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The Effect of Cochlear Dysfunction on Central Auditory Speech Test Performance

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THE EFFECT OF COCHLEAR DYSFUNCTION ON CENTRAL AUDITORY SPEECH TEST PERFORMANCE

by

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"It was the best of times,
it was the worst of times..."

Charles Dickens

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CHAPTER I

INTRODUCTION

Background of the Problem

Central auditory nervous system disorders signify lesions in the hearing mechanism from the level of the cochlear nuclei along the auditory pathways up to, and including, the auditory cortex. Central auditory disturbances due to cortical or brainstem pathology and/or cerebellar lesions are frequently characterized by difficulty in discriminating and/or interpreting complex speech signals. However, routine audiologic evaluation frequently reveals normal sensitivity when assessed by pure tone audiometry and normal speech discrimination when undistorted speech signals are used.

According to Bocca and Calearo (1960) this normal speech discrimination performance is explicable on the basis of the extrinsic redundancy of the speech signal. Speech contains information that is both redundant and superfluous for complete comprehension by normal hearing individuals. According to Teatini (1970), any sample of common language is highly redundant. This redundancy is estimated to average 50% in any given language. During transmission most speech messages receive interference from noise and reach the receiver with a certain number of errors or missing elements. External redundancy permits the receiver to correct those errors and, therefore, to receive an adequate amount of information originally contained in the message for correct interpretation. Bocca (1963) stated that the rapid and economical working of the central auditory system in transmitting speech messages is due to the extrinsic redundancy of the message itself, of the syntax, and of a combination of the two.

The central auditory system itself provides considerable neural or intrinsic redundancy because of the multiplicity of pathways and synaptic interconnections (Korsan-Bengtsen, 1973). This intrinsic redundancy permits adequate interpretation of speech messages, despite reduced extrinsic redundancy of the message or even minor impairments within the central auditory system.

Conventional speech tests contain a high degree of external redundancy. By altering the acoustic signals in a variety of ways, highly redundant speech tests can be converted into low redundancy speech tests. These so-called sensitized speech tests are based on the principle of reducing the information available in the speech signal. Such manipulations may include the following: modifying the frequency range; the rate of speech; the duration, length, or rhythm of the message; or by using competing messages or adding masking noise (Bocca, 1967). If the central auditory system is intact, the intrinsic redundancy of the speech signal will enable correct interpretation and understanding of the message. If there is significant disturbance within the central auditory nervous system, however, the intrinsic redundancy will be limited. This, in combination with the limited external redundancy of the message, will result in an inability to understand the speech message.

Individuals with central auditory pathology may have, moreover, co-existing, although unrelated, peripheral hearing loss. The audiologist is therefore confronted with the diagnostic task of evaluating the cochlear dysfunction and the central auditory dysfunction as independent entities. Peripheral and central sites, however, modify the system's response to auditory signals in fundamentally different ways (Dirks, 1974). Audiologic manifestations of cochlear dysfunction are typified by elevated pure tone thresholds ranging from mild to severe, decreased speech discrimination performance, loudness recruitment, minimal or no loudness adaptation, and pitch distortions (Schuknecht, 1970). The effect of central auditory disturbance on the perception of speech signals is less discernible and, despite the disorder, may go unnoticed by the individual. This is due to the apparent intrinsic neural redundancy of the central auditory system.

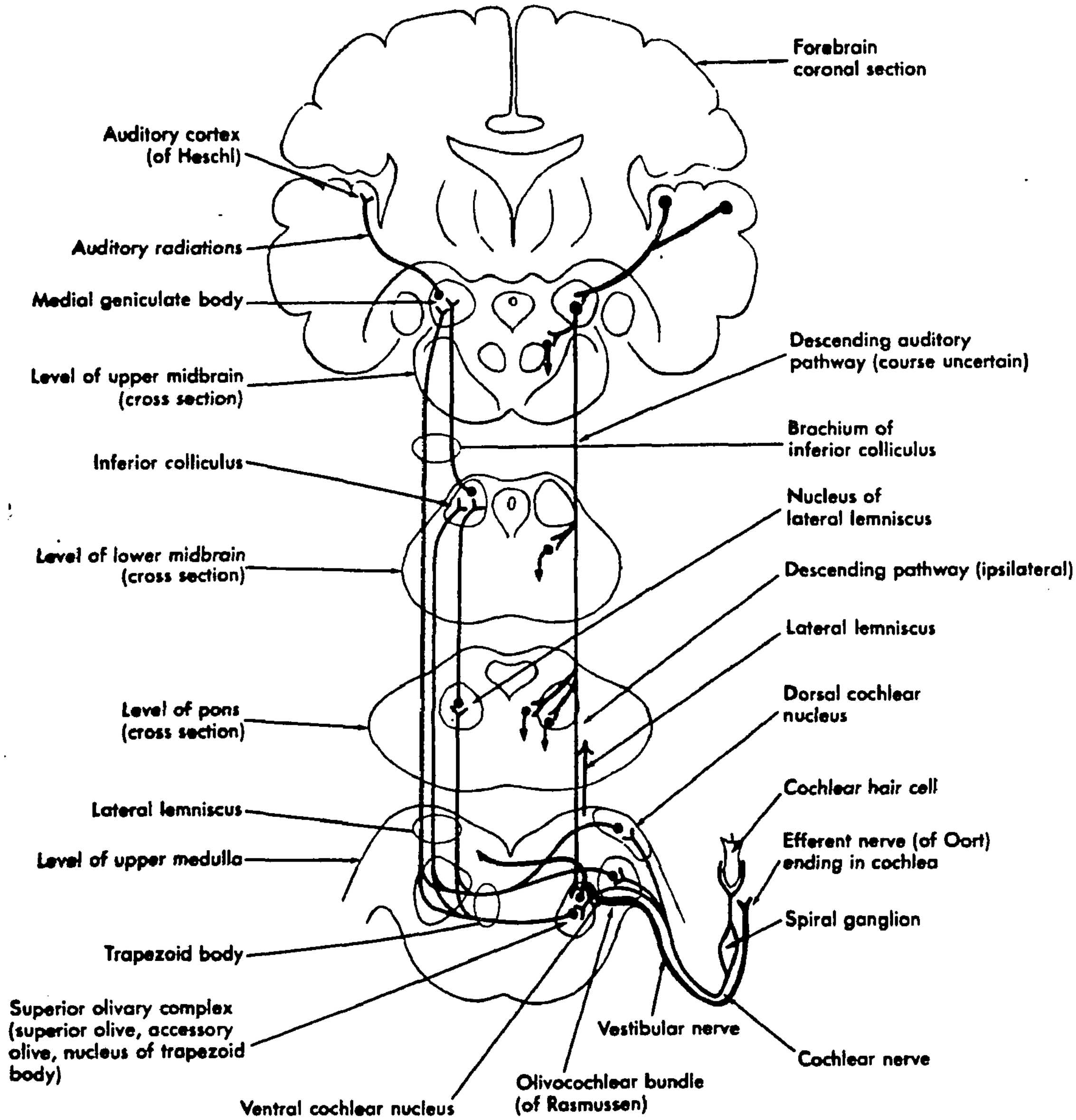
As previously mentioned, central auditory disturbance due to cortical pathology rarely demonstrates similar audiologic symptoms that are manifested by cochlear lesions. Brainstem and primary cerebellar lesions, however, may present audiologic findings of elevated pure tone thresholds and decreased speech discrimination abilities when undistorted words and sentences are used.

Overview of Anatomy of the Central Auditory System

The proposed study explores the effect of cochlear dysfunction on central auditory speech test performance. Since different tests are designed to challenge the various levels in the central auditory system, and since the specific tests will address cortical and brainstem integrity, a brief review of the relevant anatomy is in order (Figure 1.).

Auditory neurons first enter the central nervous system via the cochlear portion of the eighth cranial nerve at the level of the junction of the medulla and the pons. Upon entering the medulla, each acoustic fiber bifurcates and sends a branch to each of the two primary cochlear nuclei, the anterior and posterior ventral cochlear nuclei and the dorsal cochlear nucleus. Each first order neuron emits collaterals that synapse with second order neurons within the dorsal ventral cochlear nuclei. The majority of the second order neurons decussate via the trapezoid body to the ipsilateral and contralateral superior olives, with the contralateral receiving the greatest number of fibers. It is at the level of the superior olivary complex that stimuli from both ears are integrated for the first time into the central auditory nervous system.

FIGURE 1



Summary diagram of central auditory system with efferent system added on right.

(From, Minkler, J. (Ed.), Introduction to Neuroscience, Saint Louis: The C.V. Mosby Company, 1972.)

The ascending projection from the superior olivary complex is via the lateral lemniscus, which terminates in the central nucleus of the inferior colliculus at the midbrain level. Ascending fibers of the lateral lemniscus contain neurons of both the second and third order, with some fibers terminating in the external nucleus and others in the ventral and dorsal nuclei of the lateral lemniscus. At the commissure of Probst, which is the commissure of the lateral lemniscus, secondary decussation occurs.

The majority of axonal processes of the fibers traveling from the lower acoustic center synapse in the inferior colliculi. Most fibers from the inferior colliculus, fourth order neurons, project to the medial geniculate body via the brachium of the inferior colliculus. No ascending neurons by-pass the medial geniculate body; all terminate in the temporal lobe deep in the Sylvian fissure (Korsan-Bengtsen, 1973). The processing of information received from both ears begins in the primary auditory receptive cortex of each hemisphere. Activation of many interhemispheric association areas and transfer of information between each hemisphere via transverse commissural callosal pathways then occur for the final cortical processing of speech (Lynn and Gilroy, 1976).

Nature of the problem

There has been limited research reported concerning the effects of peripheral hearing loss occurring in the absence of central auditory pathology on tests specifically designed to diagnose central auditory impairment (Speaks, 1974). Similarly, there has been limited research reported concerning the effects of peripheral hearing loss in the presence of central auditory pathology on tests designed specifically for the evaluation and diagnosis of central auditory pathology. Despite the lack of such data, these tests are frequently performed on individuals with cochlear pathology suspected of having co-existent central pathology. Both definition of candidacy for central auditory testing in the presence of cochlear pathology and the interpretation of such test results appear arbitrary in that they are left to the discretion of the individual examiner. To date, systematic investigation of the use of a battery of central auditory speech tests with cochlear hearing impaired subjects has not been reported.

A test battery approach using low redundancy speech tests is necessary in order to assess the integrity of the central auditory nervous system at all levels. Carhart (1969) states seven possible kinds of disorders and the levels at which they occur.

1. Interference with initial ipsilateral transmission of the stimulus at the level of the eighth nerve and probably also the cochlear nuclei.

2. Breakdown in the recording processes at the cochlear nuclei.

3. Breakdown in the contralateral transmission of monaural signals from the cochlear nuclei to higher levels including the thalamocortical auditory radiations.

4. Breakdown in binaural cross-correlated functions in the low pontine regions of the trapezoid bodies and in the superior olivary complexes.

5. Dysfunction during the rostral transmission of binaurally integrated information anywhere from the superior olives through the medial genicultate bodies and auditory radiations. Levels would include the middle and upper pons, and the thalamocortical pathways.

6. Dysfunction in the initial sorting and recoding of monaural and binaural cross-correlated signals received at the auditory cortex.

7. Breakdown in interhemispheric functions due to lesions affecting the auditory cortex of one or both hemispheres or the transverse interhemispheric auditory pathways of the parietal lobes and corpus callosum.

Since clinical populations presenting symptoms suggesting central auditory pathology may have co-existing cochlear dysfunction, it is essential to know the effect of cochlear dysfunction upon central auditory speech test performance before such tests can be used for differential diagnosis.

The majority of central auditory speech tests have been standardized and validated, using populations with normal symmetrical hearing and normal undistorted speech discrimination abilities. Minimal data have been reported on how cochlear impaired individuals perform on the various central auditory speech tests. Existing data have not been related to the variables of audiogram configuration, symmetry between ears, degree of hearing loss, or undistorted speech discrimination abilities.

Purpose of the Study

The purpose of this study is to determine the effect of cochlear dysfunction on central auditory speech test performance, using a test battery approach. Potential information gained may enable us to establish more accurate criteria for candidacy for central auditory evaluation despite cochlear hearing impairment.

