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THE SSI AND NU 6 IN CLINICAL HEARING
AID EVALUATION

THESIS

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Fulfillment of the Requirements

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By

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This paper reports on the comparison of the performance of fourteen normal hearing listeners and fourteen individuals with sensorineural hearing loss on the Synthetic Sentence Identification (SSI) and the Northwestern Auditory Test No. 6 (NU 6) in order to determine whether there are differences in performance of the two groups of listeners on the SSI and NU 6 and whether either test better reflects aided improvement and residual deficit. Both measures demonstrated significant aided improvement. The results of this study do not suggest a single best discrimination test which can reflect a real-life listening situation. The primary consideration in the hearing aid evaluation is flexibility in determining the appropriate level for the primary signal and the listening conditions.

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CHAPTER I

INTRODUCTION

Clinical hearing aid evaluation remains a controversial issue in the field of audiology. The controversy revolves around whether or not support is available for the basic assumptions underlying clinical hearing aid evaluation procedures. These assumptions include the following.

1. There are differences among hearing aids which can be demonstrated using clinical tests.
2. There is an interaction between hearing aids and hearing aid users which is not constant.
3. Hearing aids can be differentiated on the basis of electro-acoustic characteristics.
4. The differences are great enough that the responsibility for hearing aid selection should rest with the audiologist.

Research has failed to conclusively support any of these assumptions. The reliability of clinical tests has been questioned (Shore, Bilger and Hirsh, 1960). The existence of significant differences among hearing aids has been demonstrated by several investigators (Jerger, Malmquist and Speaks, 1966; Olsen and Tillman, 1968), while others have failed to demonstrate differences (Shore, Bilger and Hirsh, 1960).

The differences are probably related to a number of factors. Variables would include test methods, selection of hearing aids, and experimental populations.

Another primary problem influencing the basic underlying assumptions in the hearing aid evaluation is the electro-acoustic measurement strategy. Although three sets of standards exist, The American National Standards Institute, the International Electro-technical Commissions Standard, and the Hearing Aid Industry Conference Standard, the confusion and an absence of meaningful electro-acoustic information continues. This lack of reliable and valid specifications is due partly to the specifications of the 2cc hard coupler responses which differs from real ear probe tube microphones; vented earmold differences, and the ignoring of electro-acoustic factors which have been demonstrated to have known effects on the transmission of speech (Chial and Hayes, 1974). These inaccurate and insufficient hearing aid specifications precede the problem of psycho-acoustic tests not adequately reflecting hearing aid differences, since it is the electro-acoustic tests which originally fail to delineate important electro-acoustic characteristics (Chial and Hayes, 1974).

The lack of consistent electro-acoustic and psycho-acoustic data has led to the development of a multitude of philosophies regarding hearing aid evaluation and selection. The role ascribed to the audiologist in a particular

philosophy depends upon the data that are accepted as valid. The continuum includes at one end the precise selection of a "best" hearing aid through clinical testing with hearing aids (Carhart, 1947) to the complete exclusion of aided testing with direct referral to the hearing aid dealer (Shore, Bilger and Hirsh, 1960; Wilson and Linnell, 1972).

Recently Jerger and Hayes (1976) described a new method which they feel may overcome the inherent limitations in the conventional hearing aid evaluation technique. Their approach views the hearing air evaluation as the important initial component in the process of aural rehabilitation. The procedure utilizes synthetic sentences (Speaks and Jerger, 1965) and is designed to meet the following criteria:

1. selecting the best hearing aid arrangement for the individual,
2. demonstrating differences among arrangements in a systematic manner using real life listening conditions,
3. providing information on realistic expectations of hearing aid use for patient counseling by describing aided improvement and residual deficit, and
4. making accountable rehabilitative recommendations to patients.

Jerger and Hayes (1976) feel the synthetic sentences identification (SSI) offers a more valid approximation to real speech than more traditional monosyllabic word lists and state further that monosyllables presented in quiet and noise rarely demonstrate substantial differences among

hearing aids. The use of a competing message at various levels further provides for life-like listening conditions with the SSI.

However, Beattie and Edgerton (1976) recently suggested that the use of a particular monosyllabic word list, Northwestern University Auditory Test No. 6 (NU 6), against competing noise may differentiate among hearing aids. Previously, Orchik and Oyer (1972) demonstrated significant differences between hearing aids using the NU 6 against a background of competing speech. They argued that the type of test material may not be as important as the competing signal in which it is contained.

As yet, these two speech discrimination tests, the SSI and the NU 6, have not been compared using the same population. The present investigation was proposed to compare the performance of normal hearing listeners and individuals with sensorineural hearing loss on the SSI and the NU 6 to examine the following questions:

1. Are there differences in the performance of normal-hearing listeners on the SSI and the NU 6 when a variety of listening conditions are employed?

2. For subjects with mild-to-moderate sensorineural hearing loss, how do their aided and unaided scores in a variety of listening conditions compare using the SSI and NU 6?

3. Does either the NU 6 or SSI more dramatically indicate "aided improvement" and "residual deficit" for subjects with mild-to-moderate sensorineural hearing loss?

CHAPTER II

REVIEW OF THE LITERATURE

In this chapter the appropriate literature concerning the two speech discrimination measures employed in this study, the Northwestern University Auditory Test No. 6 and the Synthetic Sentence Identification, is reviewed. A discussion of clinical hearing aid evaluation procedures is also presented.

Northwestern University Auditory Test No. 6

Speech audiometry is a major diagnostic tool in the present day audiologic test battery. Measurement of discrimination for speech is applicable in the following clinical areas:

1. to differentiate among various types of auditory pathology,
2. to measure progress in lipreading and auditory training,
3. to evaluate hearing aid performance, and
4. to predict the success of otologic surgery.

The test material most often employed to assess speech discrimination is the monosyllabic word list. A number of such lists have been developed and most have utilized some form of phonetic or phonemic balance to make the list

representative of the spoken language. That is, the frequency of occurrence of the various phonemic elements of the spoken language is represented in the word list (Egan, 1948; Silverman and Hirsh, 1952; Lehiste and Peterson, 1959; Carhart, 1965).

