I.D.) Auditory Test W-22. The test is composed of several lists, each made up of fifty monosyllabic words. The words were selected for familiarity and phonetic balance, in that each list approximates the phonetic composition of the English language (Hirsh et al., 1952). Lists 1A and 1C were used in the study and represent different orderings of the same words. Subjects were asked to write down the word they heard. The intelligibility score was denoted as percent correct.

Miami Veterans Administration Discrimination Test. The items on this test were selected from the C.I.D. W-22 word lists in order to improve equivalence among half lists and to improve the distribution of difficulty of test items (Campbell et al., 1973). Two half lists were chosen at random for inclusion in this study. The lists were combined to form one fifty item list. The fifty item list items were ordered in two ways employing a table of random numbers, which resulted in list A and list C. Subjects were required to write down the word they heard. Scores were expressed in terms of percent correct.

Modified Rhyme Test (MRT). The MRT is composed of six different lists, each composed of fifty familiar American-English monosyllabic words. The response sheets are of the closed set multiple choice format with six foils in each block. The word form in each block is consonant-vowel-consonant, consonant-vowel or vowel-consonant. "In all cases only a single initial or final consonant is varied, the remainder of the word is consistent with its foils" (Kruel et al., 1968, p. 538).

Modified Rhyme Hearing Test number one was selected for use in this study. The "a" foil was chosen as the stimulus word. Two orderings from a table of random numbers were labeled lists A and C. The subject's task was to cross out the word in each block that they thought they heard. The percent correct constituted the intelligibility score.

Synthetic Sentence Test. Three, ten sentence sets (seven words each) constructed on the bases of conditional probabilities of word sequences (Speaks and Jerger, 1965) comprise the test. Only the third order set was used in this study. Third order synthetic sentences were constructed by drawing a word at random from a thousand word pool (Thorndike-Lorge, 1944). A subject was asked to pick a word from the same pool which could reasonably follow the first word in a declarative sentence. The second word was given to another subject to choose a third word using the same criteria, etc. In this way a second order synthetic sentence was constructed. Third order sentences were based upon conditional probabilities of word triplets. Word pairs were picked at random from the second order sentences and a subject required to supply a reasonable third word. The last two words of the created triplet were given to another subject to supply a third word, etc., until a seven word sentence was fabricated.

The ten, third order sentences were ordered in two ways using a table of random numbers and were designated lists A and C. Subjects were required to write down the sentence they thought they heard. A percentage score was calculated from the number of correct words divided by the number of possible words.

Central Institute for the Deaf (C.I.D.) Everyday Sentences: Judged Intelligibility. Ten lists of ten sentences each were constructed to represent everyday American speech using specifications laid down by a Working Group (Grant Fairbanks, Chairman) of the Armed Forces National Research Council Committee on Hearing and Bio-Acoustics (Davis and Silverman, 1970). Each list was formed with fifty scorable key words.

The procedure employed in this study was suggested in a paper by Speaks et al. (1972). Each subject was asked to judge the intelligibility of each of ten sentences (0-100 percent) and write the judged percentage on a response sheet. The average of the judged percentages constituted the intelligibility score.

Two orderings of list D were constructed using a table of random numbers and labeled lists A and C.

Central Institute for the Deaf (C.I.D.) Everyday Sentences: Write Down Response. Two orderings of list H were prepared using a table of random numbers and labeled lists A and C.

Subjects were required to write down the sentences they thought they heard. A percentage score was calculated from the number of correct key words.

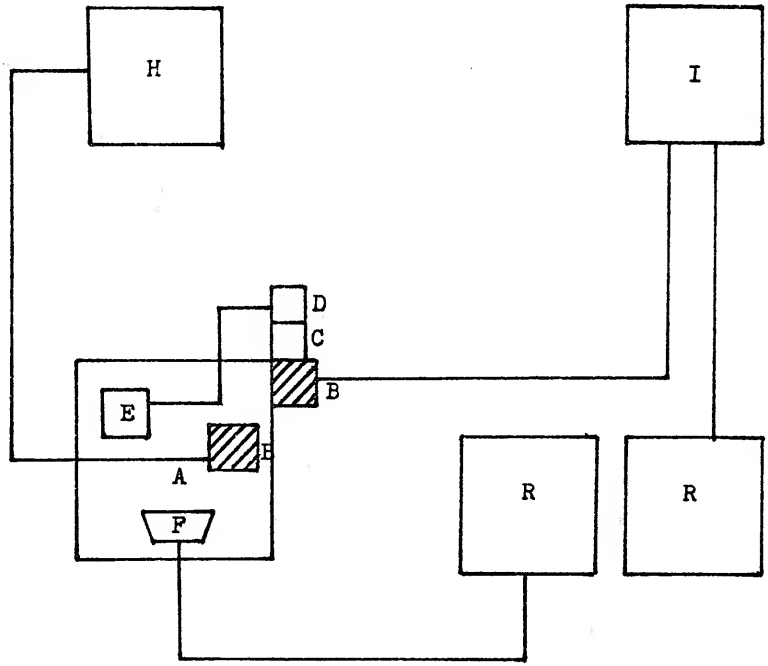
Intermodulation Distortion Test. Jerger (1967) reported the development of a test based upon a subject's ability to detect intermodulation distortion products.

Two pure tones (1 KHz and 1.6 KHz) were generated by oscillators, monitored as to frequency using a frequency counter and set to produce the same voltage output on a vacuum tube voltmeter. The pure tones were combined (intermodulated) and tape recorded at VU=0. The tapes were played through each hearing aid using the equipment shown in Figure 5 and designated the test tone. When these two sinusoids are combined and transduced by a hearing aid, distortion products are created at 400 Hz ($2f_1 - f_2$), 600 Hz ($f_2 - f_1$), 2200 Hz ($2f_2 - f_1$) and 2600 Hz ($f_1 + f_2$) (Jerger, 1967). These products will be present at greater or lesser levels depending on the hearing aid.

An identical intermodulated tone which was recorded on tape but not played through the hearing aids served as a reference tone. The reference tone and test tone were input to the instrumentation shown in Figure 6. The output from this equipment was recorded on tape and consisted of either the reference or test tone of 300 millisecond duration, followed

FIGURE 5

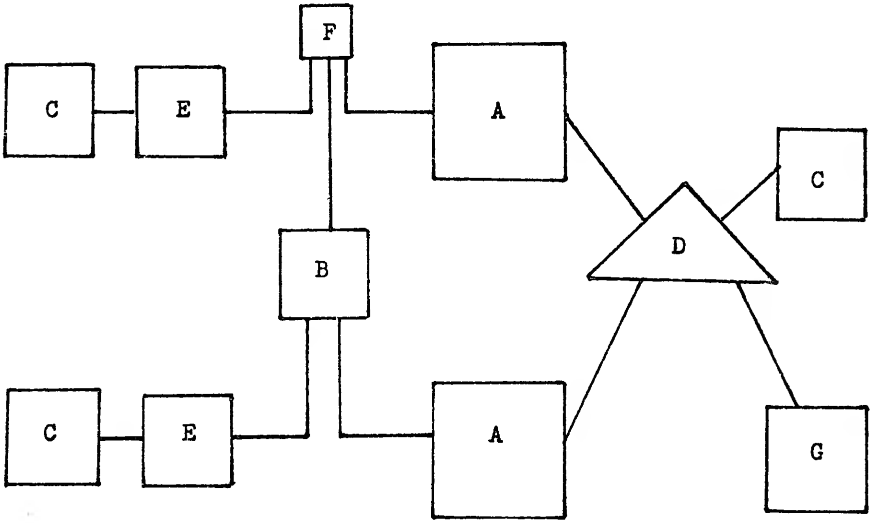
INSTRUMENTATION USED TO RECORD SPEECH DISCRIMINATION TEST THROUGH THE HEARING AIDS UNDER INVESTIGATION



A - B&K Type 4212 Hearing Aid Test Chamber
B - B&K Type Condenser Microphone
C - 2cc Coupler
D - Hearing Aid Receiver
E - Hearing Aid Body
H - B&K Type 2603 Microphone Amplifier
I - B&K Type 2107 Audio Frequency Spectrometer
R - SONY TC 106A

FIGURE 6

THE INSTRUMENTATION USED TO PRODUCE A
300 MSEC REFERENCE TONE, 200 MSEC PAUSE AND
300 MSEC COMPARISON TONE FOR THE INTERMODULATION
DISTORTION TEST



A - Electronic Switch
B - One Shot
C - SONY TC 106A Tape Recorder
D - Audio Mixer
E - Matching Transformer
F - External Trigger
G - Oscilloscope

by a silent interval of 200 milliseconds and then either the test tone or reference tone of 300 millisecond duration. The order of tone presentation was arranged according to a table of random numbers. Each comparison consisted of a reference and test tone. One comparison was made for each of the ten hearing aids under three signal-to-noise ratios.

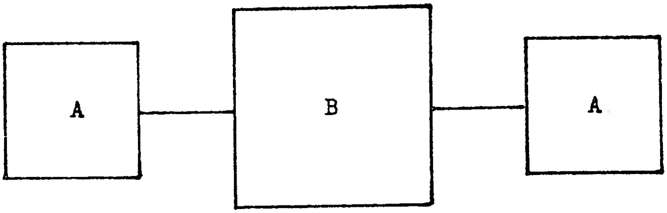
The subjects' task for each comparison was to judge whether they heard the distorted or undistorted sound first. A percentage correct score was calculated for each signal-to-noise ratio.

Quality judgments. A thirty second long passage of continuous discourse was played through each experimental hearing aid (Figure 5). Paired comparisons were constructed in which each hearing aid was the reference against which all the other hearing aids were compared (Table 1). For example, for group one, aid number one was the reference in each binary paired comparison. Each aid was compared once with each reference aid.

Subjects were asked to judge in each paired comparison whether they thought the first or second paragraph was more understandable. The total number of times an aid was judged more understandable, divided by the total number of times it appeared in a comparison resulted in a percentage score for each hearing aid.

FIGURE 7

BLOCK DIAGRAM OF INSTRUMENTATION EMPLOYED TO ELECTRONICALLY MIX SPEECH SPECTRUM NOISE WITH THE BEHAVIORAL MEASURES AT VARIOUS SIGNAL-TO-NOISE RATIOS



A - SONY TC 106A or Wollensak 1520AV Tape Recorder
B - Grason-Stadler Model 162 Speech Audiometer

TABLE 1

THE REFERENCE AND COMPARISON HEARING AIDS
FOR THE PAIRED COMPARISON QUALITY JUDGMENTS

Group	Reference Aid	Comparison Aids
1,11	1	2,3,4,5,6,7,8,9,10
2,12	2	1,3,4,5,6,7,8,9,10
3,13	3	1,2,4,5,6,7,8,9,10
4,14	4	1,2,3,5,6,7,8,9,10
5,15	5	1,2,3,4,6,7,8,9,10
6,16	6	1,2,3,4,5,7,8,9,10
7,17	7	1,2,3,4,5,6,8,9,10
8,18	8	1,2,3,4,5,6,7,9,10
9,19	9	1,2,3,4,5,6,7,8,10
10,20	10	1,2,3,4,5,6,7,8,9

Preparation of Test Recordings

The behavioral measures were recorded on magnetic tape and played through each of the ten hearing aids using the instrumentation shown in Figure 5. The tape recorded measures were played by a SONY TC 106A tape recorder through the speaker of a B&K type 4212 hearing aid test chamber. The overall level of each measure was monitored at 70 dB RMS at the face of the hearing aid microphone in the chamber. The output of the test hearing aid was applied to a condenser microphone fitted with a standard USASI 2 cubic centimeter coupler and fed into a B&K type 2107 audio frequency spectrometer. The spectrometer output was recorded by a second SONY TC 106A at VU=0.

All of the speech materials were recorded by the same native English male speaker with no detectable regionalisms.

The recordings of the behavioral measures which were played through each hearing aid were input to a Grason-Stadler Model 162 speech audiometer and electronically mixed with speech spectrum noise at various signal-to-noise ratios (Figure 7; Table 2). The output of the audiometer was recorded at VU=0 and constituted the test tapes. A 1 KHz calibration tone recorded at the same level as the behavioral measures preceded each test battery tape.

Subjects

Twenty students and faculty at the University of Florida served as subjects for this study. Each was screened for normal hearing (in at least the right ear) re: ANSI (1969).

TABLE 2

THE SIGNAL-TO-NOISE RATIOS AT WHICH EACH BEHAVIORAL MEASURE WAS MIXED WITH SPEECH SPECTRUM NOISE

	S/N Ratio
CID W-22 Word List	+8
VAH Miami Discrimination Word List	+8
Modified Rhyme Test	+2
Synthetic Sentence Discrimination Test	+2
CID Everyday Sentences - Judged Intelligibility	+2
CID Everyday Sentences - Write Down Response	+2
Intermodulation Distortion Test	0,-4,-8
Quality Judgments	+6

The age composition of the subjects fell within the range 20-35 years.

Experimental Design

Each subject listened to the hearing aid and behavioral measure list shown in Table 3. All subjects listened to the same Intermodulation Distortion Test. A reference aid was assigned to each subject for the quality judgments as listed in Table 1.

All subjects listened to the behavioral measure battery twice. The second presentation took place at least five days following the first and provided test-retest information. The order of aid and list combinations were reversed from those shown in Table 3 for the retest presentation.

Behavioral Measure Administration

Subjects were seated at desks in a room with low ambient noise or in a small sound-treated test booth. If seated outside the booth a noise attenuating muff was worn on the nontest ear. Each subject was provided with a TDH-39 earphone in a MX/41 cushion to the right ear, pencil and set of response sheets (Appendix D).

The test tapes were played through a Wollensak Model 1520AV tape recorder. The volume of the recorder was adjusted so that the 1 KHz calibration tone which preceded each test battery registered 80 dB SPL, through the earphone in a standard 6 cubic centimeter coupler, on a B&K sound level meter.

Prior to each test, the appropriate instructions were read to the subject (Appendix C). The order of test presentation was the same as the ordering of the instructions.

TABLE 3

THE HEARING AIDS THROUGH WHICH THE BEHAVIORAL MEASURES WERE RECORDED FOR EACH GROUP AND THE ORDERINGS OF THE BEHAVIORAL MEASURE TEST ITEMS (A OR C) FOR EACH GROUP

Group	Aid and Behavioral Measure Designation
1	1A,2C
2	2C,3A
3	3A,4C
4	4C,5A
5	5A,6C
6	6C,7A
7	7A,8C
8	8C,9A
9	9A,10C
10	10C,1A
11	1A,6C
12	2C,7A
13	3A,8C
14	4C,9A
15	5A,10C
16	8C,1A
17	9A,2C
18	10C,3A
19	7C,5A
20	6C,4A

Derivation of the Behavioral Scores Assigned to Each Hearing Aid

Each hearing aid was heard by four subjects (Table 3). The average score on each of the tests comprising the behavioral battery was computed for the four subjects that listened to each hearing aid. In this way a mean behavioral score on each test was associated with every one of the hearing aids.

In the case of the quality judgments, the total number of times each aid was judged more understandable was converted to a percentage of the total number of times the aid appeared in a comparison. This percentage was assigned as the quality judgment score for every aid.

The Intermodulation Distortion Test was scored as the percentage of times a subject made a correct choice through each hearing aid. The number of correct choices was divided by the total number of times the aid appeared in a comparison.

CHAPTER 3
RESULTS AND DISCUSSION

Results

The purpose of this investigation was to examine the validity of reasons surmised for disagreement in research results relating electroacoustic characteristics of hearing aids and behavioral measures. The specific question, statistical approaches and results were:

What is the Relationship Between the Electroacoustic Characteristics and the Behavioral Measures?

Table 4 shows the Pearson product-moment coefficient matrix for all electroacoustic characteristics and behavioral measures. In Table 5 the four characteristics having the highest correlation coefficients with each behavioral measure have been arbitrarily chosen. These highlight the fact that the highest correlations with each measure occur with different characteristics and with different relative strength. Measures of harmonic distortion, maximum power output, gain, bandwidth and regularity of the frequency response achieved the highest correlations with the behavioral measures. These correlations were, in the majority of cases, negative.

What is the Relationship Between Electroacoustic Characteristics?