The study hopefully will yield information on the quantitative difference in central auditory speech test performance, if any, between cochlear impaired subjects and individuals with normal peripheral hearing. Differences in performance, if any, may be qualitative and/or predictable in a consistent manner thereby allowing the differential diagnosis between the cochlear and central auditory components. Test results may suggest adjustments in presentation method, level of presentation, or in scoring procedures of the central auditory test battery that will permit valid use with a cochlear impaired population.

The study will address itself to the following questions.

1. What is the effect of cochlear disorder upon performance on selected central auditory test procedures?

2. Which central auditory speech tests are maximally affected by concomitant cochlear disorder?

3. Which central auditory speech tests are minimally affected by concomitant cochlear disorder?

4. Is the level of performance on central auditory

tests related to the level of auditory site for which the tests were intended?

5. Which of the following audiologic variables are related to performance on central auditory tests?

a. degree of hearing loss.

b. symmetry between ears.

c. audiogram configuration.

d. undistorted speech discrimination abilities.

6. Which of the following test parameters affects the performance on central auditory speech tests?

a. presentation level.

b. type of test material.

c. scoring procedures.

CHAPTER II

REVIEW OF RELATED LITERATURE

The literature concerning central auditory speech tests may be classified into three major divisions: monotic tests, dichotic tests, and test batteries that include either monotic or dichotic, or both procedures. For discussion purposes each is reviewed separately.

Monotic Test Procedures

Monotic speech tests are those in which the speech stimulus is presented to each ear individually. Comparisons are made between scores for each ear as well as with the normative data established for specific tests.

Low-Pass Filtered Speech

Bocca, Calearo, and Cassinari (1954) presented a preliminary report concerning a new method of testing hearing in temporal lobe tumor cases. Complete articulation curves were obtained for each ear separately, using a series of 10 Italian disyllabic words with an 800Hz low-pass filter presented via monitored live voice. The temporal lobe tumor patient obtained reduced scores only for the ear contralateral to the lesion. Normal subjects had reduced filtered speech scores overall; however, scores were equivalent in both ears.

A follow-up to the preliminary report was presented by Bocca, Calearo, Cassinari, and Migliavacca (1955) on 18 subjects with unilateral temporal lobe lesions. Lists of

10 disyllabic words were presented using a 1000Hz low-pass filter. Normal maximum articulation scores ranged from 60%-80% with no significant difference between ears. Thirteen of the 18 temporal lobe tumor cases revealed decreased discrimination scores in the ear contralateral to the lesion despite normal pure tone thresholds and speech discrimination for undistorted material. Surgery revealed no involvement of the auditory cortex of the temporal lobe in the remaining 5 cases where filtered speech test results were negative.

Normative data for the low-pass filtered speech test were published by Bocca (1959) that included 70%-80% scores for normals for each ear with monotic presentation at 50dB sensation level. Temporal lobe tumor patients obtained average scores of 50% for the ear contralateral to the tumor and 65%-75% for the ipsilateral ear.

Jerger (1960) adapted Bocca's filtered speech test to the English phonetically balanced 50 word lists using a low-pass filter with a cut-off frequency of 500Hz and a rejection rate of 17dB per octave. Two subjects with temporal lobe disorders who demonstrated essentially normal hearing sensitivity and normal discrimination scores for undistorted speech material scored 30% poorer with filtered speech on the ear contralateral to the lesion.

Hodgson (1967) reported on a 17-year-old female with left hemispherectomy performed to alleviate seizures and destructive behavior. Audiologic results reported pre-operatively and post-operatively, at three weeks and three months, respectively, revealed unchanged routine pure tone and speech audiometry test performance. Low-pass filtered speech with a 500Hz cut-off and 17dB per octave rejection rate yielded reduced scores on the ear contralateral to the lesion.

Willeford (1968) reported on monaural low-pass filtered speech, using a 500Hz cut-off with a rejection rate of 19dB per octave and Michigan CNC word lists. Norms were established on 150 subjects between the ages of 10 and 60 years using a standard presentation level of 50dB above the 3 frequency pure tone average. Scores of between 74% and 100% were interpreted as normal.

Time-Compressed Speech

Time-compressed speech is a method for reducing the redundancy of speech in order to increase the difficulty of the task. The earliest method for compressing the speech was to speed up the playback of the speech sample that had been tape-recorded. This had the disadvantage of causing shifts in the frequency characteristics of the signals. In order to eliminate this problem, a chop/splice procedure was used that involved manually cutting a certain segment of the recording signal and then manually splicing the remaining segments together. This had the disadvantage of being quite tedious as well as time consuming.

Bocca (1963), by using sentences instead of words, was able to introduce time-distortion. Using special time-compression devices, the rate of speech could be increased from 140 words per minute (wpm), the normal rate of speech for Italian, to 350 wpm without altering the frequency spectrum.

Articulation curves for 140 wpm, 250 wpm, and 350 wpm were presented by Calearo and Lazzaroni (1957) for normal subjects. Bocca, Calearo, and Cassinari (1957) presented the same data for temporal lobe tumor cases and for older patients aged 70-85 years. Test material consisted of 10 sentences with 6 words each with definite meaning. Test results indicated that there was a shift in detectability for the temporal lobe cases at the rate of 350 wpm greater on the ear contralateral to the lesion. The elderly subjects demonstrated larger shifts bilaterally for 250 and 350 wpm rates than the temporal lobe cases. Speech discrimination scores were severely depressed for both groups. The scores reported for the temporal lobe group indicated depressed speech discrimination bilaterally, although greater on the ear contralateral to the lesion.

The authors concluded that decreased intelligibility scores may be indicative of either cortical lesions or of an increase in synaptic transmission time along the entire central auditory pathway. According to Bocca (1963), time-compressed speech was most useful in the diagnosis of diffuse cerebral pathology and/or lesions at the level of the second neuron.

Fairbanks (1964) developed an electromechanical time-compression/expansion device that enabled investigators to record a signal, then to automatically delete and retain samples of the signal. Retained samples were then electromechanically spliced together with a resultant product that could be compressed by a specific percentage rate.

Sticht and Gray (1969) used compressed CID W-22 word lists and presented them to normals and sensorineural hearing loss patients. They concluded that time-compressed speech as they presented it did not differentiate the two groups. Beasley and Freeman (1977) attributed Sticht's and Gray's findings to simplistic test material and limited compression rates.

Since that time, normative studies for determining the validity and reliability of time-compressed speech have been generated by Beasley and Maki (1976), Beasley, Schwimmer, and Rintelmann (1972), and Beasley, Forman, and Rintelmann (1972).

Beasley, Schwimmer, and Rintelmann (1972) used time-compressed Northwestern University #6 initial consonant, syllable nucleus, and final consonant (CNC) word lists with 9 sensorineural hearing loss adults. Although the articulation function ran parallel to that of normals, the mean discrimination scores at 30%, 40%, and 50% time-compression rates were approximately 20%-30% poorer than those obtained by normal hearing individuals.

Kurzdiel, Noffsinger, and Olsen (1976) presented data on 31 patients with cortical lesions-11 diffuse, unilateral temporal lobe lesions; 4 hemispherectomies; and 16 patients with discrete unilateral temporal lobe lesions. Only the diffuse lesion group revealed scores poorer in the ear contralateral to the lesion as compared to the ipsilateral ear.

Synthetic Sentence Identification Procedure

The Synthetic Sentence Identification Procedure (SSI) was first described by Speaks and Jerger (1965). They attempted to use materials of a length sufficient to degrade the message in various ways, and desired an identification task with a closed-message set of controlled size.

To avoid the problems involved in controlling the meaning of real sentences, Speaks and Jerger developed a series of synthetic sentences based on third word order approximations. These artificial sentences were constructed as approximations to real English sentences according to rules governing the probabilities of word sequences. Each list consists of 10 synthetic sentences, each seven words in length and containing nine syllables, plus or minus one syllable. Ten lists of different random presentations of the same 10 sentences are used. The patient is given a printed list of the 10 synthetic sentences to aid in identifying the appropriate sentence. To manipulate the relative difficulty of the task, a competing message of running speech is used. Performance is measured at several message-to-competition ratios (MCR) under contralateral and/or ipsilateral competing message conditions.

Jerger, Speaks, and Trammel (1968) reported on a clinical study using the SSI with 3 patients by adding an ipsilateral competing message at OdB, s/n ratio. These cases were discussed by Jerger in 1970. Results of the 3 patients one with a right pontine glioma, brainstem; one with a right temporal lobe lesions involving the primary auditory cortex; and one with a parietal area lesions without auditory involvement as a control were presented. On the ipsilateral competing message (ICM) test, the brainstem patient had decreased scores bilaterally, with the contralateral ear performing poorer than the ipsilateral ear. The temporal lobe case had decreased scores bilaterally with slightly poorer scores on the contralateral ear. The control subject performed within normal limits. The contralateral competing message (CCM), a dichotic listening task, yielded poor performance scores on the ear contralateral to the lesions for both the brainstem and the temporal lobe cases, with the control performing within normal limits.

Jerger and Jerger (1974) reported data for the SSI-ICM and the CCM on 11 patients with intra-axial (within the brainstem without eighth nerve involvement) brainstem lesions. The MCRs were varied in 10dB steps from +10dB to -20dB for the ICM condition and, for the CCM condition, in 20dB steps from 1dB to -40dB. Results were plotted as the averages of the MCRs. Normal performance was 100% for the CCMs and ranged from 20% to 100% on the ICMs. All 11 patients exhibited poor performance on the contralateral ear only. The average performance scores for the ICM was 37% for both the ipsilateral and contralateral ears, compared with 76% for normals. For the CCM, 8 of 11 performed normally at MCR -40, the other 3 had mildly abnormal scores. The ICM was interpreted as being a measure of brainstem dysfunction.

Jerger and Jerger (1975) used the SSI as one of several tests in an attempt to establish the clinical validity of the central auditory test battery. The pathological subjects included 10 intra-axial brainstem lesions and 10 temporal lobe lesion patients. On the ICM, the brainstem group had a 40% impairment on the contralateral ear only. The temporal lobe group had a 30% decrease on the ipsilateral ear and a 40% decrease on the contralateral ear for the ICM. The CCM results were within normal limits for the brainstem group, and the temporal lobe group had a 20% deficit on the ear contralateral to the lesion.

The SSI-ICM effectively distinguished brainstem lesions (Keith, 1977; Jerger, 1975). The SSI-CCM, although capable of aiding in diagnosing temporal lobe lesions, may not be as effective as other tests (Keith, 1977).

Miscellaneous Procedures

In addition to the test procedures cited, the Rush-Hughes recordings of the Harvard PB tests have been employed to evaluate central auditory nervous system disorders. The basis of this procedure is a comparison between test performance on the ipsilateral and contralateral ears for the Rush Hughes PB word lists recordings and the CID W-22 word lists; this yields a difference score (D/S) (Goldstein, Goodman, and King, 1965; Goetzinger and Rousey, 1959; Goetzinger and Angell, 1965). In general, normal hearing subjects between the ages of 11 and 74 years perform better on the CID W-22 test than on the Rush Hughes recording of the Harvard PB test. The D/S remains relatively constant at approximately 19%. A significant increase in the D/S in one ear is usually indicative of a lesion in the primary auditory area of the contralateral temporal lobe; however, a large D/S may also suggest an ipsilateral brainstem lesion.

Interrupted speech tasks have also been used for diagnosing central auditory lesions. Discrimination of interrupted speech depends upon the number of interruptions per second (ips) as well as the ratio between the duration of the on and off time of the speech. Bocca and Calearo (1963) used monaural periodically interrupted speech at a 2-20 ips rate, with a message-silence ratio of 0.5 to evaluate patients with temporal lobe disorders. Using PB words at a presentation level of 50dBSL at a rate of

10 ips, normals obtained speech discrimination scores of 80% while patients with temporal lobe tumors scored between 48%-56% correct on the ear contralateral to the lesion. Calearo and Antonelli (1963), Antonelli (1970), Teatini (1970), and Korsan-Bengtsen (1973) used interrupted speech to diagnose patients with unilateral temporal lobe lesions as well as brainstem lesions; the common conclusion was that scores were markedly poor for the ear contralateral to the temporal lobe lesion.