The Northwestern University Auditory Test No. 6 (NU 6) is a monosyllabic word list developed to overcome many of the weaknesses inherent in previous tests of speech discrimination (Tillman and Carhart, 1966). The shortcomings of previous tests included failure to maintain phonetic balance across test lists, and an inability to differentiate between the performance of normal-hearing listeners and subjects with various auditory pathologies (Carhart, 1965).

The NU 6 is comprised of four lists of fifty monosyllabic words. Four randomizations of each list are available, giving the clinician a potential pool of sixteen lists for clinical use. The monosyllables of the NU 6 are of the CNC variety; that is, each word contains an initial consonant, a middle vowel or diphthong nucleus, and a final consonant. The use of CNC monosyllables was first applied to speech discrimination testing by Lehiste and Peterson (1959) and the words used for the NU 6 were taken almost exclusively from the word pool employed by these researchers. The four lists of the NU 6 are displayed in Appendix B.

The equivalency of the test lists as well as the test-retest reliability of the NU 6 have been previously

demonstrated (Rintelmann et al., 1973). In addition, the data provided by Rintelmann indicate that performance differences exist between normal-hearing listeners and individuals with sensorineural hearing loss. The discrimination scores were obtained in quiet at an optimal listening level (32 dB SL).

Data are available on the performance of normal-hearing adults and children aged six years with the NU 6 used against a background of white noise (Larson, Petersen and Jacquot, 1974). However, at present similar data are not available using the NU 6 against a competing background of continuous discourse. There is reason to believe that performance would differ using speech as the competing signal (Jerger, 1970).

The NU 6 has been employed previously in investigations of hearing aid performance (Orchik and Oyer, 1972; Beattie and Edgerton, 1976) and these investigations will be discussed in a later section. The results indicate that use of the NU 6 in a hearing aid evaluation procedure may enable one to differentiate among various hearing aid arrangements. However, in neither investigation was a detailed hearing aid evaluation procedure utilized as was employed in this investigation.

Synthetic Sentence Identification

A monosyllabic word list restricts the critical parameter of the changing temporal characteristics of ongoing speech. Monosyllabic word lists further burden the testing paradigm because (1) they are an open message set introducing variables which the examiner cannot control and (2) the scoring ultimately becomes one of whose speech discrimination is being tested: the audiologist's or the patient's.

Speaks and Jerger (1965) developed new speech materials referred to as synthetic or artificial sentences to alleviate the limitations associated with monosyllabic word tests. The sentences are labelled artificial because they are not "real" sentences. Nevertheless, the sequence of words that comprise the sentences does follow specific rules of syntax explaining the term synthetic sentences. The ten sentences which comprise the message set are shown in Appendix B.

The formation of the ten sentence message sets were developed on the basis of the probability of word orders in meaningful speech. Thus each new word or sequence of words was determined by the probability of following the preceding word. However, the information content and sentence length were controlled. Once these sequences of words had been generated, they were classified into orders of

approximation depending upon whether the combinations of words were randomly selected or based on the conditional probabilities of word pairs, word triplets, or longer combinations. According to the authors, these "order of approximation" (e.g., first order, second order, and third order approximation), resemble approximations to real sentences. As the order of approximation increases, the synthetic sentences more closely correspond to meaningful sentences (Jerger, 1970).

The test procedure contrasts with the traditional approach used in speech audiometry in three ways. First, the sentences comprise a closed set, meaning that the patient has before him ten choices and his response will be derived from this array of ten synthetic sentences. Secondly, the method of response is simply one of identification. The patient's task is to identify from a closed set of alternatives. Third, the use of sentences for speech identification allows for the manipulation of temporal characteristics of ongoing speech.

Jerger, Speaks, Trammell (1970) compared synthetic sentence identification with a conventional monosyllabic word test, the PB-50's. Sixty hearing impaired patients with various types and degrees of hearing loss were administered the two speech discrimination tests. The scores from these two tests were contrasted to determine if the

two would yield equivalent results. Three different test conditions were employed to examine performance as a function of intensity.

Half lists of PB-50's were presented at various intensities, from the level where performance ranged from 0-30 percent through a maximum intensity of 110dB SPL. Essentially the same procedure was employed with the SSI except the same ten sentences were randomized at each intensity. The last condition combined a competing speech message with the synthetic sentences. The two signals, primary and secondary, were administered at a constant ratio of 0 dB. Again the sentences and the passage of continuous discourse were presented through a wide intensity range to a maximum of 110 dB SPL.

The results with the two measures demonstrated a direct relationship to audiometric configuration. This prompted the authors to separate the subjects into three groups (e.g., gradual slope, sharp slope, and flat slope). The analysis of PB scores and SSI with competing speech suggests equivalent performance is found when the sensitivity loss is fairly flat through 2000 Hz. However, with a sloping audiometric contour a disparity occurred between the two and as the slope of loss increased, the PB performance became progressively poorer while SSI-MCR scores remained relatively stable. It was not possible to determine which measure more accurately reflects an individual's communicative skills.

The authors attributed this discrepancy to the fact that important spectral information for PB words are located in the frequency region above 1000 Hz (French and Steinberg, 1947), whereas for the SSI the area of energy importance to identification lies below 1000 Hz at approximately 725 Hz (Speaks, 1967). An additional point is the resistance to degradation the sentences demonstrate due apparently to the presence of supplementary contextual clues (Speaks, 1967).

As will be described later, Jerger and Hayes (1976) feel the use of the SSI offers distinct advantages in the hearing aid evaluation process.

Hearing Aid Evaluation Procedures

The clinical evaluation and selection of hearing aids has been an important facet in the aural rehabilitative program for almost thirty years. However, much controversy still exists concerning the extent to which the audiologist should be involved in the selection process. The citations to follow illustrate the philosophical differences.

Carhart (1946) first described a clinical hearing aid evaluation procedure which involved aided and unaided testing to determine a best hearing aid for a given patient. Some form of this procedure is still in use at present at many clinical facilities (Ross, 1970).

Shore, Bilger, and Hirsh (1960) conducted an investigation which raised questions as to the efficacy of the above

procedure. Three diagnostic categories of hearing loss, conductive, mixed, and sensorineural, underwent extensive testing which was repeated over four successive days. Four different hearing aid arrangements were manipulated during the tests of hearing aid performance. Results indicated that the reliability of traditional measures of speech discrimination in quiet and noise is not good enough to warrant the investment of extensive clinical study or time. If there are any differences, the investigation did not detect any when using conventional measures of speech audiometry.

