Employment of the Diagnostic Rhyme Test (Drt) With Normal-Hearing and Sensori-Neural Hearing-Impaired Listeners.

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EMPLOYMENT OF THE DIAGNOSTIC RHYME TEST (DRT) WITH NORMAL-HEARING AND SENSORI-NEURAL HEARING-IMPAIRED LISTENERS

A Dissertation

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ABSTRACT

The Diagnostic Rhyme Test (DRT) was developed by Dr. William D. Voiers in 1965 as a procedure for evaluation of communications systems. Word stimuli in the DRT are presented in an ordered arrangement for testing discrimination of six attributes: (1) voicing, (2) nasality, (3) sustention, (4) sibilation, (5) graveness, and (6) compactness. Each attribute is identified by a positive state and a negative state. Discrimination of the positive versus negative states of the six attributes is tested in a two-choice rhyme test format.

The purpose of this study was to investigate the predictive value and reliability of the DRT as a measure of speech discrimination abilities of normal-hearing and sensori-neural hearing-impaired listeners.

Twenty volunteer normal-hearing males and twenty males who had high-frequency sensori-neural hearing losses served as subjects. Four replications of the DRT 192-word corpus were presented at 50 dB SL to the two groups of listeners.

The following questions were formulated in the experimental design:

1. Are there differences in the total DRT scores for normal-hearing and sensori-neural hearing-impaired listeners?

2. Are the total DRT scores reliable?

3. Are there differences in the attribute scores of the DRT for normal-hearing and sensorineural hearing-impaired listeners?

4. Is the correctness of phoneme identification differentially related to specific attributes?

5. Are the attribute scores reliable?

6. Are there differences in the two states of each attribute for normal-hearing and sensorineural hearing-impaired listeners?

7. Are the scores for the two states of the attributes reliable?

Responses to the DRT were computer-scored and examined through the analysis of variance statistical procedure. Performance of the two groups of subjects was compared for DRT measures comprised of total DRT scores, scores for the six attributes, and scores for the present and absent states of each attribute.

The results of this study were the following:

1. Differences between normal-hearing and sensorineural hearing-impaired subjects were highly significant for the total DRT scores.

2. The reliability of the total DRT scores was high.

3. Differences in responses between the two listener groups were large and highly significant

for the attributes sustention, sibilation, graveness, and compactness. Differences between the two groups were small, but significant for the attribute voicing. There were no significant differences between the two groups for perceptual responses to the attribute nasality.

4. Orthogonal comparisons revealed that the correctness of phoneme identification was differentially related to certain attributes. Response patterns or profiles of the attributes were characteristic to each listener group.
5. The reliability of the attribute scores was high.
6. In the hearing-impaired group differences between the two states were significant for some attributes but not for others. The sensori-neural hearing loss subjects revealed significant differences between states for voicing, sustention, sibilation, and graveness. No significant differences between states were evident for nasality and compactness. For the normal group, no comparisons of present versus absent states were significant.

7. The reliability of scores was moderately high for the present state and higher for the absent state.

The DRT showed potential as a clinical audiologic procedure. However, recommendation of the DRT for clinical use was held in abeyance because of the need for additional research data.

CHAPTER I

INTRODUCTION, TERMINOLOGY, AND STATEMENT OF THE PROBLEM

Introduction

Speech discrimination testing is a traditional procedure for evaluation of auditory systems. Hearing impairment is assessed, in the main, through analysis of the listener's ability to perceive phonemes.

The discrimination tests employed most frequently are the Harvard PB-50 Tests (Egan, 1948) and the C.I.D. W-22 Auditory Tests (Hirsh et al, 1952). These tests indicate the percentage of words correctly identified. They do not provide categorical analysis of phonemic errors and perceptual confusions. A lack of reliability among lists, unequal phonetic balance, and vocabulary, experience, intelligence, and familiarity effects are reported to be limitations of the Harvard PB-50 and C.I.D. W-22 Tests (Owens, 1961).

A trend toward refinement of speech discrimination tests through specification of individual phonemic errors is evident over the past fifteen years. During this time a number of speech discrimination tests have been devised (Fairbanks, 1958; Lehiste and Peterson, 1959; House et al,

1963; Tillman et al, 1963; Kreul et al, 1968; McPherson and Pang-Ching, 1971). These tests have not been used widely for clinical testing because commercially available test tapes are limited in number and additional standardization data are needed.

One of the most recent approaches to speech discrimination testing was introduced by Dr. William Voiers and his associates at the Spring, 1965, Meeting of the Acoustical Society of America. The test, entitled the Diagnostic Rhyme Test (DRT) is based upon a type of distinctive feature analysis. Distinctive features have been defined as " . . . those aspects of the process of articulation and their acoustic consequences that serve to contrast one phoneme with others (Berko and Brown, 1960, pp. 525-26)."

A number of researchers have developed distinctive feature systems for classifying phonemes (Jakobson, Fant, and Halle, 1952; Miller and Nicely, 1955; Singh and Black, 1966; Wickelgren, 1966). Voiers (1967) selected certain of the distinctive features previously introduced by Jakobson, Fant, and Halle (1952) and Miller and Nicely (1955). In addition, he modified some of the categorical terms.

Voiers (1967) has dropped references to distinctive features and, in substitution, refers to attributes. The DRT assesses discrimination of six attributes; namely, voicing, nasality, sustention, sibilation, graveness, and

compactness, in rhyming word pairs. The initial consonants of the words differ from each other by one distinctive feature. Voiers (1967) has distinguished a positive and a negative state of each attribute. Table 1 identifies Voiers' (1967) terminology for the six attributes of the DRT along with the closely corresponding definitions from Jakobson and Halle (1956).

The relationship between Voiers' (1967) classification system and that of his predecessors is seen easily in many instances. For example, voicing positive state and voicing negative state are equated with voiced and voiceless phonemes. In certain cases, however, the comparison is not obvious. For example, sibilation positive state and sibilation negative state are modifications of Jakobson and Halle's (1956) strident and mellow classifications.

The perception of speech signals represents a complex activity which is not fully understood at the present time. According to Miller and Nicely (1955, p. 351), " . . . the development and standardization of tests for the individual features would seem to have considerable value for the diagnosis both of inefficient equipments (sic) and of hard-of-hearing people."

The DRT has proved to be suitable for evaluation of communications equipment. In a number of studies Voiers (1965, 1968, 1969) has shown that the six attributes of

Table 1

Acoustic and Genetic Definitions of the Six Attributes of the Diagnostic Rhyme Test (DRT)

ATTRIBUTES*	BINARY OPPOSITIONS**	DEFINITIONS ACOUSTICALLY	GENETICALLY
Voicing Positive Negative	 Voiced Voiceless	Presence vs. absence of periodic low frequency excitation.	Periodic vibrations of the vocal cords vs. lack of such vibrations.
Nasality Positive Negative	 Nasal Oral	Spreading the available energy over wider (vs. narrower) frequency regions by a reduction in the intensity of certain (primarily the first) formants and introduction of additional (nasal) formants.	Mouth resonator supplemented by the nose cavity vs. the exclusion of the nasal resonator.
Sustention Positive Negative	 Continuant Discontinuous	Smooth onset vs. abrupt onset. That is, absence of abrupt transition between sound and . . . silence vs. silence (at least in frequency range above vocal fold vibration) followed and/or preceded by spread of energy over a wide frequency region (either as burst or as a rapid transition of vowel formants.	Rapid turning on or off of source either through a rapid closure and/or opening of the vocal tract that distinguishes plosives (discontinuous) from constrictives (continuant) or through one or more taps that differentiate the discontinuous liquids like a flap or trill /r/ from continuant liquids like the lateral /l/.
Sibilation Positive Negative	 Strident Mellow	Higher intensity noise vs. lower intensity noise.	Rough-edged vs. smooth-edged; supplementary obstruction creating edge effects (Schneidenton) at the point of articulation distinguishes the production of the rough-edged phonemes from the less complex impediment in their smooth-edged counterparts.

Table 1--Continued

ATTRIBUTES*	BINARY OPPOSITIONS**	DEFINITIONS ACOUSTICALLY	DEFINITIONS GENETICALLY
Graveness Positive Negative	 Grave Acute	Concentration of energy in the lower (vs. upper) frequencies of the spectrum.	Peripheral vs. medial: peripheral phonemes have an ampler and less compartmented resonator than the corresponding medial phonemes. Voiers' (1967) system limits the use of peripheral phonemes to those produced anteriorly.
Compactness Positive Negative	 Compact Diffuse	Higher (vs. lower) concentration of energy in a relatively narrow, central region of the spectrum, accompanied by an increase (vs. decrease) of the total amount of energy.	Forward-flanged vs. backward-flanged. The difference lies in the relation between the volume of the resonance chamber in front of the narrowest stricture and behind this stricture. The ratio of the former to the latter is higher for the forward-flanged phonemes (wide vowels, and velar and palatal, including post-alveolar consonants) than for the corresponding backward-flanged phonemes (narrow vowels, and labial and dental, including alveolar consonants).

*Voiers (1967).

**Jakobson and Halle (1956, pp. 29-31)

the DRT are affected differentially by frequency distortion, signal-to-noise variations, speaker idiosyncrasies, and listener acuity.

The results of the DRT for one high-frequency hearing loss subject were provocative (Voiers, 1967). This individual's DRT profile scores for the six attributes were similar to the low-pass filtering profile scores. That is, voicing and nasality were little affected, but the other four attributes were adversely affected in varying degrees.

The value of the DRT for clinical speech audiometry has not been investigated systematically. According to Voiers (1967, p. 59), "Much additional research will . . . be required to evaluate the potential of the DRT for purposes of clinical audiology."

Terminology

In this section definitions of terms pertinent to the use of the DRT in the present study are given. Those terms which describe the specific attributes have been defined previously in Table 1.

Total DRT scores are defined as the adjusted percentage of correct responses for all phonemes in the DRT. This score is the mean of the adjusted percentage scores for the six attributes.

Attribute scores are defined as the adjusted percentage

of correct responses for phonemes representing an individual attribute; that is, for voicing, nasality, sustention, sibilation, graveness, and compactness. The attribute score is the mean of the positive and negative states of each attribute.

Positive state scores are defined as the adjusted percentage of correct responses for phonemes categorized as the positive state of an attribute.

Negative state scores are defined as the adjusted percentage of correct responses for phonemes categorized as the negative state of an attribute.

Statement of the Problem

The purpose of the present study is to investigate the predictive value and reliability of the DRT with normal-hearing and sensori-neural hearing-impaired listeners. The following questions were formulated to determine the clinical usefulness of the DRT:

1. Are there differences in the total DRT scores for normal-hearing and sensori-neural hearing-impaired listeners?
2. Are the total DRT scores reliable?
3. Are there differences in the attribute scores of the DRT for normal-hearing and sensori-neural hearing-impaired listeners?
4. Is the correctness of phoneme identification

differentially related to specific attributes?

5. Are the attribute scores reliable?
6. Are there differences in the two states of each attribute for normal-hearing and sensori-neural hearing-impaired listeners?
7. Are the scores for the two states of the attributes reliable?

CHAPTER II

REVIEW OF THE LITERATURE

The principles of speech audiometry are founded on the theories of many contributing sciences which include acoustics, linguistics, psychology, and physiology. Historically, milestones leading to the development of modern speech audiometry have included: (1) the research of Fletcher and his associates at the Bell Telephone Laboratories, (2) the studies at the Harvard Psycho-Acoustics Laboratories (PAL) during World War II, (3) the revision of speech materials for clinical use by the researchers at the Central Institute for the Deaf (C.I.D.), (4) the evolution of various models for speech discrimination testing, and (5) the cumulative research in speech perception. In the final section of this chapter a description of the DRT and the preliminary studies which employed the DRT will be presented.

Bell Telephone Laboratories

Fletcher and his associates (1929, 1937, 1950, 1953) made outstanding contributions to the study of the acoustics and perception of speech sounds. Fletcher and Steinberg (1929) developed lists of monosyllabic test

words which used the consonant-vowel-consonant (CVC) format. These materials were used to plot an articulation function (defined as the percentage of words correctly perceived as a function of intensity changes). The articulation function varied according to the type of test materials. Fletcher and Steinberg (1929) also composed lists of nonsense syllables, numbers, and simple sentences for different testing purposes in evaluation of communications systems.

Harvard Psycho-Acoustics Laboratories

Egan (1948) who worked at the Harvard Psycho-Acoustics Laboratories presented a test of speech intelligibility composed of monosyllabic word lists. The Harvard lists were compiled on the basis of six criteria: (1) monosyllabic structure, (2) equal average difficulty, (3) equal range of difficulty, (4) equal phonetic composition, (5) a composition representative of American English speech, and (6) words in common usage.

The phonetically-balanced lists (PB-50) were "common monosyllables" and phonetic composition was based on Dewey's (1923) report of the frequency of English speech sounds in a sample of 100,000 words. The selection of familiar words restricted the phonetic composition of the lists such that this criterion could not be strictly met.

The difficulty of selected phonetically-balanced words was evaluated by eleven listeners under several

conditions. Those words which were generally missed by the listeners were eliminated from the PB vocabulary.

The familiarity of the preliminary word lists was appraised by twenty-three listeners who rated each word as familiar (1 point), somewhat familiar (2 points), or quite unfamiliar (3 points). The points for each word were totaled and words rated 35 or more were discarded from the final lists. Egan (1948) emphasized that listeners should be given practice sessions to familiarize them with the spelling and definitions of words to be used in testing.

The final PB-lists consisted of 20 lists of 50 words which were recorded for use in rating communications systems and later, as a clinical procedure for speech audiometry.

Central Institute for the Deaf

After several years of clinical application with the PB-50 lists, researchers at the Central Institute for the Deaf reported certain deficiencies in the lists including that: (1) the vocabulary (1000 words) was too large for clinical use, (2) further restrictions on familiarity were needed, and (3) phonetic balance warranted improvement.

Hirsh et al (1952) modified the original PAL word lists with clinical practicality as their target. The C.I.D. Auditory Test W-22 vocabulary consisted of 200 monosyllabic words of which 120 were drawn from the 1000 PB-50

word pool and 80 additional words were amassed from an unspecified source. The 200 monosyllabic words were assigned to four master lists each with 50 words. Each master list was scrambled six times.

The criteria for construction of the C.I.D. W-22 lists were as follows: (1) only one syllable words could be used and no words could be repeated in the different master lists, (2) all words had to be familiar, and (3) the phonetic composition of each list had to correspond closely to that of a representative sample of English speech.

The selection of familiar words was established to reduce the effect of educational differences among subjects. One-hundred and ninety of the 200 C.I.D. W-22 words were noted to be among the first 4000 most common English words listed by Thorndike (1932). In addition, 128 of the 200 C.I.D. W-22 words are present on the Dewey (1923) list of words.

The criteria of phonetic balance was based on the phonetic composition of newsprint (Dewey, 1923) and of business telephone calls in New York City (French et al, 1930). The phonetic balance was improved over the Psycho-Acoustic Laboratory PB-50 lists as the consonants, vowels, and syllable types were analyzed to give a more balanced distribution. From the original tapes commercial disk recordings were made which are now widely used clinical speech discrimination materials.

Other Speech Discrimination Tests and Studies

Fairbanks (1958) developed a rhyme test which he termed a "Test of Phonemic Differentiation: The Rhyme Test." This rhyme test involves a completion task in which the subject fills in the initial consonant to a given word stem. A corpus of 250 monosyllabic words was selected which represented the eighteen consonants that comprise approximately ninety per cent of the consonants in the English language. On the basis of phonemic distribution and familiarity of words, fifty sets of five rhyming words each were generated for this rhyme test.