Dichotic Speech Procedures

Dichotic tests are those in which both ears are stimulated simultaneously, but each ear receives either a different stimulus or different segments of the same message (Berlin, 1972).

Broadbent (1954) studied short-term memory in normal hearing Naval recruits. He presented sets of digits simultaneously and noted that subjects responded to the right ear set prior to responding to the left ear set. In addition, they scored better in the right ear as compared to the left ear. He interpreted this as an effect of the short-term memory system.

Kimura (1961) applied Broadbent's procedure to normal hearing subjects. She presented a dichotic digits task in which a series of different digits was presented in pairs to the normal hearing subjects. She observed that the individuals scored better on stimuli presented to the right ear as compared to the left ear. She interpreted this "right-ear advantage" as reflecting not only the dominance of the left hemisphere of the brain for language and speech functions but also the relative strength of the crossed, ascending auditory pathways as compared to the uncrossed pathways. This hypothesis has been substantiated by numerous studies, including those of Katz (1962, 1968), Sparks and Geschwind (1968), Darwin (1969), and Studdert-Kennedy and Shankweiler (1970).

Kimura further observed that patients with temporal lobe lesions had difficulty attending and responding to the dichotic stimuli and demonstrated a right-ear advantage. Unilateral temporal lobectomy patients had difficulty repeating digits in the ear contralateral to the lesion. The total number of digits correctly repeated was affected by left temporal lobectomy but not right temporal lobectomy.

Calearo and Antonelli (1963), however, found no laterality effect when they used monaurally interrupted and sitorted speech. Kimura's procedure was a biaural task. She argued that the laterality effect may be revealed only through a binaural competing message, such as she had used.

Binaural Fusion Tasks

Matzker (1959) developed a dichotic integration task involving two-ear, frequency, fusions, in which a PB list of 41 bisyllabic German words were used. A different frequency portion of each test word was presented simultaneously to the two ears, with one ear receiving an 1815-2500 Hz band-pass filtered signal and the other, the identical test word via a 500-800 Hz filter. The same words were then presented again, with each ear receiving both band-pass filters simultaneously. The first procedure was then repeated in which each ear received a different frequency segment.

Matzker's data demonstrated that normals did well in all three conditions, with discrimination improving on successive trials. Individuals with brainstem pathology scored poorly on the initial presentation, showed improvement on the second, but remained at about the same level for the third trial. In 32 of 38 cases with intra-cranial expanding lesions, there was reduced ability to resynthesize.

Liden (1964), using Swedish spondees, developed a binaural resynthesis test according to Matzker's criteria, using a low-pass band filter of 560-715 Hz and a high-pass band filter of 1800-2200Hz. Subjects were 5 patients with damage in the temporal lobe and 13 patients with expanding lesions outside the temporal lobe. He obtained monotic discrimination scores for each band alone and then presented them dichotically. In no case of expanding intra-cranial lesions was the ability to resynthesize speech disturbed. His findings did not corroborate Matzker's, and he concluded that his Swedish adaptation of the binaural resynthesis test was not sensitive in identifying central auditory nervous system disorders.

Hayashi, Ohta, and Morimoto (1966), criticizing Matzker's test because of the single presentation level and the scoring method, used Japanese nonsense syllables with frequency bands of 500-800Hz and 1500-2400Hz. The high-frequency band was delivered at 30dBSL re the threshold for 1500Hz and the low-frequency band at 40dBSL re the threshold for 500Hz. In the second version of the test, both bands were delivered at 30dBSL re pure tone average. They repeated the first version and compared these results to the better score of either band-pass alone. In central cases, when the high-pass band was presented to the ear contralateral to the lesion, poor binaural function resulted. They interpreted pure binaural fusion as indicative of cortical lesions as well as brainstem lesions. Acoustic trauma cases and Meniere's cases with cochlear impairment showed normal patterns. The authors concluded that the test could be used in patients with peripheral hearing losses.

Jerger (1960) developed a test combining faint and filtered speech. Low-pass filtered speech with a cut-off frequency of 500Hz was presented at 40dBSL to one ear while the other ear received the same material as 5dBSL, without being filtered. Normals were able to synthesize the two signals and understand the speech. Individuals with temporal lobe pathology could not synthesize the signals and therefore, scored no better on biaural presentation than each ear scored monaurally.

One of the major objections to this test was the relatively low sensation level at which stimuli were presented. A minor difference in threshold measurement could significantly affect the score obtained. In addition, no normative data were provided, leaving the difference between the score for each ear as the only basis for interpreting the results.

Smith and Resnick (1969) developed a binaural fusion test using English phonetically balanced word lists. The low-pass filter was set at 360-890Hz and the high-pass filter at 1750-2200Hz. Presentation level of the low-pass filter was at 30dBSL and that of the high-pass filter at 10dBSL re the level of the low-frequency band. They presented the test dichotically with the low-frequency band to the right ear and the high-frequency band to the left ear; they then repeated the test in which they reversed the ears that were to receive the low and high-pass signals. In the third step, they presented both bands to both ears.

The test was presented to 30 normals-16 with bilateral sensorineural hearing loss, 3 with temporal lobe lesion, and 4 with brainstem lesion. The test was scored as negative if the diotic scores were superior to the dichotic scores. Only the 4 subjects with brainstem pathology obtained positive scores with diotic superiority ranging from 18%-34%.

Ivey (1969) constructed a dichotic binaural fusion test. The low-band pass filter was 500-700Hz and the high-band pass filter was set at 1900-2100Hz, with slopes of 36dB per octave. Preliminary norms for 20 adult ears yielded a mean score of 89% with a range of 75%-100%. Presentation levels were 30dB above the pure tone threshold at 500Hz for the low-pass filter and 30dB above the 2000Hz threshold for the high-pass filter. If scores appear to be unusually low, the test is repeated at successively higher sensation levels.

Lynn and Gilroy (1974, 1976) used the Ivey version of the binaural fusion test on more than 300 patients with confirmed cortical lesions, brainstem lesions, and other cranial lesions. They found the test sensitive for detecting brainstem pathology, whether primary or due to secondary compression from cerebral hemisphere tumor masses.

Palva and Jokinen (1975) reported results on over 2,000 patients tested with a binaural resynthesis procedure using a low-band pass filter of 480-720Hz and a high-pass filter of 1800-2400Hz. Diotic presentation of either band alone yielded a score of 15%-20%, whereas simultaneous presentation yielded a score of 80%. Scores were obtained for three conditions: right ear receiving both band-pass filters simultaneously; left ear receiving the same two bands; and dichotic presentation of the filtered bands.

Peripheral hearing losses frequently revealed binaural discrimination scores no better than the level of the poorer ear. Auditory cortical lesions yielded decreased scores in the ear contralateral to the lesion on the monotic test in combination with good dichotic scores. Brainstem cases yielded poor dichotic scores with either contralateral or ipsilateral depressed monotic scores.

Alternating Speech Task

The rapid alternating speech test (RASP) was developed by Lynn in 1973. It was based on the principle described by Bocca and Calearo (1963), who credited the original concept and methodology to Cherry and Taylor (1954) and Hennebert (1955).

Bocca and Calearo presented short, simple, meaningful sentences in which the message was oscillated between each ear for equal periods of time, enabling each ear to receive half the message. The period of oscillation was varied between 2 and 40 alternations per second (aps). Normal subjects scored 100% discrimination at the maximum aps rate. According to Bocca and Calearo, inability to perform this task is evidence of brainstem pathology and, perhaps, diffuse cerebral pathology. Temporal lobe pathology with auditory cortex involvement always demonstrated normal performance for this task.

Lynn's rapid alternating speech test is a series of 10 sentences, each of which alternates rapidly between the ears for equal periods of time. The RASP assessed binaural integrative functions believed to be mediated in the pons, especially the caudal region (Lynn and Gilroy, 1977).

Lynn and Gilroy obtained normative data for three different rates of alternation using 18 subjects for each rate-200 msec., 300 msec., and 400 msec. Monaural scores did not exceed an average of 11.7% for the three conditions. Normal scores for the binaural alternating condition yielded average scores of 95%-100% at all three rates. They selected the 300 msec. condition for all clinical studies.

Pathological cases, including 32 unilateral cerebral lesions, nine upper brainstem lesions, two eighth nerve lesions, and six lesions of the pons, indicated mean scores of 80% or better for all pathologicals except for lesions of the pons, which had a mean RASP score of 40%, significant at the 1% level.

Willeford (1977) presented the alternating stimuli at 300 msec. at a 30dBSL re pure tone average. Stimulus items are sentences similar to Lynn and Gilroy's. Alternating speech norms for 20 adults yielded mean scores of 99% with a range of 90%-100% with norms from 80%-100%.

<u>Competing Message Tasks Involving Binaural Separation</u>

In 1962 Jack Katz first reported on the Staggered Spondaic Word Test (SSW) as an instrument designed to diagnose central auditory impairments. In developing the SSW, Katz attempted to devise a test that would be both sensitive to auditory pathology and free of contamination in the event of peripheral hearing loss. This test employed

English spondaic words in a dichotic listening task. Two spondees are presented, one to each ear. The second part of the word in the first ear overlaps in time the first part of the word in the second opposite ear. This creates two listening conditions for each ear: non-competing (no word in the opposite ear) and competing (simultaneous word in the opposite ear).

By choosing spondaic words, Katz felt that results from peripheral hearing loss would be lower since spondees as compared to monosyllabic words are maximally intelligible over a wide range of intensities. Since spondaic words are relatively familiar, they could be used with a wide range of subjects regardless of their age, intelligence, and educational background. The fact that spondees are stable--insofar as a relationship exists between both the speech reception threshold and the pure tone average with respect to the speech frequencies--provides a high degree of test re-test reliability (Katz, 1972).

Katz first worked with different test lists ranging from 20-80 items. Eventually he selected a 40-item list (EC) consisting of 160 monosyllabic words or portions of words. One must note that this study was reported on the basis of three "suspected" central auditory lesions, one normal, and two cases of sensorineural hearing loss.

Normative SSW studies were conducted by Katz, Basil, and Smith (1963), Katz and Fishman (1964), Burgess (1964), Goldman and Katz (1965), Katz and Myrinck (1965), and Brunt (1969). In no case has any normal between the ages of 14 and 65 years had a corrected score greater than 5%.

Berlin, Chase, Kill, and Hagepanos (1965) included the SSW test in a battery of central auditory tests administered to 20 temporal lobectomy patients, ten normals, and three patients with lesions outside the temporal lobe. The SSW was found to be consistent in demonstrating the effects of temporal lobe excisions; scores were lower only in the ear contralateral to the pathology.

Katz (1968) administered the SSW to ten normals; 17 centrally impaired, including seven with lesions of the auditory cortex and ten with cortical lesions sparing the middle and posterior temporal gyrus; 23 peripheral hearing impaired, including 14 sensorineurals and nine conductives. The study was validated by establishing "blinded conditions" for the neurologist, the otologist, and the audiologist. The conclusions of the study were that the SSW was capable of differentiating between normals and the central auditory impaired as well as between the peripherally hearing impaired. In addition, central auditory dysfunction presented itself differently from non-auditory lesions.

Criteria for differential diagnosis and score interpretations were established (Katz, 1974) that included the following: (1) normal-poorest corrected SSW score on any condition not to exceed 15%; (2) central auditory impaired--a corrected SSW score greater than 25%; (3) abnormal listener or central non-auditory lesion, 16%-25% on any corrected SSW subtest. Individual ear performance was generally a more accurate indicator of central auditory functioning than either SSW condition or total score. Defective performance in one ear suggested that the dysfunction was in the contralateral hemisphere.