Shore, Bilger, and Hirsh's paper consequently resulted in a new procedure of hearing aid evaluation. Shore and Karmer in 1963 described the new procedure devised by the staff at the Central Institute for the Deaf and compared it to the previous procedure employed in the earlier investigation. The authors' primary interest in contrasting the two procedures was to determine which of the two was more effective.

The major differences with the new procedure were the following:

1. assisting the patient in purchasing an aid without recommending a specific aid,
2. more extensive use of time in patient counseling by eliminating time spent in hearing aid selection, and
3. establishment of a working rapport with the hearing aid dealers.

A questionnaire was sent to two groups of people. Group I was comprised of those adults who were tested at the CID when the conventional hearing aid selection was used. Group II included adults tested when the new procedure was in effect. Sections of the questionnaire dealt with the purchase of a hearing aid, trial with hearing aid, retest with hearing aid, and impressions of hearing aid with medical examination. The replies to these various sections were analyzed to determine if there were any significant differences. The authors recommended the use of the new procedure. The two groups were statistically different only on the following items.

1. In Group I, more adults purchased a hearing aid although not necessarily the one recommended.

2. In Group II, more adults indicated that they obtained appropriate counseling as to the nature of their hearing impairment and the selection of a hearing aid.

Resnick and Becker in 1963 criticized the rationale of conventional hearing aid selection procedures and described a new system which would eliminate the audiologist's participation in the hearing aid evaluation, selection, and counseling of the patient relative to the care and use of hearing aids. The rationale for their approach was that the audiologist is an authority on hearing problems, not hearing aids. Their new system defines the role of the audiologist in the aural rehabilitative process as one who only refers

the hearing impaired individuals to a specific hearing aid dealer after a complete audiologic assessment. The method of clinical hearing aid consultation the authors advised was formulated on these premises.

1. The audiologist role is to assess the hearing problem and counsel the patient relative to the nature of his hearing problem and briefly discuss the benefits or disadvantages of a hearing aid for that patient.
2. The patient is referred to a specific hearing aid dealer; the dealer is chosen by rotation from a list of dealers.
3. The audiologist contacts the dealer and the speech reception threshold, audiograms, and discrimination scores are reviewed.
4. Prior to the patient's departure from the clinic, an appointment is made with the hearing aid dealer.
5. Once the patient has been fitted with an aid, the dealer contacts the clinic and reports on the aid and makes an appointment for the patient at the clinic to be tested using usual audiometric test procedures for clinical hearing aid performance.

This new approach, according to Resnick and Becker, is the best solution in dealing with the total aural rehabilitation of the hearing impaired.

In a reply to Resnick and Becker, Jeffers (1963) supports the audiologist's role in the selection of a hearing aid as well as the test procedures employed. The author does not agree with Resnick and Becker's rationale for abandoning the audiologist in the selection of hearing aids.

The author acknowledges certain difficulties in the selection procedures, yet feels Resnick and Becker delegate

to the hearing aid dealer responsibilities for which he is inadequately trained. Jeffers favored modification of test procedures rather than abandonment of clinical hearing aid evaluations.

Jerger, Speaks, and Malmquist (1966) administered a sentence intelligibility test to patients demonstrating various types and degrees of hearing losses. Their intent was to discover if a performance task could reliably distinguish among hearing aids and if aids are rank ordered differently by different subjects. Three forms of a sentence intelligibility test were taperecorded through two commercially available hearing aids under three conditions purposely chosen to represent wide extremes in hearing aid performance. The sentence test utilized in this section of the investigation showed differences among the hearing aids for normal hearing and hearing impaired listeners. Thus, it appeared a behavioral task could reflect physical differences among hearing aids. Further, the authors concluded that subtle differences in hearing aid performance are just as important for the routine case (e.g., flat mild loss with good discrimination) as for the case characterized by more severe sloping loss with poor discrimination. The authors analyzed the individual performance data and it indicated that most listeners ranked the aids equivalently.

Jerger, Malmquist, and Speaks (1966) later compared three monosyllabic word intelligibility tests and a sentence

intelligibility test to investigate if both measures would reflect physical differences among hearing aids or if one would be more effective than the other. The PAL Auditory Test #8 (a sentence test), the CID W-22, CNC monosyllables, and low-pass filtered PB-50's were recorded through three hearing aids presented to thirty-six subjects with bilateral hearing loss of diverse types. The findings implied that performance differences will not necessarily be reflected by monosyllabic word lists. While sentence test results showed substantial performance differences among the three aids related to their harmonic distortion characteristics, the three monosyllabic word lists failed to reflect these differences. It should be noted that the monosyllabic word lists were presented in quiet, while the sentence task employed a competing message of continuous discourse.

The conviction that the use of a sentence-like task is the primary influence in demonstrating differences among hearing aids was questioned in an investigation by Orchik and Oyer (1972). The purpose of this study was to (1) catalogue common audiometric configurations and (2) investigate monosyllabic word lists presented in a competing message context as a behavior tool to display physical differences among hearing aids. Northwestern University Auditory Test # 6 was recorded through two hearing aids differing in frequency response and harmonic distortion. A competing message of continuous discourse was employed at a message-to-competition ratio of 10 dB.

Normal hearing adults were presented the material recorded through the hearing aids after the tapes were filtered to simulate a hearing loss with one of three audiometric configurations. The results indicated that a monosyllabic word list is able to reflect differences among hearing aids when used in a competing message context. The authors stated that the critical factor in demonstrating physical differences among hearing aids is the competing message, not the sentence task.

Beattie and Edgerton (1976) investigated the reliability of the NU 6 monosyllables in a background of white noise as an effective tool to exhibit differences among hearing aids. The subjects of this study were twenty subjects with mild-to-moderate sensorineural hearing losses. The NU 6 was modified by a background white noise at a S/N of +20 dB. The results indicated a definite interaction between subjects and hearing aids. The authors suggested that a monosyllabic word test in a background of white noise will not identify a single best aid, but can rule out a hearing aid with inferior performance characteristics.