Fairbanks (1958) indicated that the basic 250 word corpus could be used to formulate lists with controlled distributions of features. For example, an equal division of voiced and voiceless consonants in a list could be used. Fairbanks (1958, p. 600) stated that "among persons with hearing loss, degree of loss might be correlated with the voiced subscore and type of loss with the difference between the voiced and voiceless subscores, etc."

Lehiste and Peterson (1959) formulated the consonant-nucleus-consonant (CNC) word lists with the contention that word lists can be phonemically balanced on a first order basis with each phoneme assigned for equal frequency of occurrence. All CNC monosyllabic words which occurred

at least once per million words according to the Thorndike-Lorge (1944) word count were drawn. From this pool of 1263 words, the frequency of occurrence of each initial and final consonant and medial vowel was determined. Ten CNC lists of 50 words each were compiled with the same relative incidence of phonemes as tabulated for the corpus of 1263 words.

The original CNC lists were revised by Peterson and Lehiste (1962). A new criterion of word frequency of at least four per million words according to the Thorndike-Lorge (1944) count was established.

An adaptation of the CNC words (Lehiste and Peterson, 1959) for clinical and research use was introduced by Tillman et al (1963) and designated as the Northwestern University Auditory Test No. 4. The test appeared to be reliable with good equivalency among lists. However, the number of available lists was restricted to six randomizations of each of two 50-word master lists.

Since repetition of lists in testing situations would introduce uncontrolled variables (i.e., learning), Tillman and Carhart (1966) incorporated revisions and expansions of test lists in the Northwestern University Auditory Test No. 6. This test is composed of four lists of 50 CNC monosyllabic words each with four randomizations of each master list (A, B, C, and D). Articulation functions for 24 normal-hearing and 12 hypoacousic subjects using

the Northwestern University (N.U.) Test No. 6 corresponded closely to earlier findings with the N.U. Test No. 4. That is, high interlist equivalence and good test-retest reliability were retained while the number of test items was increased.

House et al (1963) presented "The Modified Rhyme Test" which consisted of 300 common monosyllabic words arranged in six equivalent lists of 50 words each. Subjects had to select a response from a closed set of six words after the stimulus word was presented. Each ensemble used the same vowel nucleus with test words and were CVC, VC, or CV monosyllables. The major sound classes were in each list.

House et al (1965) later made a number of word changes by elimination of words that were repeated more than once in the test and words that were deemed objectionable. Analysis of the six lists revealed equivalency among lists and stability of listener response to repeated presentations of the test stimuli.

Clinical application of the Modified Rhyme Test (MRT) was proposed by Kreul et al (1968) who made revisions of the recordings, the carrier phrase, timing sequences, instructions, answer sheets, and masking noise levels. The MRT is available as six tapes using three different speakers: two male speakers and one female speaker. There are two tapes per speaker. On each tape there are four lists with four different test conditions; namely, +30 S/N,

P83, P75, and +30 S/N. That is, there is speech-shaped noise on the tapes adjusted such that normal listeners tested experimentally obtained correct responses of 96 per cent at the +30 S/N conditions, 83 per cent at the P83 condition, and 75 per cent at the P75 condition.

Bell et al (1972) investigated the reliability of the clinical version of the MRT with normal and hearing-impaired listeners. It was concluded that the MRT does not provide the precision to measure differences in speech discrimination ability among normal listeners (which may be inherent in a closed-response set format), but appears to be as reliable as other speech discrimination tests when used with heterogeneous hearing-loss subjects.

Elkins (1971) reported that the MRT (male speaker one tape) differentiated normal from hearing-impaired listeners. However, the MRT failed to show differences within the hearing-impaired group for the various conditions even though the subjects had different audiometric contours.

The University of Oklahoma Speech Test #6 (Pederson, 1970) is a phoneme identification test of initial consonants, final consonants, and medial vowels presented in CVC monosyllabic words. The phonemes having the same voicing and manner features, but different place of production, are presented in a closed-response set format. The consonant subtest includes the following groups of phonemes: (1) voiced plosives, (2) voiceless plosives,

(3) voiced fricatives, (4) voiceless fricatives, and (5) affricative blends. The vowel subtest consists of eight vowels presented within a "b_t" structure.

McPherson and Pang-Ching (1971) have devised the Distinctive Feature Discrimination Test (DFDT) which consists of four word lists. A rhyme test format is used in which the response choices vary one, two, and three distinctive features from the stimulus word. The test words for the DFDT are primarily from the MRT (House et al, 1963). The distinctive feature system is adapted from Miller and Nicely (1955). Preliminary research with six normal listeners revealed a reasonable degree of inter-list reliability. The six normal subjects had different patterns of error responses under two band-pass filtering conditions: 200-1200 Hz and 200-600 Hz. Error responses were greater for certain distinctive features than for others. According to McPherson and Pang-Ching (1971, p. 11) this may indicate the possibility of finding "some kind of feature confusion profiles or patterns of feature confusions which may be typical of various pathologies."

There are a number of controversial issues with regard to the variables of materials and methods in construction and presentation of speech discrimination tests. Some of the basic issues concern the following: (1) the use of nonsense syllables, words, or sentences,

(2) real versus synthetic speech, (3) open versus closed message sets, (4) familiar versus unfamiliar words, (5) balanced versus unbalanced phonetic composition, (6) recorded versus live voice tests, (7) written versus oral responses, and (8) long versus abbreviated lists from standardized speech discrimination tests.

Pollack et al (1959) attested to the response biases, such as the listener's vocabulary, experiences, and prejudices, and word frequency effects, in tests using unknown message sets. Phonemic interconfusability becomes the prime factor being tested in a closed message set test. The trend toward closed message set tests is evident in the wide-spread application of multiple-choice tests of speech discrimination ability (Hutton et al, 1959; Kreul et al, 1968; Beyer et al, 1969; Pederson, 1970).

Speaks et al (1970) compared speech discrimination scores from synthetic sentences in a closed set to PB words in an open set. Characteristic differences in the two tests were evident with subjects who had sloping audiometric contours, but not those who had flat audiometric configurations.

A classic study of the intelligibility of nonsense syllables and monosyllabic, disyllabic, and polysyllabic words as a function of frequency filtering and intensity changes has been presented by Hirsh et al (1954). Their important findings were that: (1) intelligibility was

not significantly impaired by eliminating all frequencies above or below 1600 Hz, (2) monosyllabic words were more intelligible than nonsense syllables, and (3) different effects on intelligibility were evident with speech stimuli masked by white noise or filtered.

The criteria of word familiarity (Schultz, 1964; Owens, 1961) and phonetic balance (Tobias, 1964; Campbell, 1965) have been investigated extensively. According to Owens (1961), a response choice is highly dependent upon word familiarity. He reported higher intelligibility scores for PB-50 and W-22 word lists which were characterized by greater familiarity. The question of phonetic balance was reported by Tobias (1964) to be of minimal usefulness in speech discrimination tests. Other researchers (Elpern, 1961; Grubb, 1963a, 1963b) were of the opinion that phonetic balance was an important issue in the use of half-lists of the W-22 and PB-50 discrimination tests. Shutts et al (1964) found four 25-word lists derived from PAL PB-50 lists 1A and 2A to be highly correlated with the standard 50-word lists.

The research of Kreul et al (1969) confirmed that the level of test difficulty in discrimination testing is highly dependent upon such factors as the carrier phrase, the selection of the talker, the talker's specific utterances, and distortion influences. The use of standardized recorded discrimination tests has been advocated (Kreul

et al, 1969; Brandy, 1966).

The controversy of talkback versus writedown scoring of speech discrimination tests has been discussed by a number of researchers (Merrell and Atkinson, 1965; Hahn-Lovrinic et al, 1968; Nelson and Chaiklin, 1970). There appeared to be better control of variables such as examiner experience, testing situation bias, and monitoring levels in writedown scoring procedures. In view of these findings it is evident that a writedown scoring procedure should be the method of choice if the subject is capable of such a task.

Speech Perception Research

Over the past three decades the literature on speech perception has covered a broad spectrum of subject matter. Researchers have been interested in the analysis of the speech communication experience between a speaker and a listener. Attempts to decipher the speech code have prompted investigations of acoustic, articulatory, auditory, linguistic, neural, and physiological processes.

Liberman (1957) published a review of research aimed at the isolation of acoustic cues important in the perception of consonants. The consonant cues can be arranged into three classes including constriction sounds, transitions, and on or off nasal resonance.

The constriction sounds include the frictions of the

fricatives and affricatives and the bursts of the stops. The significant cues for these sounds are the frequency positions of the sounds, duration and nature of the onset of noise, and at times intensity. The frequencies of constriction sounds serve as cues for the place of production of the stops and some of the fricatives. The duration and the nature of the onset of the noise of the constriction sounds provide cues related to manner.

The second class of consonant cues, transitions or frequency shifts, furnish information about articulatory movements. These cues include: (1) changes in direction and extent of second and third formant transitions for perception of stop and nasal consonants corresponding to the place of production, and first formant transitions for manner of production, (2) transition duration for distinguishing stop consonants from semi-vowels, and (3) the presence or absence of a silent interval between the frequency locus and the start of a transition.

The third consonant cue concerning the on-off action of nasal resonance provides the acoustic cue for nasal consonants.

A motor theory of speech perception was postulated by Liberman (1957) based on two major findings. The first was that listeners could discriminate phonemes varying in discrete steps along a continuum about as well as they could identify speech sounds belonging to specific phonemic

categories. For example, using synthetic speech, the consonant sounds were continuous as they shifted from /b/ to /d/ to /g/, but the listeners did not perceive them as continuous. The second finding emphasized by Liberman (1957, p. 121) was that "the correspondence between articulation and sound is not always one-to-one."

Acceptance of the motor theory of speech perception has not been universal. Fant (1967) presented the following viewpoint:

> . . . support of motor theories of speech perception is not conclusive. This does not imply that . . . the 'motor' theory (is) improbable, merely that all of the arguments brought forward in support of the motor theory would equally well fit into 'non-motor' or 'sensory' theories by which the decoding proceeds without the active mediation of speech motor centers (p. 111).

More recently, Abbs and Sussman (1971) proposed a sensory theory for the perception and decoding of speech signals. They suggested that the distinctive feature system of Jakobson, Fant, and Halle (1952) may possibly be applied to their theory of feature detectors in the sensory nervous system. According to Abbs and Sussman (1971, p. 30), "the human organism . . . is uniquely structured to neurally respond to the physical cues necessary for the auditory decoding of speech."

Controversial issues regarding speech decoding processes have not been resolved. Lane (1965) presented

a critical review of evidence supporting and evidence opposing the motor theory of speech perception.

The Miller and Nicely (1955) linguistic model was the basis of the consonant taxonomy for the initial version of the DRT (Voiers, 1965). Five articulatory categories were identified: voicing, nasality, affrication, duration, and place of articulation. Miller and Nicely (1955) studied perceptual confusions by error types and frequency of occurrence of errors using as the stimuli sixteen consonants each paired with the vowel /ɑ/. Five normal listeners served as subjects and were instructed to guess at every sound they heard. The subjects' responses for varying signal-to-noise and filtering conditions were presented as confusion matrices. Final results showed that errors were random in the high-pass filtering conditions. However, under low-pass filtering and noise conditions, phoneme confusions fell into consistent patterns.

Wickelgren (1966) examined recall of consonants in short-term memory experiments. He concluded that the coding of consonants in short-term memory is based upon the distinctive features which categorize individual consonants. His data revealed that error responses were systematic and shared certain distinctive features with the correct consonant response.

Singh and Black (1966) analyzed perceptual confusions

of twenty-six consonants spoken in four languages. The overall rank ordering of the highest number of correctly perceived features among the listener groups was as follows: nasality, place, liquid, voicing, duration, friction, and aspiration.

Singh (1971) investigated the strength of certain distinctive features under varying filter conditions and signal-to-noise ratios. He found that the voicing feature was strengthened in noise but deteriorated in quiet. Perception of friction was improved with the addition of durational cues but worsened in noise. Filtering and noise conditions had little affect on nasality, liquid, and glide distinctions. Finally, in all six experimental conditions nasality was the most intense feature.

Many investigators have studied the voiced-voiceless distinctions of consonants (Tolhurst, 1949; Denes, 1955; Lisker, 1957). Using a technique with synthetic speech in which the first formant is gradually reduced or "cutback," Liberman et al (1958) demonstrated that voiced versus voiceless distinctions for stops in the initial position can be made on the basis of presence or absence of a "cutback" in the first formant. The first-formant cutback produced two changes in the stimulus: (1) the beginning frequency was gradually elevated and (2) the onset of the first formant was delayed. A rising frequency shift was identified as a cue for voiceless stops. Adding noise to

the second and third formants for the "cutback" duration increased voicelessness. However, adding noise without the "cutback" did not show such an effect.

Peters (1963) studied the dimensions of perceptual importance in consonant identification. He had subjects estimate the psychological distance between pairs of different consonants based on judgments of similarity. The subjects rated the stimuli on a nine-point scale ranging from extreme similarity to extreme dissimilarity. Results indicated that the features useful for the interpretation of the structure and dimensionality of consonants were (in order of importance): manner, voicing, and place of articulation.

Numerous studies have delineated the processes of consonant perception. The acoustic cues for stops have been discussed by Halle et al (1957), Harris et al (1958), Malécot (1958), and Hoffman (1958). Cues for the perception of nasal consonants are presented by House (1957) and Fujimura (1961). Fricative cues were researched by Heinz and Stevens (1961) and Strevens (1960).

The long-accepted generalization that individuals with high-frequency hearing impairments have great difficulty identifying high-frequency consonants (Davis and Silverman, 1962; Newby, 1958; Niemeyer, 1967; Streng et al, 1955) has been challenged by several investigators (Rosen, 1962; Rhodes, 1966; and Lawrence and Byers, 1969).

Prompted by clinical observations of the excellent speech discrimination ability of certain individuals with high-frequency sensori-neural hearing losses, Rhodes (1966) compared normals and sensori-neurals under conditions of filtered speech. CNC lists developed by Peterson and Lehiste (1962) were low-pass filtered at 1000 Hz and 2000 Hz. According to Rhodes (1966) the finding of significantly better performance of hearing-impaired listeners in the 1000 Hz low-pass filtering test may have been related to learned behavior. Rhodes (1966, p. 132) was of the opinion that the hearing-impaired individuals learned "to utilize acoustic cues that are not recognized by normal hearers."

Boothroyd (1967) measured speech discrimination abilities of hard-of-hearing children who had sensori-neural losses ranging from 45 to 95 dB (three frequency average) in the better ear, under certain high- and low-pass filtering conditions. Results of this research indicated that children with long standing high-frequency hearing losses learn to use low frequency information for decoding speech.

Siegenthaler (1949) designed a study using normal and hard-of-hearing listeners in which three factors were assessed. These included: (1) voicing of consonants, (2) pressure pattern of consonants, and (3) influence of one "sound" upon another within a word. According to

Siegenthaler (1949) normal hearing subjects could identify all three factors better than the hearing-impaired listeners. Normal hearers had the greatest number of errors in perception of pressure pattern differences. Subjects with a flat hearing loss performed about equally well for all three classes of word pairs. High-frequency hearing-loss subjects had better scores for voicing differences than for pressure pattern and vowel influence contrasts.

Rosen (1962) investigated phoneme identification in 251 sensori-neural hypacusics. The stimulus words were from various PAL lists and CID W-22 lists. Subjects responded to the CVC monosyllables by writing down the words heard. Consonants were classed according to voicing, manner of articulation, and place of articulation.