Lynn and Gilroy (1972) modified the SSW test presentation and scoring method. A total of 40 items was presented. The percentage of words repeated correctly for the first and third sequences of the right and left ears is the alternate binaural score; the percentage of words repeated correctly during the second sequence for each ear is the simultaneous binaural speech discrimination score. Lynn and Gilroy, unlike Katz, did not correct for speech discrimination losses nor did they calculate response biases. They did not specify norms for normals and various pathologicals. However, normals were reported as obtaining mean scores of 98.9% for the right ear and 98.7% for the left ear for the alternate binaural test. For the simultaneous binaural condition, mean scores of 97.4% and of 96.4% were obtained on the right and left ears, respectively. Results for five patients with posterior temporal lobe tumors ranged from 30%-70% poorer on the contralateral ear than the ipsilateral ear for the alternate binaural condition. In the simultaneous binaural condition, contralateral ear scores were 55%-98% poorer than the ipsilateral ear scores.

Temporal lobe tumors involving the anterior and/or inferior areas revealed inconsistent patterns ranging from no ear differences for either simultaneous or alternate binaural conditions to 10%-45% poorer scores on the contralateral ear, compared with those for the ipsilateral, for both conditions.

Fourteen glioma patients, half with posterior temporal lobe involvement and half with parietal lobe involvement were evaluated by Lynn, Benitez, Gilroy, and Wilner (1972) using the Lynn and Gilroy version of the SSW. Six of the seven temporal lobe tumor cases scored abnormally on the alternate binaural and simultaneous binaural conditions on the ear contralateral to the lesion; two of the seven temporal lobe tumor cases scored normally; and of the remaining five, further investigation revealed secondary involvement of the temporal lobe and/or corpus callosum.

Katz (1977) stated that since 1962 more than 10,000 individuals, both normals and pathologicals, have been evaluated with the SSW test using his version and scoring methods. According to Katz, the SSW is capable of differentiating auditory reception area lesions from non-auditory lesions. Various response biases, including ear effects, reversals, and order effects, suggest location of dysfunction within the hemisphere, but cannot identify which hemisphere is involved.

Ear effect is the difference in errors made on spondee items beginning in one ear compared with items beginning in the opposite ear. A difference of five or more errors is considered significant. In 47 cases of brain lesions, Katz (1978) reported 36% with significant ear effects--13% right and 23% left ear effects. Left ear effects indicated fronto-temporal parietal disorders; right ear effects indicated posterior tempero-parietal involvement.

Brunt (1978) discusses reversals; this occurs when the items are repeated in a different order from the way in which they are presented. Reversals provide qualitative information on lesions in the cortex but outside the primary auditory reception area, according to Katz.

Katz and Pack (1975) studied 30 patients--16 tumors, nine vascular disease, three damage from trauma, and two damage from surgery. Based on the neurologist's data from autopsy, surgical reports, radiography, or neurologic evaluation, each of the 30 lesions was well-defined, confined, and localized to one hemisphere. In order to establish precise location of the lesions, a grid pattern formed of 1 centimeter squares was placed between the sections of the brain and the grid patterns and then compared to the neurologist's findings with respect to depth and extent of the cerebral lesions.

Thirteen cases had lesions in the primary auditory reception area. The remaining 17 had lesions outside this area and were termed non-auditory reception lesions. All cases involving the auditory reception area had been diagnosed correctly both as to site of lesion and involved hemisphere. Mean corrected SSW ear error for the ear contralateral to the lesion was 53% with a range of 34%-77% error. Ear scores for non-auditory reception patients were either within normal limits or mildly abnormal Reversals were examined for the non-auditory reception lesions. The authors' results concluded that reversals suggest damage to the motor and sensory strips along the fissure of Rolando and, to some degree, in the anterior temporal lobe.

In summary, the SSW test is most useful for diagnosing central auditory problems in the primary auditory reception area. Normal or mildly abnormal scores occur with lesions outside the primary auditory area, except where the corpus callosum is involved. Reversals suggest central nervous system problems affecting the sensory and motor strip area around either the fissure of Rolando or the auditory temporal lobes.

Competing Sentence Task

Willeford (1968) developed a competing sentence task for the purpose of evaluating central auditory function. The test is comprised of a series of sentences presented dichotically. The content of these pairs of sentences is related in theme; for example, time and weather. The principle of this test is based on earlier tests developed by Jerger in 1964.

Ivey (1969) standardized the tests on 20 normal hearing subjects ranging in age from 19-33 years. Using 25 pairs of sentences, Ivey concluded that the two lists of sentences were equivalent in difficulty and that there were no significant score differences between ears. For a total of 1,000 sentences in List A, 991 were correctly repeated and, in List B, 983 were repeated correctly.

Lynn and Gilroy (1977) noted that 20 normal subjects achieved 100% discrimination scores for the primary message while receiving the competition at a -15dB ratio. No significant ear effect or bilateral asymmetry was noted. Of 22 temporal lobe tumor cases, 11 right and 11 left, all obtained reduced scores on the ear contralateral to the lesion, with a mean of 65% for the right temporal lobe tumors and one of 45% for the left temporal lobe tumors. Twenty-four deep parietal lobe tumor cases with corpus callosum involvement yielded mean scores of approximately 55% for the 14 eight-sided tumors and a mean of 60% for the left-sided tumors. Performance on the ear ipsilateral to the language dominant hemisphere was poorer than the contralateral ear regardless of which hemisphere was involved.

In summary, competing sentences are especially valuable in the evaluation of cortical and interhemispheric auditory functions with dramatic contralateral ear effects for temporal lobe lesions in the posterior region.

Test Battery Approach

Calearo and Antonelli (1963) reported on cortical hearing tests and cerebral dominance. Subjects consisted of 12 normals and 32 with unilateral temporal lobe lesions, either spontaneous or due to temporal lobe epilepsy that had required surgical removal. Interrupted as well as filtered speech tests were used. Normals did not demonstrate significant difference between right and left ear curves for either interrupted or filtered speech. The temporal lobe cases demonstrated 15%-25% loss on the ear contralateral to the lesion for filtered speech regardless of the hemisphere involved. The authors concluded that unilateral temporal lobe lesion performance is not influenced by the hemispheric location of the cerebral lesion.

Jerger (1964) evaluated 24 patients with unilateral temporal lobe lesions using undistorted faint speech, undistorted loud speech, low-pass filtered speech, two separate competing message tests, and the speech with alternating masking index test. Results obtained for the unilateral temporal lobe lesions indicated poorer scores on the ear contralateral to the lesion compared with scores for the ipsilateral ear for all the tests used. Low-pass filtered speech scores, in particular, were 20% poorer on the contralateral ear in comparison to the ipsilateral ear.

Berlin (1965) used Jerger's test battery and added the Staggered Spondaic Word Test (Katz, 1962), the Seashore Test of Musical Abilities, and simultaneous phonetically balanced words. A series of 37 patients with temporal lobectomies, 20 right and 17 left, were studied. All tests except the Seashore Test showed significantly poorer scores on the ear contralateral to the lesion regardless of the side involved.

Calearo and Antonelli (1968) reported on audiologic findings in 24 cases with brainstem lesions. Of these, eight had tumors, five multiple sclerosis, five vascular lesions, and one diffuse neurosyphylis. Sensitized speech material consisted of 10 meaningful, five-word sentences that were time-compressed from 150 wpm to 350 wpm without altering the frequency spectrum; low-pass filtered speech with a 500Hz cut-off; and a swinging speech test, which had periods of oscillation varying between 1 and 40 aps. Maximum discrimination at comfortable hearing levels was reported to be 80% for time-compressed and distorted speech and 100% for swinging speech.

The authors stated that the use of sentences for the evaluation of central auditory functioning is possible despite tone deficits which occur frequently in brainstem lesions. In 19 or 24 brainstem cases, sensitized speech test results were positive. Unlike cortical lesions, which demonstrated mild or no hearing impairment as well as unilateral deficits on the ear contralateral to the lesions, brainstem pathology demonstrated greater losses on the sensitized speech tests, frequent bilateral involvement and lack of correspondence between lesions and the affected ear.

In a separate study on cortical deafness, Antonelli, and Calearo (1968) reported on 11 subjects given sensitized speech tests that included interrupted, low-pass filtered, and swinging speech. Test scores were reduced after surgery whether or not Heschl's gyrus had been involved. Possible explanations for the reduced discrimination for filtered speech included preoperative involvement of Heschl's gyrus that had not been detected, damage to Heschl's gyrus from surgery in adjacent areas, or a secondary cortical auditory area removed during surgery.

Lynn et al (1972) reported on 14 patients with gliomas in the posterior regions of the temporal and parietal lobes of the brain. The central auditory test battery presented included the monaural low-pass filtered speech test, NU #6 word lists, dichotic speech tests, including binaural fusion, the rapid alternating speech test, competing sentence test, and the SSW test modified and classified as alternate binaural and simultaneous binaural speech discrimination scores.

Seven patients with glioma of the posterior portion of the temporal lobe presented pure tone audiometry and undistorted speech discrimination scores within normal limits. Of the seven cases, six yielded abnormal scores in the ear contralateral to the lesion for monaural low-pass filtered speech, competing sentences, and alternate and simultaneous binaural tests. Binaural fusion (re-synthesis) and rapid alternating speech test scores were within normal limits unless there was secondary brainstem involvement. In the seven patients with gliomas in the parietal lobe, audiometric findings varied with the location, size, and extent of the tumor.

In 30 other cases with deep parietal lobe lesions involving the corpus callosum, abnormal scores with simultaneous binaural and competing sentence tests in the left or ipsilateral ear were obtained. Abnormal findings may occur from secondary involvement of the temporal lobe due to pressure and edema, although to a lesser degree than with primary temporal lobe lesions.

Lynn and Gilroy (1974, 1976) reported on the effects of brain lesions on the perception of monotic and dichotic speech tests in a series of more than 300 patients. The test battery was the same as the one just described. To summarize the results, unilateral temporal lobe lesions usually demonstrated abnormal test performance in the ear contralateral to the lesion on monotic and dichotic speech tests. When deep lesions affected the corpus callosum, however, the right ear performance was usually superior to the left ear regardless of hemisphere involved. Deep lesions impair scores on the ear ipsilateral to the language dominant hemisphere. Involvement of the brainstem due to pressure revealed abnormal binaural fusion abilities. Parietal lobe tumor cases usually performed normally on the monaural distorted speech tests, in which scores were bilaterally symmetrical. If the auditory region of the temporal lobe or brainstem was involved, monotic scores were either abnormal in the ear contralateral to the lesions or were depressed bilaterally. Parietal lobe lesions resulted in reduced scores for dichotic speech tests in the left ear, despite involvement of either hemisphere when the transverse interhemispheric auditory pathways were involved in the region of the corpus callosum. Test scores seemed to be affected most with lesions located in the posterior portion of the brain rather than due to involvement in the anterior or inferior region.

Distorted Speech Test Battery Approach

Korsan-Bengtsen (1970) presented preliminary data on a new distorted speech test battery, in Swedish, consisting of interrupted speech, frequency distorted speech, time-compressed speech, and a competing sentence test. In 1973 she presented an extensive study on distorted speech audiometry based on the preliminary work. The central test battery consisted of 500 Swedish sentences varying in length from 4-8 words, none of which were difficult or uncommon. Twenty lists of 25 sentences each were formed. The specific tests included interrupted speech at varying interruption rates (ips) of 10, 7, and 4 ips; frequency distorted speech fed into three band pass filters, each one-third octave wide and having respective center frequencies of 500Hz, 640Hz, and 800Hz; time-compressed speech at two different rates, 220 wpm and 290 wpm; and a competing sentence test.

These tests were standardized on 195 normal hearing subjects ranging in age from 17 to 60 years. This battery was presented to three groups of patients with peripheral hearing loss. Group I consisted of 11 subjects with 14 ears having pure conductive hearing loss; Group II, eight subjects having 15 ears with moderate sensorineural hearing loss, congenital etiology; Group III, ten subjects having ten ears with acquired sensorineural hearing loss. Individuals with conductive peripheral hearing loss scored almost as well as normals on the central auditory speech test battery. The congenital sensorineural hearing loss patients did very well, scoring similarly to the normals on the tests. The acquired sensorineural hearing loss group scored lower on all four subtests.

Thirty-three patients with intra-cranial lesions were then evaluated with the test battery. Twenty-six had temporal lobe lesions, three had tumors in other parts of the hemisphere, four had brainstem tumors. Of the temporal lobe tumors, 11 had unilateral lesions involving the auditory cortex. There was a large difference between ears, with the ear contralateral to the lesion performing more poorly than the ipsilateral ear. The most striking differences were in the interrupted speech at 10 ips, with a mean difference of nearly 65% at 50dBSL: a 50% mean difference at 50dBSL for time-compressed speech at a rate of 290 wpm; and a 32% difference at 50dBSL with frequency distorted speech.