A recent paper by Jerger and Hayes (1976) described a new method utilizing the SSI for the aural rehabilitation of the hearing impaired individual. The method reflects the philosophy that clinical selection of hearing aid performance is an integral part of the total rehabilitative process, and should be executed by an audiologist.

According to the authors, the new hearing aid technique has the following advantages.

1. Reproduction of a real life listening situation can be achieved with the synthetic sentences, which in turn will provide a valid task in the selection of different aids.

2. The ability to create different degrees of listening conditions improves the likelihood of delineating differences among aids.

3. The hearing aid arrangement which would best benefit the use can be selected.

4. Realistic counseling of patients is possible by depicting the expected benefit from the aid relative to a normal listener's performance as well as residual deficits.

5. By the use of audiometric task such as the SSI, satisfaction relative to the benefit one can expect to gain from an aid will increase the accountability of hearing aid recommendations.

The primary message of ten synthetic sentences and the secondary message of continuous discourse are presented at different combinations of intensity levels. The level of the sentences is set at 60 dB SPL and remains at this level throughout the evaluation. However, the intensity of the competing message is varied between 40 dB SPL and 80 dB SPL. This combination of intensity levels between the primary and secondary message is supposedly analogous to real life listening conditions. Jerger utilizes as many as five

different listening conditions: very easy, easy, average, difficult, and very difficult.

To evaluate the new procedure, those patients for whom amplification was recommended were sent a questionnaire form as a follow-up survey on the success of the audiometric pre-evaluation to predict user satisfaction or dissatisfaction. The indexes from the questionnaire that best predicted satisfaction with amplification were patient's age and performance in the difficult listening situation (MCR-10). Jerger indicates that the satisfied user emerged at the difficult listening situation because in easier listening situations the conditions are not as stressful. The more difficult the listening task, the more likely the hearing aid is placed in a more stressful situation, hence the benefit emerges. The authors emphasize the significance of this finding suggesting this may be the most important facet of their new method of hearing aid evaluation.

Summary

The preceding review has described the controversy surrounding clinical hearing aid evaluations. A new philosophy has been reported recently which suggests that hearing aid evaluation can and should be an important first step in the aural rehabilitative process. This philosophy is coupled to a test procedure which differs markedly from more conventional test procedures.

There is support in the literature to suggest that straight forward modifications of conventional test procedures would result in information that would be equally useful in the aural rehabilitation process.

The present investigation was proposed to compare the SSI procedure with the NU 6 monosyllabic word lists modified through the use of a competing message. The experiment compared the performance of both normal-hearing subjects and individuals with mild-to-moderate sensorineural hearing loss. Thus, the efficacy of both procedures was examined in the same population enabling evaluation of several questions.

1. Are there differences in the performance of normal-hearing listeners on the SSI and the NU 6 when a variety of listening conditions are employed?

2. For subjects with mild-to-moderate sensorineural hearing loss, how do their aided and unaided scores in a variety of listening conditions compare using the SSI and NU 6?

3. Does either the NU 6 or SSI more dramatically indicate "aided improvement" and "residual deficit" for subjects with mild-to-moderate sensorineural hearing loss?

CHAPTER III

EXPERIMENTAL PROCEDURES

Subjects

The subjects of this investigation were fourteen normal hearing subjects between the ages of eighteen and twenty-five years and fourteen adult subjects with mild to moderate sensorineural hearing loss. The age range for the fourteen bilateral sensorineural subjects was twenty-six to seventy-six years, while the average age was fifty-seven years. The age range for the three unilateral sensorineural subjects was twenty-three to fifty-nine years, with an average age of thirty-five years. Eleven of these subjects had a bilateral hearing impairment and the remaining three had a unilateral hearing loss. Normal hearing was defined as no threshold poorer than 20 dB HL (ANSI, 1969) for the octave frequencies from 500 through 4000 Hz.

In the subjects with a bilateral hearing impairment, a mild to moderate hearing loss was defined as a pure-tone average (500, 1000, and 2000 Hz) in the better ear of 30 dB or greater, but less than or equal to 65 dB (ANSI, 1969). The three subjects with a unilateral hearing loss had a pure-tone average in the impaired ear averaging 74 dB. The mean pure-tone audiograms for the sensorineural group with

unilateral and bilateral hearing losses are shown in Figures 1 and 2.

Fig. 1--Mean pure tone audiogram and standard deviation (bilateral sensorineural subjects).

Fig. 2--Mean pure tone audiogram and standard deviation (unilateral sensorineural subjects).

Test Environment

All subjects were tested via sound-field in a double-walled acoustically treated room (IAC Series 1200). Normal hearing listeners and subjects with a bilateral hearing loss were seated at 0 degrees azimuth relative to the primary source and 180 degrees relative to the competing message. Subjects with a unilateral hearing loss were seated with the affected ear toward the primary signal.

The test stimuli were delivered via a two-channel clinical audiometer (Beltone CR-5000) and associated tape deck. Calibration checks of the audiometer output were carried out daily.

Test Stimuli

The test stimuli consisted of tape recorded versions of the synthetic sentences (SSI) and the Northwestern Auditory Test No. 6 (NU 6). A competing message of continuous discourse with James Jerger as the talker was used with both discrimination tests. The talker for the primary signal on the SSI was James Jerger and for the NU 6 was William Rintelmann.

Experimental Procedure

Normal Hearing Listeners

The data were gathered in one session. A pure tone audiogram was obtained for each subject at the octave frequencies from 250 through 8000 Hz. Listener performance

was assessed at various message-to-competition ratios (MCR) with both the synthetic sentences and the NU 6 as the primary signal. The primary signal was a constant 60dB SPL and the MCR was varied from +20 to -30dB in 10 dB steps.

Sensorineural Hearing Loss Subjects

The data for this group were also obtained in one session. A pure tone audiogram was obtained for each subject at the octave frequencies from 250 through 8000 Hz. Speech discrimination scores were established under earphones at a level 40dB above the pure tone average.

Aided and unaided performance was assessed using the same hearing aid in four listening conditions based upon the normal data. Twelve of the fourteen sensorineural hearing loss subjects used their hearing aids throughout the testing. The two without their own aid were fitted with an appropriate hearing aid for the experiment. Half of the subjects were administered the NU 6 first, and the other half the SSI.