As shown in Table 4 some characteristics are naturally correlated because they are a measure of the same independent

TABLE 4

THE PEARSON CORRELATION MATRIX BETWEEN THE ELECTROACOUSTIC CHARACTERISTICS AND BEHAVIORAL MEASURES, AND THE LEGEND TO ABBREVIATIONS USED IN THE MATRIX

TABLE 4 - CONTINUED

	MPO5	MPO1	MPO2	MPOA	GF5	GF1	GF2	GFA	GS5	GS1
MPO5	1.00000	0.87322	0.91081	0.93523	0.86122	0.82790	0.69737	0.84517	0.78806	0.84068
MPO1	0.87322	1.00000	0.83681	0.86069	0.68646	0.65221	0.50175	0.65379	0.51707	0.61696
MPO2	0.91081	0.83681	1.00000	0.85129	0.58651	0.71903	0.72450	0.71170	0.48126	0.67625
MPOA	0.93523	0.86069	0.85129	1.00000	0.74023	0.76767	0.67317	0.77061	0.61815	0.74595
GF5	0.86122	0.68646	0.58651	0.74023	1.00000	0.88974	0.72551	0.92910	0.96298	0.89230
GF1	0.82790	0.65221	0.71903	0.76767	0.88974	1.00000	0.90812	0.98640	0.90512	0.98154
GF2	0.69737	0.50175	0.72450	0.67317	0.72551	0.90812	1.00000	0.92040	0.77233	0.88712
GFA	0.84517	0.65379	0.71170	0.77061	0.92910	0.98640	0.92040	1.00000	0.93225	0.97392
GS5	0.78806	0.51707	0.48126	0.61815	0.96298	0.90512	0.77233	0.93225	1.00000	0.92833
GS1	0.84068	0.61696	0.67625	0.74595	0.89230	0.98154	0.88712	0.97392	0.92833	1.00000
GS2	0.83074	0.64555	0.80341	0.70755	0.79227	0.95304	0.95379	0.94727	0.82346	0.95786
GSA	0.85010	0.61025	0.66715	0.74172	0.91634	0.97406	0.80642	0.98310	0.95232	0.95418
HDA	0.75719	0.53752	0.50224	0.62614	0.96060	0.91815	0.79023	0.95173	0.97740	0.91371
HDB	0.79043	0.71290	0.64248	0.74620	0.90080	0.76026	0.65856	0.82605	0.85528	0.77501
HD12	0.77861	0.79084	0.68003	0.70025	0.83665	0.69602	0.55714	0.76627	0.74826	0.69439
HD16	0.78519	0.76748	0.58161	0.77060	0.86714	0.73952	0.62083	0.79180	0.75719	0.74329
HD4A	0.81708	0.72847	0.65234	0.76471	0.94090	0.82323	0.70119	0.87531	0.89371	0.82803
HD1	0.87185	0.65760	0.72130	0.78485	0.89372	0.98208	0.80554	0.97719	0.91670	0.95667
HD2	0.75121	0.57088	0.71308	0.72403	0.76903	0.88950	0.83806	0.90208	0.81747	0.91763
HD3	0.76088	0.63029	0.74633	0.74829	0.72778	0.83490	0.78340	0.82839	0.77122	0.87703
HDAA	0.72572	0.55509	0.55753	0.67711	0.71407	0.79312	0.74734	0.79717	0.78827	0.86677
HDAD	0.76073	0.62594	0.74114	0.75743	0.79705	0.90357	0.95726	0.90077	0.84456	0.93240
HD15	0.67900	0.40633	0.59533	0.58593	0.72689	0.85368	0.88625	0.86544	0.83012	0.90660
HD3K	0.70651	0.46789	0.64283	0.63339	0.72607	0.92548	0.85109	0.80402	0.81408	0.87508
HD45	0.67260	0.67756	0.54147	0.62574	0.65034	0.74050	0.76504	0.75719	0.73512	0.80304
HD6	0.63429	0.45801	0.62075	0.55873	0.68658	0.73372	0.75563	0.75160	0.73540	0.77537
HDAC	0.59081	0.45695	0.63102	0.61751	0.69560	0.79759	0.82520	0.81403	0.78775	0.85636
OIMD5	0.87940	0.60886	0.65004	0.78250	0.95954	0.97124	0.84400	0.99179	0.96113	0.96372
OIMD1	0.78851	0.55276	0.72836	0.73252	0.93038	0.91421	0.64550	0.95200	0.85585	0.93131
OIMD2	0.53084	0.32600	0.44388	0.45127	0.60432	0.59048	0.75407	0.67653	0.61523	0.56685
OIMDA	0.83521	0.62184	0.70548	0.75337	0.90635	0.94547	0.93093	0.98248	0.91410	0.93746
O'MD5	0.82356	0.50902	0.55352	0.72367	0.87960	0.94043	0.84840	0.94223	0.91653	0.94752
O'MD1	0.81216	0.63372	0.51542	0.67058	0.90249	0.81090	0.60890	0.82728	0.88424	0.84185
O'MD2	0.65059	0.39679	0.59527	0.56260	0.63826	0.71972	0.85517	0.77270	0.67135	0.71020
O'MDA	0.83987	0.60757	0.63277	0.72381	0.89551	0.90385	0.82209	0.92637	0.91171	0.92605
HAIC4	0.13317	0.01189	-0.17256	-0.01577	0.12221	-0.02140	-0.11140	0.00008	0.02705	-0.06526
HAIC8	-0.17052	-0.46157	-0.47136	-0.46607	0.02827	-0.09207	-0.00384	0.00869	0.05792	-0.06415
HAICT	0.09813	-0.03641	-0.21410	-0.06311	0.11892	-0.02053	-0.10614	0.00182	0.03157	-0.07169
HSHC4	-0.33730	-0.20955	-0.19552	-0.26861	-0.53460	-0.39926	-0.31940	-0.44803	-0.62578	-0.50303
HSHC8	-0.30686	-0.30310	-0.22713	-0.40275	-0.02421	-0.18609	-0.32485	-0.18057	-0.04869	-0.23506
HSHCT	-0.40639	-0.26331	-0.32690	-0.34506	-0.43773	-0.38414	-0.37123	-0.42276	-0.51926	-0.49470
TPI	0.37372	0.08604	0.05046	0.17343	0.19229	0.11489	0.06705	0.13681	0.26631	0.24622
CIO	-0.79980	-0.65851	-0.45371	-0.63725	-0.81779	-0.65037	-0.43249	-0.68076	-0.76734	-0.69461
VAH	-0.73223	-0.67311	-0.38549	-0.61839	-0.78821	-0.54737	-0.30062	-0.59227	-0.65035	-0.54303
MET	-0.75464	-0.56666	-0.30843	-0.56070	-0.69330	-0.45456	-0.10870	-0.45368	-0.63192	-0.53097
SST	-0.36124	-0.26020	-0.01389	-0.21483	-0.55333	-0.20926	-0.17198	-0.36975	-0.47770	-0.28146
ESJ	-0.44298	-0.37469	-0.17477	-0.34162	-0.30857	-0.09549	0.02602	-0.14179	-0.26743	-0.12356
ESW	-0.21762	-0.06251	0.15665	-0.03374	-0.13092	0.19760	0.23582	0.09912	-0.10805	0.08603
OJ	-0.25356	-0.32840	-0.02514	-0.21020	-0.28485	0.04826	0.23081	-0.01295	-0.21181	-0.02990
IMOTD	-0.40228	-0.51403	-0.52627	-0.51029	-0.15591	-0.42113	-0.24058	-0.29255	-0.12530	-0.40585
IMOT4	-0.36191	-0.25112	-0.15174	-0.27819	-0.19370	-0.19897	0.01093	-0.14144	-0.15064	-0.24048
IMOT8	-0.50986	-0.62395	-0.63023	-0.62299	-0.25754	-0.45745	-0.28036	-0.35289	-0.16214	-0.41620

TABLE 4 - CONTINUED

	GS2	GSA	HD4	HD8	HD12	HD16	HDAA	HD1	HD2	HD3
MPD5	0.83064	0.85010	0.76719	0.79043	0.77861	0.78518	0.81708	0.87185	0.75121	0.76088
MPD1	0.64555	0.61095	0.53752	0.71290	0.70984	0.76748	0.72947	0.65760	0.57988	0.63029
MPD2	0.80341	0.66915	0.50224	0.54248	0.68903	0.68461	0.65294	0.72130	0.73908	0.74693
MPDA	0.79755	0.74172	0.62514	0.74620	0.73025	0.77940	0.76471	0.78485	0.72403	0.74929
CF5	0.79227	0.91634	0.96560	0.90080	0.83565	0.86714	0.94080	0.89372	0.76903	0.72778
CF1	0.95304	0.97406	0.91335	0.76926	0.69602	0.73952	0.82323	0.98208	0.89950	0.63480
CF2	0.95379	0.95642	0.79323	0.66856	0.55714	0.62083	0.70119	0.80554	0.89896	0.79340
CFA	0.94727	0.98310	0.95173	0.82695	0.74427	0.79190	0.87531	0.97719	0.90209	0.82839
GS5	0.92346	0.95232	0.97749	0.85588	0.74926	0.79718	0.89371	0.91670	0.91747	0.77122
GS1	0.95786	0.99418	0.91371	0.77501	0.60838	0.74329	0.82803	0.99467	0.91763	0.87703
GS2	1.00000	0.95472	0.91386	0.72657	0.65338	0.70053	0.76441	0.96921	0.94965	0.90604
GSA	0.95472	1.00000	0.93531	0.81550	0.72631	0.77464	0.85987	0.99174	0.92235	0.87764
HD4	0.91386	0.93551	1.00000	0.94135	0.73786	0.78728	0.89065	0.90419	0.78820	0.70522
HD8	0.72657	0.81550	0.94135	1.00000	0.96905	0.93540	0.99102	0.77251	0.79273	0.79060
HD12	0.65338	0.72631	0.73786	0.96905	1.00000	0.99455	0.96157	0.69764	0.73819	0.75580
HD16	0.70053	0.77464	0.78728	0.98540	0.99455	1.00000	0.98066	0.74048	0.78537	0.78437
HDAA	0.76441	0.85987	0.89065	0.99102	0.96157	0.98066	1.00000	0.82353	0.81639	0.79352
HD1	0.96921	0.99174	0.90412	0.77251	0.69764	0.74048	0.82353	1.00000	0.91166	0.87887
HD2	0.94365	0.92235	0.78820	0.79273	0.73919	0.78537	0.81639	0.91166	1.00000	0.96184
HD3	0.90604	0.87764	0.70522	0.78060	0.75590	0.78437	0.79352	0.87887	0.96184	1.00000
HDA4	0.87072	0.86834	0.69639	0.76680	0.72739	0.75760	0.77447	0.86128	0.93031	0.93256
HD8B	0.95129	0.94049	0.79341	0.80254	0.75435	0.79239	0.82657	0.93812	0.99169	0.94680
HD15	0.91947	0.91095	0.77454	0.70967	0.60894	0.67356	0.73204	0.88000	0.96556	0.91535
HD3K	0.90835	0.95361	0.74306	0.74364	0.66157	0.71781	0.75560	0.97419	0.96627	0.94232
HD45	0.84981	0.82247	0.54208	0.73906	0.68601	0.72900	0.73343	0.80247	0.94308	0.95675
HD6	0.83573	0.91445	0.64690	0.75763	0.70441	0.74623	0.74899	0.78893	0.94161	0.95028
HDAC	0.88837	0.57048	0.71014	0.74567	0.67272	0.72480	0.75113	0.84837	0.96516	0.95423
OIMD5	0.91917	0.97180	0.35692	0.83391	0.76420	0.80136	0.88593	0.97144	0.86635	0.81481
OIMD1	0.95264	0.94385	0.86042	0.78801	0.70833	0.76598	0.82332	0.93070	0.95641	0.84097
OIMD2	0.61410	0.62025	0.67238	0.61235	0.44317	0.59511	0.59233	0.57805	0.53170	0.34660
OIMDA	0.93441	0.95976	0.93420	0.53621	0.73135	0.78502	0.85771	0.94334	0.89006	0.79607
CIMD5	0.92569	0.96821	0.95232	0.83007	0.76774	0.81139	0.87025	0.95202	0.95523	0.91665
CIMD1	0.72713	0.84024	0.86669	0.86017	0.82355	0.84657	0.89359	0.82202	0.77074	0.76967
CIMD2	0.79490	0.74839	0.65300	0.59452	0.45913	0.52549	0.60264	0.73106	0.75978	0.63566
CIMDA	0.98437	0.93870	0.90119	0.84673	0.77198	0.81442	0.87848	0.91616	0.90371	0.85309
HAICA	-0.15170	-0.06193	0.11515	-0.18745	-0.24467	-0.23929	-0.13719	-0.04266	-0.34994	-0.44903
HAICD	-0.20872	-0.07889	0.13692	-0.17267	-0.28144	-0.23754	-0.11646	-0.12411	-0.24837	-0.43167
HAICT	-0.16556	-0.06694	0.12366	-0.19577	-0.26145	-0.25073	-0.14226	-0.05333	-0.35690	-0.44989
HSHCA	-0.42646	-0.54168	-0.43251	-0.67381	-0.65125	-0.67671	-0.65309	-0.47294	-0.62906	-0.68399
HSHCD	-0.36595	-0.22637	0.03540	-0.23359	-0.30152	-0.30948	-0.20283	-0.23600	-0.52667	-0.54380
HSHCT	-0.47469	-0.51033	-0.18699	-0.63019	-0.62714	-0.65128	-0.59637	-0.45619	-0.68607	-0.72969
IOI	0.20254	0.24674	0.12100	0.05259	-0.00074	0.01791	0.05400	0.25655	0.14225	0.10696
CIO	-0.54721	-0.65389	-0.73981	-0.88544	-0.50886	-0.90016	-0.83440	-0.65509	-0.61884	-0.61981
VAH	-0.38440	-0.55330	-0.60384	-0.71222	-0.72939	-0.71350	-0.74213	-0.53271	-0.34201	-0.30719
HOT	-0.39222	-0.54411	-0.54724	-0.53595	-0.52935	-0.51877	-0.55918	-0.54901	-0.32220	-0.30523
SST	-0.11295	-0.30892	-0.54572	-0.40033	-0.44144	-0.44641	-0.50482	-0.25095	-0.07182	0.04805
FSJ	-0.11170	-0.20098	-0.18977	-0.49308	-0.54158	-0.50772	-0.44330	-0.15797	-0.22360	-0.22284
FSW	0.17849	0.04796	-0.02553	-0.24825	-0.23164	-0.21470	-0.19197	0.11131	0.11198	0.02366
OJ	0.09521	-0.05775	-0.13648	-0.51593	-0.59602	-0.54402	-0.45606	-0.00236	-0.05995	-0.13102
IMDTD	-0.41246	-0.32077	-0.11772	-0.10689	-0.23942	-0.20152	-0.17032	-0.40285	-0.35324	-0.43622
IMDTA	-0.12912	-0.17930	-0.12362	-0.14106	-0.24865	-0.22500	-0.18767	-0.18745	-0.18049	-0.16199
IMDTB	-0.46805	-0.35853	-0.17729	-0.15217	-0.26986	-0.24061	-0.21697	-0.44822	-0.40615	-0.49503