The nine temporal lobe lesions not affecting the auditory cortex showed only small differences in performance between the ipsilateral and contralateral ears at 35dBSL. The six patients with temporal lobe lesions close to the auditory cortex demonstrated a difference between contralateral and ipsilateral ears on the interrupted speech and time-compressed speech. The group with intra-cranial lesions in other parts of the hemisphere revealed normal test findings for the distorted tests. The brainstem lesions, mainly right-sided, revealed reduced scores on the ipsilateral ear for all four distorted speech tests. This was interpreted as indicating damage to the cochlear nuclei on the same side.

Based on these test results, Korsan-Bengtsen concluded that the most sensitive tests for revealing central hearing losses are interrupted speech at 10 ips and time-compressed speech at 290 wpm. These findings are contradictory to those of Bocca and his group, who found that the frequency distorted speech tests proved to be the most sensitive indicator of auditory cortex pathology. These disparate conclusions, however, could be a reflection of any one--or combination--of the following factors:

(a) the inherent differences between languages; (b) differences in the composition of the two subject groups; (c) the procedure employed for distorting the speech stimuli; (d) the type of sentence materials that was employed; and (e) the differences in auditory lesion.

Central Auditory Procedures with Peripheral Hearing Impaired

Roeser, Johns, and Price (1976) explored dichotic listening in 36 subjects with varying degrees of bilateral symmetrical sensorineural hearing loss. An equal number of subjects with normal hearing was used as controls. Two dichotic tests were used: a digit test designed according to Kimura's procedure (1961) and consonant/vowel (CV) nonsense syllables obtained from the Kresge Research Laboratories.

The experimental group had a mean age of 41.4 years, within a range of 20.4-55.7 years. The subjects were grouped according to their speech reception thresholds (SRT) in the poorer ear, although no attempt was made to control audiogram configuration. Twelve subjects had both SRT's falling within the mild range, 20-34 dBHL; 12 subjects had at least one SRT in the moderate range, 35-49dBHL; and 12 subjects had at least one SRT in the moderate-to-severe range, 50-70dBHL. Speech discrimination for undistorted CID W-22 words in the mild group was 81.6 ± 13.9% right, 81.3 ± 14.7% left; moderate 64.8 ± 18.8% right, 63.$ ± 19.1% left; moderate-to-severe 57.7

$\pm$ 20.5% right, and 56.4 $\pm$ 19.0% left.

On the dichotic digit test, normal hearing subjects averaged 86% correct, compared with 62% correct for the hearing loss subjects. On the dichotic consonant-vowel (CV) nonsense syllables, normals averaged 52%, as against 34% for the hearing loss subjects. The mean number of correct stimuli decreased significantly using dichotic digits and nonsense CV syllables for the hearing impaired subjects. As a group, the sensorineural hearing loss subjects showed no difference between ears in the dichotic digits test. A small right ear advantage was observed for the CV nonsense syllables, but the finding was not statistically significant. Ear laterality did not vary with the degree of hearing loss. The decreased scores for the digits and nonsense syllable tests were related directly to the monaural speech scores; the greater the degree of hearing loss, the poorer the score.

The authors concluded that hemispheric representation of speech and language processing as determined by dichotic listening tests was affected by sensorineural hearing loss.

Winkelaar and Lewis (1977) discussed the use of a central auditory test battery comprising the competing sentence test, rapid alternating speech, and the SSW on three patients with known central auditory pathology. Three case reports were given however, for patients No. 1 and 2, only the SSW test results were reported.

Patient No. 1 had a moderate sensorineural hearing loss at 2000-8000Hz in the right ear and a mild/moderate sensorineural hearing loss at 2000-8000Hz in the left ear, with an 88% PB score bilaterally. On the SSW, the right competing condition yielded a greater than 70% error score, which was interpreted as left temporal lobe pathology with involvement of the primary auditory center. Right ear response bias suggested a diffuse lesion involving the anterior portion of the temporal lobe. Neurological evaluation identified the lesion in the area of Heschl's gyrus as well as in the inferior and anterior areas of the temporal lobe of the left hemisphere.

Patient No. 2 had normal pure tone and speech audiometry results; central auditory test results, as well as neurological diagnosis, were similar to those of patient No. 1.

Patient No. 3 had a bilateral sensorineural hearing loss, with mild to profound sloping beginning at 500Hz. The right SRT was 35dB with a PB score of 50% while the left SRT was 30dB with a PB score of 76%. The SSW revealed right competing ear condition having a 30% error. The competing sentence test score was 70% for the right and 60% for the left ear. The RASP score was 50%. Data on presentation levels of all three tests were not included. Neurologic diagnosis based on arteriogram and pneumoecephalogram, EEG, and skull X-rags suggested a tumor deep in the left thalamic region.

The authors concluded that the effects of the peripheral lesion on both the competing sentence and rapid alternating speech test results must be considered, but did not elaborate.

Central auditory testing with 70 sensorineural hearing loss subjects was stuided by Miltenberger, Dawson, and Raica (1978). The age of the individuals ranged from 13-65 years. All had received otologic evaluation. The severity of the hearing losses and slopes were nòt described. Each subject received a standard audiologic assessment including impedance audiometry. The central test battery consisted of the competing sentence test, monaural low-pass filtered speech, binaural fusion test, a rapid alternating speech test. Of the 70 tested, 16 scored within normal limits on the complete test battery. However, upon examination of both the range and mean scores of the hearing thresholds, hearing was well within normal limits at 250-2000Hz; 3000Hz thresholds were not included, but results at 4000Hz ranged from 10-80dB with a mean of 40dB in the left ear and from 20-70dB with a mean of 35dB in the right ear; 8000Hz ranged from 0-70dB with a mean of 45dB for both the left and right ears. Twelve subjects failed the competing sentence test. Unfortunately, the scores obtained by these subjects were not included, nor were data on the degree of hearing loss, audiogram configuration, or PB max. Seventeen subjects failed the binaural fusion test, with 10 of these 17 failing in only one ear; six of the failures were attributed to the losses at 500Hz or 2000Hz, which were the only two frequencies that the presentation levels were based on. On the rapid alternating speech test, 15 subjects failed, but only when they had also failed one or more of the other subtests. Of the 54 subjects who failed the test battery, 43 failed the low-pass filtered speech test in at least one ear.

This study was the first of its kind in attempting to present data for a central auditory speech test battery on individuals with sensorineural hearing loss. Its value is limited, however, inasmuch as the authors did not give more complete information as to the etiology of the losses, degree of hearing loss, audiogram configuration, and specific criteria for inclusion in the study. The presentation levels for each test and the scores obtained for each individual subtest were also not included.

Miltenberger, Caruso, Correia, Love, and Winkelmann (1979) reported on the use of a central auditory processing battery with six professional divers presenting peripheral auditory, vestibular, or central symptoms that occurred following decompression. As described by Willeford, the test battery included the competing sentence, binaural fusion, rapid alternating speech, and monaural low-pass filtered speech tests. Norms used were based on scores obtained using the test battery on 20 adult subjects.

Complete audiograms were presented on the six subjects.

Five had pure tone thresholds within normal limits at 250-2000Hz; of these four had mild to moderate sensorineural hearing losses at 4000-8000Hz and the remaining one a mild/severe sensorineural hearing loss in one ear and normal hearing in the other. All three cases with central decompression sickness scored poorly on various combinations of tests. It is interesting to note that the scores were not borderline abnormal but extremely depressed, thus leaving no doubt that this performance was not due to the peripheral component.

The three peripheral decompression cases consisted of one with normal hearing at 250-8000Hz bilaterally; one with moderate sensorineural hearing loss at 4000-8000Hz bilaterally; and one with normal hearing in the left ear and a mild low frequency sensorineural hearing loss in the right. Two of these cases scored normally on the complete central auditory test battery. The third case scored normally on all tests except the right competing sentence and right filtered speech, which were both mildly abnormal.

The results of this study suggest that this central battery can be used to confirm or rule out central auditory system disorders in a population with peripheral hearing loss.

<u>Summary</u>

Based on reported literature the following generalizations can be made:

1. The clinical reliability and validity of auditory speech tests for the evaluation of central auditory nervous system disorders has been well-established for a population between the ages of 18 and 60 years, with bilateral, symmetrical, hearing sensitivity and speech discrimination performance within normal limits.

2. A test battery approach is generally recommended for the evaluation of the central auditory system in an attempt to challenge its integrity at all levels.

3. Monotic and dichotic low-redundancy speech tests generally reveal different patterns for temporal lobe and brainstem pathology.

   a. Unilateral temporal lobe lesions score abnormally on the ear contralateral to the lesion.

   b. Research has demonstrated that dichotic tests are more effective for diagnosing lesions in the posterior portion of the temporal lobe than in areas of the anterior or inferior region of the temporal lobe.

   c. Cortical lesions with involvement of the interhemispheric auditory pathways in the region of the corpus callosum generally yield decreased scores on the left ear regardless of which hemisphere has been damaged since the left ear signal must first travel the contralateral route to the right temporal lobe for preliminary auditory analysis, and then travel via interhemispheric auditory pathways to the left temporal lobe where linguistic analysis takes place. Scores are depressed due to the additional neural relay in reaching the left hemisphere as well as to the loss of information as it crosses the involved interhemispheric pathways.

d. If deep parietal lobe lesions are accompanied by secondary involvement of the temporal lobe due to compression, scores for monotic and/ or dichotic speech tests will be depressed either in the ear contralateral to the lesion or bilaterally.

e. If unilateral temporal lobe lesions are accompanied by pressure or edema involving the brainstem, binaural fusion and resynthesis test scores will be abnormal.

f. Lesions of the pons in the caudal region will yield depressed scores on the brainstem procedures, especially for the rapid alternating speech task.

g. Brainstem lesions may perform poorly on monotic and/or dichotic speech tests with eith ipsilaterally or bilaterally depressed scores. There may be lack of correspondence between the side of the lesion and the ear(s) yielding the depressed scores.

4. The extent to which peripheral hearing disorders contaminate central auditory speech test performance is not well-established. A question remains as to whether peripheral hearing impairment can be subtracted from central auditory speech test results without sacrificing diagnostic accuracy.

5. Which, if any, tests can be used with confidence for the diagnosis of central auditory pathology in the presence of peripheral hearing disorders still remains unanswered.

CHAPTER III

METHOD

Subjects

The subjects were selected from the caseload of the Division of Otolaryngology of the Downstate Medical Center, State University of New York, and from the Queens Otologic Medical Developmental Center.

The experimental group consisted of 33 subjects, 15 males and 18 females. Ages ranged from 18-58 years, with a group mean age of 43.1 years; the mean age for males was 43.3 and for females, 42.9 years.

All subjects had a primary complaint of hearing loss and were seen for otologic consultation and examination by the otolaryngologist. Based upon clinical history, previous otologic work-ups, X-rays of the mastoids, internal auditory canals, polytomography of the temporal bone (where performed), and complete cochleo-vestibular as well as neurologic evaluation, etiology and site of lesion of the hearing loss were established.

Presumptive etiology with respect to hearing loss for the 33 patients included eight with endolymphatic hydrops, eight with congenital hearing loss, nine with acoustic trauma, four with noise-induced hearing losses, two with ototoxic loss, and two with viral disorder.

All subjects had sensorineural hearing loss which were medically diagnosed to have cochlear site of lesion.

The individuals were divided into subgroups based on their respective pure tone audiogram configurations. Audiogram configurations were defined as follows (Katz, 1978):

1. Flatness--total threshold difference no greater than 29dBHL within the range of 500, 1000, and 2000Hz.
2. Flat mild--average hearing test loss at 500, 1000, and 2000Hz from 27-40dBHL.
3. Flat moderate--average hearing test loss at 500, 1000, and 2000Hz from 41-55dBHL.
4. Flat severe--average hearing test loss at 500, 1000, and 2000Hz from 56-70dBHL.
5. Sloping mild--total slope of 14dBHL per octave or less.
6. Sloping moderate--total slope of 15-25dBHL per octave.
7. Sloping severe--total slope of 30dBHL or greater per octave.
8. Trough-shaped--flat configuration up to 1000Hz with upward slope to 8000Hz.
9. Other--any configuration that does not fall into one of the above categories.
10. Symmetrical hearing loss--less than 20dBHL difference between ears.
11. Asymmetrical hearing loss--20dBHL or greater difference between ears.