According to Rosen (1962, pp. 295-296) analysis of phoneme confusions for voicing and manner of articulation distinctions revealed the following:

> 1. Voiced stops, semivowel glides, and no consonants were easier to discriminate than other consonants in either the initial or final position in the syllable.
>
> 2. Voiced fricatives, voiceless fricatives, and consonant clusters were more difficult to discriminate than other consonants in either the initial or final position in the syllable.
>
> 3. The discrimination scores for the pooled voiceless stops were not different from the discrimination scores for all consonants pooled.
>
> 4. Discrimination scores for the pooled initial nasal sounds were not different from the

score for all initial consonants pooled.

> 5. The discrimination for pooled initial affricatives was not different from the score for all initial consonants pooled.

Rosen (1962) indicated that place of articulation errors appeared to be related to the degree of sensori-neural hearing impairment. The data revealed that for initial consonants the scores for bilabial, labio-dental, and lingua-dental sounds were lower than those for alveolar and post-alveolar sounds. The results for the palatal, velar, and glottal sounds were higher than for all other consonants in the initial position. In the final position scores were better for the palatal, alveolar, and glottal sounds.

Cox (1970) studied consonant discrimination errors in a CVC closed-response set. Four test conditions which included unfiltered stimuli and three low-pass filtered stimuli were presented to twenty sensori-neural hearing-impaired listeners. His data are presented in confusion matrices. Under all test conditions the feature of place had a greater number of error responses than did the voicing and manner features. As the stimuli were low-pass filtered below 2000 Hz, error responses increased for all features.

Green (1971) used linguistic feature analysis to study consonant confusions at various sensation levels for normal-hearing and hearing-impaired listeners. She

reported that recognition of the place feature was the most difficult for all subjects. Recognition of the nasality feature was easiest for the subjects. There were significant differences between the normal-hearing and hearing-impaired subjects for the number of correct responses and response errors for place, opening, friction, and a combination of all three features. The two groups did not reveal significant differences in error responses to the voicing and nasality features.

The Diagnostic Rhyme Test (DRT)

The DRT was constructed by Voiers et al (1965) for evaluation of voice-communication systems and speech processing devices. The DRT was designed for practical application of fundamental principles of speech perception. The original version of the DRT employed the sixteen consonants from the Miller and Nicely (1955) study. These consonants were used in four vowel contexts. The primary change from Miller and Nicely's (1955) consonant taxonomy was to use a three-dimensional binary opposition system for place of articulation. The revised DRT tested the following oppositions: front versus middle, middle versus back, and back versus front. The most recent form of the DRT is Form IV.

The DRT (Form IV) is a two-choice rhyme test composed of 96 rhyming word pairs (192 separate items).

Consonant dicrimination of the six attributes: voicing, nasality, sustention, sibilation, graveness and compactness, is tested. The attributes are evaluated in word pairs in which the initial consonants are "minimally opposed." The difference between the two consonants is a single consonant attribute. The only exception to the criteria of a "uni-dimensional" difference involves the compactness attribute. According to Voiers (1967, p. 14):

> While the phoneme pairs /k-p/, /g-b/, /k-t/ and /g-d/ differ primarily with respect to compactness, they might be considered to differ secondarily in terms of graveness since the first member of each pair has a neutral status with respect to graveness while the second member of each pair has a positive status with respect to this attribute. However, the exclusion of all of these pairs would result in a seriously biased sample of circumstances in which compactness is criterial of phonemic identity.

The six attributes have equal representation in a corpus of 96 rhyming word pairs. The speech materials for Form IV are given in Table 2. The classification of the twenty-three consonants according to the taxonomy for the six attributes is presented in Table 3.

The consonant pairs in the DRT for each attribute are as follows: voicing /v-f/, /b-p/, /d-t/, /g-k/, /z-s/ and /ʒ̂ - ʃ̂/; nasality /m-b/ and /n-d/; sustention /v-b/, /f-p/, /θ-t/, /ð-d/, and /ʃ- ʃ̂/; sibilation /z-ð/, /ʃ̂-k/, /ʒ̂-g/, and /s-θ/; graveness /w-r/, /p-t/, /m-n/, /b-d/, and /f-θ/; compactness (back *vs.* front) /j-w/, /k-p/,

Table 2

Speech Materials Used in Form IV of the Diagnostic Rhyme Test (DRT)

1.	DAUNT-TAUNT	25.	BOND-POND	49.	VAULT-FAULT	73.	JOCK-CHOCK
2.	MOOT-BOOT	26.	MOAN-BONE	50.	NEWS-DUES	74.	NOTE-DOTE
3.	SHEET-CHEAT	27.	VILL-BILL	51.	VEE-BEE	75.	THICK-TICK
4.	JAB-GAB	28.	JEST-GUEST	52.	SANK-THANK	76.	CHAIR-CARE
5.	POT-TOT	29.	FOUGHT-THOUGHT	53.	WAD-ROD	77.	BONG-DONG
6.	GHOST-BOAST	30.	COOP-POOP	54.	SHOW-SO	78.	YOU-RUE
7.	ZED-SAID	31.	VAST-FAST	55.	DENSE-TENSE	79.	GAFF-CALF
8.	GNAW-DAW	32.	KNOCK-DOCK	56.	MOSS-BOSS	80.	MOM-BOMB
9.	SHOES-CHOOSE	33.	THOSE-DOZE	57.	FOO-POOH	81.	THOUGH-DOUGH
10.	CHEEP-KEEP	34.	SING-THING	58.	ZEE-THEE	82.	JILT-GILT
11.	BANK-DANK	35.	MET-NET	59.	FAD-THAD	83.	PENT-TENT
12.	GOT-DOT	36.	CAUGHT-TAUGHT	60.	HOP-FOP	84.	YAWL-WALL
13.	DINT-TINT	37.	BEAN-PEEN	61.	GIN-CHIN	85.	VEAL-FEEL
14.	NECK-DECK	38.	MAD-BAD	62.	MEND-BEND	86.	NAB-DAB
15.	THONG-TONG	39.	VOX-BOX	63.	SHAW-CHAW	87.	VON-BON
16.	CHEW-COO	40.	JOE-GO	64.	JUICE-GOOSE	88.	SOLE-THOLE
17.	WEED-REED	41.	BID-DID	65.	PEAK-TEAK	89.	FIN-THIN
18.	SHAG-SAG	42.	YEN-WREN	66.	GAT-BAT	90.	KEG-PEG
19.	VOLE-FOAL	43.	ZOO-SUE	67.	GOAT-COAT	91.	DUNE-TUNE
20.	NIP-DIP	44.	NEED-DEED	68.	MITT-BIT	92.	MEAT-BEAT
21.	FENCE-PENCE	45.	THAN-DAN	69.	THEN-DEN	93.	SHAD-CHAD
22.	SAW-THAW	46.	CHOP-COP	70.	JAWS-GAUZE	94.	JOT-GOT
23.	POOL-TOOL	47.	FORE-THOR	71.	MOON-NOON	95.	BOWL-DOLE
24.	YIELD-WIELD	48.	HIT-FIT	72.	KEY-TEA	96.	GILL-DILL

Table 3

Consonant Taxonomy Used in the Construction of the DRT (Form IV)*

	/m/	/n/	/v/	/ð/	/z/	/ʒ/	/ʒ̂/	/b/	/d/	/g/	/w/	/r/	/l/	/j/	/f/	/θ/	/s/	/ʃ/	/ʃ̂/	/p/	/t/	/k/	/h/
Voicing	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-
Nasality	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sustention	-	-	+	+	+	+	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	+
Sibilation	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-
Graveness	+	-	+	-	-	o	o	+	-	o	+	-	o	o	+	-	-	o	o	+	-	o	o
Compactness	-	-	-	-	-	+	+	-	-	+	-	-	o	+	-	-	-	+	+	-	-	+	+

*Key: + (positive state)

- (negative state)

o (neutral state)

/h-f/, and /g-b/; (back vs. middle) /k-t/, /j-r/, /g-d/, and /ʃ-s/.

Test items for each attribute as represented by a particular consonant sound are presented in eight vowel contexts using the vowels /i/, /ɪ/, /ɛ/, /æ/, /u/, /o/, /ɔ/, and /ɑ/. Each vowel is used in twelve pairs for a total of 96 rhyming word pairs.

The six attributes appear in sixteen sets of word pairings in a fixed order as follows: (1) voicing, (2) nasality, (3) sustention, (4) sibilation, (5) graveness, and (6) compactness.

A total of 192 words is presented on each test tape. According to Voiers et al (1967) stimulus words are selected randomly, but with the restriction that the positive state and negative state items are represented an equal number of times in each vowel context.

Voiers (1967, 1968, 1969) has reported a number of preliminary studies designed to assess the effect of various transmission conditions (speech masked, noise masked, low-pass filtered, high-pass filtered, etc.) on DRT scores. These data provided reference points for evaluating various types of communication deficiencies.

Voiers (1967) fabricated tapes of the DRT word items using five speakers whose voices were characterized as: (1) trained, (2) neutral I, (3) neutral II, (4) low-pitched, and (5) high-pitched. These tapes were administered to a

crew of eight experienced listeners. Results revealed that the DRT scores reflected speaker differences to some extent. A significant finding was that under ideal speaker conditions "the various attributes of consonant phonemes are neither perfectly nor equally discriminable, though the differences are generally small (Voiers, 1967, p. 21)."

The preliminary experiment involving the effect of frequency distortion on DRT scores is particularly germane to the present investigation. The DRT was administered under five high-pass and five low-pass filtering conditions to an experienced eight-man listening crew. At each condition a different scrambling of the DRT was used. The low-pass conditions were: 200-596 Hz, 200-992 Hz, 200-1460 Hz, 200-2089 Hz, and 200-2921 Hz. The high-pass conditions were: 596-4000 Hz, 992-4000 Hz, 1460-4000 Hz, 2089-4000 Hz, and 2921-4000 Hz. Frequencies were attenuated at 42 dB/octave beyond the filter cutoff points. The presentation level was at 80 dB re .0002 dyne/cm^2 for the unfiltered speech. Various degrees of attenuation of this level were inevitable due to filtering effects.

Results showed that the DRT total scores were not affected very much by high-pass filtering. However, low-pass filtering (high frequency distortion) had striking effects on the DRT total scores. This effect increased as the upper cutoff point fell below 1460 Hz. In a comparison of the DRT total scores to the Fairbanks Rhyme Test scores,

Voiers (1967) found that sensitivity to frequency distortion was approximately the same for both tests. The DRT was reportedly "somewhat more sensitive to extreme high frequency distortion (Voiers, 1967, p. 36)."

Analyses of frequency distortion characteristics on the six attribute scores of the DRT were relevant. Generally, low frequency distortion did not have differential effects on the six consonant attributes. According to Voiers (1967) quantitative agreement with Miller and Nicely's (1955) finding that low frequency distortion produces random errors was not evident with the DRT results. Such errors may have been obscured due to the restriction of response options inherent in a closed-message set.

High frequency distortion effects on the DRT attribute scores were apparent. Voiers' (1967) results for these conditions were in agreement with Miller and Nicely's (1955) report that errors are predictable in high frequency distortion conditions. As the upper cutoff frequency was decreased below 1460 Hz, differences among the six attributes were more pronounced. In general, high frequency distortion scores for voicing and nasality were slightly reduced, scores for sustention were moderately reduced, and scores for sibilation, graveness, and compactness were greatly reduced.

In summary, the foregoing review of the literature covered the development of speech discrimination tests and

related research during the past few decades. Of particular interest was the DRT developed by Voiers (1965).

On the basis of preliminary studies (Voiers, 1965; 1967; 1968; 1969) it was contended that the DRT is an effective speech intelligibility test. The DRT has been used successfully in testing communications systems but has not been standardized for clinical use. Previous research has supported that the six attributes of the DRT have different degrees of sensitivity to frequency distortion. This would suggest that normal-hearing and hearing-impaired listeners would show characteristic response patterns for the six attributes of the DRT. The closed-set paradigm and simple response and scoring procedures make the DRT applicable to a clinical population.

The merits of a distinctive feature framework for discrimination testing have been declared by numerous investigators. However, at the present, no standardized discrimination tests based upon distinctive feature models are available as part of the clinical audiologist's testing program.

In view of the above, the present study was designed to evaluate the usefulness and reliability of the DRT with normal-hearing and sensori-neural hearing-impaired listeners.

CHAPTER III

METHODOLOGY

Test Materials

The test materials for this investigation were the DRT 192-word corpus described in Chapter II. Tapes were specially prepared for the present study. These included four scramblings of the DRT 192-word corpus, instructions and six preliminary practice items, and a separate 48-item practice test which were recorded under the direction of Dr. William D. Voiers at Tracor, Inc., Austin, Texas.

The speaker was a twenty-seven year old male of General American dialectal background with extensive experience in recording speech testing materials. He spoke with normal vocal effort and articulation. Previous research (Voiers, 1971) involving twelve male speakers revealed that this speaker yielded a highly typical pattern of DRT scores under a diversity of transmission conditions.

Recordings were made in a double-wall Industrial Acoustics Company (IAC) modular unit of 10' x 13' x 7' interior dimensions. The speaker was positioned in a chair approximately four feet from one corner of the room, facing the opposite corner. A padded restraining ring was used to maintain the orientation and the

position of his head during the recording sessions. Materials to be recorded were mounted on an easel located slightly below and to the side of the speaker's line of vision. A small timing light, mounted on the easel, was used to maintain a constant rate of utterance.

The recording was done with a General Radio 1560-P5 microphone located on the axis of the breath stream at a distance of 20 cm. from the speaker's lips. Stimulus words were recorded on Ampex 434 tape at 15 inches per second through the use of an Ampex, Model 440.3, tape recorder. The tape recorder was situated in an adjacent room and gain was adjusted to yield an average reading of -2 dB VU for vowel peaks.

Two members of the laboratory staff monitored the recordings for uniformity of pitch and articulation. Uncertain utterances were immediately re-recorded. Larger segments of questionable quality were also re-recorded at the end of each session.

A 1000 Hz calibrational tone was recorded on each channel of the master tape at -2 dB VU. Master tapes were then evaluated by a crew of experienced listeners and re-edited when necessary. Formal tests were conducted and scored to evaluate the acceptability of the quality and intelligibility of the master tapes.

Four randomizations of the 192-word corpus of the DRT were prepared. Each set of six attribute words was

introduced with a non-test filler word. These filler items served only to isolate successive sets of attributes. The filler items had no other function in this experimental study and were not scored.

The test tapes were copied from the master tape items onto Ampex 631 magnetic tape at $7\frac{1}{2}$ inches per second through the use of a Nagra, Model 3, tape recorder. Items were spaced three seconds apart with a 15 second pause after the last item on the response sheet. This timing sequence was determined from preliminary work by this investigator with five subjects who found these time intervals adequate for performance of the experimental task.

Subjects

Twenty normal-hearing volunteer listeners and twenty sensori-neural hearing-impaired listeners from the clinical population of the Audiology and Speech Pathology Service of the Veterans Administration Hospital, New Orleans, Louisiana, served as subjects. They met the following criteria:

1. Native English speakers capable of reading the DRT test items.
2. No disorders of articulation.
3. No known history of neurological disorders.
4. Male subjects.

5. Audiologic criteria.

   a. Normal-hearing subjects.

      (1) Hearing at 15 dB or better from 250-8000 Hz bilaterally with differences between air and bone conduction measures no greater than 5 dB (American National Standards Institute, ANSI, 1969).

      (2) Score of 96% or better as measured by a new disk recording of the C.I.D. W-22 Discrimination Test.

   b. Sensori-neural hearing-impaired subjects.

      (1) A pure tone configuration showing a precipitous high-frequency sensori-neural hearing loss. A precipitous loss was defined as hearing acuity 20 dB or better through 1000 Hz and a loss of 30 dB or poorer than that obtained at 1000 Hz for higher frequencies.