TABLE 4 - CONTINUED

	HD44	HDAB	HD15	HD3K	HD45	HD6	HDAC	QIMD5	QIMD1	QIMD2
MDD5	0.72572	0.70979	0.67900	0.70681	0.67240	0.63429	0.69081	0.87940	0.78851	0.53088
MDD1	0.55509	0.62594	0.40693	0.46780	0.47756	0.45901	0.45605	0.69886	0.58276	0.32500
MDD2	0.65783	0.74114	0.33533	0.64083	0.64147	0.62075	0.63102	0.69004	0.72806	0.44388
MDD4	0.67711	0.78743	0.59593	0.63339	0.63574	0.50873	0.61781	0.78990	0.73282	0.48127
GE5	0.71457	0.75705	0.72490	0.72607	0.63014	0.64649	0.69560	0.98054	0.83038	0.62432
GE1	0.79012	0.90357	0.65358	0.82549	0.74050	0.73372	0.79759	0.97124	0.93421	0.59048
GE2	0.74734	0.85726	0.88625	0.85109	0.76504	0.75963	0.82520	0.84450	0.94550	0.75407
GE4	0.79717	0.90077	0.86644	0.84402	0.75719	0.75159	0.81403	0.98179	0.95200	0.67653
GS5	0.79827	0.84456	0.83012	0.81308	0.73512	0.73540	0.78775	0.94313	0.85095	0.61923
GS1	0.86677	0.93530	0.90000	0.87308	0.80004	0.79837	0.85636	0.96379	0.93331	0.56685
GS2	0.87072	0.85128	0.91947	0.90835	0.84081	0.83573	0.88937	0.91017	0.95264	0.61410
GSA	0.86894	0.94049	0.91095	0.89361	0.82247	0.81445	0.87048	0.97180	0.94385	0.62225
HD4	0.49690	0.79341	0.77454	0.74305	0.64208	0.64690	0.71014	0.95692	0.86042	0.67038
HD8	0.76680	0.80254	0.70947	0.74364	0.73906	0.75763	0.74567	0.83391	0.78991	0.61235
HD12	0.72739	0.75435	0.69934	0.66157	0.68601	0.70441	0.67272	0.76420	0.70883	0.44817
HD15	0.75760	0.79239	0.67356	0.71781	0.72900	0.74623	0.72490	0.80136	0.76598	0.50511
HDAA	0.77447	0.82657	0.73294	0.75560	0.73343	0.74909	0.75113	0.88593	0.82332	0.59233
HD1	0.95128	0.93812	0.99300	0.87418	0.80247	0.75833	0.84837	0.97146	0.93070	0.57905
HD2	0.93031	0.98169	0.96556	0.96627	0.94308	0.94181	0.96516	0.85635	0.95641	0.53170
HD3	0.99256	0.95680	0.91539	0.94232	0.95675	0.95029	0.95423	0.81481	0.86067	0.38660
HD44	1.00000	0.97285	0.91437	0.94177	0.96264	0.96799	0.95740	0.79175	0.92929	0.36132
HDAB	0.97285	1.00000	0.94029	0.96039	0.94647	0.94502	0.96115	0.87950	0.92146	0.47593
HD15	0.91437	0.94029	1.00000	0.98961	0.95019	0.93933	0.98113	0.80902	0.94091	0.53999
HD3K	0.94177	0.96039	0.93961	1.00000	0.97970	0.96706	0.99565	0.79468	0.92707	0.50315
HD45	0.96264	0.94647	0.75919	0.97970	1.00000	0.99296	0.99190	0.71149	0.85972	0.40739
HD6	0.96790	0.94502	0.73333	0.96706	0.99296	1.00000	0.98502	0.70650	0.84176	0.41415
HDAC	0.95740	0.96115	0.98113	0.99565	0.99190	0.98502	1.00000	0.76419	0.90287	0.47193
QIMD5	0.79175	0.97950	0.80302	0.79468	0.71149	0.70650	0.76419	1.00000	0.89222	0.61380
QIMD1	0.92929	0.92146	0.94091	0.92707	0.85972	0.84176	0.90287	0.89222	1.00000	0.65378
QIMD2	0.36132	0.47593	0.53999	0.50315	0.40739	0.41415	0.47193	0.61380	0.65378	1.00000
QIMDA	0.76191	0.87189	0.86516	0.84385	0.75541	0.74780	0.81258	0.95069	0.95555	0.78554
CIMD5	0.99619	0.96775	0.92485	0.91122	0.86814	0.86300	0.90250	0.93457	0.93387	0.53403
CIMD1	0.74508	0.80005	0.70322	0.70192	0.67485	0.69192	0.69931	0.89660	0.73907	0.45668
CIMD2	0.56219	0.69306	0.77125	0.74048	0.65121	0.62970	0.70642	0.72890	0.81349	0.81959
CIMDA	0.91401	0.90942	0.96915	0.85264	0.73277	0.72502	0.83886	0.93513	0.89767	0.62925
HAICA	-0.48685	-0.34755	-0.30924	-0.35980	-0.40645	-0.55398	-0.43419	0.07109	-0.13590	0.19937
HAICB	-0.43906	-0.32925	-0.19404	-0.30428	-0.44907	-0.41378	-0.34340	-0.01019	-0.09996	0.20433
HAICT	-0.50750	-0.36351	-0.31359	-0.37304	-0.51764	-0.56853	-0.44763	0.06642	-0.11924	0.21065
HSHCA	-0.75595	-0.65655	-0.67315	-0.72477	-0.78613	-0.79709	-0.75410	-0.43997	-0.53401	-0.12042
HSHCB	-0.50481	-0.47511	-0.40999	-0.56052	-0.65640	-0.61466	-0.59042	-0.10039	-0.43004	-0.01759
HSHCT	-0.77241	-0.65568	-0.71207	-0.77239	-0.85268	-0.84815	-0.80559	-0.39603	-0.57953	-0.11047
TOT	0.29123	0.22200	0.29954	0.33683	0.32610	0.23507	0.30303	0.15649	0.20626	-0.02965
CID	-0.67009	-0.66502	-0.52333	-0.55476	-0.57040	-0.59760	-0.57105	-0.70677	-0.61177	-0.33982
VAH	-0.30584	-0.38019	-0.25554	-0.26525	-0.22157	-0.20437	-0.24005	-0.64745	-0.45961	-0.40661
MRT	-0.44759	-0.63635	-0.34153	-0.33472	-0.36419	-0.30970	-0.35440	-0.57519	-0.38642	-0.16642
SST	0.01675	-0.66130	-0.04595	-0.01245	0.06112	0.05853	0.01435	-0.37551	-0.25599	-0.50960
SSJ	-0.30476	-0.25549	-0.15519	-0.19842	-0.29952	-0.29647	-0.24057	-0.20106	-0.14278	-0.15405
SSW	0.04323	0.09249	0.07323	0.03498	-0.02022	0.01007	0.02387	0.05478	0.07503	-0.19277
QJ	-0.21929	-0.12150	0.02942	-0.04380	-0.16274	-0.19411	-0.09404	-0.10010	0.04224	0.02965
IMDTD	-0.41931	-0.41557	-0.23265	-0.23859	-0.28286	-0.25957	-0.25967	-0.30034	-0.26916	0.26906
IMDTA	-0.15601	-0.18139	-0.13946	-0.13474	-0.17014	-0.11193	-0.14165	-0.15021	-0.20613	0.21472
IMDTB	-0.38653	-0.45052	-0.26705	-0.28721	-0.20809	-0.27235	-0.28388	-0.42466	-0.30213	0.19197

TABLE 4 - CONTINUED

	QIMDA	CIMD5	CIMD1	CIMD2	CIMDA	HAICA	HAICB	HAICT	HSHCA	HSHCB
MPD5	0.93621	0.82356	0.91215	0.65058	0.83937	0.13317	-0.37052	0.08813	-0.38730	-0.30684
MPD1	0.62184	0.59902	0.63372	0.39579	0.60757	0.01182	-0.46157	-0.03641	-0.20956	-0.30310
MPD2	0.70548	0.65452	0.51542	0.58627	0.63277	-0.17206	-0.49136	-0.21410	-0.19652	-0.52913
MPDA	0.75337	0.72367	0.68358	0.56260	0.72381	-0.01577	-0.46607	-0.06311	-0.26861	-0.49275
GF5	0.90635	0.87960	0.90239	0.63826	0.89591	0.12221	0.02927	0.11892	-0.53450	-0.02421
GF1	0.94547	0.54049	0.91370	0.71972	0.90395	-0.02140	-0.00207	-0.02053	-0.39926	-0.19608
GF2	0.93963	0.86840	0.63390	0.85517	0.82209	-0.11140	-0.00384	-0.10614	-0.31940	-0.32455
GFA	0.93248	0.94223	0.52729	0.77273	0.92637	0.00095	0.00869	0.00182	-0.44903	-0.19057
GS5	0.91410	0.91653	0.89424	0.67135	0.91171	0.02705	0.05792	0.03167	-0.62578	-0.04869
GS1	0.93796	0.56752	0.84185	0.71620	0.92609	-0.06526	-0.09415	-0.07168	-0.50693	-0.23604
GS2	0.93461	0.92568	0.72713	0.79490	0.88437	-0.15170	-0.20872	-0.15556	-0.42646	-0.30585
GSA	0.95976	0.96821	0.84324	0.74809	0.93870	-0.06183	-0.07988	-0.06684	-0.54169	-0.22637
HD4	0.91420	0.85232	0.85659	0.69300	0.90119	0.11515	0.10692	0.12966	-0.49261	0.03640
HD8	0.93621	0.83007	0.85017	0.59452	0.84673	-0.13745	-0.17267	-0.19577	-0.67391	-0.23959
HD12	0.73135	0.76774	0.32955	0.45913	0.77108	-0.24457	-0.29344	-0.26145	-0.65125	-0.30152
HD16	0.78502	0.81139	0.91657	0.52549	0.81442	-0.23928	-0.23754	-0.25073	-0.67671	-0.30848
HDAA	0.86771	0.57025	0.93359	0.60264	0.87849	-0.13719	-0.11646	-0.14226	-0.65309	-0.20293
HD1	0.74334	0.95202	0.92292	0.73106	0.91616	-0.04266	-0.12411	-0.09333	-0.47284	-0.23600
HD2	0.82006	0.95523	0.77274	0.75378	0.90371	-0.34824	-0.24937	-0.35690	-0.62906	-0.52557
HD3	0.79607	0.91595	0.76367	0.63566	0.85398	-0.44903	-0.43167	-0.46989	-0.68322	-0.54390
HD4A	0.75151	0.86419	0.74508	0.56219	0.81491	-0.48695	-0.43909	-0.50750	-0.75596	-0.50453
HD4B	0.87182	0.55775	0.90205	0.69306	0.89842	-0.34755	-0.32525	-0.36351	-0.65655	-0.47511
HD15	0.86516	0.92485	0.70522	0.77125	0.86916	-0.30924	-0.19403	-0.31355	-0.67335	-0.49989
HD3K	0.84395	0.91122	0.70192	0.74048	0.85224	-0.35999	-0.30428	-0.37306	-0.72477	-0.56052
HD45	0.75541	0.86914	0.57485	0.65121	0.79977	-0.42545	-0.44397	-0.51764	-0.78615	-0.65640
HD6	0.74782	0.86350	0.69192	0.62970	0.79592	-0.55389	-0.41378	-0.56853	-0.79709	-0.61666
HDAC	0.81258	0.90250	0.69231	0.75642	0.83986	-0.43419	-0.34340	-0.44763	-0.75410	-0.59942
QIMD5	0.95062	0.93457	0.88460	0.72989	0.93513	0.07108	-0.01019	0.06642	-0.43927	-0.10032
QIMD1	0.95555	0.93397	0.71327	0.81349	0.89767	-0.13520	-0.00906	-0.13924	-0.53601	-0.43004
QIMD2	0.74964	0.53803	0.45358	0.81859	0.62825	0.19907	0.20433	0.21095	-0.12042	-0.01759
QIMDA	1.00000	0.91742	0.73776	0.85446	0.92756	0.03243	0.01143	0.03198	-0.43295	-0.21395
CIMD5	0.91742	1.00000	0.90736	0.74702	0.97473	-0.15476	-0.13931	-0.16131	-0.61918	-0.34973
CIMD1	0.73776	0.90736	1.00000	0.60962	0.53984	0.00961	-0.08537	0.00331	-0.58821	-0.13514
CIMD2	0.85446	0.74702	0.60962	1.00000	0.82410	0.13870	0.00927	0.13262	-0.24509	-0.34133
CIMDA	0.92756	0.97473	0.53984	0.82410	1.00000	-0.01608	-0.08659	-0.02420	-0.55325	-0.28756
HAICA	0.03243	-0.15476	0.30361	0.13870	-0.01608	1.00000	0.44996	0.33574	0.53161	0.52973
HAICB	0.01143	-0.13931	-0.25537	0.00927	-0.08659	0.44996	1.00000	0.53042	0.33849	0.72553
HAICT	0.03198	-0.16131	0.00331	0.13262	-0.02420	0.33574	0.53042	1.00000	0.53259	0.57780
HSHCA	-0.43285	-0.61918	-0.58821	-0.24509	-0.55325	0.53161	0.33849	0.53259	1.00000	0.43639
HSHCB	-0.21585	-0.36573	-0.13514	-0.34133	-0.28756	0.52973	0.72553	0.57780	0.43639	1.00000
HSHCT	-0.42420	-0.61630	-0.51744	-0.31459	-0.54327	0.60813	0.50036	0.62996	0.25184	0.69997
IFI	0.14493	0.16860	0.11393	0.14360	0.15993	0.20215	-0.43568	0.15353	-0.36075	-0.29950
CIO	-0.63908	-0.71916	-0.81162	-0.24255	-0.68650	0.10166	0.17673	0.20018	0.67500	0.12074
VAH	-0.57232	-0.52807	-0.71500	-0.26267	-0.57692	-0.36694	-0.01257	-0.35167	0.28969	-0.13956
MET	-0.44940	-0.45236	-0.61788	-0.19908	-0.50470	-0.32203	0.31600	-0.27103	0.44556	0.00977
SST	-0.30906	-0.25058	-0.42137	-0.14950	-0.31427	-0.44077	-0.40977	-0.46073	0.10990	-0.39920
FSJ	-0.19384	-0.33619	-0.56557	-0.16630	-0.41270	0.05375	0.44214	0.10618	0.44440	0.31241
FSW	0.00299	-0.01520	-0.24543	-0.07573	-0.12972	-0.25294	0.24355	-0.21494	0.30418	0.11465
QJ	-0.01906	-0.16835	-0.47005	0.13900	-0.22216	0.19272	0.34788	0.21889	0.53015	0.07353
IMDTB	-0.16582	-0.34482	-0.24517	0.10579	-0.20479	0.28277	0.42723	0.31256	0.01169	0.29780
IMDTA	-0.08936	-0.29124	-0.34515	0.05002	-0.24151	-0.09979	0.26630	-0.35765	0.21754	0.36299
IMDTP	-0.25439	-0.41646	-0.39695	-0.22012	-0.38863	0.01997	0.41159	0.06137	-0.07245	0.31576

TABLE 4 - CONTINUED

	HSHCT	IRI	CID	VAH	MRT	SST	FSJ	FSW	OJ	IMDTD
MPD5	-0.40639	0.37972	-0.70980	-0.73223	-0.75464	-0.36124	-0.44298	-0.21762	-0.26356	-0.40229
MPD1	-0.26331	0.08604	-0.65951	-0.67311	-0.55666	-0.26020	-0.37469	-0.06251	-0.32940	-0.51403
MPD2	-0.32490	0.05086	-0.46973	-0.38549	-0.39943	-0.01899	-0.17477	0.15665	-0.02814	-0.52627
MPDA	-0.31506	0.17343	-0.63725	-0.61939	-0.56070	-0.21483	-0.34162	-0.03374	-0.21020	-0.51020
GF5	-0.43773	0.15929	-0.81779	-0.78921	-0.69330	-0.55333	-0.30857	-0.13092	-0.28495	-0.16551
GF1	-0.39414	0.11489	-0.65937	-0.54737	-0.45456	-0.22926	-0.02549	0.19760	0.04825	-0.42113
GF2	-0.37123	0.06706	-0.43249	-0.30062	-0.12970	-0.17198	0.02602	0.23592	0.23981	-0.24058
GF4	-0.42276	0.13681	-0.69076	-0.58227	-0.49369	-0.35975	-0.14179	0.09912	-0.01295	-0.29255
GS5	-0.51926	0.26631	-0.75734	-0.65935	-0.63182	-0.47770	-0.26743	-0.10905	-0.21191	-0.12530
GS1	-0.49470	0.24422	-0.69591	-0.54393	-0.53997	-0.28346	-0.19356	0.08603	-0.02990	-0.40985
GS2	-0.47468	0.20254	-0.54721	-0.38449	-0.30222	-0.11285	-0.11170	0.17849	0.09521	-0.41246
GS4	-0.51033	0.24674	-0.63189	-0.55330	-0.54411	-0.30892	-0.20098	0.04796	-0.05775	-0.32077
HD4	-0.38690	0.12100	-0.73991	-0.59084	-0.54724	-0.54572	-0.18977	-0.02563	-0.13648	-0.11772
HD8	-0.63019	0.05259	-0.89544	-0.71222	-0.53595	-0.49033	-0.49309	-0.24925	-0.51593	-0.10689
HD12	-0.62714	-0.00274	-0.90386	-0.72839	-0.52935	-0.34144	-0.54168	-0.23164	-0.59602	-0.23942
HD16	-0.65129	0.01791	-0.90216	-0.71350	-0.51877	-0.44641	-0.50772	-0.21470	-0.54402	-0.20152
HDSA	-0.59637	0.05490	-0.89140	-0.74213	-0.55918	-0.50432	-0.44330	-0.19197	-0.45606	-0.17032
HP1	-0.45612	0.25955	-0.65539	-0.53271	-0.54801	-0.25095	-0.15797	0.11131	-0.06236	-0.40285
HP2	-0.69607	0.14225	-0.61994	-0.34201	-0.32220	-0.07182	-0.22360	0.11193	-0.05985	-0.35324
HP3	-0.72969	0.12656	-0.63291	-0.30719	-0.33523	0.04825	-0.22284	0.09366	-0.18102	-0.43622
HD44	-0.77241	0.25129	-0.67050	-0.30584	-0.44759	0.01675	-0.30474	0.04323	-0.21829	-0.41931
HD48	-0.69569	0.22200	-0.65302	-0.38019	-0.43635	-0.06130	-0.25549	0.09249	-0.12150	-0.41557
HD15	-0.71207	0.29554	-0.59331	-0.25554	-0.34159	-0.04595	-0.15518	0.07333	0.02942	-0.23255
HD3K	-0.77238	0.33683	-0.55376	-0.26525	-0.39472	-0.01245	-0.19849	0.03498	-0.04390	-0.23955
HD45	-0.85258	0.32619	-0.57340	-0.22157	-0.35419	0.06112	-0.29852	-0.02322	-0.16274	-0.28996
HD5	-0.84815	0.23507	-0.53769	-0.20437	-0.30970	0.05853	-0.29647	0.01067	-0.19411	-0.26967
HDAC	-0.80553	0.30303	-0.57305	-0.24005	-0.35440	0.01435	-0.24057	0.02387	-0.09404	-0.25847
OIMD5	-0.38693	0.15639	-0.70637	-0.64745	-0.57519	-0.37551	-0.20106	0.05478	-0.10010	-0.30034
OIMD1	-0.57353	0.20596	-0.61177	-0.45361	-0.39692	-0.25599	-0.14278	0.07503	0.04224	-0.25916
OIMD2	-0.11047	-0.02095	-0.31982	-0.40661	-0.16642	-0.59860	-0.15406	-0.19277	0.02955	0.26836
OIMDA	-0.42420	0.14408	-0.58709	-0.57232	-0.44849	-0.32996	-0.18384	0.00259	-0.01906	-0.16582
CIMD5	-0.61639	0.18569	-0.71916	-0.52907	-0.49236	-0.25058	-0.33919	-0.01520	-0.16935	-0.34492
CIMD1	-0.51744	0.11399	-0.81362	-0.71500	-0.61789	-0.42137	-0.56557	-0.24543	-0.47006	-0.24517
CIMD2	-0.31859	0.13360	-0.24155	-0.26267	-0.19909	-0.14950	-0.16530	-0.07673	0.13890	0.10579
CIMD4	-0.54327	0.15503	-0.69559	-0.57602	-0.50400	-0.31427	-0.41290	-0.12972	-0.22216	-0.20479
HAICA	0.60813	0.20915	0.19166	-0.36694	-0.32201	-0.44077	0.06375	-0.25294	0.19272	0.29277
HAICB	0.50036	-0.43569	0.17671	-0.03257	0.31690	-0.40977	0.44214	0.24355	0.34799	0.42723
HAICT	0.62996	0.15353	0.20019	-0.35167	-0.27303	-0.46073	0.10618	-0.21494	0.21882	0.31256
HSHCA	0.95184	-0.36075	0.67500	0.29869	0.44556	0.10090	0.44440	0.30419	0.53015	0.01169
HSHCB	0.69997	-0.29650	0.12074	-0.13258	0.00977	-0.38820	0.31241	0.11465	0.07353	0.29769
HSHCT	1.00000	-0.37140	0.59236	0.19340	0.34599	-0.03574	0.45778	0.28000	0.44672	0.09917
IRI	-0.37140	1.00000	-0.09911	-0.17429	-0.70552	0.00390	-0.17009	-0.41215	-0.01724	-0.02969
CID	0.59236	-0.09911	1.00000	0.93062	0.64910	0.62220	0.59517	0.31669	0.65431	0.32647
VAH	0.19340	-0.17429	0.93062	1.00000	0.76406	0.94349	0.53762	0.45905	0.53477	0.17987
MRT	0.34599	-0.70552	0.64910	0.76406	1.00000	0.46349	0.47801	0.49713	0.44659	0.20594
SST	-0.03574	0.00390	0.62220	0.94349	0.46349	1.00000	0.36412	0.47894	0.39820	-0.14473
FSJ	0.45778	-0.17009	0.59517	0.53762	0.47801	0.36412	1.00000	0.81544	0.85767	0.07450
FSW	0.28000	-0.41215	0.31669	0.45905	0.49713	0.47894	0.81544	1.00000	0.70391	-0.35983
OJ	0.44672	-0.01724	0.65431	0.53477	0.44659	0.39820	0.85767	0.70391	1.00000	-0.03996
IMDTD	0.09917	-0.02969	0.32647	0.17987	0.20594	-0.14473	0.07450	-0.35983	-0.03996	1.00000
IMDT4	0.29541	-0.33597	0.43215	0.49204	0.45364	0.30906	0.54189	0.38547	0.31375	0.53746
IMDT8	0.03752	-0.00514	0.12537	0.11121	0.20941	-0.36590	0.07341	-0.35135	-0.07782	0.71865