The four listening conditions described for the NU 6 were easy (+20dB), average (0dB), difficult (-10dB), and very difficult (-20dB). The MCR's employed for the SSI were easy (+20dB), average (0dB), difficult (-20dB), and very difficult (-30dB). Again, the primary signal was a constant 60dB SPL at all listening conditions. The two procedures were compared as to how they demonstrated aided improvement and residual deficit (Jerger and Hayes, 1976).

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter the results obtained for normal hearing and sensorineural subjects on the Northwestern Auditory Test No. 6 (NU 6) and Synthetic Sentence Identification (SSI) will be reviewed. The data were analyzed using a repeated measures analysis of variance design for the main effects of discrimination test (NU 6 or SSI), message-to-competition ratio (MCR), and their appropriate interactions. The analysis of variance tables are shown in Appendix C.

Normal Hearing Subjects: NU 6 vs. SSI

Discrimination scores were obtained at MCR's of 20dB, 10dB, 0dB, -10dB, -20dB, and -30dB for fourteen normal-hearing listeners. Generally the discrimination scores were greater for the SSI than for the NU 6. This difference was statistically significant ($p=0.000005$). A significant main effect for MCR was also evident as discrimination scores for both measures declined with increasing speech competition ($p=.000005$).

The mean discrimination scores as a function of MCR are shown in Table I for the NU 6 and SSI. As can be seen, at each MCR except +20, the scores for the NU 6 were poorer than scores for the SSI.

TABLE I
MEAN DISCRIMINATION SCORE IN PERCENT AS A
FUNCTION OF MCR FOR THE NORMAL
HEARING SUBJECTS

Test	MCR in dB					
	+20	+10	0	-10	-20	-30
NU 6	99.1	96.6	96.1	95.1	60.3	16.3
SSI	98.6	100.0	100.0	100.0	99.3	64.3

Further, it should be noted that the difference between the two tests varied as a function of MCR. The differences at the easy listening conditions were very slight, being 1 percent at an MCR of +20dB and 4 percent at +10dB. However, at the more difficult listening conditions, a rather large difference was observed: 39 percent at -20dB MCR and 48 percent at -30dB. This interaction of discrimination test and MCR was statistically significant ($p=0.000005$).

Sensorineural Subjects: NU 6 vs. SSI

Based upon the data for normal-hearing subjects, MCR's at four levels of difficulty were selected. These four conditions were selected as providing equivalent scores for the two discrimination tests using normal-hearing subjects. MCR's of 20, 0, -10, and -20dB were selected with the NU 6, while MCR's of 20, 0, -20, and -30dB were utilized for the SSI. A comparison of the normal listener's performance at each MCR is illustrated in Table II.

TABLE II
MEAN DISCRIMINATION SCORE IN PERCENT AT THE MCR'S
SELECTED FOR USE WITH SENSORINEURAL
HEARING LOSS GROUP

SSI	MCR in dB	MCR in dB	NU 6
98	+20	+20	99
100	0	0	96
99	-20	-10	95
64	-30	-20	60

The NU 6 and SSI were then administered, at the MCR's listed above, to fourteen subjects with sensorineural hearing loss.

Although discrimination scores for the sensorineural subjects were generally lower than those obtained for normal-hearing listeners, a comparison of the two measures (NU 6 and SSI) yielded similar statistical finds.

The mean discrimination scores for the sensorineural group are displayed in Table III as a function of MCR.

TABLE III
MEAN DISCRIMINATION SCORES IN PERCENT FOR THE
SENSORINEURAL GROUP (AIDED AND UNAIDED
SCORES WERE COMBINED FOR
THIS ANALYSIS)

Test	Easy	Average	Difficult	Very Difficult
NU 6	56.1	45.7	26.1	18.7
SSI	88.2	82.8	42.1	25.0

The aided and unaided conditions have been combined. As can be observed, scores on the SSI were significantly greater than those obtained for the NU 6 ($p=0.000005$). This trend was observed in both aided and unaided situations as will be discussed below.

Scores also declined significantly with increasing speech competition ($p=.000005$). The relationship between scores for the two discrimination tests again varied as a function of MCR, which resulted in a significant test by MCR interaction ($p=.00004$). However, in contrast to normal-hearing listeners, the differences in discrimination scores were greatest in the easier listening conditions and smaller for the more difficult MCR's. For example, at the most difficult MCR, the mean score for the SSI was only 7 percent higher than that for the NU 6. For the two easiest MCR's, however, the mean SSI score was more than 30 percent greater.

Unaided Performance: NU 6 vs. SSI

The sensorineural hearing loss subjects displayed significantly better unaided performance on the SSI than on the NU 6 ($p=0.000005$). Also, unaided performance declined significantly for both measures with increasing MCR as shown in Table IV ($p=0.000005$).

As the listening condition became more difficult, the differences between scores for the two discrimination tests declined. The mean difference at the least difficult listening condition was approximately

36 percent, while at the most difficult MCR, the difference was only slightly more than 5 percent.

TABLE IV
MEAN DISCRIMINATION SCORES IN PERCENT FOR THE
SENSORINEURAL GROUP IN THE
UNAIDED CONDITION

MCR		NU 6	SSI	Difference
NU 6	SSI			
+20	+20	46.57	82.14	35.57
0	0	34.57	76.42	41.85
-10	-20	16.85	35.00	18.15
-20	-30	12.57	17.85	5.28

This interaction for unaided scores between the discrimination test and MCR was statistically significant ($p=0.004$).

Aided Performance: NU 6 vs. SSI

An analysis of aided discrimination scores on the NU 6 and SSI yielded similar findings as the unaided comparison. These data are displayed in Table V.

TABLE V
DISCRIMINATION SCORE IN PERCENT FOR THE SENSORI-
NEURAL GROUP IN THE AIDED CONDITION

MCR		NU 6	SSI	Difference
NU 6	SSI			
+20	+20	65.71	94.28	28.57
0	0	56.85	89.28	32.43
-10	-20	35.42	49.28	13.86
-20	-30	24.86	32.14	7.28

Performance on the SSI was generally better than on the NU 6 ($p=0.000005$). Also, discrimination scores declined with increasing MCR ($p=0.000005$). Finally, the difference between the two measures was greatest (30 percent) at the easier listening conditions while for the most difficult listening conditions, the difference fell to about 8 percent. This resulted in a significant test by MCR interaction ($p=0.02$).