      (2) Score of 88% or less as measured by a new disk recording of the C.I.D. W-22 Discrimination Test.

      (3) Tolerance for speech delivered at 50 dB SL above the SRT.

The mean age of the normal-hearing subjects was 29.5

years and was 40.0 years for the hearing-loss subjects.

Audiometric information concerning the pure tone air-conduction thresholds, speech reception thresholds, and discrimination scores for the better ear of the normal-hearing subjects is presented in Table 4. Similar measures for the sensori-neural hearing-impaired group are given in Table 5.

Apparatus

The present study was conducted at the Audiology and Speech Pathology Service of the Veterans Administration Hospital, New Orleans, Louisiana. The subjects were tested with an Allison 22 audiometer for the pure tone and speech audiometry. The DRT tapes were presented to the subjects from a Viking Model 87 tape deck through the Allison 22 audiometer. The subjects wore TDH 39-earphones. Tests were administered in an Industrial Acoustics Company, Model 1200-A, test suite. A schematic diagram of the testing equipment and environment is presented in Figure 1.

Calibration

Immediately prior to the accumulation of data for this study, the complete audiologic system was calibrated by factory-trained technicians contracted by the Veterans Administration Hospital. Calibrational levels were maintained throughout the study. Checks were made with a

Table 4

Audiometric Thresholds and Speech Discrimination Scores in the Test Ear of Twenty Normal-Hearing Subjects

Subj.	250	500	1000	2000 (Hz)	4000	8000	SRT	DISC.
1.	10	5	-5	0	10	15	2	100%
2.	5	5	-5	-5	0	10	0	100%
3.	5	0	-10	0	15	5	2	100%
4.	0	-5	-10	-10	0	-5	-6	100%
5.	0	-5	0	-5	-5	-5	-6	100%
6.	0	0	-10	-10	0	-5	-6	100%
7.	0	-5	-10	-10	0	-5	-4	100%
8.	10	5	10	10	10	15	4	100%
9.	10	0	-5	0	15	0	2	98%
10.	15	5	5	0	15	0	6	98%
11.	10	15	5	0	5	0	6	100%
12.	0	-5	-10	-10	-5	0	-4	100%
13.	10	0	-5	0	10	-5	-2	100%
14.	5	0	5	10	5	10	2	100%
15.	10	0	-5	-5	5	5	-4	100%
16.	10	5	0	5	15	10	0	100%
17.	5	0	0	0	10	10	2	100%
18.	10	0	0	-5	15	0	-2	100%
19.	5	0	0	-5	10	0	-2	100%
20.	0	0	5	5	15	5	2	100%

Table 5

Audiometric Thresholds and Speech Discrimination Scores in the Test Ear of Twenty Hearing-Impaired Subjects

Subj.	250	500	1000	2000 (Hz)	4000	8000	SRT	DISC.
1.	10	5	20	60	75	80	18	78%
2.	10	10	5	60	60	65	14	84%
3.	10	5	15	55	75	60	10	78%
4.	5	5	10	60	70	45	14	82%
5.	10	5	5	50	60	45	8	88%
6.	10	10	20	70	70	60	22	76%
7.	10	10	10	70	80	NR	20	76%
8.	10	10	10	40	70	60	14	86%
9.	15	10	15	60	50	45	16	88%
10.	5	0	5	45	100	NR	10	82%
11.	10	10	20	60	NR	NR	10	82%
12.	10	10	10	70	75	75	14	82%
13.	10	10	15	75	85	65	16	78%
14.	10	5	10	45	75	35	12	88%
15.	15	10	10	75	75	85	12	88%
16.	10	5	5	50	60	75	8	84%
17.	5	0	5	45	80	70	6	82%
18.	15	10	0	60	90	60	8	86%
19.	5	0	10	75	NR	NR	12	86%
20.	5	5	10	75	95	90	12	66%

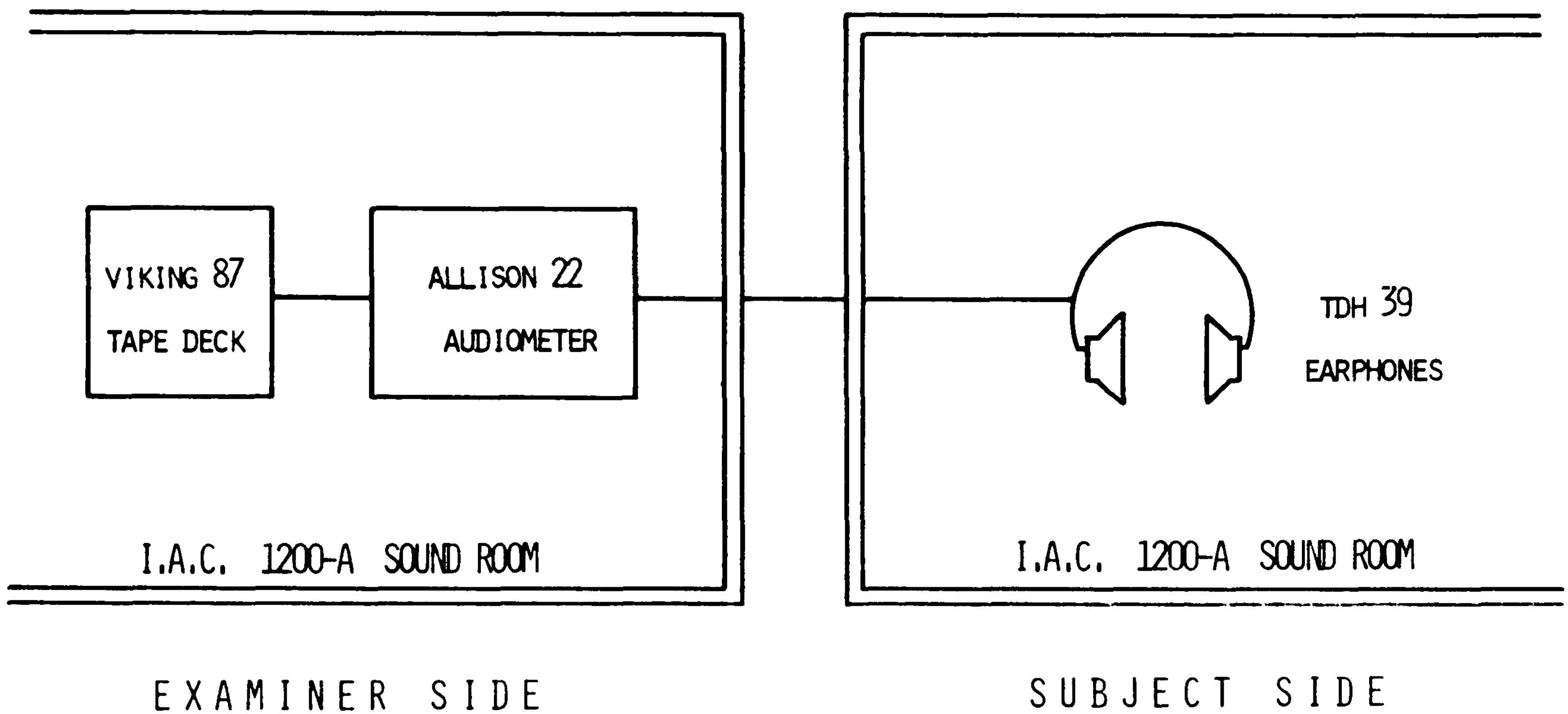

Figure 1. Schematic Diagram of Testing Equipment and Environment

Bruel-Kjaer Audiometer Calibrator System Type 3502. A schematic diagram of the calibration arrangement is shown in Figure 2.

The same earphone was used throughout the study. The calibration of the earphone was checked three times during each test session: initially, before running the tape of instructions and preliminary practice items; secondly, during the subject's thirty-minute rest period between tapes; and finally, at the conclusion of testing.

The level of the speech stimuli was established by measuring the sound pressure level (SPL) of the 1000 Hz calibration tone as recorded on each test tape and played through the Allison 22 audiometer at a 70 dB hearing level (HL) to yield a reading of 77 dB SPL at the earphone. This level did not deviate more than ±2 dB during testing. The above calibration procedure satisfied requirements set by the American National Standards Institute (ANSI) 1969 specifications. The checklist for equipment and calibration readings is presented in Appendix A.

Test Procedure

Each subject was tested in two phases. In phase one the subject was interviewed and the audiologic tests, instructions, and practice items were given. Phase two commenced with the experimental tasks. The checklist for testing procedures of phase two is shown at the bottom of

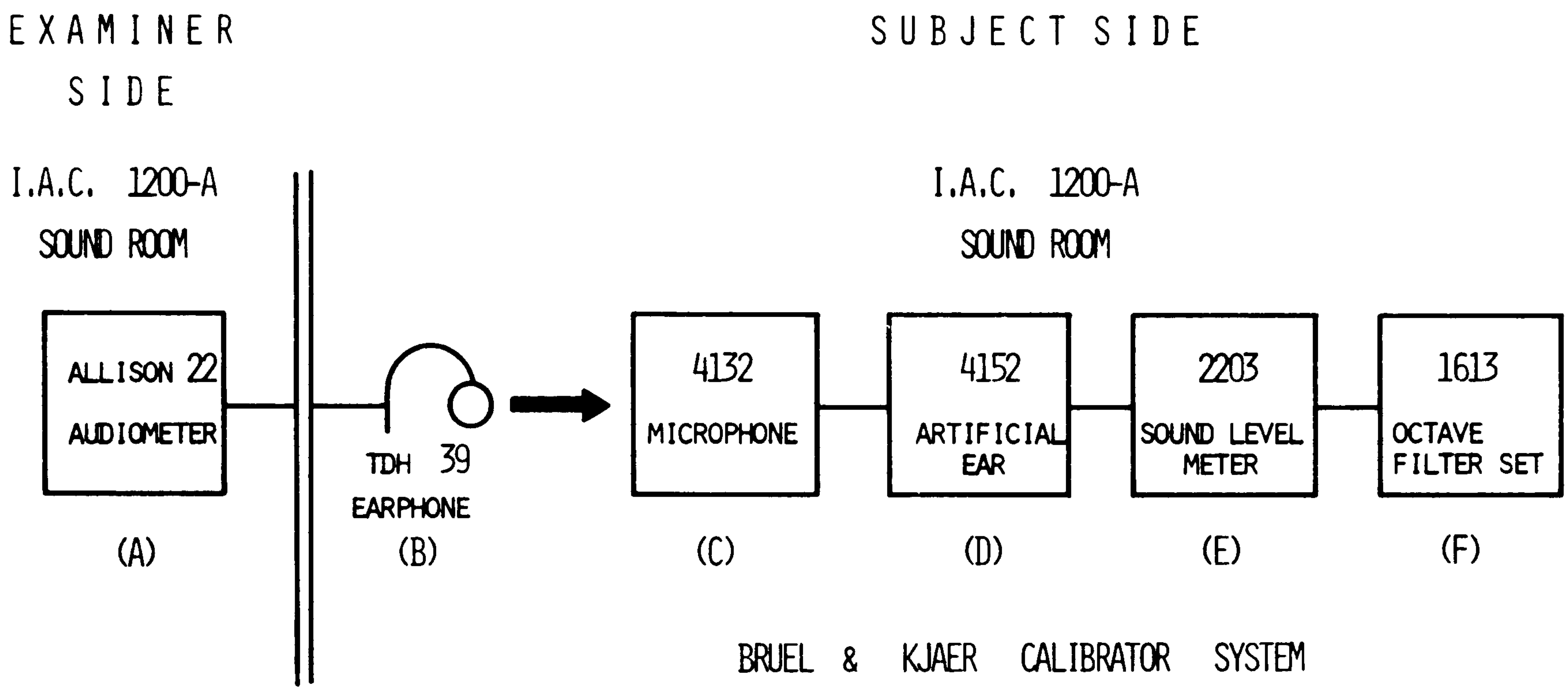

Figure 2. Schematic Diagram of the Calibrational Instrumentation Using the Bruel & Kjaer Type 3502 Audiometer Calibrator System

the page in Appendix A.

The audiometric tests consisted of pure tone and speech audiometry. Pure tone air and bone conduction thresholds were obtained bilaterally at 250, 500, 1000, 2000, 4000, and 8000 Hz. The pure tone thresholds were established through the use of the Hughson-Westlake technique (Carhart and Jerger, 1959).

Speech reception thresholds (SRT) were measured by starting with maximum attenuation and presenting spondee words in ascending steps to the point of 50 per cent correct identification of spondee words (usually three out of six words). A new disk recording of the C.I.D. Auditory Test W-1 (spondee words) was used.

A test for threshold of discomfort (TD) for speech was given to determine whether subjects could tolerate speech at 50 dB SL above the SRT. The speech discrimination test and the DRT were administered at 50 dB SL above the SRT. Speech discrimination ability was measured through the use of a new disk recording of the C.I.D. Auditory Test W-22.

For all listeners the test ear was determined on the basis of the audiologic criteria outlined for subjects. The selection of the subject's better ear as the test ear eliminated the need for masking.

Following approximately a thirty-minute rest period, the subject received: (1) a general explanation concerning

the nature of the experimental task, (2) taped instructions and preliminary practice items, and (3) a 48-item practice tape. The above procedures concluded phase one. Subsequently, the four 192-word corpus randomizations of the DRT were presented in phase two.

In phase one after a verbal explanation of the experimental task, the subject was given a printed sheet of instructions and six preliminary practice test items (see Appendix B), two pencils, and a clip board. Upon completion of the recorded instructions and practice items, the subject's responses were checked to verify his comprehension of and compliance with the experimental task. To insure familiarization with the DRT and the speaker's voice, a second practice task was administered. The response form for this practice test is shown in Appendix C.

For the experimental task, packets of response forms for each 192-item DRT were given to the subjects. Sample response forms are presented in Appendix D. Each response form had 48 test word pairs with the six attributes represented in a fixed order. The initial word in each pair of test items was based on random assignment. Two different sets of response forms were used: DRT IV-1 and DRT IV-3. Each set had eight pages labeled A through H.

The administration time for the instructions and practice items was approximately 15 minutes. Each 192-word

corpus required 15 minutes. To minimize fatigue effects, subjects were allowed frequent rest periods. Five-minute rest periods were given after the practice items, after the first DRT tape, and after the third DRT tape. A rest period of approximately 30 minutes followed the presentation of the second 192-word corpus. The total testing time for phase one and phase two was approximately three hours.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The primary objective of the present study was to determine the predictive value and reliability of the DRT with normal-hearing and sensori-neural hearing-impaired listeners. DRT measurements consisted of the total DRT scores, the mean scores for each of the six attributes, and the mean scores for each state of the six attributes.

Scoring of the response packets was facilitated by computer processing. Since the DRT involves a two-choice task, a correction formula for the effect of chance was applied to all scores. The adjusted score (S) was obtained from the following correction formula:

$$S = \frac{100\ (R - W)}{T}$$

where R is the number of correct responses, W is the number of incorrect responses, and T is the total number of stimulus items.

Differences in performance on the DRT measures for normal-hearing and hearing-impaired groups were examined through statistical treatment using the analysis of variance procedure. The data were analyzed with a

split-plot arrangement of treatments in a completely randomized design where the main factor was group (normal and sensori-neural hearing-impaired) with 20 subjects per group and 4 repetitions of the test on each subject. The sub-factor was the six attributes. Reliability for the repeated measurements was estimated through the use of analysis of variance and intraclass correlation.