12. Unilateral hearing loss--hearing within normal limits (as defined below) for one ear, hearing loss in the opposite ear.

Criteria for inclusion into the cochlear group

The criteria for peripheral cochlear hearing loss consisted of the following:

1. Pure tone thresholds: The subject was required to have pure tone thresholds of 30dBHL or greater at two or more frequencies between 250Hz and 4000Hz and no greater than 60dBHL at two or more frequencies between 250Hz and 4000Hz (ANSI 1969).

   Bone conduction thresholds were required to be within 10dBHL of the air conduction thresholds obtained at each of the frequencies between 250-4000Hz.

2. Speech audiometry: Speech discrimination scores based on PI-PB functions for monosyllabic words were required to be 40% or better bilaterally.

3. Clinical history and otologic medical findings compatible with cochlear disease.

4. No middle ear pathology upon otologic examination.

5. No suggestion of middle ear pathology as assessed by impedance audiometry in accordance with guidelines reported by Feldman (1976).

6. Audiometric test results consistent with cochlear site of lesion. This included speech discrimination scores (PB max) or 50% or better; positive SISI scores of 80% or higher at frequencies that demonstrated pure tone thresholds of 60dBHL or greater (Jerger, 1973); tone decay (Carhart Method) no greater than 20dBHL bilaterally (Jerger, 1973); presence of the acoustic reflexes at 500, 1000, and 2000Hz bilaterally at any level between 70dBHL and 110dBHL; negative acoustic reflex decay at 500 and 1000Hz, bilaterally.
7. No neurologic or audiologic evidence or suspicion of central auditory pathology.
8. Age range between 18 and 58 years.
9. Native speakers of English.

Criteria for inclusion into the normal hearing group

A group of seven individuals with normal hearing was tested as a control group. Normal was defined as having

1. Pure tone thresholds between 0 and 25dBHL (ANSI-1969 reference thresholds) at frequencies of 250, 500, 1000, 2000, and 4000 Hz;
2. Speech reception thresholds no greater than 30dBHL;
3. Speech discrimination scores of 90% or better, as measured by tape-recorded NU#6 word lists at 40dBHL with respect to speech reception threshold;

4. Normal findings on impedance audiometry, including both positive acoustic reflexes at 500, 1000, and 2000Hz and negative acoustic reflex decay at 500 and 1000Hz;
5. No neurologic or audiometric evidence or suspicion of central auditory disorder;
6. Age range between 18 and 58 years;
7. Native speakers of English.

Description of Test Batteries

I. "Peripheral" test battery.

A. Pure tone audiometry, including air and bone conduction thresholds, were obtained at 250, 500, 1000, 2000, 4000, 6000, and 8000Hz.

B. Speech reception thresholds for spondiac words were obtained using monitored live voice.

C. Speech discrimination testing was performed using commercially available tape-recorded NU#6 word lists.

A complete PI-PB function (performance intensity functions for phonemically balanced monosyllabic words) was performed at three to six different speech levels, depending upon the individual's hearing, to a maximum presentation level of 90dBHL. Whenever cross-over was possible, the opposite ear was masked with white noise at a level 20dBHL lower than the presentation level for the test ear (Jerger, 1971).

D. Impedance audiometry included tympanometry, contralateral acoustic reflexes at 500, 1000, 2000, and 4000Hz; reflex decay measurement at 500 and 1000Hz; and absolute impedance in ohms.

E. Tone decay testing using the Carhart Procedure at 2000Hz, bilaterally (Carhart, 1957).

F. Short increment sensitivity index (SISI) testing at 2000Hz, bilaterally (Jerger, Shedd, Harford, 1959).

II. <u>Central auditory test battery</u>.

All the central auditory speech tests used were taped material, commercially available (see description of individual tapes for source of materials). Each of these tapes used calibration tones of 1000Hz.

A. Dichotic Competing Sentence Test (Binaural Separation Test) (Willeford, 1968).
Two different sentences are presented simultaneously, one to each ear. Standard presentation consists of the primary channel message at 35dBSL re pure tone average

(P.T.A.) of 500, 1000, and 2000Hz to one ear and a secondary channel competing message presented at 50dBSL re P.T.A. The subject is asked to repeat the message in a given ear and to ignore the message in the other ear. The tape was obtained through the University of Colorado State.

B. Staggered Spondaic Word Test (Katz, 1962). Two spondees are presented, one to each ear. The second part of the spondee presented in the first ear overlaps in time the first part of the spondee in the second (opposite) ear. The sequence is: half a spondee in the right ear only, without competing word; right ear with simultaneous competing word; right ear with simultaneous competing word in the left ear; and half a spondee in the left ear only without competing word.

The standard presentation level is 50dBSL above the P.T.A. for each ear with both ears receiving stimuli. In individuals with hearing impairment and/or recruitment, a presentation level of 30dBSL is permitted. The tape was obtained from Auditec of St. Louis.

C. Synthetic Sentence Identification Test (Jerger, 1973).

The test consists of a single list of ten synthetic sentences, seven words each, representing a third-order approximation to actual English sentences. Ten lists of different random presentations of the same ten sentences are used. A competing message is used to increase the difficulty of the task. This continuous discource is presented to either the opposite ear (contralateral competing message test) or to the same ear as are the sentences (ipsilateral competing message test). Performance is measured at several message-to-competition ratios (MCRs).

1. Contralateral competing message test: sentences to the test ear, competition to the opposite ear. The MCR is varied using 20dBHL steps from 0 to -40dBHL.
2. Ipsilateral competing message test: sentences and competing message to the same ear. The MCR is varied using 10dBHL steps from +10dBHL to -20dBHL. The tape was obtained from Auditec of St. Louis.

D. Binaural Fusion Test (brainstem resynthesis).

This procedure is based on Matzker's procedure (1959). The material used in the current test was developed by Ivey (1969). A low-pass band segment of 500-700Hz of a spondee word is presented to one ear at the same time that a high-pass band segment of 1900-2100Hz is presented to the other ear.

Normals have difficulty repeating the words with either band played alone, but they are able to fuse the two segments correctly when receiving the two bands simultaneously. Standard presentation levels calls for a low-band segment at a sensation level of 30dBSL re pure tone threshold for 500Hz to one ear and the high-band pass segment at a sensation level of 30dBSL re pure tone threshold for 2000Hz to the other ear.

The tape was obtained from the University of Colorado State.

E. Rapid Alternating Speech Test.

The test design was based on a principle described by Bocca and Calearo (1963). This test was developed by Lynn (1973).

Ten stimulus sentences are presented in alternating bursts each lasting 300 msec., first to one ear and then to the other. These sentences can be repeated easily by normals. Standard presentation level is 30dBSL re P.T.A. for both ears.

The tape was obtained from the University of Colorado State.

F. Monaural Los-Pass Filtered Speech:

Michigan CNC Word Lists are used (Willeford, 1968).

Frequencies below 500Hz are passed and frequencies above 500Hz are rejected at a rate of 18dB per octave. Standard presentation level is 50dBSL re P.T.A.

The tape was obtained from the University of Colorado State.

Each individual received the necessary otologic and audiologic evaluations in order to qualify for inclusion in the experimental or control group described previously. All testing was performed in a Suttle sound-isolated double room suite meeting ANSI specifications. A dual-channel 1701 Grason Stadler Audiometer with TDH 49 earphones was used. All central auditory speech test material as well as the NU#6 CNC word lists was presented via tapes using a SONY three head stereo tape recorder, TC 377. The impedance audiometer used was either an American

Electromedics 1083 or the Madsen Bridge Z071.

Central auditory speech test battery presentation order was determined according to a 7x7 standard Latin Square design (Griffin, 1962), A through G (see Figure 2). The following letters were assigned to these subtests:

A--Competing Sentence Test

B--Filtered Speech Test-Monaural Low-Pass

C--Binaural Fusion Test

D--Rapid Alternating Speech Test

E--Staggered Spondaic Word Test

F--Synthetic Sentence Identification Test-
Contralateral Competing Message

G--Synthetic Sentence Identification Test-
Ipsilateral Competing Message

An attempt was made to present each of the seven subtests according to their respective standard presentation level(s). In some cases, this was not possible due to the degree of the pure tone threshold levels, to tolerance problems and/or recruitment. Table 1 presents the levels and test conditions for each of the subtests.

Test Instructions

Test instructions to the subjects for the specific central auditory speech tests were given by the examiner using live voice. For the SSW instructions were repeated on the tape prior to the administration of each subtest (see Appendix).

FIGURE 2

7 x 7 LATIN SQUARE DESIGN

A	B	C	D	E	F	G
B	C	D	E	F	G	A
C	D	E	F	G	A	B
D	E	F	G	A	B	C
E	F	G	A	B	C	D
F	G	A	B	C	D	E
G	A	B	C	D	E	F

TABLE 1

SUMMARY OF PRESENTATION LEVELS AND TEST CONDITIONS
FOR CENTRAL AUDITORY TEST BATTERY

Test	Standard Presentation Level	Other Presentation Level(s)[a]
Competing Sentences	35dBSL primary message, 50dBSL competing message re P.T.A.	25dBSL primary message, 40dBSL competing message re P.T.A.
	Test #1: Items 1a-10a primary message, 1b-10b competing message.	Test #3: Items 1b-10b primary message, 1a-11a competing message.
	Test #2: Items 11a-20a primary message, 11b-20b competing message.	Test #4: Items 11b-20b primary message, 11a-20a competing message.
		15dBSL primary message, 30dBSL competing message re P.T.A. if standard presentation level cannot be used.
Staggered Spondaic Word Test	50dBSL re P.T.A. Test items #1-80	40dBSL re P.T.A. if 50dBSL cannot be used.
	30dBSL re P.T.A. Test items #81-160	
Synthetic Sentence Identification Test Contralateral Competing Message	30dBSL re P.T.A.: MCR-40 where thresholds permit	20dBSL re P.T.A.: MCR-40 where thresholds permit.
	List #1[b] Items 1-10 List #2[b] Items 1-10	List #3:[b] Items 1-10 List #3:[b] Items 1-10
Ipsilateral Competing Message	30dBSL re P.T.A.; MCRO, MCR-10 List #5:[b] Items 1-10 List #6:[b] Items 1-10	20dBSL re P.T.A.; MCRO, MCR-10 List #7:[b] Items 1-10 List #8:[b] Items 1-10

(a) Presentation levels used in addition to standard levels are specified for each test individually
(b) If SSI-ICM is presented prior to SSI-CCM, then the List numbers are reversed.

TABLE 1-Continued

Test	Standard Presentation Level	Other Presentation Level(s)[a]
Filtered Speech: Low-pass, monaural	50dBSL re P.T.A. List #1a: Items 1-25 List #2a: Items 1-25	30dBSL re P.T.A. List #1b: Items 26-50 List #2b: Items 26-50 40dBSL re P.T.A. if 50dBSL cannot be used
Binaural Fusion	30dBSL; low-pass re 500Hz pure tone threshold. 30dBSL; high-pass re 2000Hz pure tone threshold. Test #1a: Items 1-10 Test #1b: Items 11-20	40dBSL; low-pass re 500Hz pure tone threshold. 40dBSL; high-pass re 2000Hz pure tone threshold. Test #2a: Items 1-10 Test #2b: Items 11-20
Rapid Alternating Speech	30dBSL re P.T.A. List A: Items 1-10	20dBSL re P.T.A. List B: Items 1-10 40dBSL re P.T.A. List C: Items 1-10

(a) Presentation levels used in addition to standard levels are specified for each test individually

(b) If SSI-ICM is presented prior to SSI-CCM, then the List numbers are reversed

Scoring Procedures.