Aided Benefit and Residual Deficit

Recall that one of the major questions of this study involved comparison of aided improvement and residual deficit for the sensorineural subjects as indicated by the two experimental speech discrimination tests. Aided improvement and residual deficit were terms coined by Jerger and Hayes (1976) in evaluating clinical hearing aid performance. Aided benefit refers to the difference between the patient's unaided and aided performance, whereas residual deficit is the difference between the sensorineural subject's aided discrimination and the normal hearing subject's discrimination for the same listening condition.

The aided improvement demonstrated by these subjects is presented in Table VI as a function of MCR. A significant aided improvement was found ($p=0.000005$). These same data are illustrated in Figures 3 and 4. As can be seen in Table VI, the aided improvement demonstrated using the NU 6 was somewhat greater than that for the SSI at three of the four MCR's. The mean difference ranged from 4 percent in

the "difficult" MCR to 10 percent in the "average" condition. For the remaining MCR, the aided improvement for the SSI was greater by 2 percent. The difference between the two discrimination tests in demonstrating aided improvement was not significant, however ($p=0.16$).

TABLE VI
MEAN AIDED IMPROVEMENT IN PERCENT AS
A FUNCTION OF MCR

Test	MCR			
	Easy	Average	Difficult	Very Difficult
NU 6	19.14	22.28	18.57	12.28
SSI	12.14	12.86	14.28	14.28
Difference	7.0	9.42	4.29	2.0

Just as differences in overall performance decreased with increasing competition, so did aided improvement using the NU 6. For the SSI, however, aided improvement remained relatively constant across MCR. The main effect for MCR in aided improvement was not significant ($p=0.83$). Further, the nonsignificant interaction for discrimination test and MCR ($p=0.65$) suggests that from a statistical standpoint, the relationship between aided improvement for the NU 6 and SSI did not vary with MCR.

NU 6

*Normals

oAided

øUnaided

Fig. 3--Mean aided improvement and residual deficit using Nu 6.

* Normals

o Aided

ø Unaided

Fig. 4--Mean aided improvement and residual deficit using SSI.

As mentioned earlier, three of the sensorineural subjects had unilateral hearing losses. The aided improvement for these subjects is displayed in Table VII. The findings were similar to the data presented earlier for the entire sensorineural group in that aided improvement was somewhat greater for the NU 6 in three of four listening conditions although the magnitude of the difference was changed.

TABLE VII
MEAN DISCRIMINATION SCORE IN PERCENT OF
UNILATERAL HEARING LOSS SUBJECTS

Tests	MCR			
	Easy	Average	Difficult	Very Difficult
<u>NU 6</u>				
Unaided	82.6	49.3	28.0	18.6
Aided	88.0	64.0	50.6	20.0
Aided Improvement	5.34	14.6	22.6	1.34
<u>SSI</u>				
Unaided	100.0	96.6	46.6	23.3
Aided	100.0	100.0	56.6	36.6
Aided Improvement	0.0	3.34	10.0	13.3

A significant contrast was found, however, for the subjects with unilateral hearing loss in that aided improvement increased with increasing MCR, especially for the SSI.

This finding is consistent with the common report from subjects with a unilateral hearing loss that they have difficulty primarily in the presence of background noise. This is especially true when the competing signal is directed toward their better ear.

As defined by Jerger and Hayes (1976), residual deficit refers to the difference between the aided performance of the sensorineural group and the performance of the normal hearing group at a given MCR. The sensorineural group in this investigation exhibited a significant residual deficit ($p=0.000005$). The mean residual deficit as a function of MCR is shown in Table VIII for both discrimination tests. These data may also be reviewed in Figures 3 and 4.

TABLE VIII
MEAN RESIDUAL DEFICIT IN PERCENT
AS A FUNCTION OF MCR

Residual Deficit	MCR			
	Easy	Average	Difficult	Very Difficult
NU 6	33.4	39.2	59.7	35.43
SSI	4.28	10.71	50.0	32.1
Difference	29.1	28.5	9.71	3.29

As can be readily seen, the results obtained with the NU 6 indicated a greater residual deficit than that found with the SSI. This was expressed in a significant effect for discrimination test ($p=0.000005$). The magnitude of

residual deficit varied significantly with MCR for both discrimination tests ($p=0.000005$).

Table VIII also demonstrates that the difference in residual deficit obtained with the two discrimination tests varies as a function of MCR. The difference becomes smaller with increasing MCR and is manifested in a significant test by MCR interaction ($p=0.01$).

For the subjects with a unilateral hearing loss, the findings in terms of residual deficit were similar to those found in the examination of aided improvement. Residual deficit was greater for the NU 6 and the magnitude of the residual deficit was greater in the more difficult listening conditions. These data are displayed in Table IX.

TABLE IX
MEAN RESIDUAL DEFICIT IN PERCENT
AS A FUNCTION OF MCR
(Unilateral Loss)

MCR		NU 6	SSI
NU 6	SSI		
+20	+20	11	- 1
0	0	31	0
-10	-20	44.34	42.34
-20	-30	40	27.34

Discussion

Normal-Hearing Subjects: NU 6 vs. SSI

The superior scores on the SSI exhibited by the normal hearing subjects is not surprising and reflects the differences inherent in the two speech discrimination tests. The NU 6 is an open-set, monosyllabic word list. It is especially dependent upon the subjects familiarity with the language, as a test item could be any English monosyllabic word. The SSI, on the otherhand, involves selecting from a closed set of alternatives, which the subject has before him at all times.

The manner in which the discrimination scores differ is interesting as differences are greatest at the more difficult listening situations. Evidently, for normal-hearing subjects, the advantages of a closed-set format become important only under difficult listening conditions. This is in contrast to the effect demonstrated in listeners with sensorineural hearing loss to be discussed below.