Data summary sheets of errors by repetitions and attributes are shown for each subject in the normal group in Appendix E. Each sensori-neural hearing-impaired subject is presented in Appendix F. These data sheets can be examined for repetitions along the vertical dimension and for attributes along the horizontal dimension. Within each test repetition, each of the six attributes was tested 32 times: 16 items for positive state and 16 items for negative state phonemes. Entries within the cells identified as P (present state) and A (absent state) display the number of error responses in 16 presentations. Entries identified as T (total) reveal the number of error responses in 32 presentations of an attribute. Accordingly, each subject provided 192 responses in each repetition or a total of 768 responses for the complete set of four repetitions.

Question 1

Are there differences in the total DRT scores

for normal-hearing and sensori-neural hearing-impaired listeners?

The total DRT scores for the two groups of listeners are presented in Table 6. Listeners with normal hearing obtained total DRT scores of 97.12 per cent. Sensori-neural hearing-impaired listeners obtained total DRT scores of 78.17 per cent.

Table 6

Means and Differences for the Total DRT and Attributes for 20 Normal-hearing and 20 Sensori-neural Hearing-impaired Subjects

Attribute	Groups Normal	Impaired	Difference[1]
Voicing	98.29	93.77	4.52*
Nasality	100.00	98.06	1.94
Sustention	95.17	71.43	23.74*
Sibilation	97.90	66.98	30.92*
Graveness	92.06	59.40	32.66*
Compactness	99.30	79.39	19.91*
Total DRT	97.12	78.17	

[1] $LSD_{.05} = 3.00$

$*p < .05$

The analysis of variance for total DRT scores is presented in Table 7. Highly significant F values of 68.16 for groups and 18.35 for subjects within a group

were computed. The observed difference in the total DRT scores for the two listener groups is significant at the .01 level.

Table 7

Analysis of Variance for the Total DRT Scores

Source of Variation	df	Mean Square	F
Group	1	14386.85	68.16**
Subjects/Group	38	211.07	18.35**
Rep/Subj/Group	120	11.50	
Total	159		

**$p < .01$

The finding of a significant difference in the total DRT scores permits an affirmative answer to the research question _Are there differences in the total DRT scores for normal-hearing and sensori-neural hearing-impaired listeners?_ Inspection of the data in Table 6 and the graphic display in Figure 3 further suggests that the magnitude of difference in total DRT scores for the two groups is reduced considerably by the high percentage of correct responses in the sensori-neural group for the voicing and nasality attributes.

Question 2

Are the total DRT scores reliable?

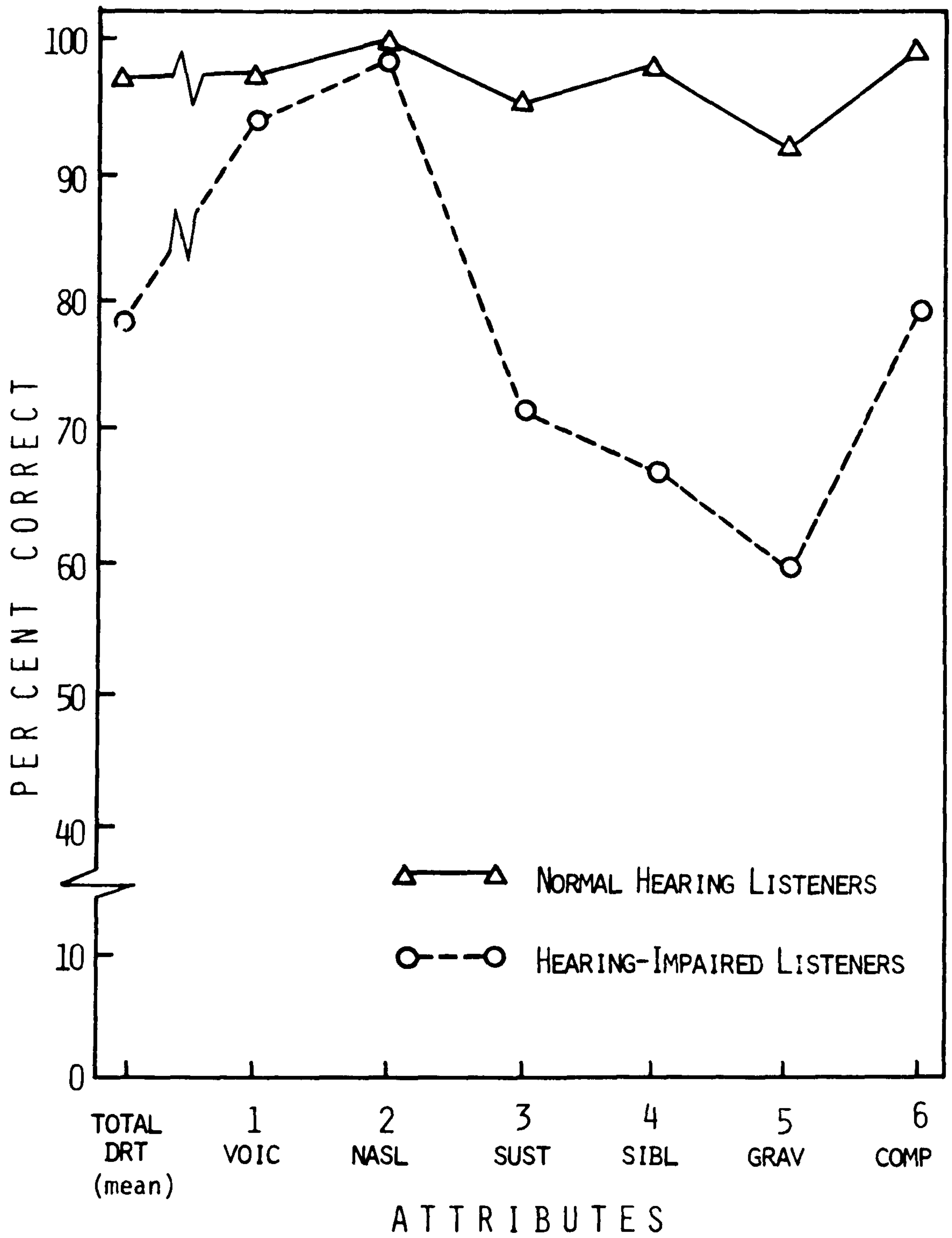

Figure 3. Percentages of Correct Responses to the Total and the Six Attributes of the DRT for the Normal-Hearing Listeners and the Sensori-Neural Hearing-Impaired Listeners

The reliability of the total DRT scores obtained in four repetitions per subject for each group was examined through the analysis of variance presented in Table 7.

A high level of repeatability for subjects is suggested by the highly significant F ratio of 18.35 for differences among subjects with the two groups. The intraclass correlation was computed and found to be .81: this _r_ is significant at the .01 level. On the basis of the above findings the research question _Are the total DRT scores reliable?_ is answered affirmatively.

Question 3

> _Are there differences in the attribute scores of the DRT for normal-hearing and sensori-neural hearing-impaired listeners?_

The mean attribute scores obtained by the two listener groups are reported in Table 6 and are shown graphically in Figure 3. Means of the six attributes disclose profile patterns for normals and sensori-neurals with scores for certain attributes being similar for the two groups and scores for other attributes being markedly dissimilar.

The least significant difference (LSD) value of 3.00 indicates that the obtained differences between the two listener groups are significant at the .05 level for voicing, sustention, sibilation, graveness, and compactness.

It should be pointed out that the difference scores for voicing are low but significant; whereas, the other attributes mentioned above reveal large differences between the two groups of subjects. The attribute nasality is not significantly different for the normals and sensori-neurals.

The data were treated by analysis of variance to test the significance of differences among the attributes. The results of this analysis are displayed in Table 8.

Table 8

Analysis of Variance for Attribute Scores

Source of Variation	df	Mean Square	F
Group	1	86188.39	68.10**
Subject/Group	38	1265.67	18.37**
Rep/Subj/Group	120	68.90	
Attribute	5	12504.66	134.46**
Group x Attribute	5	6820.47	73.34**
Error	790	93.00	
Total	959		

**$p < .01$

The analysis of variance in Table 8 indicates a highly significant F value of 134.46 for differences among the attributes. In addition, the group by attribute interaction is highly significant with an F value of 73.34. This implies that each listener group had a distinctive

way of responding to the attributes, although some of the attributes distinguished the two groups to a greater extent.

Inspection of the above data indicates that the research question _Are there differences in the attribute scores of the DRT for normal-hearing and sensori-neural hearing-impaired listeners?_ should be answered with a qualified _yes_. The need for qualification is imposed by the finding of significant interaction and can be seen in the graphic representation of attribute scores displayed in Figure 3. In brief, a number of differences are readily apparent, but the employment of a sweeping generalization is precluded.

Question 4

Is the correctness of phoneme identification differentially related to specific attributes?

In order to assess the attribute patterns distinctive to each group of subjects, orthogonal comparisons were conducted. The analysis of variance for the two sets of orthogonal comparisons shown in Table 9 in conjunction with the means for the orthogonal comparisons in Table 10 can be used to delimit the attributes of perceptual importance for the two listener groups. These data are seen graphically in Figure 3.

Table 9

Analysis of Variance for Orthogonal Comparisons of Attribute Scores Within Groups

Source of Variation[1]	df	Mean Square	F
Normal-hearing Subjects			
1, 2 *vs*. 3, 4, 5, 6	1	976.06	10.50**
1 *vs* 2	1	115.60	1.24
3, 4 *vs*. 5, 6	1	57.80	<1.00
3 *vs*. 4	1	291.60	3.14
5 *vs*. 6	1	2073.60	22.30**
Hearing-impaired Subjects			
1, 2 *vs*. 3, 4, 5, 6	1	75757.06	814.59**
1 *vs*. 2	1	739.60	7.95**
3, 4 *vs*. 5, 6	1	12.80	<1.00
3 *vs*. 4	1	774.40	8.33**
5 *vs*. 6	1	16000.00	172.04**

[1] 1: Voicing, 2: Nasality, 3: Sustention, 4: Sibilation, 5: Graveness, and 6: Compactness

**$p < .01$

Inspection of the comparisons within the normal group indicates that the mean of voicing and nasality is significantly different from the mean of sustention, sibilation, graveness, and compactness (1, 2 *vs*. 3, 4, 5, 6). A second notable observation is that graveness is significantly different from compactness (5 *vs*. 6). The remaining orthogonal comparisons for normal listeners are not significant.

Table 10

Means for Orthogonal Comparisons of Attribute Scores Within Groups

Groups	Means for Comparisons[1]		
	1, 2 vs. 3, 4, 5, 6		
Normal-hearing	99.15	vs.	96.11**
Hearing-impaired	95.92	vs.	69.30**
	1 vs. 2		
Normal-hearing	98.29	vs.	100.00
Hearing-impaired	93.77	vs.	98.06**
	3, 4 vs. 5, 6		
Normal-hearing	96.54	vs.	95.68
Hearing-impaired	69.21	vs.	69.40
	3 vs. 4		
Normal-hearing	95.17	vs.	97.90
Hearing-impaired	71.43	vs.	66.98**
	5 vs. 6		
Normal-hearing	92.06	vs.	99.30**
Hearing-impaired	59.40	vs.	79.39**

[1] 1: Voicing, 2: Nasality, 3: Sustention, 4: Sibilation, 5: Graveness, and 6: Compactness

$^{**}p < .01$

The findings with regard to the sensori-neural hearing-impaired group parallel the results for the normal

group to a certain degree. That is, the hearing-impaired listeners also have significant differences for the comparisons of voicing and nasality *vs.* sustention, sibilation, graveness, and compactness (1, 2 *vs.* 3, 4, 5, 6) and for graveness *vs.* compactness (5 *vs.* 6). In addition, highly significant differences are found for the comparisons of voicing *vs.* nasality (1 *vs.* 2) and sustention *vs.* sibilation (3 *vs.* 4).

In summary, the orthogonal comparisons examined above indicate an affirmative answer to the question *Is the correctness of phoneme identification differentially related to specific attributes?* The significant differences observed with the normal-hearing subjects are replicated with the sensori-neural hearing-impaired subjects. With the latter group, however, additional significant differences are found: the comparisons of voicing *vs.* nasality (1 *vs.* 2) and sustention *vs.* sibilation (3 *vs.* 4).

Question 5

Are the attribute scores reliable?

The reliability of the attribute scores for four repetitions was obtained from the analysis of variance seen in Table 8. The F of 18.37 reveals highly significant differences among listeners. The intraclass correlation coefficient of .81 is significant at the .01 level and substantiates the high degree of repeatability for

individual subjects. Thus, an affirmative answer is given to the above research question.

Question 6

Are there differences in the two states of each attribute for normal-hearing and sensori-neural hearing-impaired listeners?

The means and differences for the present and absent states of each attribute for the two listener groups are presented in Table 11. The mean scores are displayed graphically in Figure 4.

In the normal group differences between the present state and absent state of each attribute are not significant (LSD = 3.85). Perception of differences between the two states by the sensori-neural hearing-impaired subjects is significant at the .05 level for the attributes voicing, sustention, sibilation, and graveness. There are no significant differences between states for the attributes nasality and compactness.

The results of the analysis of variance for the present state are given in Table 12. Differences between the normal-hearing and hearing-impaired groups are highly significant with F = 78.43. Results of the analysis for the present state reveals highly significant differences among the individual attributes. The highly significant F = 54.23 for the interaction of group by attributes

demonstrates that differences existing among the attributes for the present state are not the same for both groups of listeners.