TABLE 4 - CONTINUED

	IMDTA	IMDTB
MDD5	-0.36191	-0.50596
MDD1	-0.29112	-0.62385
MDD2	-0.15174	-0.63023
MDDA	-0.27815	-0.62599
GE5	-0.10372	-0.25754
GT1	-0.10907	-0.25745
GE2	0.01097	-0.28036
GEA	-0.16144	-0.35287
GS5	-0.15964	-0.16214
GS1	-0.24048	-0.41620
GS2	-0.12012	-0.46805
GSA	-0.17930	-0.35453
HDA	-0.12362	-0.17729
HDB	-0.14106	-0.15217
HD12	-0.26875	-0.20986
HD16	-0.22500	-0.24061
HDA4	-0.18767	-0.21037
HD1	-0.19715	-0.40822
HD2	-0.19940	-0.40615
HD3	-0.16123	-0.45503
HDDA	-0.16631	-0.39653
HD15	-0.13966	-0.24705
[illegible]	-0.13476	-0.25721
HD45	-0.17014	-0.25830
HD6	-0.11193	-0.27236
HDAC	-0.13165	-0.25308
QIMD5	-0.15021	-0.42466
QIMD1	-0.20613	-0.20213
QIMD2	0.21472	0.13197
QIMDA	-0.08026	-0.25439
CIMD5	-0.23128	-0.41546
CIMD1	-0.34515	-0.32695
CIMD2	0.15002	-0.32012
CIMDA	-0.26151	-0.28863
[illegible]	-0.09079	0.01987
[illegible]	0.26400	0.41158
[illegible]	-0.05766	0.06137
[illegible]	0.21754	-0.07265
[illegible]	0.35095	0.31576
[illegible]	0.29531	0.03752
ITI	-0.33507	-0.00514
CID	0.43215	0.12537
VEH	0.40204	0.11121
HDT	0.65364	0.22941
SSC	0.30206	-0.36550
SJ	0.54180	0.07341
SSW	0.39547	-0.35135
HJ	0.21375	-0.07782
IMDTN	0.53746	0.71865
IMDTA	1.00000	0.30300
IMDTB	0.30300	1.00000

TABLE 4 - CONTINUED

LEGEND OF ABBREVIATIONS USED FOR
ELECTROACOUSTIC AND BEHAVIORAL MEASURES

MPO5	Maximum Power Output at .5 KHz
MPO1	Maximum Power Output at 1 KHz
MPO2	Maximum Power Output at 2 KHz
MPOA	Maximum Power Output Average of .5,1,2 KHz
GF5	Gain with 50 dB Input at .5 KHz
GF1	Gain with 50 dB Input at 1 KHz
GF2	Gain with 50 dB Input at 2 KHz
GFA	Gain with 50 dB Input Average of .5,1,2 KHz
GS5	Gain with 70 dB Input at .5 KHz
GS1	Gain with 70 dB Input at 1 KHz
GS2	Gain with 70 dB Input at 2 KHz
GSA	Gain with 70 dB Input Average of .5,1,2 KHz
HD4	Harmonic Distortion at .4 KHz with .4 KHz Input
HD8	Harmonic Distortion at .8 KHz with .4 KHz Input
HD12	Harmonic Distortion at 1.2 KHz with .4 KHz Input
HD16	Harmonic Distortion at 1.6 KHz with .4 KHz Input
HDAA	Harmonic Distortion Average of .4,.8,1.2,1.6 KHz
HD1	Harmonic Distortion at 1 KHz with 1 KHz Input
HD2	Harmonic Distortion at 2 KHz with 1 KHz Input
HD3	Harmonic Distortion at 3 KHz with 1 KHz Input
HD4A	Harmonic Distortion at 4 KHz with 1 KHz Input
HDAB	Harmonic Distortion Average of 1,2,3,4 KHz
HD15	Harmonic Distortion at 1.5 KHz with 1.5 KHz Input
HD3K	Harmonic Distortion at 3 KHz with 1.5 KHz Input
HD45	Harmonic Distortion at 4.5 KHz with 1.5 KHz Input
HD6	Harmonic Distortion at 6 KHz with 1.5 KHz Input
HDAC	Harmonic Distortion Average of 1.5,3,4.5,6 KHz
QIMD5	Quadratic Intermodulation Distortion at .5 KHz
QIMD1	Quadratic Intermodulation Distortion at 1 KHz
QIMD2	Quadratic Intermodulation Distortion at 2 KHz

TABLE 4 - CONTINUED

QIMDA	Quadratic Intermodulation Distortion Average of .5,1,2 KHz
CIMD5	Cubic Intermodulation Distortion at .5 KHz
CIMD1	Cubic Intermodulation Distortion at 1 KHz
CIMD2	Cubic Intermodulation Distortion at 2 KHz
CIMDA	Cubic Intermodulation Distortion Average of .5,1,2 KHz
HAICA	H.A.I.C. Bandwidth Above 1 KHz
HAICB	H.A.I.C. Bandwidth Below 1 KHz
HAICT	H.A.I.C. Bandwidth Total
HSHCA	H.S.H.C. Bandwidth Above 1 KHz
HSHCB	H.S.H.C. Bandwidth Below 1 KHz
HSHCT	H.S.H.C. Bandwidth Total
IRI	Index of Response Irregularity
CID	C.I.D. W-22 Word List
VAH	Veterans Administration Discrimination Test
MRT	Modified Rhyme Test
SST	a synthetic sentence test
ESJ	C.I.D. Everyday Sentences: Judged Intelligibility
ESW	C.I.D. Everyday Sentences: Write Down Response
QJ	Quality Judgments
IMDT0	Intermodulation Distortion Test S/N=0 dB
IMDT4	Intermodulation Distortion Test S/N=-4 dB
IMDT8	Intermodulation Distortion Test S/N=-8 dB
CIDRT	C.I.D. W-22 Word List Retest
VAHRT	Veterans Administration Discrimination Test Retest
MRTRT	Modified Rhyme Test Retest
SSTRT	a synthetic sentence test retest
ESJRT	C.I.D. Everyday Sentences: Judged Intelligibility Retest
ESWRT	C.I.D. Everyday Sentences: Write Down Response Retest

TABLE 4 - CONTINUED

QJRT	Quality Judgments Retest
IMDT0RT	Intermodulation Distortion Test S/N=0 dB Restest
IMDT4RT	Intermodulation Distortion Test S/N=-4 dB Retest
IMDT8RT	Intermodulation Distortion Test S/N=-8 dB Retest

TABLE 5

SUMMARY OF THE FOUR HIGHEST PEARSON CORRELATION COEFFICIENTS BETWEEN EACH BEHAVIORAL MEASURE AND THE ELECTROACOUSTIC CHARACTERISTICS

Behavioral Measure	Characteristics	r
CID	HD12	-.909
	HD16	-.909
	HDAA	-.894
	HD8	-.885
VAH	GF5	-.788
	HDAA	-.742
	MPO5	-.732
	HD12	-.728
MRT	MPO5	-.755
	IRI	-.756
	GF5	-.683
	GS5	-.632
SST	GF5	-.553
	HD4	-.546
	QIMD2	-.509
	HDAA	-.505
ESJ	CIMD1	-.566
	HD12	-.542
	HD16	-.508
	HD8	-.493

TABLE 5 - CONTINUED

Behavioral Measure	Characteristics	r
ESW	IRI	-.412
	HSHCA	+.304
	HAICA	-.253
	HD8	-.248
QJ	HD12	-.596
	HD16	-.544
	HSHCA	+.530
	HD8	-.516
IMDT1	MPO2	-.526
	MPO1	-.514
	MPOA	-.510
	HD3	-.436
IMDT4	HSHCB	+.363
	MPO5	-.362
	CIMD1	-.345
	IRI	-.336
IMDT8	MPO2	-.630
	MPO1	-.624
	MPOA	-.623
	MPO5	-.510

r = Pearson Correlation Coefficient

variable dimension. For example, all measures of maximum power output (MPO5, MPO1, MPO2, MPOA) in a hearing aid were predicted to be highly intercorrelated because they all measure dimensions associated with maximum power output.

Further inspection of the matrix reveals that many characteristics not naturally expected to be correlated have, in fact, high correlations. These characteristics cannot be assumed to be independent of the characteristics with which they have a high relationship, and to a greater or lesser extent, are a measure of the same source of variability. For example, MPO5 was not only highly correlated with other measures of maximum power output but also with measures of cubic and quadratic intermodulation distortion, harmonic distortion and gain. Changes, therefore, in intermodulation distortion, harmonic distortion and gain will affect measures of maximum power output and vice versa. This dependence indicates that there was an interaction between characteristics. An electroacoustic measurement, therefore, is never a totally independent variable, but the sum of the moment-to-moment interactions with many of the other characteristics.

Reference to solitary electroacoustic characteristics in the literature is probably not accurate. It is possibly more descriptive to refer to interaction effects and define the major components in the interaction. Not only would such a description more closely approximate what is actually occuring between characteristics, but permits a multi-dimensional appraisal of the interactions affecting speech intelligibility.

What is the Relationship Between Behavioral Measures?

Table 4 reveals that, in general, the correlation coefficients between behavioral indices were low. This is interpreted to suggest that each measure is affected by essentially different sources of variance. Several exceptions to this generalization are notable: CID correlates +.83 with VAH; VAH correlates +.76 with MRT; ESJ correlates +.81 with ESW and +.86 with QJ; ESW correlates +.70 with QJ; IMDT1 correlates +.72 with IMDT8. The correlations indicate that these measures are not totally insensitive to the same sources of variance, and to some extent are redundant. The degree of independence of the behavioral measures, however, is remarkable, because these measures were all designed to estimate and quantify speech intelligibility. The correlations of Table 4 signify that either all of the measures are not estimating speech intelligibility or that the measures are quantifications of essentially different and independent dimensions of speech intelligibility.

How are the Scores on the Behavioral Measures Influenced by the Electroacoustic Characteristics?

To attempt to answer this question a multiple regression analysis was performed between the electroacoustic characteristics and the behavioral measures.

Statistical approach. A multiple regression analysis generates a linear combination of independent variables which will correlate as highly as possible with a dependent variable and produces a regression equation. The regression equation can be used to predict the value of the dependent variable from a set of independent variables.

The normalized beta weights, associated with the regression equation, can be used to reflect the strength and direction of the relationship between each independent variable and the dependent variable. The larger the beta weight, the stronger the influence on the dependent variable.

The multiple correlation coefficient (R) can be squared to reveal how much of the variance of the dependent variable can be explained by the prediction equation.

The multiple regression procedure was used in this study to produce a prediction equation for each behavioral score from a set of electroacoustic characteristics, provide information as to the relative strength of effect of each characteristic on behavioral scores and to calculate the percent of variance in behavioral scores which can be accounted for by a group of electroacoustic characteristics.

Special considerations on the use of multiple regression analysis. Interpretation of the multiple correlation coefficient and predictions from the regression equations can be misleading if certain assumptions for use of the analysis are violated.

The first assumption stems from the fact that the multiple regression coefficient is dependent upon the subject-to-independent variable ratio. According to Nunnally (1963) an unbiased R can be expected when the ratio approaches 13 to 1. Lesser ratios have an increasingly larger chance of generating a R which is biased upward. The number of independent variables in this study was forty-two and the number of subjects equalled twenty. This ratio would be inappropriate for a multiple regression analysis because the R would always, misleadingly, approach unity (McNemar, 1969).

Since it is often not possible, in behavioral research, to have many subjects relative to the number of independent variables, two procedures can be used which reduce the upward bias on the R. One procedure would be to employ a data reduction technique to minimize the number of independent variables. Such a technique would improve the subject-to-independent variable ratio. An obliquely rotated factor analysis is a reduction procedure and was employed in this study. A second procedure would be to use a formula which would estimate the reduction in the R due to a less than ideal subject-to-independent ratio. The technique is known as the correction for shrinkage and was applied to all of the Rs generated by the multiple regression analysis.

Factor analysis. Given the correlation coefficients for a set of variables, factor analytic techniques can be used to lessen the number of variables by grouping them on the basis of patterns of interactions. The smaller number of grouped variables or factors can be taken as source variables accounting for interrelations in the data (Nie et al., 1970). In other words, the factors are extracted from a large set of independent variables on the basis of common patterns of variability. The variables placed into each factor grouping, therefore, covary with each other and are not independent variables. The factor groupings, however, are as independent as possible given a particular set of data. The end result of a factor analysis is a set of factors and factor loadings which indicate the relative importance of each independent variable to the factor grouping. For example, given two measurements of harmonic distortion and three of gain, factor one might have high loadings on harmonic distortion and low loadings on gain. The factor would be referred to as one reflecting harmonic distortion effects. The name given to the factor grouping is arbitrary and is determined by the investigator upon inspection of the factor loadings on the independent variables.

Rotation of factors is a technique which manipulates the factors so that a variable (or highly inter-correlated group of variables) loads very high on one factor, but approximates zero on the other extracted factors.

The rotation can be performed assuming little or no correlation between variables (orthogonal) or assuming that some dimensions of the variables are correlated (oblique). Oblique rotations are commonly accepted as more accurately representing the clustering of variables because few variables are completely orthogonal.