A discrepancy existed when comparing the scores obtained in this experiment on the SSI to the norms Jerger and Hayes reported (1976). The difference between the two groups' discrimination scores may be explained in terms of the age of the subjects employed. Although not mentioned in their report, Jerger and Hayes' normative data closely approximate the average performance of normal hearing listeners between ages twelve and sixty-five reported by Orchik and Burgess

(1977). These authors found that SSI performance declines as a function of age. The authors obtained discrimination scores for four age categories: 10-12 years, 20-29 years, 40-49 years, and over 60 years. The results of their investigation revealed that discrimination on the SSI for the age group 20-29 was significantly better than all other age categories. Therefore, the higher discrimination scores in the present report may be attributed to the age of normal listeners utilized.

Sensorineural Subjects: NU 6 vs. SSI

The sensorineural subjects also displayed superior performance on the SSI. The explanation is undoubtedly the same as that expressed for similar findings with normal-hearing subjects. Specifically, the closed-set format of the SSI represents an easier task for the subject.

However, one interesting contrast is that the magnitude of the difference between the two discrimination tests decreased with increasing MCR. It would appear that with a sensorineural hearing loss the listening situation affects the advantage of a closed-set task in a different manner than that found in subjects with normal hearing. As the listening condition becomes more difficult, the additional cues of the SSI lose much of their influence. This feature is apparent whether one examines aided and unaided scores individually or in combination.

Aided Improvement and Residual Deficit

The significant aided improvement ($p=0.000005$) suggests that these subjects with sensorineural hearing loss demonstrated significantly better speech discrimination while wearing amplification. This is consistent with these individuals expressed satisfaction with their hearing aid arrangement.

Although the aided improvement indicated by the results with the NU 6 was somewhat greater than that indicated by the SSI, the difference was not significant ($p=0.16$). Thus, it would appear that at least for this population, both the NU 6 and the SSI are equally efficient as clinical tools to demonstrate aided benefit.

The significant residual deficit observed with this population ($p=0.000005$) supports the contention expressed by many clinicians to their hearing-impaired patients that a hearing aid will not restore hearing to normal. That residual deficit increases significantly ($p=0.01$) as the listening condition becomes more difficult is also consistent with the common complaint by individuals with sensorineural hearing loss of greatest difficulty hearing in noisy environments.

The significantly greater residual deficit which resulted when the NU 6 was employed may be explained when one considers the overall performance of these subjects in the aided and unaided conditions. As shown in Figures 3 and 4, the

unaided scores on the SSI were significantly better than those obtained for the NU 6. Thus, while both measures showed similar aided improvement, the higher scores on the SSI left less margin for residual deficit.

A significant question remains as to which measure more accurately reflects this population's real-life aided performance. This group of hearing impaired listeners characterized themselves as receiving significant benefit from amplification, which was reflected in the results of both tests. Thus, whatever degree the discrimination tests accurately reflected real-life benefit was accomplished in an equivalent manner for this population.

In terms of residual deficit, a significant difference between discrimination tests was found. The NU 6 indicated greater residual deficit, especially in the easier listening conditions. This group of hearing-impaired individuals reported that their aided communication was least affected in easier listening conditions, such as face-to-face conversation with no more than two persons. The results of the NU 6, therefore, probably overestimated the residual deficit for the listeners at the two easier MCR's.

The results do not necessarily imply the SSI is preferable to the NU 6 in clinical hearing aid evaluation. In this structured situation, the additional cues offered the listener in the easier listening conditions resulted in higher discrimination scores. If the NU 6 had been administered at a higher intensity level, 65dB SPL, for example,

the results could certainly have been different. The results simply reflect that the two tests are different and thus yield different results. Further research is needed to determine which measure, if either, more accurately reflects the real-life performance of the hearing aid user.

Summary

The present study was conducted to compare two speech discrimination tests, the SSI and the NU 6. Two experiments were conducted using two different groups of subjects. The first experiment utilized fourteen normal hearing subjects. Normal data gathered established the appropriate message to competition ratios (MCR) to be used in the second experiment. The second experiment employed fourteen subjects with a mild-to-moderate sensorineural hearing loss.

The results of the first experiment indicated that normal hearing subjects perform differently on the two discriminations tests, scoring higher on the SSI. The improved performance was most evident in the more difficult listening conditions. The differences between the two measures were attributed to the characteristics of the closed set paradigm.

The results of the second experiment were similar to the results obtained with normal hearing subjects in that discrimination scores were higher on the SSI. However, the differences between the two measures decreased in the more difficult listening conditions, which was in contrast to the

performance of normal hearing listeners. It was also found that speech discrimination was improved significantly with amplification on both the NU 6 and the SSI. Therefore, for this experimental group, either test measure could have been utilized to demonstrate aided improvement. Although, with both measures discrimination was improved with amplification, it was demonstrated that amplification cannot restore hearing to normal. This feature was manifested in a significant residual deficit on both tests.

The NU 6 displayed a greater residual deficit which was explained by the significantly higher unaided scores on the SSI leaving less margin for residual deficit.

The results of this study do not suggest a single discrimination test for all clinical hearing aid situations. For example, a disadvantage of the SSI that is frequently overlooked is the requirement that the subject be able to read. During testing with the sensorineural hearing loss group, a seventy-year-old male subject was discovered to be unable to read the sentences on the SSI, after completing the NU 6. He was, therefore, eliminated from the study.

The prominent theme should be one of flexibility. The clinician should not necessarily question which discrimination test to employ, but rather what is the appropriate level for the primary signal and what listening conditions are required based upon the type and degree of hearing loss.

Results from this paper suggest further research should examine the influence of the degree of hearing loss on the SSI and NU 6. It seems reasonable to assume that differences noted in the present investigation might be magnified with subjects demonstrating more severe hearing losses.

One of the goals of the hearing aid evaluation is to select an appropriate hearing aid arrangement for a particular individual. No attempt was made in the present study to determine which of the two procedures could best differentiate among hearing aid arrangements in individual cases. Such an investigation would be useful in determining the overall efficiency of each method.