Table 11

Means and Differences Between the Present and Absent States of Each Attribute

Attribute	Present	Absent	Difference[1]
Normal-hearing Subjects			
Voicing	99.22	97.34	1.88
Nasality	100.00	100.00	0.00
Sustention	96.56	93.75	2.81
Sibilation	97.19	98.59	1.40
Graveness	92.50	91.56	.94
Compactness	99.38	99.22	.16
Hearing-impaired Subjects			
Voicing	96.09	91.41	4.68*
Nasality	98.91	97.19	1.72
Sustention	74.84	67.97	6.87*
Sibilation	75.00	58.91	16.09*
Graveness	55.47	63.28	7.81*
Compactness	81.25	77.50	3.75

[1] $LSD_{.05} = 3.85$

$*p < .05$

Table 13 gives results of the analysis of variance for the absent state. Highly significant differences $F = 50.88$ are shown between the normal-hearing and hearing-impaired subjects. The highly significant F for attributes ($F = 69.79$) confirms differences among the attributes for

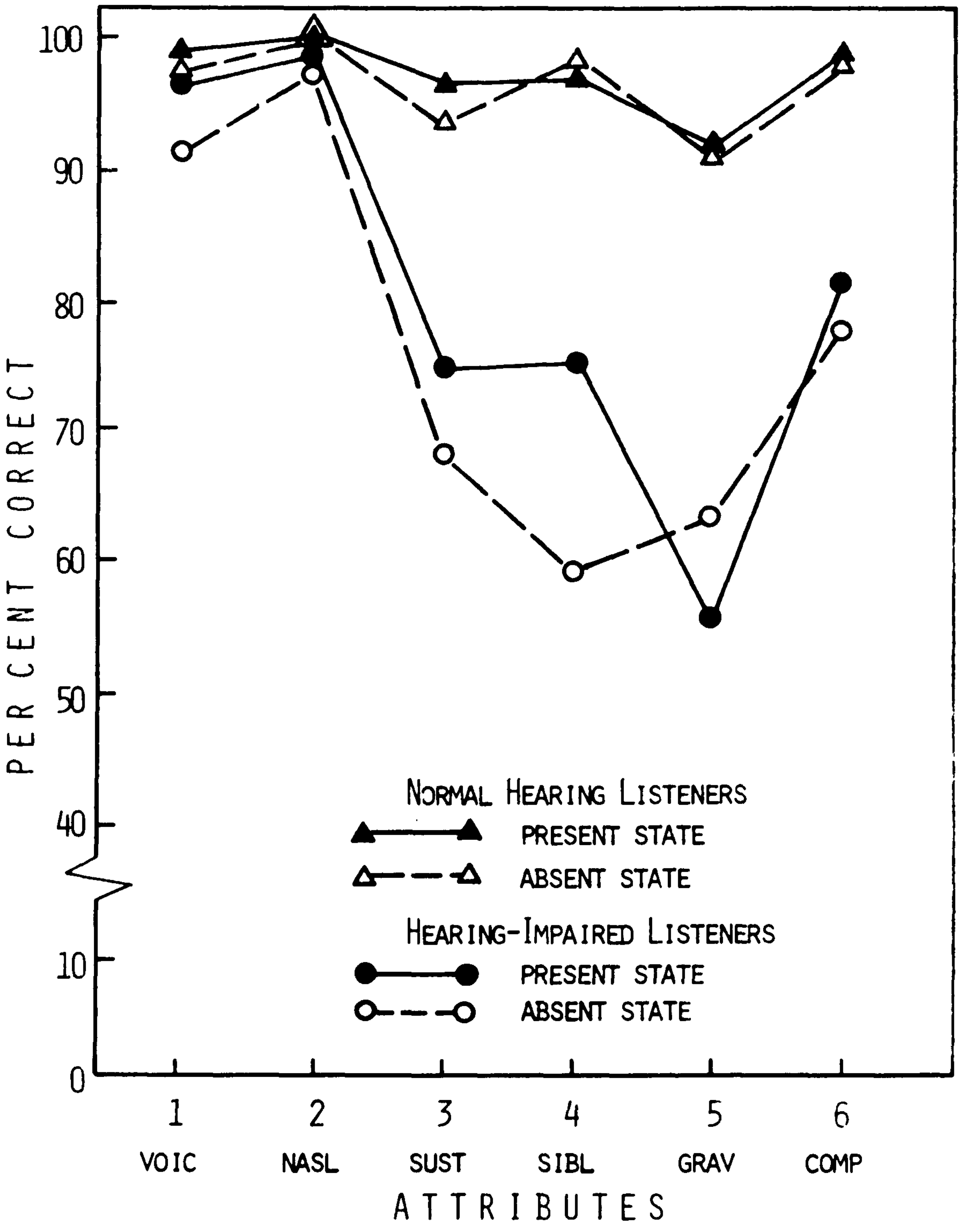

Figure 4. Percentages of Correct Responses to the Present State and the Absent State of the Six Attributes of the DRT for the Normal-Hearing Listeners and the Sensori-Neural Hearing-Impaired Listeners

the absent state. The group by attributes interaction is highly significant with F = 44.43 which indicates that each group had characteristic responses to the absent state of the attributes.

Table 12

Analysis of Variance for the
Present State of the Attributes

Source of Variation	df	Mean Square	F
Group	1	71113.44	78.43**
Subject/Group	38	906.72	7.38**
Rep/Subj/Group	120	122.88	
Attribute	5	13779.20	104.14**
Group x Attribute	5	7175.55	54.23**
Error	790	132.31	
Total	959		

**$p < .01$

Question 7

Are the scores for the two states of the attributes reliable?

The analysis of variance for four repetitions discloses a highly significant difference among the individual listeners in response to the present state (F = 7.38) and to the absent state (F = 17.28). The intraclass correlation is .61 for the present state and .80 for the absent state.

These tests for reliability indicate good repeatability of subjects for each of the opposing states of the attributes.

Table 13

Analysis of Variance for the
Absent State of the Attributes

Source of Variation	df	Mean Square	F
Group	1	102868.70	50.88**
Subject/Group	38	2021.96	17.28**
Rep/Subj/Group	120	117.02	
Attribute	5	12350.55	69.79**
Group x Attribute	5	7862.01	44.43**
Error	790	176.96	
Total	959		

**$p < .01$

Discussion

The DRT, unlike the C. I. D. W-22 Test, permits analysis of articulatory and acoustic cues by breaking down the speech message into six attributes: voicing, nasality, sustention, sibilation, graveness, and compactness. Each attribute is subdivided into two states: present and absent.

The two opposing states of an attribute were tested in a paired-choice discrimination test. Discrimination

of phonemes is, in part, determined by one's ability to perceive one or more cues from a set of several cues; for example, the parameters of intensity, duration, and frequency and interactions of these parameters.

An examination of the perceptual response patterns of normal-hearing and sensori-neural hearing-impaired listeners to the six attributes of the DRT reveals the relative importance of acoustic and articulatory cues in phoneme distinctions. The two groups of listeners were selected primarily on the basis of their audiometric configurations. That is, the hearing-impaired subjects had a characteristic high-frequency sloping audiometric configuration above 1000 Hz. The assumption appears warranted that differences in listeners' perceptions of phonemes may be related to the audiometric contours distinguishing the two groups.

A review of the profile patterns of the attributes reveals that there were significant differences between the normal-hearing and sensori-neural hearing-impaired listeners. In addition, a significant interaction was noted among the attributes for each listener group. Certain attributes proved more sensitive than others to reduced auditory acuity. Among the hearing-loss subjects, scores for voicing and nasality were most like those of the normal-hearing subjects. The greatest differences between the two groups appeared when sustention, sibilation,

graveness, and compactness were compared. In the following discussion, attention will be focused on the perceptual response patterns or profiles of the attributes. Each attribute will be examined separately in the order designed in the DRT.

1. Voicing: The voicing attribute, which contrasts voiced and unvoiced phonemes, promoted extremely high identification accuracy with measures of 98.29 per cent for normal listeners and 93.77 per cent for sensori-neural hearing-impaired listeners. Voiced phonemes tended to be more discriminable than unvoiced phonemes. The normal subjects obtained scores of 99.22 per cent for voiced phonemes and 97.34 per cent for unvoiced phonemes. The hearing-impaired subjects scored 96.09 per cent for voiced phonemes and 91.41 per cent for unvoiced phonemes. The difference between the two listener groups for the voicing attribute was small but statistically significant at the .05 level.

A number of researchers have analyzed cues for voiced versus unvoiced phoneme distinctions. Voicing is characterized by the inclusion of energy between 120 and 150 cps for the average male speaker (Newby, 1958). Halle et al (1957) showed that spectrograms reveal vowel transition differences associated with voiced/voiceless contrasts of stop consonants.

According to Fant (1967, p. 118):

> The distinction between /g/ and /k/, or /d/ and /t/, or /b/ and /p/ is that of an earlier onset of voicing after the explosion and also a greater amount of voicing in the previous stopgap. If the stopgap is devoiced, its duration is relatively shorter for the voiced phoneme, at least when expressed as a ratio of the previous length of the vowel.

In an analysis of confusions of voiced and voiceless consonants paired to three different stems: /il/, /ul/, and /al/, Cox (1970) indicated that for sensori-neural hearing-impaired subjects discrimination of the voicing feature was poorer as band width decreased.

The results of the present study show close agreement with other studies of voicing distinctions. In using a multiple-choice discrimination test with hearing-impaired subjects, Owens and Schubert (1968) found very low error rates for perception of voiced versus voiceless phonemes. In a test of phoneme recognition, Green (1971) reported that the voicing feature did not differentiate between normal-hearing and sensori-neural hearing-impaired listeners. In the present study the voicing attribute did distinguish the two listener groups, but differences were small and both groups had scores above 90 per cent for correct identification of voiced/ voiceless phonemes.

Miller and Nicely (1955) found that elimination of frequencies above 1000 Hz did not appreciably affect voicing distinctions. Voiers (1967) concluded that the voicing attribute was highly recognizable even with

low-pass filtering at 596 Hz.

On the basis of the above studies and the present research it appears that sufficient cues for voicing are available in the frequency region below 1000 Hz. The fact that both groups of listeners had normal auditory acuity below 1000 Hz would account for the high percentage of correct identifications of voiced and unvoiced phonemes. In addition, there may be little difference, if any, in the ability of the subjects to distinguish onset time and duration of the contiguous vowel. Lisker and Abramson (1967) found these factors to be of importance in the perception of voicing differences among stops.

2. Nasality: This attribute involves contrasts of nasal versus oral phonemes. In a comparison of the nasality attribute with the other five attributes, nasality had the highest percentage of correct responses for both groups of listeners. The normal-hearing subjects achieved scores of 100 per cent correct identification and the impaired-hearing subjects, 98.06 per cent. Normal listeners had scores of 100% for both states. Whereas, nasal phonemes were slightly more discriminable than oral phonemes (98.91 per cent versus 97.19 per cent). The differences in the nasal *vs.* oral comparisons were not significantly different for the two listener groups.

Nasal phonemes are characterized by the presence of relatively strong intensity in the region of 200-300 Hz,

a spectral prominence in the middle frequency range, a large separation between the first formant and higher formants, and the presence of nulls throughout the frequency spectrum (House, 1957; Fujimura, 1962). According to Fant (1967, p. 119) "nasalization is seen by the presence of the voice bar in the entire word and comparable in intensity to the first formant."

The results of tests of the nasality attribute in the DRT appear consistent with other studies. Owens and Schubert (1968) reported that nasal phonemes were rarely confused with non-nasal phonemes in a speech discrimination test administered to "hearing-impaired" subjects. Cox (1970) found that nasal errors were low in various test conditions of unfiltered and low-pass filtered speech stimuli presented to sensori-neural hearing-impaired subjects. According to Green (1970) there is no significant difference in the ability of normals and sensori-neurals to recognize the nasality feature. Both groups of subjects were able to perceive with relative ease test items for the nasality feature in Green's (1970) distinctive feature test.

Miller and Nicely (1955) indicated that the perception of nasality was not materially affected by a reduction of frequency cues above 1000 Hz. This is further substantiated by Voiers' (1967) data that nasal versus oral distinctions were not affected by low-pass filtering at 596 Hz.

In view of the research cited above, it seems that

sufficient cues for nasality distinctions are present in the frequencies below 1000 Hz. Since the audiometric configurations of both groups of listeners tested in this study showed normal hearing acuity below 1000 Hz, the ability of these listeners to identify the nasality attribute is not surprising. The results of this study in conjunction with the previous research cited above suggest that energy in the middle frequency region is not a critical cue for the perception of nasality.

3. Sustention: The attribute sustention involves the discrimination of sustained versus interrupted phonemes. In the system proposed by Voiers (1967), the phonemes tested are restricted to fricative versus plosive contrasts. In the present study the two groups of listeners differed significantly in their ability to differentiate sustained from interrupted phonemes. The mean correct scores were 95.17 per cent and 71.43 per cent for normal-hearing and sensori-neural hearing-impaired subjects, respectively. For both groups sustained phonemes were easier to identify than their interrupted counterparts. Correct identification percentages were 96.56 per cent for the positive (sustained) state and 93.75 per cent for the negative (interrupted) state in the normal-hearing group. The sensori-neurals obtained scores of 74.84 per cent for the positive state and 67.97 per cent for the negative state.

Fricatives have characteristic high-frequency cues

(Strevens, 1960; Heinz and Stevens, 1961). However, according to Lawrence and Byers (1969) and Farr (1969) voiceless fricatives may be identified by cues such as intensity, duration, and low-frequency energy in the absence of high-frequency cues. Liberman (1957) reported that duration and the nature of the onset of noise in fricatives and stops provide cues related to manner. Halle et al (1957) indicated that the burst of the stop release and the formant transition in the adjacent vowel are two major cues for stop consonants.

The findings reported herein for sustention, specifically fricative versus plosive contrasts, are in conformance with results reported in other studies (Siegenthaler, 1954; Cox, 1970; Voiers, 1967). Siegenthaler (1954) indicated that listeners with sloping audiometric pure tone contours above 1000 Hz had difficulty with stop-fricative distinctions. According to Cox (1970, p. 85) sensori-neural listeners had "a definite interconfusability between stops and fricatives." Voiers (1967) revealed that perception of the attribute sustention was influenced by low-pass filtering with consistent decreases in intelligibility as the upper cutoff frequency fell below 1460 Hz.

In view of the present findings with sensori-neural hearing-impaired subjects and the studies cited above, it appears that frequency cues above 1000 Hz are important

in discrimination of fricatives versus plosives. It is probable that perception of frequency cues in the region above 1000 Hz enables higher accuracy in the identification of phonemic contrasts for the attribute sustention.

4. Sibilation: A review of Voiers' (1967) classification of the attribute sibilation and of the two subclasses (strident and mellow) will be helpful in the examination of the results obtained in this portion of the study. Since both theoretical and operational definitions of sibilation subclasses found in the literature are difficult to interpret, a list-type definition best serves as a point of departure for the following discussion.

In the present study the perception of /s *vs.* θ /, /ʃ̂ *vs.* k/, /ʒ̂ *vs.* g/, and /z *vs.* ð / is compared. Voiers (1967) in conformance with his predecessors (Jakobson, Fant, and Halle, 1952) classes the first phonemes in each of the above pairings as *strident* and their opposites as *mellow*. The above classification scheme appears to be based on the relative differences in intensities, with the presence of noise as a common characteristic.

Differences in the ability of normals and sensorineurals to perceive strident versus mellow contrasts were statistically significant. The mean correct scores for sibilation (strident and mellow scores combined) were 97.90 per cent for the normal group and 66.98 per cent

for the sensori-neural group.

Subjects with normal-hearing obtained scores of 97.19 per cent for strident phonemes and 98.59 per cent for mellow phonemes. Sensori-neural hearing-impaired listeners obtained scores of 75.00 per cent for strident phonemes and 58.91 per cent for mellow phonemes. This difference between the two states in the hearing-loss group was statistically significant. Mellow phonemes, classed as weaker intensity sounds, were more difficult for subjects in the sensori-neural group to perceive.

In view of the above data, it is evident that distinctions made between strident and mellow phonemes were difficult for sensori-neural hearing-loss subjects. According to Denes and Pinson (1963) certain phonemes, particularly within the fricative class, are distinguished on the basis of their relative intensities. A loss of hearing acuity in the high frequencies reduces the overall intensity of phonemes (Sanders, 1971). It appears that in the hearing-impaired group the reduction of hearing acuity above 1000 Hz effectively diminished high-frequency cues as well as intensity cues which, in turn, contributed to the reduced identification scores for strident and mellow phonemes.

The last two attributes in the DRT, graveness and compactness, are specified by Voiers (1967) to test phonemic distinctions related to place of articulation.

The attributes graveness and compactness will be discussed in sequence. Following this, a discussion of the cues for differentiation of place and the findings of comparative studies will be presented.

5. Graveness: Voiers (1967) delimits the employment of the term graveness to a comparison of phonemes produced in the front of the oral cavity (grave) versus phonemes produced in the mid-region of the oral cavity (acute). This classification scheme departs from that of Jakobson, Fant, and Halle (1952), wherein, the velar phonemes are included with labial phonemes as exemplifying grave consonants. The rationale for the Jakobson, Fant, Halle (1952) classification scheme is that both the labials and velars result from a peripheral place of production and can be compared with those sounds that are produced medially.

For the graveness attribute the performance of normal-hearing subjects was significantly different from that of the sensori-neural loss subjects. The mean correct scores were 92.06 per cent for the normals and 59.40 per cent for the sensori-neurals.

An analysis of scores for front phonemes (positive state) versus middle phonemes (negative state) revealed that normal subjects did not have significant differences in perception of these two states. Their scores were 92.50 per cent for front phonemes and 91.56 per cent for middle phonemes. Differences in perception of front versus middle

contrasts for sensori-neural hearing-impaired listeners were significant with scores of 55.47 per cent for front phonemes and 63.28 per cent for middle phonemes. This finding that sensori-neurals tended to have more difficulty with perception of front phonemes is somewhat in agreement with Rosen's (1962) study. He reported that test scores were lower for phonemes produced in the anterior portion of the oral cavity as compared with phonemes produced in the alveolar or post-alveolar regions.