An obliquely rotated factor analysis was performed on the forty-two electroacoustic characteristics. Table 6 shows the extracted factor patterns. Five factors were determined from the forty-two characteristics. Inspection of the factor loadings for each factor reveals that GF2 loads highest on factor one; HSHCT loads highest on factor two; MPO1 loads highest on factor three; HD12 loads highest on factor four and

TABLE 6

FACTOR LOADINGS FOR EACH OF THE FIVE FACTORS
ON THE ELECTROACOUSTIC CHARACTERISTICS

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
MPO5	+0.031	-0.017	+0.263	-0.088	-0.231
MPO1	+0.003	-0.105	+0.442	-0.202	-0.018
MPO2	+0.153	-0.020	+0.426	+0.019	+0.105
MPOA	+0.068	-0.050	+0.400	-0.092	-0.044
GF5	+0.058	-0.034	-0.024	-0.248	-0.122
GF1	+0.216	+0.007	+0.021	-0.040	+0.002
GF2	+0.327	+0.047	+0.010	+0.129	+0.105
GFA	+0.204	+0.005	+0.001	-0.066	-0.011
GS5	+0.073	+0.048	-0.144	-0.171	-0.135
GS1	+0.155	+0.065	-0.005	-0.028	-0.077
GS2	+0.220	+0.081	+0.090	+0.081	+0.003
GSA	+0.151	+0.066	-0.025	-0.046	-0.075
HD4	+0.150	-0.027	-0.134	-0.185	-0.059
HD8	-0.008	+0.020	+0.026	-0.330	+0.061
HD12	-0.069	+0.006	+0.125	-0.383	+0.093
HD16	-0.038	+0.021	+0.083	-0.353	+0.088
HDAA	+0.015	+0.006	+0.017	-0.321	+0.043
HD1	+0.164	+0.052	+0.035	-0.014	-0.084
HD2	+0.143	+0.155	+0.017	+0.004	+0.076
HD3	+0.048	+0.185	+0.076	-0.037	+0.047
HD4A	+0.000	+0.221	+0.019	-0.047	+0.001
HDAB	+0.091	+0.159	+0.041	-0.025	+0.014
HD15	+0.132	+0.212	-0.088	+0.087	-0.032
HD3K	+0.080	+0.228	-0.037	+0.060	-0.045
HD45	+0.011	+0.265	+0.004	+0.028	-0.013
HD6	+0.020	+0.258	-0.025	-0.011	+0.059
HDAC	+0.061	+0.243	-0.038	+0.042	-0.008
QIMD5	+0.158	-0.021	+0.020	-0.123	-0.065

TABLE 6 - CONTINUED

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
QIMD1	+0.191	+0.095	+0.006	+0.029	-0.004
QIMD2	+0.312	-0.089	-0.046	+0.029	+0.073
QIMDA	+0.227	+0.004	-0.000	-0.035	-0.011
CIMD5	+0.110.	+0.102	-0.029	-0.077	-0.036
CIMD1	-0.002	+0.012	-0.028	-0.275	-0.087
CIMD2	+0.296	+0.026	+0.007	+0.169	-0.035
CIMDA	+0.125	+0.051	-0.021	-0.097	-0.060
HAICA	+0.100	-0.281	+0.033	+0.060	-0.424
HAICB	+0.263	-0.211	-0.431	-0.073	+0.153
HAICT	+0.123	-0.288	-0.013	+0.049	-0.387
HSHCA	+0.257	-0.299	+0.198	+0.227	+0.094
HSHCB	+0.072	-0.280	-0.259	-0.215	-0.004
HSHCT	+0.225	-0.334	+0.079	+0.112	+0.063

IRI loads highest on factor five (see Table 4). Other high factor loadings can be discerned within each factor. Since the purpose of the analysis was to reduce the number of independent variables for input into a multiple regression analysis, and because with twenty subjects a subject-to-independent variable ratio of 4 to 1 was thought to be the lowest possible for reliable and interpretable results, five factors were the maximum that could be extracted. Selection of the highest loadings for each factor, however, assures that the most influential variables under each factor will be included in the multiple regression.

The name given to each factor was determined by the variable having the highest loading on the factor. Factor one was termed a gain factor, two a bandwidth factor, three a maximum power output factor, four a harmonic distortion factor and five a regularity of frequency response factor.

Multiple regression analysis. The independent variables derived through use of the factor analysis (GF2, HSHCT, MPO1, HD12, IRI) were multiply regressed against each of the behavioral measures (CID, VAH, MRT, SST, ESJ, ESW, QJ, IMDTO, IMDT4, IMDT8). Table 7 shows the summary table of the analysis for each behavioral measure. The electroacoustic characteristics under each behavioral measure are arranged in order of decreasing influence upon the measure.

Table 7 reveals that all of the multiple regression coefficients are high (with the conspicuous exception of IMDT4 where R = .50). This suggests that the five selected variables account for a large percentage of the variability

TABLE 7

MULTIPLE REGRESSION ANALYSIS OF EACH BEHAVIORAL MEASURE WITH THE FIVE HIGHEST FACTOR LOADING ELECTROACOUSTIC CHARACTERISTICS

Measure	Characteristic	beta	R	R^2	R_s	R_s^2
CID	HD12	-1.51	.94	.88	.91	.84
	MPO1	+ .44				
	HSHCT	- .30				
	IRI	- .25				
	GF2	+ .09				
VAH	HD12	-1.93	.94	.89	.92	.85
	HSHCT	-1.06				
	IRI	- .63				
	MPO1	+ .58				
	GF2	+ .13				
MRT	HD12	-1.28	.98	.96	.90	.95
	IRI	+1.00				
	HSHCT	- .68				
	MPO1	+ .26				
	GF2	+ .19				
SST	HD12	-2.47	.88	.78	.83	.69
	HSHCT	-1.46				
	MPO1	+1.38				
	IRI	- .66				
	GF2	+ .01				
ESJ	HD12	- .85	.71	.50	.57	.32
	GF2	+ .49				
	IRI	- .19				
	MPO	+ .09				
	HSHCT	+ .06				

TABLE 7 - CONTINUED

Measure	Characteristic	beta	R	R^2	R_s	R_s^2
ESW	HD12	-1.40	.74	.55	.62	.39
	MP01	+ .73				
	IRI	- .68				
	GF2	+ .52				
	HSHCT	- .47				
QJ	HD12	-1.39	.93	.87	.91	.82
	GF2	+ .81				
	MP01	+ .37				
	IRI	- .13				
	HSHCT	- .08				
IMDT0	MP01	-1.43	.69	.48	.54	.29
	HD12	+1.37				
	HSHCT	+ .69				
	IRI	+ .35				
	GF2	+ .05				
IMDT4	MP01	- .43	.50	.25	.14	.02
	GF2	+ .28				
	HSHCT	+ .279				
	IRI	- .21				
	HD12	+ .12				
IMDT8	MP01	-1.66	.82	.67	.74	.55
	HD12	+1.52				
	HSHCT	+ .68				
	IRI	+ .39				
	GF2	- .07				

beta = normalized beta weights

R, R^2 = multiple regression coefficient and its square

R_s, R_s^2 = multiple regression coefficient corrected for shrinkage and its square in each of the behavioral measures.

The squared multiple regression coefficient (R^2) can be interpreted as the amount of variance in each behavioral measure which can be accounted for by the five characteristics. In these data the range is 96% of the variance in MRT to 25% of the variance in IMDT4 which can be accounted for by the five characteristics

A second observation concerns the importance of each of the five characteristics to the behavioral measures. The normalized beta weights provide information as to the relative importance of a characteristic to the overall R. The characteristics listed under each measure are arranged from greatest to least importance as dictated by the value of the normalized beta weights. The relative importance of each of the five electroacoustic characteristics is different for each behavioral measure. One consistency, however, through CID, VAH, MRT, SST, ESJ, ESW and QJ is that in these measures harmonic distortion at 1.2 KHz with a .4 KHz input has the highest relative importance (highest beta weight). More consistency appears in ranking important characteristics between the Intermodulation Distortion Tests, but it must be remembered that these tests are merely different signal-to-noise ratios of the same stimulus material.

Correction for shrinkage of R. As was mentioned earlier a small subject-to-independent variable ratio can bias the R upward in a misleading fashion. Estimation of the R with reduced bias can be obtained using the following formula:

$$\hat{R}^2 = 1 - (1 - R^2)\,\frac{N - 1}{N - n}$$

TABLE 8

PEARSON CORRELATION COEFFICIENTS FOR EACH BEHAVIORAL TEST AND RETEST (QJ THROUGH IMDT8RT ARE GROUPED DATA)

Behavioral Measures	r	r^2
CID with CIDRT	.816	.666
VAH with VAHRT	.871	.759
MRT with MRTRT	.767	.588
SST with SSTRT	.563	.317
ESJ with ESJRT	.771	.594
ESW with ESWRT	.650	.423
QJ with QJRT	.827	.760
IMDTO with IMDTORT	.981	.962
IMDT4 with IMDT4RT	.768	.590
IMDT8 with IMDT8RT	.473	.224

where:

$\hat{R}^2$ = squared R corrected for shrinkage

R^2 = obtained R

N = number of subjects

n = number of variables

Through the use of factor analysis the number of variables was reduced to five. Table 7 reveals the shrunken R for each obtained R in the multiple regression analysis. The shrunken R is believed to be a better ie., less biased, estimate of the R based on the subject-to-independent variable ratio in these data.

The correction for shrinkage due to the subject-to-independent variable ratio employed in the study appears as R_s and R_s^2 in Table 7. This procedure reduced to a greater or lesser extent the R for each behavioral measure. The greatest changes occurred in ESJ (.71 to .57), ESW (.74 to .62), IMDTO (.69 to .54) and IMDT4 (.50 to .14). These lower Rs because of the less than optimal subject-to-independent variable ratio are believed to be more realistic estimates of the effect of the five characteristics upon each behavioral measure. The squared shrunken R provides the same information as R^2 and so the percent of variance in each behavioral measure explained by the five characteristics ranged from 95% in MRT to 2% in IMDT4.

<u>What is the Coefficient of Reliability for Each of the Behavioral Measures?</u>

Pearson product-moment correlation coefficients are shown in Table 8 for behavioral measure test-retest scores. The squared coefficients are also included, which indicate the percentage of the variance in one measure which can be accounted for by the other.

Inspection of the table reveals that the test-retest reliability for the majority of the measures employed in this study was good. The synthetic sentence test ($r = .563$); the C.I.D. Everyday Sentence Test: write down response ($r = .650$) and Intermodulation Distortion Test at signal-to-noise ratio of -8 dB ($r = .473$) were the only behavioral measures having conspicuously low reliability coefficients, ie., $r < .70$.

Cross Validation of Statistical Results

The data reduction procedure used to reduce the number of independent variables in this study entailed selection of only those variables having the highest loadings on each of five factors. These five characteristics were, in turn, used as the independent variables in multiple regression analysis. The possibility exists that in another sample of subjects, the highest factor loadings on each factor would be different and thus the R and beta weights different. If any predictive confidence is to be placed in the R and beta weights a cross validation is usually required. The validation method usually employed is to use the set of regression equations derived from the first sample to calculated predicted scores on the second sample. A correlation is calculated between the predicted scores and actual scores, the strength of the correlation providing information as to how stable the original regression equations were and, therefore, the confidence to be placed in the R and beta weights.

It was not possible to run this standard type of cross validation. However, since there were available test and retest scores on the same subjects a modified cross validation was devised. If it could be shown that the Rs and beta weights in the test and retest data maintained some degree of stability in terms of relative value, then the Rs and beta weights could be regarded as stable predictors of the importance of the characteristics to the behavioral scores. A critical assumption in this analysis is that the test and retest scores for every behavioral measure are highly correlated. A low correlation between test and retest scores would confound the validation. With low reliability between scores, differences in the R and beta weights could be caused by the use of characteristics chosen on the basis of chance high factor loadings in the original sample, or produced by the instability of the test measure.

Table 9 displays the multiple regression analysis of the behavioral measure retest scores. As in Table 8 the electro-acoustic characteristics are ordered in terms of decreasing beta value for each behavioral measure. Multiple regression coefficients and squared multiple regression coefficients are also presented.

A quick comparison of the obtained values in Tables 8 and 9 leads to the conclusion that only the R of ESW (.74 to .90), IMDTO (.69 to .59) and IMDT4 (.50 to .60) change appreciably between test and retest.

The relative orderings of the characteristics on the basis of beta weights for the test and retest data are presented

TABLE 9

MULTIPLE REGRESSION ANALYSIS OF THE BEHAVIORAL MEASURE RETEST SCORES WITH THE FIVE HIGHEST FACTOR LOADING ELECTROACOUSTIC CHARACTERISTICS

Measure	Characteristic	beta	R	R^2
CID	HD12	-.94	.80	.64
	GF2	+.16		
	HSHCT	-.05		
	MPO1	+.05		
	IRI	-.02		
VAH	HD12	-1.93	.96	.92
	HSHCT	-1.10		
	IRI	- .62		
	MPO1	+ .55		
	GF2	+ .15		
MRT	HD12	-1.50	.98	.96
	IRI	-1.03		
	HSHCT	- .69		
	MPO1	+ .46		
	GF2	+ .456		
SST	HD12	-2.5	.78	.61
	MPO1	+1.6		
	IRI	- .36		
	GF2	- .08		
	HSHCT	- .03		
ESJ	HD12	-1.13	.77	.60
	GF2	+ .60		
	IRI	- .49		
	MPO1	+ .25		
	HSHCT	- .22		

TABLE 9 - CONTINUED

Measure	Characteristic	beta	R	R^2
ESW	HD12	-1.62	.90	.81
	MP01	+ .89		
	IRI	- .52		
	GF2	+ .48		
	HSHCT	- .18		
QJ	HD12	-1.18	.94	.88
	MP01	+ .68		
	GF2	+ .62		
	IRI	- .28		
	HSHCT	+ .26		
IMDT0	MP01	-1.14	.59	.35
	HD12	+1.01		
	HSHCT	+ .48		
	IRI	+ .26		
	GF2	- .09		
IMDT4	HD12	- .55	.60	.36
	GF2	+ .16		
	MP01	- .09		
	HSHCT	+ .07		
	IRI	+ .01		
IMDT8	HSHCT	+ .72	.83	.69
	HD12	+ .61		
	GF2	- .50		
	MP01	+ .29		
	IRI	- .15		

beta = normalized beta weight

R, R^2= multiple regression coefficient and its square in Table 10. Also included in parentheses is the Pearson product-moment correlation between the test and retest scores on each behavioral measure.

The relative rankings for VAH, MRT, ESJ, QJ, IMDTO are identical for the test and retest. ESW showed one change in ordering and the rest of the measures show multiple changes. It should be noted that multiple shifts occurred in the measures having relatively low reliability coefficients. The notable exception is CID which, while the reliability coefficent was high, there were still multiple changes in the relative ordering of characteristics.

The cross validation of the measures with high correlation coefficients and none or one change in ordering must be assumed to be excellent, ie., the R and beta weights are reliable predictors of relative importance of the five characteristics to these behavioral measures. The cross validation of the measure with low reliability coefficients and multiple ordering changes must remain suspect because of possible confounding introduced by the variability in the behavioral measures themselves. CID while having a high reliability coefficient should not be assumed to be cross validated and, therefore, the R and beta weights are too unstable to use as reliable predictors of the relative effect of the characteristics on CID scores.

TABLE 10

RANK ORDERINGS OF THE FIVE CHARACTERISTICS DERIVED FROM THE FACTOR ANALYSIS FOR EACH BEHAVIORAL TEST AND RETEST

	(.82)		(.87)		(.77)		(.56)	
	CID	CIDRT	VAH	VAHRT	MRT	MRTRT	SST	SSTRT
HD12	1	1	1	1	1	1	1	1
GF2	5	2	5	5	5	5	5	4
MP01	2	3.5	4	4	4	4	3	2
IRI	4	5	3	3	2	2	4	3
HSHCT	3	3.5	2	2	3	3	2	5

	(.77)		(.65)		(.83)		(.98)	
	ESJ	ESJRT	ESW	ESWRT	QJ	QJRT	IMDTO	IMDTORT
HD12	1	1	1	1	1	1	2	2
GF2	2	2	5	4	2	3	5	5
MP01	4	4	2	2	3	2	1	1
IRI	3	3	3	3	4	4	4	4
HSHCT	5	5	4	5	5	5	3	3

	(.77)		(.47)	
	IMDT4	IMDT4RT	IMDT8	IMDT8RT
HD12	5	1	2	2
GF2	2	2	5	3
MP01	1	3	1	4
IRI	4	5	4	5
HSHCT	3	4	3	1

(__) = reliability coefficient for each behavioral measure

Discussion of Results

The validity of the reasons conjectured for the disagreement in research results relating electroacoustic characteristics of hearing aids and behavioral measures designed to estimate and quantify speech can now be discussed with reference to the results of this study.

Inadequate appraisal of electroacoustic characteristic interaction has been suggested as a reason for the differences in observed research results. The correlation matrix relating the electroacoustic characteristics studied in this investigation (Table 4) showed that there are patterns of interactions among the characteristics so that no one characteristic is ever an independent variable. Each characteristic is affected by the moment-to-moment interaction with all of the other characteristics. For example, maximum power output at 1 KHz (MPO1) is highly inter-correlated ($r = > .80$) with GF5, GF1, GFA, GS1, GS2, GSA, HDAA, HD1, QIMD5, QIMDA, CIMD5, CIMD1 and CIMDA. At another moment with different input levels and materials, battery voltage changes or component deterioration the interactions and the relative strengths of the interactions might be quite different. Smaldino (1972) found a similar result in a correlation matrix prepared in a similar fashion.

The occurence of moment-to-moment interaction between electroacoustic characteristics requires that investigators perform cautious and systematic assessment of hearing aid electroacoustics. Different procedures involving different test stimuli, at different levels, will probably each create a unique set of moment-to-moment interactions. Each set of interactions probably affects speech intelligibility in different ways and so result in contradictory conclusions. Results from this study, therefore, tend to support the conjecture that electroacoustic interactions have not been adequately assessed and controlled in hearing aid studies relating electroacoustic characteristics to speech intelligibility. The obvious need is for a standardized set of procedures and materials to assess the relationships between intelligibility and electroacoustic characteristics.