1. Competing Sentence Test. Regardless of presentation level, there are 10 test items presented. Each correctly repeated sentence was given a score of 10%. In the test scoring, partially correct responses received no credit.

2. Staggered Spondaic Word Test. This test was scored using two different procedures. The standard scoring method, according to Katz (1962), includes correcting the SSW score for any speech discrimination deficit.

Twenty items, with a total of 80 syllables, were used in each presentation of this study. There are four conditions scored separately for each ear; right non-competing, right competing, left competing, and left competing. A multiple of 5.0 is employed to obtain the raw percent of error. The test is computed in percent of error. The score is corrected for any discrimination deficit. The percent of error on the NU#6 CNC word list at 40dBSL is subtracted from the raw SSW score.

The performance of the right ear is obtained by averaging the two numbers representing the performance of the right ear, with right non-competing and right competing. The same procedure is followed to calculate the performance of the left ear.

Response biases are scored according to the number of reversals and for ear and order effect. Five or more errors for a particular response bias is considered significant. The type of response bias has diagnostic implications with respect to site of lesion. Since half-lists were used, response biases were not calculated.

The second scoring method used was that of Lynn and Gilroy (1972). Only the number of correct responses is scored for each of the four conditions: right non-competing, right competing, left competing, and left non-competing. These conditions are classified by different terms. The percent of words repeated correctly for the first and third sequences of the right and left ears is the alternate binaural score. The first and third sequence of the right ear correspond to Katz' left non-competing conditions. The percent of words repeated correctly during the second sequence for each ear is the simultaneous binaural score; this corresponds to Katz' right and left competing conditions.

Scores are reported in percent correct for the alternate binaural conditions and for the simultaneous binaural conditions. No corrections are made for speech discrimination losses. No response biases are calculated.

3. Synthetic Sentence Identification Test; Contralateral Competing Message and Ipsilateral Competing Message. Both the SSI-CCM and ICM are scored in the same manner. Each list presented consisted of ten test items. The individual identified the answer by giving the assigned number of the test item hear. Each correct response is worth 10%. The test is scored in percent correct.

4. Monaural Low-Pass Filtered Speech Test. The version of this test presented for this study consisted of 25 items each. The value per item was 5%. The word must be repeated perfectly in order to be scored as correct. If any question existed as to the response, the individual was asked to spell the word. The test was scored in percent correct; the number of words correct was multiplied by 5%.

5. Binaural Fusion Test. Each of the tests in this study comprised ten spondee words. Each word had a value of 10%. In order to receive credit for the test word, both syllables had to be repeated correctly. The number of correct responses was multiplied by ten in order to obtain a score of percent correct.

6. Rapid Alternating Speech Test. Each of the three lists in this test consisted of ten sentences. Each sentence had a value of 10%. In order for the individual to receive the 10%, every word in the sentence had to be exact. The number correct was multiplied by ten in order to obtain a score in percent.

Normative Data For Central Auditory Test Battery

The reported norms for the seven subtests comprising the central auditory speech test battery are set forth in Table 2.

TABLE 2

NORMATIVE DATA FOR THE CENTRAL AUDITORY SPEECH TESTS

Test	Normative Data
Competing Sentences	80%-100% correct (Willeford, 1968).
Staggered Spondaic Word Test	-7%, over-corrected; -6% to 10%, normal; 11% to 20%, mildly abnormal; 21% to 40%, moderately abnormal; 41% to 100%, severely abnormal; these scores are for ear condition and are in% error (Katz, 1973).
Synthetic Sentence Identification	
Contralateral Competing Message	80%-100% correct for message-to-competition ratios of -40 and -30 (Jerger, 1973).
Ipsilateral Competing Message	80%-100% correct for message-to-competition ratio of 0, 70%-90% correct for message-to-competition ratio of -10 (Jerger, 1973).
Monaural Low-pass Filtered Speech	74%-100% correct (Willeford, 1968). 66%-94% correct (Miltenberger, et al, 1978).
Binaural Fusion	75%-100% correct (Willeford, 1968). 60%-100% correct (Miltenberger, et al, 1978).
Rapid Alternating Speech	80%-100% correct (Lynn, 1973).

CHAPTER IV

RESULTS

The results of this study were subjected to both descriptive and statistical analysis. These two methods were applied to each of the seven individual tests in the study as well as to the tests as a battery.

DESCRIPTIVE ANALYSIS

Performance by the cochlear hearing impaired subjects on each of the seven tests was examined to determine the effects of presentation level, audiogram configuration, degree of hearing loss, age and sex of the individual, order of test presentation, and undistorted speech discrimination abilities. The results of each of these seven subtests are presented individually, and the effects of the above variables are discussed in relation to the presentation levels.

Competing Sentence Test (CST)

Mean competing sentence test scores were computed in percent correct by averaging all scores obtained with (1) the right ear receiving the primary message and the left receiving the competing message and then (2) the left ear receiving the primary message and the right ear receiving the competing message. Of the 33 subjects, 32 were administered the CST at both 35dBSL and 25dBSL presentation levels. These data, along with the reported norms (Willeford, 1968), are set forth in Table 3.

TABLE 3

MEANS, STANDARD DEVIATION, AND RANGES OF COMPETING SENTENCE TEST SCORES FOR COCHLEAR IMPAIRED SUBJECTS (N=32). SCORES ARE INDICATED IN PERCENT CORRECT

Presentation Level	Condition	Mean	SD	Range
35dBSL*	right primary	95.31	13.20	50-100
	left primary	95.62	8.81	70-100
25dBSL	right primary	97.81	5.09	80-100
	left primary	97.50	8.37	60-100
NORMS (Willeford, 1968)				80-100

*Standard presentation level.
Right primary=right ear receives primary message, left ear receiving competing message.
Left primary=left ear receives primary message, right ear receives competing message.

At 35dBSL, the standard presentation level, 28 of these subjects scored 80% or better. There did not appear to be any pattern related to etiology, audiogram configuration, degree of hearing loss, or undistorted speech discrimination ability that would account for the scores obtained by these four subjects on one or both of the test conditions. Three of these subjects, however, were able to score 80% or better at the 25dBSL presentation level. The remaining individual had a mild, flat hearing loss due to endolymphatic hydrops.

In examining the data there does not appear to be an appreciable difference in mean scores with respect to presentation level or condition. The standard deviation between the right ear receiving the primary message and the left ear receiving the primary message shows a difference between conditions at both presentation levels. The left primary conditions demonstrate similar scores at both presentation levels while the right primary condition scores are dissimilar, with the greatest difference occurring at 35dBSL and the least at 25dBSL. There is a fairly large range in scores for all conditions except the right primary at 25dBSL. Variability on the CST, with the right ear receiving the primary message, was due to poor performance by three subjects. At 25dBSL, with the left ear receiving the primary message, only one subject scored poorly, thereby giving the impression that there was wide variability in test performance by many cochlear impaired subjects.

In summary, the mean scores suggest that the cochlear impaired subjects as a group performed in a fashion similar to subjects with normal hearing. When compared with reported norms, 31 of the 32 cochlear impaired individuals scored within normal limits at the 25dBSL presentation level.

Staggered Spondaic Word Test (SSW)

The SSW test was presented to 33 subjects at 30dBSL and to 26 subjects at 50dBSL. Mean scores for the SSW according to Katz' procedure (Katz, 1962) were computed by averaging percent error for the right and left ear conditions at both presentation levels. These data as well as reported norms (Katz, 1973) are presented in Table 4.

Of the 33 subjects tested at the 30dBSL presentation level, three scored abnormally and six scored in the severely over-corrected category. No patterns or trends were discerned among these subjects. At the 50dBSL presentation level, five ears scored greater than 11% error and two ears obtained severely over-corrected scores. Five of the six individuals who obtained these scores demonstrated sloping audiogram configurations.

The data in Table 4 show a wide range of scores for both presentation levels and ear conditions, ranging from severely over-corrected scores to severely abnormal scores. The wide variability of scores is most probably due to the correction for peripheral hearing loss, which frequently

TABLE 4

MEANS, STANDARD DEVIATIONS, AND RANGES OF SSW TEST SCORES FOR ALL COCHLEAR IMPAIRED SUBJECTS USING KATZ' SCORING PROCEDURE WITH HALF LISTS. SCORES ARE INDICATED IN PERCENT ERROR.

Presentation Level	Condition	N	Mean	SD	Range
30dBSL	Right ear	33	-9.35	16.73	-44 - 30
	Left ear	33	-5.02	14.31	-48 - 17
50dBSL	Right ear	26	-1.03	11.81	-41 - 17
	Left ear	26	2.13	16.37	-31 - 48
Norms (Katz, 1973)	Over Corrected	Normal	Mildly Abnormal	Moderately Abnormal	Severely Abnormal
	- -7	-6 -10	11 - 20	21 - 40	41 - 100

results in over-corrected scores for cochlear impaired individuals, as well as the use of half-lists. The standard deviations are similar for the right ear condition at 30dBSL and the left ear condition at 50dBSL. The right ear condition at 50dBSL reflects the smallest standard deviation, while that of the left ear at 30dBSL is somewhat greater. Despite this discrepancy, the mean corrected SSW test scores obtained by the cochlear impaired subjects as a group suggest performance within normal limits for all conditions at both presentation levels.

Mean scores for the SSW test according to Lynn and Gilroy's procedures (Lynn and Gilroy, 1972) were computed by averaging percent correct for the right and left ears for both the alternate binaural conditions and the simultaneous binaural conditions at the two presentation levels (see Table 5). When examining the data, 15 of the 33 subjects scored below 85% at 30dBSL on one or more conditions. Subjects with sloping audiogram configurations tended to score more poorly than others, with a total of nine scoring below 85%. A difference between ears occurred, with the right ears scoring higher than the left ears in both the simultaneous and the alternating binaural conditions. Of the 33 ears, none of the right as compared to five of the left scored below 85% of the alternating binaural condition while three of the right, compared with

TABLE 5

MEANS, STANDARD DEVIATIONS, AND RANGES OF SSW TEST SCORES FOR COCHLEAR IMPAIRED SUBJECTS ACCORDING TO LYNN AND GILROY'S (1977) SCORING PROCEDURES. SCORES ARE INDICATED IN PERCENT CORRECT

Presentation Level	Condition	Right ear				Left ear		
		N	Mean	SD	Range	Mean	SD	Range
30dBSL	Alternating Binaural	33	97.42	4.69	80-100	93.48	11.14	55-100
	Simultaneous Binaural	33	92.57	7.51	75-100	86.51	12.93	45-100
50dBSL	Alternating Binaural	26	94.03	5.83	85-100	92.88	9.29	65-100
	Simultaneous Binaural	26	88.84	12.19	70-100	86.34	16.93	55-100
Norms	Alternating Binaural		98.80	1.8	95-100	98.70	2.0	95-100
	Simultaneous Binaural		97.30	2.2	90-100	96.40	3.8	90-100

nine of the left, scored poorer than 85% of the simultaneous binaural condition. At the 50dBSL presentation level none of the 26 subjects scored below 85% in the right alternating binaural condition, while seven scored below 85% in the right simultaneous binaural condition. Of the left alternating binaural condition, three scored below 85%, while on the simultaneous binaural condition, ten scored below 85%.

There appears to be an appreciable difference between ears, with the right ear scoring better than the left ear at both presentation levels and for both conditions. The standard deviation as well as the range in scores is less for the right ear than the left ear for both presentation levels and conditions.

Inspection of the data does not suggest any trends indicative of etiology or degree of hearing loss; however, individuals with sloping audiogram configurations tended to score more poorly than those with other types of configurations. When compared with reported norms, the cochlear impaired subjects as a group performed more poorly than normal hearing individuals.

Synthetic Sentence Identification Test-Contralateral Competing Message (SSI-CCM)

Mean SSI-CCM scores were computed in percent correct for (1) the subjects who received the primary message in the right ear with competition in the left ear, and (2) those who received the primary message in the left ear with competition in the right ear. Four separate scores were obtained, two at the standard presentation level of 30dBSL and two at 20dBSL, all at message-to-competition ratios (MCR) of -40dB or -30dB, depending upon the degree of hearing loss. These data, along with established norms (Jerger, 1973), are presented in Table 6.