In the present study both listener groups had difficulty with perception of /f/ versus /θ/. These phonemes accounted for 25 per cent of the items designed for assessment of the attribute graveness. According to Delattre (1958) the phonemes /f/ and /θ/ are very similar acoustically. Lawrence and Byers (1969) found that listeners with high-frequency hearing losses confused the /f/ and /θ/ phonemes. Miller and Nicely (1955, p. 347) stated that:

> The distinctions between /f/ and /θ/ . . . are among the most difficult for listeners to hear and it seems likely that in most natural situations the differentiation depends more on verbal context and on visual observation of the talker's lips than it does on the acoustic difference.

An explanation of the uncertainty in the /f/ versus /θ/ discrimination may be that in the transmission of these phonemes over the audiologic system low intensity,

high frequency acoustical cues were reduced. The interaction of transmission distortion and distortion due to high frequency hearing loss compounded the difficulty of the discrimination task for the sensori-neural hearing-impaired subjects.

6. Compactness: This attribute, according to Voiers (1967), specifically tests discrimination of back versus middle and back versus front place of articulation. The back phonemes are classed as compact (positive state) and the middle and front phonemes are classed as diffuse (negative state). The mean correct scores for compactness (average of the positive and negative states) in the normal-hearing group were 99.30 per cent and in the sensori-neural loss group were 79.39 per cent. This difference between the two groups was statistically significant.

Normals obtained scores of 99.38 per cent and 99.22 per cent for the present and absent states, respectively. The sensori-neurals scored 81.25 per cent for the present state and 77.50 per cent for the absent state. In the hearing-impaired group the difference between the two states was statistically significant.

Difficulty in perception of place differences appears to be related to the acoustic similarity of certain phonemes classified as middle and back phonemes. For example, Delattre (1958) mentioned the acoustic likeness of the phonemes /d/ and /g/; /t/ and /k/. In addition,

discrimination of the phonemes /s/ and /ʃ/ was included among the test items for compactness. Miller and Nicely (1955) reported that the middle /s/ is distinguished from the back /ʃ/ by the relative concentration of energy in the high frequencies. Lawrence and Byers (1969) have previously reported that the phonemes /s/ and /ʃ/ were confused by high-frequency hearing-loss subjects.

Since the attributes graveness and compactness are both concerned with the factor of place of articulation, a summarizing discussion concerning these two attributes may be helpful. The results of the present study are compatible with Voiers' (1967) data which indicates that graveness and compactness were greatly affected by high frequency attenuation above 1460 Hz. In both the present study and Voiers' (1967) study the attribute graveness was affected more severely than compactness.

A number of studies indicate that normal and hearing-impaired listeners experience difficulty in identifying phonemes which differ primarily in place of production (Oyer and Doudna, 1959; Rosen, 1962; Schultz and Boros, 1965; Owens and Schubert, 1968; Cox, 1970; Green, 1970). The degree of difficulty appears to increase when the listeners consist of subjects with sensori-neural hearing impairments.

In the foregoing discussion the six attributes were presented. It will be recalled that the total DRT score

is an average of the six attribute scores. In the following paragraphs the total DRT scores will be discussed.

In the present study the total DRT scores were significantly higher for normal listeners than for sensori-neural hearing-impaired listeners. The total DRT scores were 97.12 per cent and 78.17 per cent for the normals and sensori-neurals, respectively. This difference between the two listener groups appears to be related to the effect of high-frequency loss on the perception of certain attributes: primarily, sustention, sibilation, graveness, and compactness.

The results of the present study for the total DRT scores are in agreement with Voiers' (1967) report that the total DRT scores were sensitive to high-frequency distortion. He found that with low-pass filtering as the upper cut-off was decreased below 1460 Hz, the total DRT scores were consistently reduced. In unfiltered conditions the total DRT scores were little affected.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of the present study was to investigate the predictive value and reliability of the DRT for the measurement of speech discrimination abilities of normal-hearing and sensori-neural hearing-impaired listeners. The DRT was developed by Dr. William D. Voiers in 1965 for evaluation of communications systems. However, it had not been applied for evaluation of the human auditory system.

The framework of the DRT is a form of distinctive feature analysis. Discrimination of the positive versus negative states of six attributes is tested in a two-choice rhyme test. The six attributes chosen for analysis are: voicing, nasality, sustention, sibilation, sustention, graveness, and compactness.

Twenty volunteer normal-hearing males served as subjects in a control group. Twenty males, obtained from the Veterans Administration Hospital in New Orleans, Louisiana, who had high-frequency sensori-neural hearing losses were subjects in an experimental group. Four repetitions of the DRT 192-word corpus were presented

at 50 dB SL to the two groups of listeners.

The following questions were asked in the experimental design:

1. Are there differences in the total DRT scores for normal-hearing and sensori-neural hearing-impaired listeners?
2. Are the total DRT scores reliable?
3. Are there differences in the attribute scores of the DRT for normal-hearing and sensori-neural hearing-impaired listeners?
4. Is the correctness of phoneme identification differentially related to specific attributes?
5. Are the attribute scores reliable?
6. Are there differences in the two states of each attribute for normal-hearing and sensori-neural hearing-impaired listeners?
7. Are the scores for the two states of the attributes reliable?

Responses to the DRT were examined through statisical treatment using the analysis of variance procedure. Performance of the two groups was compared for DRT measures comprised of total DRT scores, scores for the six attributes, and scores for the present and absent states of each attribute.

The findings of this study can be summarized as follows:

1. Differences between normal-hearing and sensori-neural hearing-impaired subjects are highly significant for the total DRT scores.
2. The reliability of the total DRT scores is high.
3. Differences in responses between the two listener groups are large and highly significant for the attributes sustention, sibilation, graveness, and compactness. Differences between the two groups are small, but significant, for the attribute voicing. There are no significant differences between the two groups for perceptual responses to the attribute nasality.
4. Orthogonal comparisons reveal that the correctness of phoneme identification is differentially related to certain attributes. Response patterns or profiles of the attributes are characteristic to each listener group.
5. The reliability of the attribute scores is high.
6. In the hearing-impaired group differences between the two states are significant for

some attributes but not for others. Sensori-neural loss subjects reveal significant differences between states for voicing, sustention, sibilation, and graveness. No significant differences between states are evident for nasality and compactness. For the normal group, no comparisons of present versus absent states are significant.

7. The reliability of scores is moderately high for the present state and higher for the absent state.

In summary, the present study demonstrates the predictive value and reliability of the DRT with a selected population of normal-hearing and sensori-neural hearing-impaired listeners. Perception of the six attributes appears to be related to hearing acuity. All normal-hearing subjects had higher performance levels than the hearing-impaired subjects. However, the difference between groups was greater for certain attributes. The attributes sustention, sibilation, graveness, and compactness distinguished the two listener groups to a large degree. The two groups had minimal difficulty in perception of the attributes nasality and voicing.

Conclusions

Based upon this initial work, it is concluded

that the DRT offers potential for use as a clinical audiologic procedure. The employment of a distinctive feature system appears to be a feasible approach to predicting a listener's speech discrimination ability. The present study shows close agreement with other studies that distinctive features (or attributes) are differentially affected by auditory distortion from hearing loss or frequency filtering. The breakdown of speech into the six attributes voicing, nasality, sustention, sibilation, graveness, and compactness, seems to provide a more meaningful measure of discrimination ability than the use of traditional speech discrimination tests such as the PAL PB-50 and the C.I.D. W-22 tests.

Utilization of a closed-message set in the design of the DRT promotes objectivity in evaluating and scoring listener responses. The DRT response forms are easily scored following test administration through the use of special overlays or templates. For more extensive analysis the DRT response forms are designed for computer processing.

At the present time, recommendation of the DRT for clinical use must be held in abeyance until additional standardization and validation studies are available. A number of areas hold interest for further investigation. These include studies of (1) the effect of different degrees and types of hearing impairment on the DRT scores, (2) age and educational readiness for the DRT, (3) masking

effects with the DRT, (4) measurement of discrimination ability with amplification devices such as hearing aids, and (5) phonemic and word-pair confusions within the DRT. The ultimate usefulness of the Diagnostic Rhyme Test will be determined only with further compilation of research data.

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APPENDICES

APPENDIX A

Name__________________________ Date____________

EQUIPMENT CHECKLIST

___1. Turn on the Allison 22 audiometer.

___2. Clean tape playback heads.

___3. Put 1000 Hz calibration tone on Viking 87 tape recorder.

___4. Set HL of audiometer to 70 dB.

___5. Check calibration using the Bruel and Kjaer Audiometer Calibrator System Type 3502.

a.___ (initial) b.___ (midpoint) c.___ (final)

PROCEDURE CHECKLIST

___1. Red earphone on test ear: ________.

___2. Tape of instructions and six practice items.

___3. Practice tape (48 items).

___4. Five-minute rest period.

___5. Test tape (192 items). Tape No.___. Form No.___.

___6. Five-minute rest period.

___7. Test tape (192 items). Tape No.___. Form No.___.

___8. Thirty-minute rest period.

___9. Test tape (192 items). Tape No.___. Form No.___.

__10. Five-minute rest period.

__11. Test tape (192 items). Tape No.___. Form No.___.

APPENDIX B

Name____________________ Birthdate_________ Date_________

Classification____________________ Ear_____ List_________

INSTRUCTIONS AND PRACTICE ITEMS

This is a test of your ability to understand spoken words. You will be given pairs of rhyming words as shown on the answer sheets.

Underline the word you hear. If you are not sure, guess at the word.

You will now hear six practice items. Are you ready?

TENT - DENT	CHILL - KILL
MOON - BOON	BARK - DARK
PAT - FAT	CONE - TONE

If you have any questions about what you are to do in this test, raise your hand.

Listen carefully. Underline the word you hear. Guess at the word if you are not sure. Give an answer to every item. Are you ready? Please turn the page.

DRT IV-(1) **APPENDIX C** A

PRACTICE TEST

~~*BOB - GOB~~	~~GOOT - TOOT~~
DAUNT - TAUNT	POND - BOND
MOOT - BOOT	BONE - MOAN
SHEET - CHEAT	BILL - VILL
GAB - JAB	GUEST - JEST
TOT - POT	FOUGHT - THOUGHT
BOAST - GHOST	POOP - COOP
~~RIP - LIP~~	~~LEAP - REAP~~
SAID - ZED	FAST - VAST
GNAW - DAW	KNOCK - DOCK
SHOES - CHOOSE	DOZE - THOSE
KEEP - CHEEP	SING - THING
DANK - BANK	NET - MET
DOT - GOT	CAUGHT - TAUGHT
~~ROAD - LOAD~~	~~LEWD - RUDE~~
TINT - DINT	BEAN - PEEN
DECK - NECK	MAD - BAD
TONG - THONG	BOX - VOX
CHEW - COO	JOE - GO
REED - WEED	DID - BID
SAG - SHAG	WREN - YEN
~~LOT - ROT~~	~~LAW - RAW~~
FOAL - VOLE	ZOO - SUE
DIP - NIP	NEED - DEED
FENCE - PENCE	THAN - DAN
THAW - SAW	CHOP - COP
POOL - TOOL	FORE - THOR
YIELD - WIELD	FIT - HIT
~~LAP - RAP~~	~~LEST - REST~~

NAME ______________________ DATE ________________

*Filler items are designated by black line.

**This form has been reduced for binding specifications.

APPENDIX D**

SAMPLE RESPONSE FORM***

DRT IV-(3) D

*~~BEST - TEST~~	~~PAN - PAN~~
VAULT - FAULT	JOCK - CHOCK
NEWS - DUES	NOTE - DOTE
BEE - VEE	TICK - THICK
THANK - SANK	CARE - CHAIR
ROD - WAD	DONG - BONG
SO - SHOW	RUE - YOU
~~RID - LID~~	~~REEK - LEAK~~
DENSE - TENSE	GAFF - CALF
BOSS - MOSS	MOM - BOMB
POOH - FOO	THOUGH - DOUGH
THEE - ZEE	JILT - GILT
THAD - FAD	TENT - PENT
HOP - FOP	WALL - YAWL
~~ROW - LOW~~	~~LOOT - ROOT~~
GIN - CHIN	VEAL - FEEL
MEND - BEND	NAB - DAB
CHAW - SHAW	VON - BON
JUICE - GOOSE	THOLE - SOLE
PEAK - TEAK	FIN - THIN
GAT - BAT	PEG - KEG
~~LOCK - ROCK~~	~~WRONG - LONG~~
GOAT - COAT	DUNE - TUNE
BIT - MIT	BEAT - MEAT
DEN - THEN	CHAD - SHAD
JAWS - GAUZE	GOT - JOT
NOON - MOON	BOWL - DOLE
KEY - TEA	GILL - DILL
~~RAMP - LAMP~~	~~LEND - REND~~

*Filler items are designated by black line.
**This form has been reduced for binding specifications.
***One out of a set of eight pages.

APPENDIX D—Continued**

SAMPLE RESPONSE FORM*** DRT IV-(3) G

~~*COB - ROB~~	~~COOT - TOOT~~
TAUNT - DAUNT	BOND - POND
MOOT - BOOT	MOAN - BONE
CHEAT - SHEET	VILL - BILL
JAB - GAB	GUEST - JEST
TOT - POT	FOUGHT - THOUGHT
GHOST - BOAST	COOP - POOP
~~LIP - RIP~~	~~REAP - LEAP~~
SAID - ZED	VAST - FAST
GNAW - DAW	KNOCK - DOCK
CHOOSE - SHOES	THOSE - DOZE
KEEP - CHEEP	THING - SING
BANK - DANK	NET - MET
GOT - DOT	CAUGHT - TAUGHT
~~ROAD - LOAD~~	~~RUDE - LEWD~~
TINT - DINT	BEAN - PEEN
NECK - DECK	MAD - BAD
THONG - TONG	BOX - VOX
COO - CHEW	GO - JOE
REED - WEED	DID - BID
SAG - SHAG	YEN - WREN
~~LOT - ROT~~	~~RAW - LAW~~
FOAL - VOLE	ZOO - SUE
DIP - NIP	DEED - NEED
FENCE - PENCE	THAN - DAN
THAW - SAW	COP - CHOP
TOOL - POOL	FORE - THOR
WIELD - YIELD	FIT - HIT
~~RAP - LAP~~	~~REST - LEST~~

*Filler items are designated by black line.
**This form has been reduced for binding specifications.
***One out of a set of eight pages.