The implication of the results is that standardized behavioral measures, sensitive to differences in electroacoustic interactions should be employed in studies relating these interactions to intelligibility. Conclusions, therefore, on the relationship between interactions and intelligibility would be based upon subject differences rather than differences in the sensitivity of the behavioral measures. A standardized measure would provide an index of subject performance which could be duplicated in any clinic. The result, therefore, would be recommendation of hearing aids which have been assessed along the same parameters. This would provide a systematic and consistent approach to evaluation procedures rather than the inconsistencies in recommendation which currently occur. For example, assessment of performance of a particular subject on the same two hearing aids might be reversed when two different behavioral measures are employed. The results of the assessment would be used to recommend a different hearing aid with each behavioral measure. While perhaps an extreme example, the point is that the behavioral measure can influence the outcome of the hearing aid selection procedure, while our goal is to select the aid on the basis of optimal subject performance alone. Use of standard behavioral procedures would reduce the inconsistencies introduced by the test procedure.

A further advantage of standard behavioral measures is that a very thorough investigation of how electroacoustic interactions affect the measure would be possible. With concerted effort, the many complexities of interactions could be traced and related to subject performance. This sort of analysis is not available for any behavioral measure to date, but obviously is the most critical assessment that can be performed if the measure is to be used (as most are) to influence the future design characteristics of hearing aids.

The final reason offered to account for the disagreement in research results is poor test-retest reliability of the behavioral measures employed. The different characteristics that have been related to intelligibility could be a function of the unreliability of the test instrument and, therefore, not clearly reflect the relationship between electroacoustic characteristics and intelligibility. The coefficients of reliability for every measure used in this study was shown in Table 8. It is clear that except for IMDT8, ESW and SST high coefficients of reliability ($r > .70$) were found in these data. The occurence of low coefficients, however, indicates that they can occur in this type of research. Caution must be exercised, in that reliability of a behavioral measure cannot be assumed in studies relating electroacoustic characteristics and intelligibility. Although not specifically investigated here, the reliability of a behavioral measure could change when used with different electroacoustic interactions. The implication, therefore, is that a reliability coefficient should be calculated for each behavioral measure used in a study of this sort. Failure to quantify the reliability of the measure can, at least, confound and, at worst, invalidate the conclusions relating the measures to the interactions.

Audiologists are often called upon to recommend one hearing aid over another, based upon evaluation procedures which involve a client's response on behavioral measures designed to estimate and quantify speech intelligibility.

It is clear that the behavioral measures studied in this investigation were not affected in the same way by the five electroacoustic characteristics. This implies that the estimates of intelligibility derived from these measures would be different between aids, not only because of subject performance differences, but because the test itself interacted differently with different electroacoustic interactions. Estimates of a client's performance, therefore, would be confounded by the test instrument. Since the audiologist is concerned with the performance of the client when recommending hearing aids, it behooves the clinician to use behavioral measures which can be confidently interpreted as indices of unconfounded performance.

One way of reducing the uncontrolled confounding of estimates of performance would be to use a standardized test measure. The requirements of such a measure would be that it be affected by electroacoustic interaction differences and that it be reliable. A number of behavioral measures presumably meet these requirements. Most, however, have not been analyzed in terms of what kinds of electroacoustic interactions affect them and to what degree, nor has there been any massive attempt to estimate the reliability of measures passed through hearing aids.

The results of this study indicates that the Veterans Administration Discrimination Test (VAH), the Modified Rhyme Test (MRT), the C.I.D. Everyday Sentences: judged intelligibility test (ESJ), quality judgments (QJ) and the Intermodulation Distortion Test at a signal-to-noise ratio of 0 dB (IMDTO) are sensitive to differences in electroacoustic interactions, and are stable and reliable behavioral measures. The order and strength of effect of each electroacoustic characteristic were different (HD12 was most influential in all but IMDTO, see Table 11) in every measure. It might be assumed, therefore, that each measure was sampling a different combination of electroacoustic interactions.

A possible application of these data would be to use the five behavioral measures as a test battery for use in hearing aid selection procedures. Scores obtained on each measure by a patient could be analyzed in terms of the electroacoustic characteristics which have primary influence on each measure. For example, a patient might be given the five tests through a particular hearing aid, resulting in the following performance scores: VAH = 80%, MRT = 86%, ESJ = 90%, QJ = 70%, IMDTO = 68%.

TABLE 11

THE BETA WEIGHTS OF THE FIVE BEHAVIORAL MEASURES DETERMINED TO BE SENSITIVE TO ELECTROACOUSTIC INTERACTION DIFFERENCES, STABLE AND RELIABLE

VAH	beta	MRT	beta	ESJ	beta	QJ	beta	IMDTO	beta
HD12	-1.93	HD12	-1.28	HD12	-.85	HD12	-1.39	MP01	-1.43
HSHCT	-1.06	IRI	+1.00	GF2	+.49	GF2	+.81	HD12	+1.37
IRI	-.63	HSHCT	-.68	IRI	-.19	MP01	+.37	HSHCT	+.69
MP01	+.58	MP01	+.26	MP01	+.09	IRI	-.13	IRI	+.35
GF2	+.13	GF2	+.19	HSHCT	+.06	HSHCT	-.08	GF2	+.05

For this particular patient and hearing aid the inconsistent scores would be those derived from the quality judgment material and the Intermodulation Distortion Test. Reference to Table 11 reveals that in order of strength of effect harmonic distortion, gain, maximum power output, regularity of the frequency response curve and bandwidth combine to affect performance on QJ and maximum power output, harmonic distortion, bandwidth, regularity of the frequency response and gain affect IMDTO. Since harmonic distortion is an influential variable on all measures but IMDTO, and performance on VAH, MRT, and ESJ was higher than QJ and IMDTO, harmonic distortion is probably not affecting the patient's performance.

Gain is influential on QJ and ESJ, but performance on ESJ is not very different than VAH and MRT, so gain is probably not most influential to this patient. In a like manner regularity of the frequency response and bandwidth can be shown to not be variables influencing this patient's performance. Maximum power output, however, is third in influence on QJ and first on IMDTO. The same characteristic is fourth on the other measures, and has relatively low influence. A reasonable conjecture, therefore, would be that the patient's performance using the particular aid was influenced by maximum power output. The clinician might then adjust the maximum power output and readminister the test battery. For instance an increase in maximum power output might increase QJ to 82% and IMDTO to 79% leaving the other scores about the same.

Another aid using the same subject might produce a different pattern of results with a different characteristic having primary influence. The key to selection, however, depends upon whether the influential characteristic can be adjusted to the point where scores on the measure sensitive to the particular characteristic become consistent with the other obtained scores.

The possibility exists, of course, that because of interactions among characteristics a change in one will change how the other characteristics affect the behavioral measures. In this sense a method of minimal changes must be employed, wherein, adjustments are made on characteristics so that other characteristics are minimally affected.

Of course if low scores are obtained on all measures, either the patient cannot effectively use amplification or is sensitive to parameters of intelligibility not represented by the five measures.

High scores on all of the measures indicates that no presented combination of electroacoustic characteristics adversely affects the patient's ability to perceive speech.

This strategy is hypothetical, but serves to suggest a way in which information concerning the relationship between electroacoustic interactions can be systematized and practically used in hearing aid selection procedures. Evaluations of patient performance on behavioral measures passed through hearing aids are presently inconsistent and, may be invalid. An outline for change is needed; what is described might serve as a first step toward such a plan.

Implications to Further Research

The results of this investigation suggest some directions that further research may take.

The statistical analysis could be confirmed and precision increased with the following amendments. While the results of this investigation were cross validated in a modified fashion, a traditional cross validation employing another sample of subjects is believed to be necessary before absolute confidence can be placed in the predictive worth of the multiple regression coefficients and beta weights. Another, larger sample, should also be drawn and subjected to the same test materials to reduce the chance of bias introduced by a low subject-to-independent variable ratio. A ratio of 10 to 1 is believed to be reasonable. While provisions were made in the present study for a low ratio, it would be of interest to test the estimates generated by the provisional techniques against completely unbiased results. Finally, a larger sample would permit inclusion of more independent variables into the regression analyses. The factor technique employed in this study may have capitalized upon chance high factor loadings. Inclusion of some of the other variables with high loadings could reduce these chance effects.

The degradation of the behavioral measures in this study was speech spectrum noise at specific signal-to-noise ratios. These ratios were arbitrarily selected to avoid an expected ceiling effect of the better fidelity hearing aids. Other ratios and other kinds of interference such as intellective masking or environmental noises might be tried to approximate various listening environments. Such information would be important to determine if different electroacoustic interactions affect intelligibility in different noise environments frequented by a hearing aid user.

It would be very important to perform this same type of experiment with various sorts of hearing impaired individuals. Jerger and Thelin (1968) asserted in a paper comparing normal and hearing impaired individuals responses to hearing aid amplified speech, that persons with flat sensorineural losses approximated normal hearing responses, however, a decreasing correlation existed with increasing audiometric slope. From these results they concluded that "one cannot generalize from behavioral results on normals to behavioral results on all hearing impaired subjects" (Jerger and Thelin, 1968 p. 175).

It is suggested here that Jerger and Thelin's statement may, indeed, be the case and that the electroacoustic interactions found to be important to normals may not have the same relationships in various hearing impaired individuals.

The behavioral measures employed in this study were chosen on the basis of accessability and representation of the major types of measures. The selection was in no way inclusive of all of the behavioral measures employed in hearing aid selection procedures. It would be important to perform the analyses suggested in this study on the majority of routinely employed measures. Statements as to sensitivity to electroacoustic interaction and reliability could, then, be consolidated across most measures and, therefore, begin to provide comprehensive data on all tests routinely employed in hearing aid evaluation.

The hearing aids employed in this study represented a limited sample of the range of electroacoustic characteristics. It would be important to use a larger number of hearing aids in order to include a greater number of possible electroacoustic interactions. A larger sample would also increase the confidence that regression predictions were made upon a representative sample of the entire hearing aid population.

CHAPTER 4
SUMMARY AND CONCLUSIONS

Audiologists are often called upon to recommend hearing aids for their clients. The evaluative procedures used to make these recommendations involve the client's performance on behavioral measures designed to estimate and quantify speech intelligibility. It is documented in the research literature that electroacoustic characteristics of hearing aids can affect speech intelligibility, however, there is disagreement as to which characteristics have the most profound affect. Reasons conjectured for the disagreement include (1) behavioral measure unreliability, (2) inadequate assessment of electroacoustic interactions, and (3) use of behavioral measures which are affected by different electroacoustic characteristics and/or interactions.

In order to test the validity of these conjectures forty-two discrete electroacoustic measurements were made on each of ten hearing aids. Ten behavioral measures C.I.D. W-22 Word Lists (CID), V.A. Discrimination Test (VAH), Modified Rhyme Test (MRT), a synthetic sentence test (SST), C.I.D. Everyday Sentences: judged intelligibility (ESJ) and write down response (ESW), a quality judgment passage (QJ) and the Intermodulation Distortion Test at three S/Ns (IMDTO, -4,-8)) were recorded through the same aids, degraded with speech spectrum noise and presented to ten normal hearing listeners.

Except for the synthetic sentence test, C.I.D. Everyday Sentences: write down response and the Intermodulation Distortion Test (-8 dB) all of the behavioral measures had coefficients of reliability $>$ .75 and were, therefore, concluded to be stable estimates of speech intelligibility.

High inter-correlations between electroacoustic measurements was interpreted to imply that characteristics are not truly independent and each represents the moment-to-moment interactions with all of the other characteristics. The supposition, therefore, that interaction effects upon speech intelligibility requires a systematic appraisal was confirmed. Assessment of unitary characteristics, apart from interactions with other characteristics, was determined to be unrealistic and, perhaps, misleading.

Five factors labelled harmonic distortion, maximum power output, bandwidth, gain and regularity of frequency response were extracted from the electroacoustic measurements. Comparison of beta weights produced by a multiple regression between the five factors and each behavioral measure showed that each behavioral measure was affected by the factors in a different order and with different strength. The supposition that behavioral measures are affected by relatively different electroacoustic interactions was, therefore, confirmed in these data. Comparison of research results, based upon different behavioral measures, was decided to be inappropriate and, maybe, misleading, because the sensitivity of different measures to electroacoustic interactions do not appear to be equivalent.

On the basis of the multiple regression analysis, cross validation and reliability coefficients, the Veterans Administration Discrimination Test, the Modified Rhyme Test, C.I.D. Everyday Sentences: judged intelligibility, quality judgments and the Intermodulation Distortion Test (0 dB) were determined to be stable and reliable estimates of speech intelligibility.

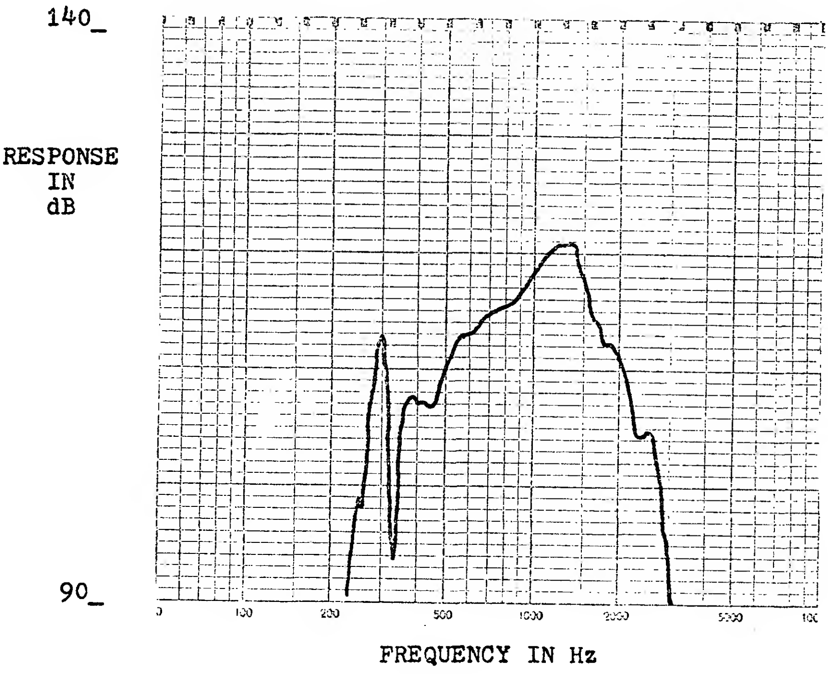
An approach to hearing aid selection procedures was suggested which employed a battery of behavioral measures made up of the reliable and stable measures in these data. The approach used knowledge of differential sensitivity of behavioral measures to electroacoustic interactions to predict speech intelligibility through a hearing aid.

Finally, implications to further research were outlined and included replication, cross validation, use of other behavioral measures, utilization of other hearing aids, employment of other degradations of the behavioral measures, and use of subjects having various types and degree of hearing impairment.