Finally, a question which must eventually be considered is, "Do our test procedures actually reflect a real-life listening situation and, if so, does the aided performance demonstrate the amount of benefit the patient is likely to obtain?" At present, a generally accepted measure of hearing handicap does not exist. Attempts have been made to devise such a tool (High, Fairbanks and Glorig, 1964) with limited success. As yet no attempt has been made to relate the patient's subjective impression of the benefit he receives from the hearing aid in different listening conditions to the results obtained in the hearing aid evaluation. The need exists for research to examine this relationship and establish the accountability of clinical hearing aid evaluation.

APPENDICES

APPENDIX A

SYNTHETIC SENTENCES AS CONTAINED ON THE RESPONSE
BOX HELD BY THE SUBJECT

Alternative Sentences

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. Woman view men with green paper should

APPENDIX B

N.U. AUDITORY TEST #6
N.U. RESEARCH P.B. LIST I FORM B

1. burn	26. size
2. lot	27. pool
3. sub	28. vine
4. home	29. chalk
5. dime	30. laud
6. which (or witch)	31. goose
7. keen	32. shout
8. yes	33. fat
9. boat	34. puff
10. sure	35. jar
11. hurl	36. reach
12. door	37. rag
13. kite	38. mode
14. sell	39. tip
15. nag	40. page
16. take	41. raid
17. fall	42. raise
18. week	43. bean
19. death	44. hash
20. love	45. limb
21. tough	46. third
22. gap	47. jail
23. moon	48. knock
24. choice	49. whip
25. king	50. met

N.U. AUDITORY TEST #6
N.U. RESEARCH P.B. LIST II FORM B

1. live	26. hush
2. voice	27. dead
3. ton	28. pad
4. learn	29. mill
5. match	30. merge
6. chair	31. juice
7. deep	32. keg
8. pike	33. gin
9. room	34. nice
10. read (to read)	35. numb
11. calm	36. chief
12. book	37. gaze
13. dab	38. young
14. loaf	39. keep
15. goal	40. tool
16. shack	41. soap
17. far	42. hate
18. witch	43. turn
19. rot	44. rain
20. pick	45. shawl
21. fail	46. bought
22. said	47. thought
23. wag	48. bite
24. haze	49. lore
25. white	50. south

N.U. AUDITORY TEST #6
N.U. RESEARCH P.B. LIST III FORM B

1. sheep	26. germ
2. cause	27. thin
3. rat	28. name
4. bar	29. ditch
5. mouse	30. tell
6. talk	31. cool
7. hire	32. seize
8. search	33. dodge
9. luck	34. youth
10. cab	35. hit
11. rush	36. late
12. five	37. jug
13. team	38. wire
14. pearl	39. walk
15. soup	40. date
16. half	41. when
17. chat	42. ring
18. road	43. check
19. pole	44. note
20. phone	45. gun
21. life	46. beg
22. pain	47. void
23. base	48. shall
24. mop	49. lid
25. mess	50. good

N.U. AUDITORY TEST #6
N.U. RESEARCH P.B. LIST IV FORM B

1. rose	26. back
2. dog	27. hall
3. time	28. bath
4. such	29. tire
5. have	30. peg
6. mob	31. perch
7. bone	32. chain
8. sail	33. make
9. rough	34. long
10. dip	35. wash
11. join	36. food
12. check	37. mood
13. wheat	38. neat
14. thumb	39. tape
15. near	40. ripe
16. lease	41. hole
17. yearn	42. gas
18. kick	43. came
19. get	44. vote
20. lose	45. lean
21. kill	46. red
22. fit	47. doll
23. judge	48. shirt
24. should	49. sour
25. pass	50. wife

APPENDIX C.

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Normal-hearing Listeners)

Source	DF	Sum of Sq.	MS	F	P
Blocks	13	2600.57	200.04	3.74	0.00004
Treatments	11	103362.48			
SSI vs. NU 6	1	11335.71	11335.71	211.98	0.000005
MCR	5	76233.62	15246.72	285.12	0.000005
Test by MCR	5	15793.14	3158.63	59.07	0.000005
Residual	143	7646.86	53.47		
Total	167				

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Sensorineural Aided and Unaided Combined)

Source	DF	Sum of Sq.	MS	F	P
Blocks	27	81629.48	3023.31	8.57	0.000005
Treatments	7	134465.13			
SSI vs. NU 6	1	29302.88	29302.88	83.05	0.000005
MCR	3	96613.63	32204.54	91.28	0.000005
Test by MCR	3	8548.63	2849.54	8.08	0.00004
Residual	189	66682.38	352.82		
Total	223	282776.98			

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Sensorineural Unaided)

Source	DF	Sum of Sq.	MS	F	P
Blocks	13	37239.00	2864.54	6.98	0.000005
Treatments	7	69698.14			
SSI vs. NU 6	1	17801.29	17801.29	43.37	0.000005
MCR	3	46077.00	15359.00	37.42	0.000005
Test by MCR	3	5819.86	1939.95	4.73	0.00413
Residual	91	37351.86	410.46		
Total	111	144289.00			

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Sensorineural Aided)

Source	DF	Sum of Sq.	MS	F	P
Blocks	13	30530.46	2348.50	7.46	0.000005
Treatments	7	65465.96			
SSI vs. NU 6	1	11808.04	11808.04	37.53	0.000005
MCR	3	50674.68	16891.56	53.69	0.000005
Test by MCR	3	2983.25	994.42	3.16	0.02839
Residual	91	28631.54	314.63		
Total	111	124627.96			

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Aided Improvement)

Source	DF	Sum of Sq.	MS	F	P
Blocks	13	19292.46	1484.04	4.73	0.000005
Treatments	7	1397.96			
SSI vs. NU 6	1	612.89	612.89	1.95	0.16549
MCR	3	276.11	92.04	0.29	0.83001
Test by MCR	3	508.96	169.65	0.54	0.65543
Residual	91	28537.54	313.60		
Total	111	49227.96			

ANALYSIS OF VARIANCE FOR REPEATED MEASURES
(Residual Deficit)

Source	DF	Sum of Sq.	MS	F	P
Blocks	13	30530.46	2348.50	7.46	0.000005
Treatments	7	33183.72			
SSI vs. NU 6	1	8750.29	8750.29	27.81	0.000005
MCR	3	20788.01	6929.34	22.02	0.000005
Test by MCR	3	3645.41	1215.14	3.86	0.01192
Residual	91	28631.54	314.63		
Total	111	92345.72			

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