APPENDIX E

Data Summary Sheets for Twenty Normal-Hearing Subjects

SUBJECT 1

REP	VOIC P	VOIC A	VOIC T	NASL P	NASL A	NASL T	SUST P	SUST A	SUST T	SIBL P	SIBL A	SIBL T	GRAV P	GRAV A	GRAV T	COMP P	COMP A	COMP T
1	1	1	2	0	0	0	1	0	1	1	0	1	1	0	1	0	0	0
2	1	0	1	0	0	0	3	1	4	0	0	0	1	0	1	0	0	0
3	0	1	1	0	0	0	1	0	1	0	0	0	1	1	2	0	0	0
4	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0
TOTAL	2	2	4	0	0	0	5	2	7	2	0	2	3	1	4	0	0	0

SUBJECT 2

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0
2	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1
TOTAL	0	0	0	0	0	0	2	1	3	1	0	1	0	3	3	1	0	1

SUBJECT 3

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
2	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
3	0	1	1	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0
4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	4	4	0	0	0	0	1	1	0	1	1	0	3	3	0	1	1

SUBJECT 4

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	1	1	0	0	0	2	0	2	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0
4	0	0	0	0	0	0	1	1	2	0	0	0	1	0	1	0	0	0
TOTAL	0	0	0	0	0	0	1	2	3	0	0	0	6	1	7	0	0	0

SUBJECT 5

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
2	0	0	0	0	0	0	0	0	0	1	1	2	0	1	1	0	0	0
3	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0
TOTAL	0	0	0	0	0	0	0	0	0	3	1	4	0	4	4	0	0	0

SUBJECT 6

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	1	1	0	0	0	0	2	2	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	1	0	2	2	0	0	0
TOTAL	0	0	0	0	0	0	0	1	1	1	0	1	0	6	6	0	0	0

SUBJECT 7

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	1	1	0	0	0	0	2	2	0	0	0
2	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
TOTAL	0	0	0	0	0	0	0	1	1	1	0	1	1	4	5	0	0	0

SUBJECT 8

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	1	0	0	0	1	0	1	0	0	0	2	0	2	0	0	0
TOTAL	0	2	2	0	0	0	1	0	1	0	1	1	4	1	5	0	0	0

SUBJECT 9

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	1	0	1	0	0	0	1	1	2	1	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
TOTAL	0	1	1	0	0	0	2	0	2	0	0	0	2	2	4	2	1	3

SUBJECT 10

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
2	0	1	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0
3	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0
4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	2	2	0	0	0	0	1	1	0	0	0	1	3	4	0	0	0

SUBJECT 11

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	1	0	1	0	0	0	0	0	0	0	0	0	4	1	5	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0
3	0	0	0	0	0	0	0	0	0	0	1	1	2	0	2	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
TOTAL	1	0	1	0	0	0	0	0	0	0	1	1	9	1	10	0	0	0

SUBJECT 12

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	1	1	0	0	0	1	2	3	0	0	0
2	0	0	0	0	0	0	0	1	1	1	0	1	1	1	2	0	0	0
3	0	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0
4	0	1	1	0	0	0	0	0	0	1	0	1	1	1	2	0	0	0
TOTAL	0	2	2	0	0	0	0	2	2	3	0	3	3	5	8	0	0	0

SUBJECT 13

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	1	1	2	1	0	1	1	1	2	0	0	0
2	0	0	0	0	0	0	0	2	2	1	1	2	1	0	1	0	0	0
3	0	0	0	0	0	0	0	3	3	1	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	1	3	4	0	0	0	1	0	1	0	0	0
TOTAL	0	1	1	0	0	0	2	9	11	3	1	4	3	1	4	0	0	0

SUBJECT 14

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
2	0	1	1	0	0	0	0	1	1	0	0	0	3	1	4	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3	0	0	0
4	1	0	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0
TOTAL	1	1	2	0	0	0	0	1	1	0	0	0	6	5	11	0	0	0

SUBJECT 15

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
2	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
TOTAL	0	0	0	0	0	0	0	0	0	0	1	1	3	0	3	0	0	0

SUBJECT 16

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	2	1	3	0	0	0	0	2	2	0	0	0
2	0	0	0	0	0	0	0	0	0	1	0	1	1	1	2	0	1	1
3	1	0	1	0	0	0	0	2	2	0	0	0	0	2	2	0	0	0
4	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0
TOTAL	1	0	1	0	0	0	2	4	6	1	0	1	1	6	7	0	1	1

SUBJECT 17

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	5	5	0	0	0	0	1	1	0	0	0
2	0	0	0	0	0	0	0	4	4	0	0	0	1	2	3	0	0	0
3	0	0	0	0	0	0	3	1	4	1	0	1	0	1	1	0	0	0
4	0	0	0	0	0	0	1	2	3	0	0	0	1	0	1	0	0	0
TOTAL	0	0	0	0	0	0	4	12	16	1	0	1	2	4	6	0	0	0

SUBJECT 18

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	0	0	0	0	1	1	0	1	1	1	0	1
2	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
TOTAL	0	1	1	0	0	0	0	1	1	0	2	2	0	3	3	1	0	1

SUBJECT 19

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
4	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
TOTAL	0	0	0	0	0	0	1	1	2	0	0	0	2	1	3	0	0	0

SUBJECT 20

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0
2	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
3	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0
4	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	1	1
TOTAL	0	0	0	0	0	0	2	1	3	2	1	3	1	1	2	0	1	1

APPENDIX F

Data Summary Sheets for Twenty Hearing-Impaired Subjects

SUBJECT 1

REP	VOIC P	VOIC A	VOIC T	NASL P	NASL A	NASL T	SUST P	SUST A	SUST T
1	0	0	0	0	0	0	2	1	3
2	0	0	0	0	0	0	0	2	2
3	0	0	0	0	0	0	0	4	4
4	0	0	0	0	0	0	1	3	4
TOTAL	0	0	0	0	0	0	3	10	13

REP	SIBL P	SIBL A	SIBL T	GRAV P	GRAV A	GRAV T	COMP P	COMP A	COMP T
1	1	4	5	3	1	4	0	1	1
2	0	3	3	2	0	2	0	1	1
3	2	3	5	3	1	4	2	2	4
4	3	6	9	5	2	7	0	1	1
TOTAL	6	16	10	13	4	17	2	5	7

SUBJECT 2

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	2	3	5	0	1	1	3	4	7	1	2	3
2	1	0	1	1	0	1	1	3	4	1	3	4	4	5	9	1	3	4
3	0	0	0	0	0	0	1	3	4	1	3	4	5	3	8	1	0	1
4	0	2	2	0	0	0	1	4	5	2	2	4	1	3	4	1	3	4
TOTAL	1	2	3	1	0	1	5	13	18	4	9	13	13	15	28	4	8	12

SUBJECT 3

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	2	1	3	0	2	2	2	4	6	1	1	2
2	0	0	0	0	0	0	0	4	4	1	2	3	5	4	9	1	1	2
3	0	0	0	0	0	0	0	2	2	2	2	4	2	3	5	3	1	4
4	0	0	0	0	0	0	2	1	3	2	0	2	3	3	6	1	1	2
TOTAL	0	1	1	0	0	0	4	8	12	5	6	11	12	14	26	6	4	10

SUBJECT 4

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	1	1	2	2	4	0	3	3	2	1	3	0	1	1
2	0	0	0	0	0	0	2	3	5	1	1	2	4	1	5	1	2	3
3	0	0	0	0	0	0	0	0	0	0	2	2	4	0	4	1	1	2
4	0	0	0	0	0	0	1	1	2	4	5	9	1	1	2	0	1	1
TOTAL	0	0	0	0	1	1	5	6	11	5	11	16	11	3	14	2	5	7

SUBJECT 5

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	1	3	4	4	0	4	1	1	2
2	0	1	1	0	0	0	2	1	3	0	1	1	3	0	3	1	1	2
3	0	0	0	0	0	0	1	0	1	0	0	0	4	1	5	0	0	0
4	0	1	1	0	0	0	0	2	2	0	1	1	3	0	3	1	0	1
TOTAL	0	2	2	0	0	0	3	3	6	1	5	6	14	1	15	3	2	5

SUBJECT 6

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	1	2	3	1	0	1	3	1	4	1	2	3	5	6	11	1	1	2
2	2	4	6	0	1	1	4	1	5	2	1	3	2	3	5	2	1	3
3	1	2	3	0	0	0	1	1	2	1	3	4	5	6	11	1	3	4
4	0	2	2	1	0	1	1	2	3	1	5	6	3	3	6	2	1	3
TOTAL	4	10	14	2	1	3	9	5	14	5	11	16	15	18	33	6	6	12

SUBJECT 7

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	0	0	1	5	6	4	5	9	0	2	2
2	0	1	1	0	0	0	2	0	2	1	4	5	5	3	8	2	3	5
3	0	0	0	0	0	0	2	1	3	0	0	0	1	4	5	0	1	1
4	0	1	1	0	0	0	0	0	0	0	2	2	5	4	9	0	2	2
TOTAL	0	2	2	0	0	0	4	1	5	2	11	13	15	16	31	2	8	10

SUBJECT 8

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	1	1	2	2	3	5	4	1	5	0	2	2
2	2	2	4	0	0	0	3	3	6	0	2	2	2	4	6	2	2	4
3	0	0	0	0	0	0	4	3	7	1	0	1	3	1	4	2	2	4
4	0	1	1	0	0	0	0	2	2	1	1	2	3	2	5	3	1	4
TOTAL	2	4	6	0	0	0	8	9	17	4	6	10	12	8	20	7	7	14

SUBJECT 9

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	0	4	4	0	3	3	5	2	7	0	4	4
2	0	1	1	0	1	1	5	6	11	0	3	3	3	4	7	5	2	7
3	0	1	1	0	0	0	3	5	8	1	3	4	4	2	6	3	3	6
4	0	1	1	1	0	1	5	4	9	1	4	5	3	2	5	4	3	7
TOTAL	0	4	4	1	1	2	13	19	32	2	13	15	15	10	25	12	12	24

SUBJECT 10

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	2	0	2	0	1	1	2	3	5	2	0	2
2	0	2	2	0	0	0	0	3	3	1	3	4	4	2	6	3	1	4
3	0	0	0	0	0	0	1	0	1	0	3	3	4	0	4	0	0	0
4	1	0	1	0	1	1	1	1	2	2	1	3	2	2	4	0	0	0
TOTAL	1	3	4	0	1	1	4	4	8	3	8	11	12	7	19	5	1	6

SUBJECT 11

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	5	5	0	1	1	2	2	4	7	6	13	4	5	9	0	3	3
2	2	2	4	0	1	1	2	3	5	6	4	10	4	3	7	3	3	6
3	2	2	4	0	0	0	3	5	8	5	2	7	5	2	7	5	3	8
4	0	0	0	0	1	1	1	6	7	3	2	5	4	6	10	3	2	5
TOTAL	4	9	13	0	3	3	8	16	24	21	14	35	17	16	23	11	11	22

SUBJECT 12

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	1	2	3	0	1	1	5	5	10	3	8	11	3	6	9	1	6	7
2	1	0	1	0	0	0	5	7	12	2	9	11	6	6	12	2	4	6
3	1	0	1	1	1	2	7	8	15	4	10	14	5	4	9	2	8	10
4	0	2	2	0	0	0	4	6	10	1	9	10	4	6	10	2	4	6
TOTAL	3	4	7	1	2	3	21	26	47	10	36	46	18	22	30	7	22	29

SUBJECT 13

REP	VOIC			NASL			SUST			SIBL			GRAV			COMP		
	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	4	2	6	3	6	9	5	4	9	2	2	4
2	0	0	0	0	0	0	1	1	2	3	1	4	5	4	9	3	1	4
3	0	0	0	0	0	0	1	1	2	2	2	4	3	1	4	3	0	3
4	1	1	2	0	0	0	3	1	4	5	1	6	2	2	4	1	2	3
TOTAL	1	1	2	0	0	0	9	5	14	13	10	23	15	11	26	9	5	14

SUBJECT 14

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	4	4	0	1	1	2	2	4	1	1	2
2	1	1	2	1	0	1	1	2	3	1	1	2	0	4	4	1	1	2
3	1	0	1	0	0	0	1	1	2	1	1	2	3	2	5	1	0	1
4	1	1	2	0	0	0	0	1	1	3	0	3	0	3	3	0	0	0
TOTAL	3	2	5	1	0	1	2	8	10	5	3	8	5	11	16	3	2	5

SUBJECT 15

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	1	0	1	3	6	9	4	3	7	1	1	2
2	0	1	1	0	0	0	0	0	0	2	3	5	3	1	4	1	1	2
3	0	0	0	0	0	0	3	1	4	1	3	4	3	2	5	1	0	1
4	0	1	1	0	0	0	0	0	0	3	2	5	4	1	5	1	1	2
TOTAL	0	2	2	0	0	0	4	1	5	9	14	23	14	7	21	4	3	7

SUBJECT 16

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	0	0	6	4	10	9	8	17	4	3	7	6	3	9
2	0	0	0	0	1	1	5	5	10	5	4	9	4	0	4	3	5	8
3	0	0	0	0	0	0	5	6	11	2	1	3	5	3	8	3	1	4
4	0	1	1	0	0	0	3	3	6	6	3	9	4	4	8	2	4	6
TOTAL	0	2	2	0	1	1	19	18	37	22	16	38	17	10	27	14	13	27

SUBJECT 17

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	0	0	0	0	0	0	3	3	2	4	6	4	3	7	0	1	1
2	1	0	1	0	0	0	2	0	2	0	2	2	3	0	3	0	0	0
3	1	0	1	0	0	0	0	0	0	0	4	4	2	2	4	0	0	0
4	0	0	0	0	0	0	2	0	2	1	3	4	2	2	4	2	0	2
TOTAL	2	0	2	0	0	0	4	3	7	3	13	16	11	7	18	2	1	3

SUBJECT 18

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	1	1	2	0	0	0	3	6	9	1	6	7	4	4	8	1	2	3
2	1	0	1	0	1	1	4	5	9	1	3	4	5	3	8	3	0	3
3	1	2	3	1	1	2	4	7	11	2	6	8	7	4	11	2	1	3
4	0	1	1	0	2	2	3	7	10	2	5	7	2	5	7	1	1	2
TOTAL	3	4	7	1	4	5	14	25	39	6	20	26	18	16	34	7	4	11

SUBJECT 19

REP	VOIC P	VOIC A	VOIC T	NASL P	NASL A	NASL T	SUST P	SUST A	SUST T	SIBL P	SIBL A	SIBL T	GRAV P	GRAV A	GRAV T	COMP P	COMP A	COMP T
1	0	0	0	0	0	0	6	2	8	4	4	8	5	5	10	1	2	3
2	0	1	1	0	0	0	2	1	3	7	3	10	6	6	12	1	4	5
3	0	1	1	0	0	0	0	2	2	3	3	6	2	3	5	1	3	4
4	0	0	0	0	0	0	2	1	3	2	2	4	3	4	7	1	4	5
TOTAL	0	2	2	0	0	0	10	6	16	16	12	28	16	18	34	4	13	17

SUBJECT 20

	VOIC			NASL			SUST			SIBL			GRAV			COMP		
REP	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T	P	A	T
1	0	1	1	0	1	1	2	6	8	5	11	16	5	4	9	3	3	6
2	0	0	0	0	2	2	4	4	8	5	4	9	5	5	10	4	4	8
3	1	0	1	0	1	1	4	4	8	4	5	9	8	6	14	1	4	5
4	0	0	0	0	0	0	2	5	7	4	9	13	4	6	10	2	1	3
TOTAL	1	1	2	0	4	4	12	19	31	18	29	47	22	21	43	10	12	22

VITA

Marie Hiern Olroyd was born in Morgan City, Louisiana, on June 12, 1941. Her undergraduate and graduate studies were done in the area of audiology and speech pathology at the Louisiana State University. She received a Bachelor of Science Degree in 1963, a Master of Arts Degree in 1965, and a Doctor of Philosophy Degree in 1972.

In the summer, 1963, she was employed as a speech clinician at the Speech and Hearing Clinic of Greater St. Petersburg, Inc., in St. Petersburg, Florida. During the academic year 1963-64 she received a traineeship grant for graduate study from the Neurological and Sensory Disease Service of the U. S. Department of Health, Education, and Welfare. In 1964-65 she was a research audiologist at the Tulane University School of Medicine. In September, 1965, she was granted an audiology traineeship at the Veterans Administration Hospital, New Orleans, Louisiana, which was renewed during her years of doctoral study. She is presently a speech and hearing specialist with the Orleans Parish School System, New Orleans, Louisiana.