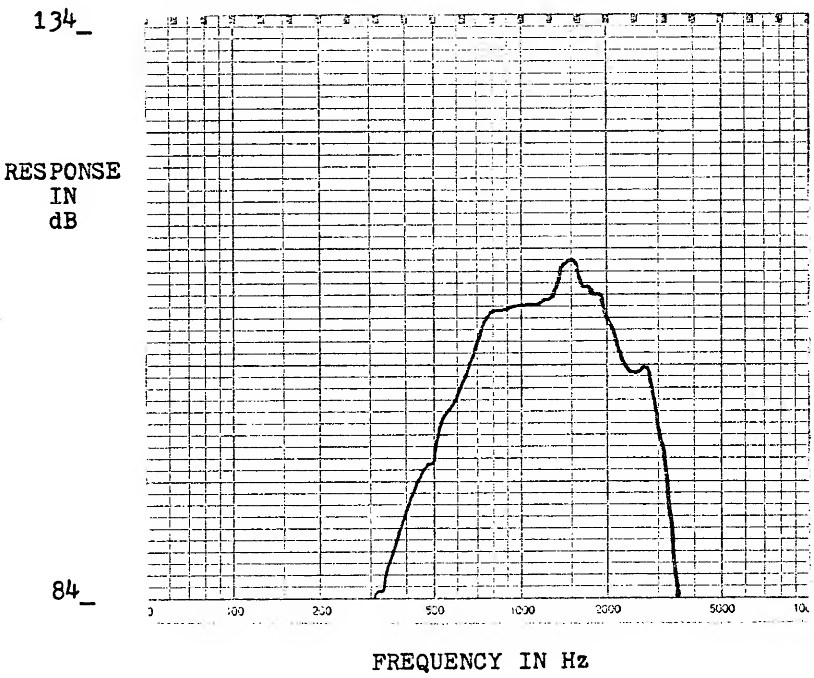
APPENDIX A

FREQUENCY RESPONSE CURVES

FREQUENCY RESPONSE CURVE OF AID NUMBER TWO
USING THE 2 CC COUPLER



FREQUENCY RESPONSE CURVE OF AID NUMBER THREE
USING THE 2 CC COUPLER



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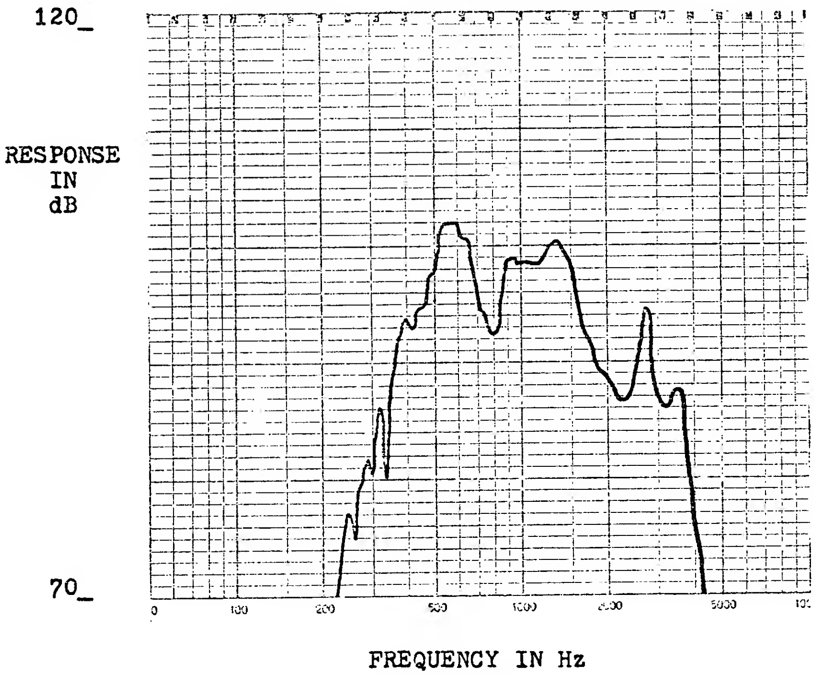
USING THE 2 CC COUPLER

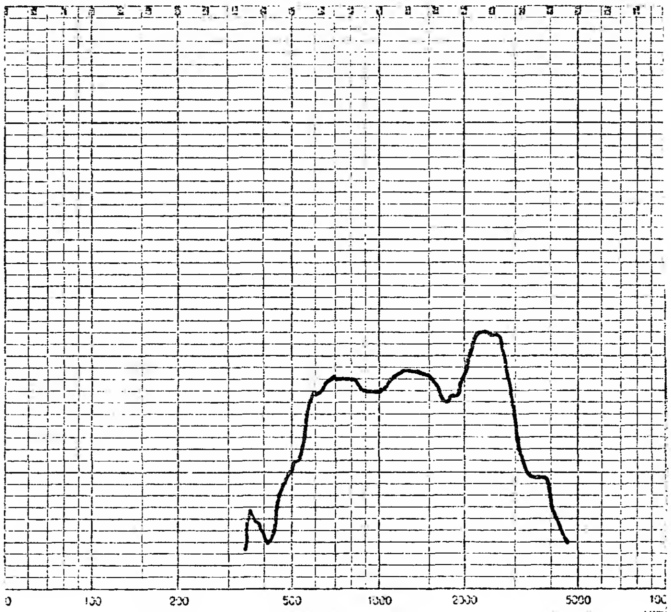


FREQUENCY RESPONSE CURVE OF AID NUMBER FIVE
USING THE 2 CC COUPLER

120_

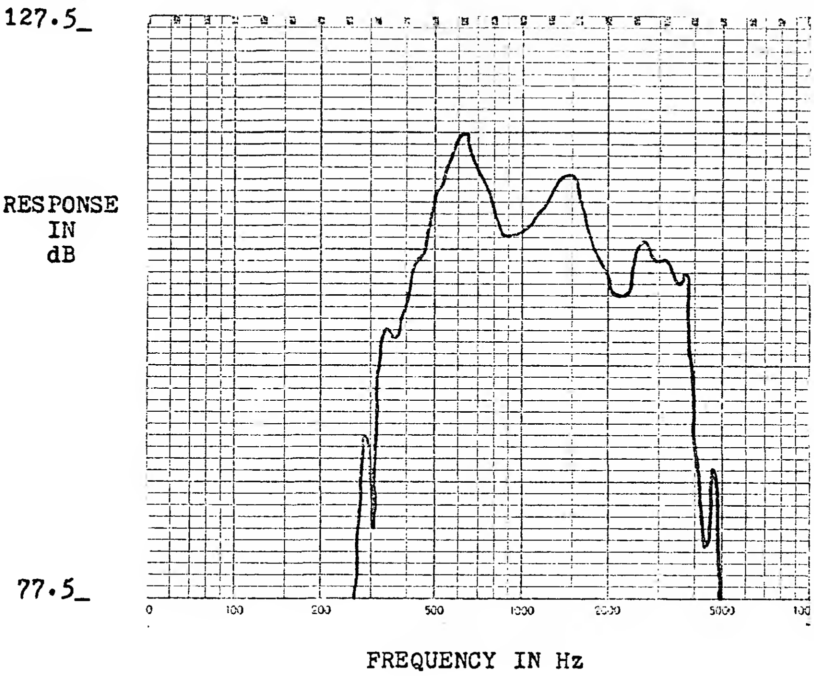
RESPONSE
IN
dB

70_

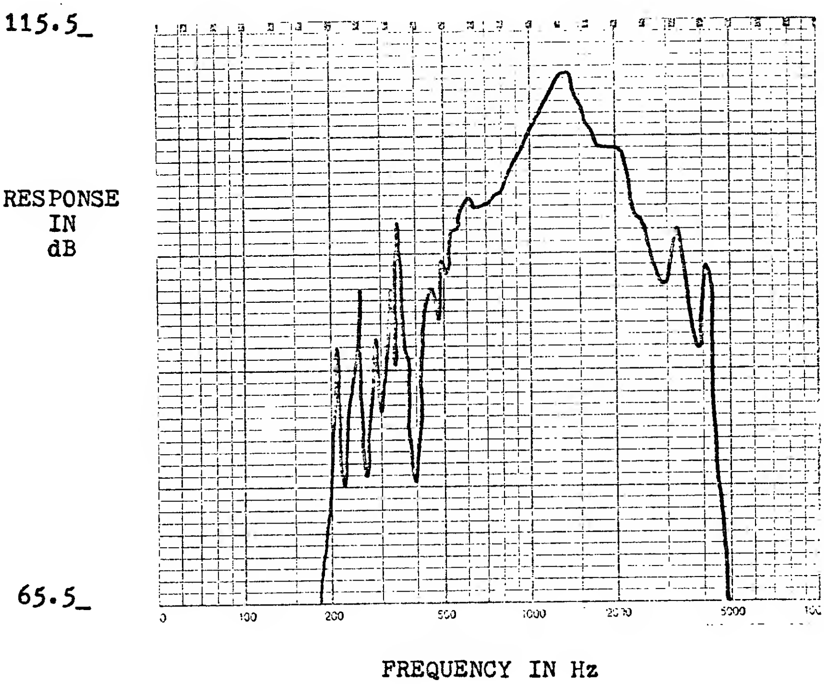


FREQUENCY IN Hz

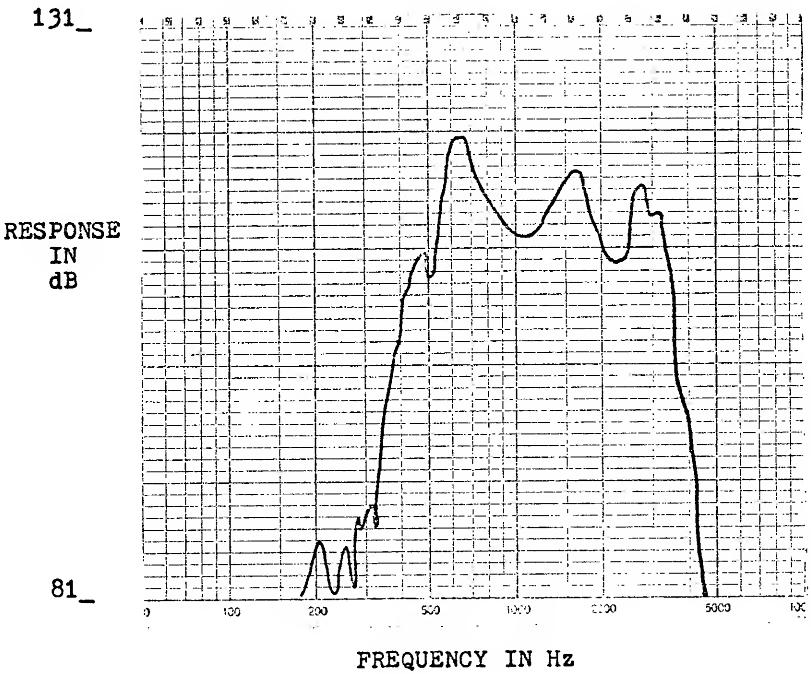
FREQUENCY RESPONSE CURVE OF AID NUMBER SIX
USING THE 2 CC COUPLER



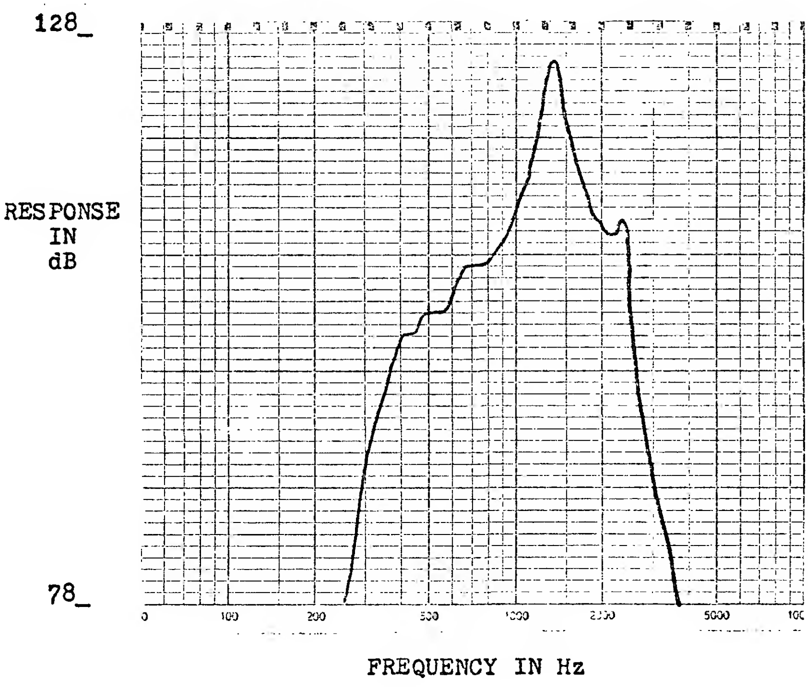
FREQUENCY RESPONSE CURVE OF AID NUMBER SEVEN
USING THE 2 CC COUPLER



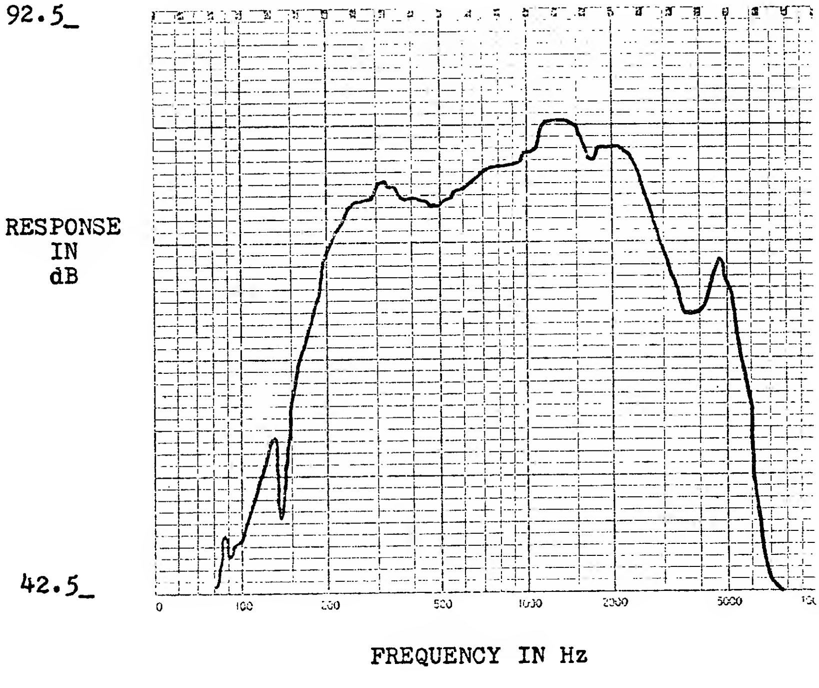
FREQUENCY RESPONSE CURVE OF AID NUMBER EIGHT
USING THE 2 CC COUPLER



FREQUENCY RESPONSE CURVE OF AID NUMBER NINE
USING THE 2 CC COUPLER



FREQUENCY RESPONSE CURVE OF AID NUMBER TEN
USING THE 2 CC COUPLER



APPENDIX B

STIMULUS MATERIALS COMPRISING THE BEHAVIORAL MEASURES

C.I.D. W-22 WORD LISTS

List A

1. an	26. you
2. yard	27. as
3. carve	28. wet
4. us	29. chew
5. day	30. see
6. toe	31. deaf
7. felt	32. them
8. stove	33. give
9. hunt	34. true
10. ran	35. isle
11. knees	36. or
12. not	37. law
13. mew	38. me
14. low	39. none
15. owl	40. jam
16. it	41. poor
17. she	42. him
18. high	43. skin
19. there	44. east
20. earn	45. thing
21. twins	46. dad
22. could	47. up
23. what	48. bells
24. bathe	49. wire
25. ace	50. ache

List C

1. felt	26. yard
2. bells	27. thing
3. owl	28. ran
4. jam	29. law
5. what	30. high
6. them	31. chew
7. isle	32. me
8. bathe	33. ace
9. none	34. see
10. it	35. mew
11. up	36. him
12. stove	37. day
13. an	38. ache
14. not	39. hunt
15. skin	40. you
16. us	41. she
17. earn	42. dad
18. deaf	43. true
19. wet	44. could
20. as	45. give
21. or	46. low
22. there	47. poor
23. east	48. twins
24. knees	49. wire
25. carve	50. toe

V.A. HOSPITAL DISCRIMINATION TEST

List A

1. reed	26. good
2. gun	27. right
3. light	28. well
4. deck	29. tune
5. then	30. gum
6. king	31. mock
7. cap	32. heat
8. work	33. rain
9. not	34. cut
10. rule	35. tell
11. fan	36. bus
12. hive	37. fawn
13. call	38. wet
14. moon	39. kid
15. tough	40. lamb
16. might	41. those
17. foam	42. robe
18. ride	43. need
19. days	44. soap
20. hook	45. life
21. less	46. hit
22. time	47. bell
23. bad	48. five
24. base	49. dark
25. knit	50. keen

List C

1. robe	26. fawn
2. foam	27. dark
3. cut	28. lamb
4. wet	29. bad
5. tune	30. hook
6. knit	31. well
7. fan	32. base
8. moon	33. gun
9. call	34. less
10. not	35. deck
11. soap	36. cap
12. those	37. reed
13. hive	38. mock
14. ride	39. keen
15. five	40. hit
16. time	41. good
17. tell	42. bell
18. heat	43. kid
19. work	44. right
20. gum	45. tough
21. rule	46. might
22. then	47. king
23. life	48. rain
24. need	49. bus
25. light	50. days

MODIFIED RHYME TEST

List A

1. sing	26. hear
2. book	27. sad
3. nest	28. sun
4. kith	29. kick
5. pun	30. cut
6. fill	31. peace
7. foil	32. way
8. bust	33. ten
9. jig	34. meat
10. sake	35. sip
11. kit	36. dig
12. came	37. teach
13. sold	38. sud
14. map	39. pill
15. gale	40. led
16. raw	41. top
17. dent	42. late
18. page	43. bean
19. fame	44. rang
20. duck	45. seep
21. rave	46. hark
22. will	47. pin
23. pass	48. tab
24. peel	49. bat
25. bun	50. hot

List C

1. top	26. bean
2. pin	27. meat
3. bat	28. came
4. hot	29. seep
5. cut	30. hark
6. peace	31. peel
7. jig	32. gale
8. sake	33. rang
9. fame	34. rave
10. duck	35. will
11. sud	36. page
12. tab	37. teach
13. raw	38. led
14. pill	39. hear
15. ten	40. sad
16. kick	41. sun
17. foil	42. pun
18. bust	43. late
19. sold	44. sin
20. map	45. dig
21. way	46. nest
22. book	47. kit
23. fill	48. kith
24. dent	49. sing
25. pass	50. bun

THIRD-ORDER SYNTHETIC SENTENCE MESSAGE SETS

List A

1. Small boat with a picture has become
2. Built the government with the force almost
3. Go change your car color is red
4. Forward march said the boy had a
5. March around without a care in your
6. That neighbor who said business is better
7. Battle cry and be better than ever
8. Down by the time is real enough
9. Agree with him only to find out
10. Women view men with green paper should

List C

1. March around without a care in your
2. Built the government with the force almost
3. Women view men with green paper should
4. Down by the time is real enough
5. Go change your car color is red
6. Small boat with a picture has become
7. That neighbor who said business is better
8. Forward march said the boy had a
9. Battle cry and be better than ever
10. Agree with him only to find out

C.I.D. EVERYDAY SENTENCES
JUDGED INTELLIGIBILITY

List A

1. It's time to go.
2. If you don't want these old magazines, throw them out.
3. Do you want to wash up?
4. It's a real dark night so watch your driving.
5. I'll carry the package for you.
6. Did you forget to shut off the water?
7. Fishing in a mountain stream is my idea of a good time.
8. Fathers spend more time with their children than they used to.
9. Be careful not to treak your glasses!
10. I'm sorry.

List C

1. I'll carry the package for you.
2. If you don't want these old magazines, throw them out.
3. I'm sorry.
4. Fathers spend more time with their children than they used to.
5. Do you want to wash up?
6. It's time to go.
7. Did you forget to shut off the water?
8. It's a real dark night so watch your driving.
9. Fishing in a mountain stream is my idea of a good time.
10. Be careful not to break your glasses!

C.I.D. EVERY DAY SENTENCES - WRITE DOWN RESPONSE

List A

1. Believe me!
2. Let's get a cup of coffee.
3. Let's get out of here before it's too late.
4. I hate driving at night.
5. There was water in the cellar after that heavy rain yesterday.
6. She'll only be gone a few minutes.
7. How do you know?
8. Children like candy.
9. If we don't get rain soon, we'll have no grass.
10. They're not listed in the new phone book.

List C

1. If we don't get rain soon, we'll have no grass.
2. I hate driving at night.
3. Let's get a cup of coffee.
4. Believe me!
5. Let's get out of here before it's too late.
6. They're not listed in the new phone book.
7. Children like candy.
8. There was water in the cellar after that heavy rain yesterday.
9. How do you know?
10. She'll only be gone a few minutes.

PASSAGE FOR QUALITY JUDGMENTS

Frost need not have a multitude of crystal structures. Each object on which it appears is unique, and each dramatically alters the appearance of the frost itself. Nowhere are the pure crystalline forms as striking as on the surface of frozen streams and ponds where clusters of fernlike frost lie like jeweled fossils embedded in ice. And on the windowpanes, especially in unheated rooms, irregularities in the glass, dust particles, swirling currents of air and the melting and refreezing of the crystals produce frost ferns, and feathers, flowers, shells and stars.

APPENDIX C

INSTRUCTIONS TO SUBJECTS FOR THE BEHAVIORAL MEASURES

INSTRUCTIONS FOR W-22 AND
VAH MIAMI WORD LISTS

Your attention please. This is a test to see how well you can hear words in a background of noise. On your answer sheet there are blank spaces numbered one through fifty. I will say a word for each blank. You are to decide what word I said and write it in the blank. If you are not sure of a word, guess. Leave no blanks. For example: for number one you might hear, "number one, write the word ham." You would then write the word "ham" in the blank space numbered one, and so on. Some of the words will be difficult to hear, listen carefully and remember, leave no blank spaces. You will have only five seconds to write the word, so write quickly. Are there any questions?

INSTRUCTIONS FOR THE MODIFIED RHYME TEST

Your attention please. This is a test to see how well you can hear words in a background of noise. There are fifty numbered blocks on your answer sheet. In each block there are six words. The speaker will say the number of the block and then the test word. Listen carefully and decide which word in the block was spoken and draw a line through it. For example, the speaker might say: "number one, you will mark the blank please," you would then cross out the word said in block number one and so on. Some of the words will be difficult to hear, if you are not sure of a word, take a guess. Leave no block unmarked. You will have about five seconds to mark the word so work quickly. Are there any questions?

INSTRUCTIONS FOR SYNTHETIC SENTENCES

This is a test to see how well you can hear sentences in a background of noise. First, however, I want you to practice listening to the sentences that will be used in the test. Do nothing, just listen....(present practice sentences).

Now get ready for the test. There are ten sentences in the test. On your answer sheet there are ten blank spaces. The speaker will say the number of the blank and then a sentence. Listen carefully and decide what sentence was spoken. Write the sentence in the blank space. Some of the sentences will be difficult to hear. If you are not sure of a sentence, guess. Leave no empty blanks.

PRACTICE SENTENCES:

1. GO CHANGE YOUR CAR COLOR IS RED
2. AGREE WITH HIM ONLY TO FIND OUT
3. DOWN BY THE TIME IS REAL ENOUGH
4. MARCH AROUND WITHOUT A CARE IN YOUR
5. FORWARD MARCH SAID THE BOY HAD A
6. BATTLE CRY AND BE BETTER THAN EVER
7. BUILT THE GOVERNMENT WITH THE FORCE ALMOST
8. THAT NEIGHBOR WHO SAID BUSINESS IS BETTER
9. SMALL BOAT WITH A PICTURE HAS BECOME
10. WOMEN VIEW MEN WITH GREEN PAPER SHOULD

INSTRUCTIONS FOR C.I.D. EVERYDAY SENTENCES JUDGED INTELLIGIBILITY

This test will be used to determine how well you can hear sentences in a background of noise. There are ten sentences in the test. On your answer sheet there are ten blank spaces. The speaker will say the number of the blank and then a sentence. Listen carefully and decide how well you understood the sentence (0-100%). If you do not understand any of the sentence put zero percent in the blank for that sentence. If you understood the sentence completely put one hundred percent in the blank. If you understood just part of a sentence, decide what percent you understood and put that in the blank. Some of the sentences will be difficult to understand, so listen carefully. Decide on a percent for each sentence, leave no empty blanks. You will have five seconds to write the percentage. Are there any questions?

INSTRUCTIONS FOR C.I.D. EVERYDAY SENTENCES
WRITE DOWN RESPONSE

Your attention please. This is another test to see how well you can hear sentences in a background of noise. There are ten sentences in the test. On your answer sheet there are ten blank spaces. The speaker will say the number of the blank and then a sentence. Listen carefully and decide what sentence was spoken. Then write the sentence in the blank. Some of the sentences will be difficult to hear, if you are not sure of a sentence, guess. Leave no empty blanks. You will have fifteen seconds to write each sentence. Are there any questions?

INSTRUCTIONS FOR QUALITY JUDGMENTS

Your attention please. This is a test to determine the relative understandability of paragraphs in a background of noise. There are nine items on your answer sheet. For each item you will hear two paragraphs in a background of noise. Listen carefully and decide which paragraph is more understandable to you. Circle first or second paragraph to indicate your preference. For example, if you decide for item number one that the second paragraph is more understandable than the first, circle the word "second" and so on. You will have only five seconds to make your decision, so work quickly. Are there any questions?

INSTRUCTIONS FOR INTERMODULATION TEST

Your attention please. This is a test to see how well you can hear the difference between two sounds in a background of noise. There are thirty items on your answer sheet. For each item you will hear two short sounds in a background of noise. Listen carefully and decide whether you heard the distorted or undistorted sound first. Circle the word distorted or undistorted for each item. For example: for number one you might decide that the first sound was the distorted one. You would then circle "distorted" for item number one. For item number two you might decide that the first sound was the undistorted one. You would then circle "undistorted" for number two and so on.

Make a decision for each item, leave no uncircled items. You will have five seconds to make your decision. Are there any questions?

APPENDIX D

SAMPLE SUBJECT RESPONSE FORMS

C.I.D. W-22 WORD LIST Name____________

Write the words you think you hear in the blanks. If you are not sure of a word, guess. Leave no empty blanks.

1. ____________ 26. ____________
2. ____________ 27. ____________
3. ____________ 28. ____________
4. ____________ 29. ____________
5. ____________ 30. ____________
6. ____________ 31. ____________
7. ____________ 32. ____________
8. ____________ 33. ____________
9. ____________ 34. ____________
10. ____________ 35. ____________
11. ____________ 36. ____________
12. ____________ 37. ____________
13. ____________ 38. ____________
14. ____________ 39. ____________
15. ____________ 40. ____________
16. ____________ 41. ____________
17. ____________ 42. ____________
18. ____________ 43. ____________
19. ____________ 44. ____________
20. ____________ 45. ____________
21. ____________ 46. ____________
22. ____________ 47. ____________
23. ____________ 48. ____________
24. ____________ 49. ____________
25. ____________ 50. ____________

VAH MIAMI WORD LIST Name________________

Write the words you think you hear in the empty blanks. If you are not sure of a word, guess. Leave no empty blanks.

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________
12. ____________________
13. ____________________
14. ____________________
15. ____________________
16. ____________________
17. ____________________
18. ____________________
19. ____________________
20. ____________________
21. ____________________
22. ____________________
23. ____________________
24. ____________________
25. ____________________
26. ____________________
27. ____________________
28. ____________________
29. ____________________
30. ____________________
31. ____________________
32. ____________________
33. ____________________
34. ____________________
35. ____________________
36. ____________________
37. ____________________
38. ____________________
39. ____________________
40. ____________________
41. ____________________
42. ____________________
43. ____________________
44. ____________________
45. ____________________
46. ____________________
47. ____________________
48. ____________________
49. ____________________
50. ____________________

MODIFIED RHYME TEST Name____________________

Draw a line through the word in each block that you think you hear. If you are not sure of a word, guess. Leave no block unmarked.

1.		2.		3.		4.		5.	
sing	sit	look	shook	vest	rest	kill	kid	putt	puff
sin	sill	cook	took	nest	test	kit	king	pub	pun
sip	sick	hook	book	best	west	kith	kiss	pup	pug
6.		7.		8.		9.		10.	
fin	fig	toil	boil	rust	must	rig	pig	sane	save
fit	fib	foil	soil	just	gust	wig	big	safe	same
fill	fizz	coil	oil	dust	bust	jig	fig	sale	sake
11.		12.		13.		14.		15.	
bit	hit	came	cape	hold	cold	mass	map	sale	pale
sit	wit	cane	cake	fold	gold	math	man	gale	bale
fit	kit	cave	case	told	sold	mad	mat	male	tale
16.		17.		18.		19.		20.	
raw	saw	rent	went	pace	pale	came	game	dub	dull
paw	thaw	dent	sent	page	pay	name	fame	dun	duck
jaw	law	tent	bent	pave	pane	same	tame	dud	dug
21.		22.		23.		24.		25.	
rake	rave	bill	hill	pan	pang	keel	peel	bus	bun
ray	raze	fill	will	pad	pass	reel	eel	buff	buck
rate	race	kill	till	pat	path	feel	heel	bug	but
26.		27.		28.		29.		30.	
heath	heat	sag	sack	gun	nun	tick	pick	cuff	cup
heave	hear	sat	sass	run	sun	sick	wick	cud	cub
heal	heap	sap	sad	bun	fun	lick	kick	cuss	cut
31.		32.		33.		34.		35.	
peace	peak	pay	way	den	pen	seat	beat	dip	hip
peach	peat	gay	may	hen	men	meat	heat	rip	sip
peal	peas	say	day	ten	then	feat	neat	lip	tip
36.		37.		38.		39.		40.	
dip	din	team	teak	sub	sun	pig	pill	fed	red
dim	did	tease	tear	sung	sup	pin	pick	shed	wed
dig	dill	teach	teal	sud	sun	pip	pit	bed	led

41.

mop	shop
top	hop
cop	pop

42.

lane	lame
lace	lay
lake	late

43.

beach	beat
bean	beak
bead	beam

44.

sang	hang
gang	bang
rang	fang

45.

seep	seed
seem	seethe
seen	seek

46.

park	dark
mark	bark
lark	hark

47.

pin	din
sin	tin
fin	win

48.

tab	tang
tan	tam
tack	tap

49.

bath	back
bat	ban
base	bad

50.

hot	not
tot	got
lot	pot

FORM C

MODIFIED RHYME TEST   Name________________

Draw a line through the word in each block that you think you hear. If you are not sure of a word, guess. Leave no block unmarked.

1. mop shop top hop cop pop	2. pin din sin tin fin win	3. bath back bat ban bass bad	4. hot not tot got lot pot	5. cuff cup cud cub cuss cut
6. peace peak peach peat peal peas	7. rig pig wig big jig fig	8. sane save safe same sale sake	9. came game name fame same tame	10. dub dull dun duck dud dug
11. sub sun sung sup sud sum	12. tab tang tan tam tack tap	13. raw saw paw thaw jaw law	14. pig pill pin pick pip pit	15. den pen hen men ten then
16. tick pick sick wick lick kick	17. toil boil foil soil coil oil	18. rust must just gust dust bust	19. hold cold fold gold told sold	20. mass map math man mad mat
21. pay way gay may say day	22. look shook cook took hook book	23. fin fig fit fib fill fizz	24. rent went dent sent tent bent	25. pan pang pad pass pat path
26. beach beat bean beak bead beam	27. seat beat meat heat feat neat	28. came cape cane cake cave case	29. seep seed seem seethe seen seek	30. park dark mark bark lark hark
31. keel peel reel eel feel heel	32. sale pale gale bale male tale	33. sang hang gang bang rang fang	34. rake rave ray raze rate race	35. bill hill fill will kill till
36. pace pale page pay pave pane	37. team teak tease tear teach teal	38. fed red shed wed bed led	39. heath heat heave hear heal heap	40. sag sack sat sass sap sad

FORM C

41.		42.		43.		44.		45.	
gun	nun	putt	puff	lane	lame	dip	hip	dip	din
run	sun	pub	pun	lace	lay	rip	sip	dim	did
bun	fun	pup	pug	lake	late	lip	tip	dig	dill

46.		47.		48.		49.		50.	
vest	rest	bit	hit	kill	kid	sing	sit	bus	bun
nest	test	sit	wit	kit	king	sin	sill	buff	buck
best	west	fit	kit	kith	kiss	sip	sick	bug	but

SYNTHETIC SENTENCES

Name__________________

Write the sentences you think you hear in the blanks. If you are not sure of a sentence, guess. Leave no empty blanks.

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____

C.I.D. EVERYDAY SENTENCES Name____________________

judged intelligibility

Write the percent of the sentence that you think you understand (0-100%). Make a decision for each sentence. Leave no empty blanks.

1. ____________%
2. ____________%
3. ____________%
4. ____________%
5. ____________%
6. ____________%
7. ____________%
8. ____________%
9. ____________%
10. ____________%

C.I.D. EVERYDAY SENTENCES Name________________

Write the sentences you think you hear in the blanks. If you are not sure of a sentence, guess. Leave no empty blanks.

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____

QUALITY JUDGMENTS Name____________________

Circle the word first or second to indicate which paragraph was most understandable. Make a decision for each pair of paragraphs. Leave no item uncircled.

1.	first	second
2.	first	second
3.	first	second
4.	first	second
5.	first	second
6.	first	second
7.	first	second
8.	first	second
9.	first	second

INTERMODULATION TEST Name________________

Circle the word distorted or undistorted to indicate which sound you hear first for each item. Make a decision for each item. Leave no item uncircled.

1.	distorted	undistorted	16.	distorted	undistorted
2.	distorted	undistorted	17.	distorted	undistorted
3.	distorted	undistorted	18.	distorted	undistorted
4.	distorted	undistorted	19.	distorted	undistorted
5.	distorted	undistorted	20.	distorted	undistorted
6.	distorted	undistorted	21.	distorted	undistorted
7.	distorted	undistorted	22.	distorted	undistorted
8.	distorted	undistorted	23.	distorted	undistorted
9.	distorted	undistorted	24.	distorted	undistorted
10.	distorted	undistorted	25.	distorted	undistorted
11.	distorted	undistorted	26.	distorted	undistorted
12.	distorted	undistorted	27.	distorted	undistorted
13.	distorted	undistorted	28.	distorted	undistorted
14.	distorted	undistorted	29.	distorted	undistorted
15.	distorted	undistorted	30.	distorted	undistorted

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BIOGRAPHICAL SKETCH

Joseph Smaldino was born in Silver Creek, New York, on 29 October 1944. He lived in Angola, New York, through high school and graduated from Lake Shore Central School, Angola, New York, in June, 1963. Undergraduate studies were undertaken at Union College, Schenectady, New York, from which he received a B.S. with honors in Biology and was elected to Sigma Xi on June, 1967. A two year period was spent, immediately following graduation, at the State University of New York at Albany, Albany, New York, where he undertook graduate training in Biology. Starting in September 1969, he entered the Graduate School of the University of Connecticut, Storrs, Connecticut, to pursue a Master of Arts degree in Speech, Hearing and Language Science. During this period he held several Rehabilitation Administration Fellowships and was employed at the Psychophysiological Section of the Submarine Medical Research Laboratory, Groton, Connecticut. In June, 1972, he received his M.A. and was elected to Phi Kappa Phi.

In September, 1972, he entered the Graduate School of the University of Florida, Gainesville, Florida, to begin work toward the degree of Doctor of Philosophy in the Speech Department. During this period of study he was awarded a traineeship in audiology at the Veterans Administration Hospital, Gainesville, Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scolarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Edward C. Hutchinson, Chairman
Associate Professor of Speech

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scolarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Daniel E. Sellers, Cochairman
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scolarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the Department of Speech in the College of Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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