All 33 cochlear impaired subjects scored 80% or better in both the right and left ears at 30dBSL. Mean scores for the right and left ears are quite similar; the range of scores is restricted and the standard deviations are quite small. When compared with reported norms, all 33 subjects scored within the normal range. At 20dBSL presentation level, one female subject, aged 48 years, scored below 80% in both ears. Despite similar mean scores for both presentation levels there is a wider range of variability in that there are larger standard deviations at 20dBSL than at 30dBSL.

The SSI-CCM at 20dBSL displayed wide variability in test scores with large standard deviations. Inspection of the data show that these scores reflect performance by only one subject who was able to score wtihin normal limits at 30dBSL. All other subjects scored 80% or better in the right and 90% or better in the left ear.

<u>Synthetic Sentence Identification Test-Ipsilateral Competing Message (SSI-ICM)</u>

Mean scores for the SSI-ICM were computed by

TABLE 6

MEANS, STANDARD DEVIATIONS, AND RANGES OF SYNTHETIC SENTENCE IDENTIFICATION TEST-CONTRALATERAL COMPETING MESSAGE SCORES FOR COCHLEAR IMPAIRED SUBJECTS. SCORES ARE INDICATED IN PERCENT CORRECT.

Presentation Level	Condition	N	Mean	SD	Range
30dBSL*	Right primary	33	99.09	3.84	80-100
	Left primary	33	99.39	2.93	90-100
20dBSL	Right primary	33	97.57	7.91	60-100
	Left primary	31	97.81	10.70	40-100
Norm (Jerger, 1973)					80-100

*Standard presentation level

averaging the percent correct for each of the following conditions: (1) 30dBSL at MCR OdB, (2) 30dBSL at MCR -10dB, and (3) 20dBSL at MCR OdB for the right and left ears, in turn. These data, along with reported norms (Jerger, 1973), appear in Table 7.

Inspection of the data reveals better performance by the left ear than the right ear for all conditions. At the standard presentation level of 30dBSL, MCR 0dB, 22 of the 28 right ears and 28 of the 32 left ears scored 80% or better. The left ear demonstrated smaller standard deviations and less variability in scores than the right ear at both presentation levels. At 20dBSL, MCR 0dB, mean scores were similar to those obtained at 30dBSL, MCR 0dB, with 17 of the 20 right ears and 21 of the 23 left ears scoring 80% or better. Mean scores for the cochlear impaired subjects as a group, however, suggest performance within the normal range when compared with reported norms.

Performance becomes poorer as the MCR is decreased from 0dB to -10dB, as would be expected, since the task becomes more difficult as the MCR is decreased. The mean left ear score was appreciably higher than that of the right. The standard deviation and variability of scores were similar for both ears, however. The large standard deviations and wide variability suggest that the SSI-ICM, at -10dB MCR, is particularly sensitive to cochlear dysfunction, in light of no other existing peripheral or

TABLE 7

MEANS, STANDARD DEVIATIONS, AND RANGES OF SYNTHETIC SENTENCE IDENTIFICATION TEST-IPSILATERAL COMPETING MESSAGE FOR COCHLEAR IMPAIRED SUBJECTS. SCORES ARE INDICATED IN PERCENT ERROR.

Presentation Level	Condition	N	Mean	SD	Range
30dBSL; OdBMCR *	Right ear	28	86.66	19.31	20-100
	Left ear	32	90.30	11.03	60-100
Norm (Jerger, 1973)					80-100
20dBSL	Right ear	20	87.00	18.60	20-100
	Left ear	23	89.56	15.21	50-100
30dBSL; -10dBMCR*	Right ear	28	63.44	16.96	40-100
	Left ear	29	76.89	16.71	40-100
Norm					70-90

*Standard presentation level.

central disorders in this population. The left ear was within the range of normal while the right ear was below the range of normal for reported norms. No other trends or patterns were noted with respect to performance.

Monaural Low-Pass Filtered Speech (MLPF)

The MLPF test scores were computed in percent correct by averaging all the scores obtained for each ear at 50dBSL (the standard presentation level) and at 30dBSL. These data, along with established norms (Willeford, 1968; Miltenberger et al, 1978), are in Table 8. A total of 30 right and 32 left ears were tested at 50dBSL, in which only seven ears scored above 42% and another four ears, between 66% and 72%. Of these five ears, three reflected the normal hearing ears of individuals with unilateral losses.

Inspection of the data reveals similar mean scores for right and left ears at both presentation levels. The standard deviation is similar for both ears. The range indicates wide variability for all conditions suggesting that this test is particularly sensitive to cochlear dysfunction. It appears that MLPF test performance is greatly affected by the presence of cochlear impairment regardless of etiology, audiogram configuration, degree of hearing loss, age, and/or sex. Performance is exceedingly poor for the cochlear impaired subjects as a group, and scores are substantially depressed in comparison to those of reported norms for normal hearing persons.

TABLE 8

MEANS, STANDARD DEVIATIONS AND RANGES OF MONAURAL LOW-PASS FILTERED SPEECH TEST SCORES FOR COCHLEAR IMPAIRED SUBJECTS. SCORES ARE INDICATED IN PERCENT CORRECT.

Presentation Level	Condition	N	Mean	SD	Range
50dBSL*	Right ear	30	40.26	24.51	12-96
	Left ear	32	36.62	24.19	0-88
30dBSL	Right ear	33	35.15	18.47	0-72
	Left ear	33	41.57	21.67	0-76
Norm (Willeford, 1968)					74-100
(Miltenberger et al, 1978)					66-94

*Standard presentation level.

Binaural Fusion Test (BFT)

Mean BFT scores were computed by averaging the percent correct for each of two conditions; condition one, in which the right ear received the low-pass filtered segment and the left ear received the high-pass filtered segment (RE); condition two, in which the left ear received the low-pass filtered segment and the right ear received the high-pass filtered segment (LE). Presentation levels of 30dBSL and 40dBSL are based on the 500Hz air conduction threshold for the low-pass filtered segment and on the 2000Hz air conduction threshold for the high-pass filtered segment. All 33 subjects participated at the 30dBSL, and 32 of the 33 subjects participated at the 40dBSL presentation levels. The data along with reported norms (Willeford, 1968; Miltenberger et al, 1978), are set forth in Table 9.

Examination of the data suggests that overall performance is influenced by presentation level, with both RE and LE conditions at 40dBSL yielding higher scores than the comparable conditions at 30dBSL. The RE condition scores are somewhat better than LE condition scores for both presentation levels. Standard deviations are greater at 30dBSL than at 40dBSL, with a wide range of variability for all conditions and levels. When compared with reported norms (Willeford, 1968), the cochlear impaired subjects as a group performed within the range of normal at 40dBSL but not at 30dBSL.

TABLE 9

MEANS, STANDARD DEVIATIONS, AND RANGE OF BINAURAL FUSION TEST SCORES FOR COCHLEAR IMPAIRED SUBJECTS. SCORES ARE INDICATED IN PERCENT CORRECT.

Presentation Level	Condition	N	Mean	SD	Range
30dBSL	Right ear: low pass Left ear: high pass	33	74.24	27.72	0-100
	Left ear: low pass Right ear: high pass	33	70.00	25.98	10-100
40dBSL	Right ear: low pass Left ear: high pass	32	82.81	16.89	20-100
	Left ear: low pass Right ear: high pass	32	79.37	18.85	40-100
Norms (Willeford, 1968)			89.00		75-100
(Miltenberger et al, 1978)					60-100

Rapid Alternating Speech Test (RASP)

Mean RASP scores were computed in percent correct by averaging all the scores obtained at each of the three presentation levels. Thirty-two subjects were administered the RASP at 30dBSL (one standard presentation level) and at 40dBSL. Twenty-four individuals were administered the test at 20dBSL. The data, along with established norms (Lynn, 1973), are presented in Table 10.

Examination of the data suggests that mean scores for 20dBSL and 30dBSL are similar; performance at 40dBSL is better. Standard deviations as well as a wide range in scores are similar at all three presentation levels. Only seven subjects failed to score 80% or better at any of the three levels. No specific patterns were noted. Only two subjects failed to score 70% or better at one of the three presentation levels. Both individuals were males who had severe sloping audiogram configurations--one with an etiology of acoustic trauma and the other, a noise-induced hearing loss. Comparison with established norms reveals that at 40dBSL the cochlear impaired subjects as a group fall within the range of normal.

Analysis of Central Auditory Test Battery (CAB)

Analysis of the seven subtests comprising the test battery indicates that only three, or 11%, of the 33 cochlear impaired subjects scored within normal limits at one or both of the presentation levels according to reported norms. If one eliminates the monaural low-pass filtered

TABLE 10

MEANS, STANDARD DEVIATIONS, AND RANGE OF RAPID ALTERNATING SPEECH TEST SCORES FOR COCHLEAR IMPAIRED SUBJECTS. SCORES ARE INDICATED IN PERCENT CORRECT.

Presentation level	N	Mean	SD	Range
20dBSL	24	79.67	19.46	20-100
30dBSL*	32	79.37	17.18	50-100
40dBSL	32	84.78	17.64	30-100
Norm (Lynn and Gilroy, 1973)	80-100	99.00		90-100

*Standard presentation level.

speech test, the only test on which the majority of cochlear impaired subjects as a group performed very poorly, then 11, or 33.3%, of the 33 subjects scored within the range of normal on the remaining battery consisting of six subtests.

Further examination suggests that the failure to score within the normal range by the other two-thirds of the cochlear impaired group on the test battery is largely due to their poor performance on the RASP and the SSI-ICM at -10dBMCR. As a group the cochlear impaired subjects appear to perform well on those tests primarily used for the diagnosis of cortical lesions, such as the SSW, the CST, and the SSI-CCM. Performance for the tests used primarily for the diagnosis of brainstem lesions appears to be more variable, with the BFT and the SSI-ICM, MCR 0dB yielding better scores than the RASP and the SSI-ICM, MCR -10dB.

In summary, (1) the variables degree of hearing loss, symmetry between ears, etiology of hearing loss, age, sex of the individual, and test order presentation did not appear to affect performance by the cochlear impaired subjects (2) the variables that affected test performance included presentation level, audiogram configuration, ear, and undistorted speech discrimination abilities. (3) the cochlear impaired subjects as a group were able to perform within the normal range according to reported norms for the following tests with some qualifying conditions:

1. Competing Sentence Test.
2. Synthetic Sentence Identification Test-Contralateral Competing Message.
3. Synthetic Sentence Identification Test-Ipsilateral Competing Message: MCR OdB, right and left ear; and MCR-10dB, left ear only.
4. SSW test--Katz' scoring procedure.
5. Binaural Fusion Test: 40dBSL presentation level.
6. Rapid Alternating Speech Test: 40dBSL presentation level.

Despite the good performance there appears to be a wide range of variability for scores on all tests except the SSI-CCM.

Mean scores obtained by the cochlear impaired subjects as a group for each of the central tests as compared with normal hearing individuals and those with confirmed central auditory pathology as reported in the literature, are shown in Table 11.

These scores suggest differences of ±10% between the cochlear impaired and normal hearing individuals for the SSI-CCM, the CST, the SSW, the SSI-ICM, OdB MCR, the BFT at 40dBSL, and the SSI-ICM, -10dB MCR, left ear. The SSI-ICM, -10dB MCR, right ear, suggests a 16.56% difference score. The RASP suggests a difference of 14.22% at 40dBSL, with the cochlear impaired scoring poorer than the

TABLE 11

MEAN SCORES FOR NORMAL HEARING INDIVIDUALS/COCHLEAR IMPAIRED INDIVIDUALS/AND INDIVIDUALS WITH CENTRAL AUDITORY PATHOLOGY. SCORES ARE IN PERCENT CORRECT.

TEST	NORMAL HEARING	COCHLEAR IMPAIRED		CENTRAL TEMPORAL LOBE RIGHT	LEFT	DEEP PARIETAL RIGHT	LEFT	TEMPORAL LOBE POSTERIOR
Competing Sentence	35dBSL	35dBSL	35dBSL	35dBSL	35dBSL	35dBSL	35dBSL	35dBSL
Right primary	90.00	95.31	97.81	90.00	45.00	90.00	60.00	IPSIL. 84.00
Left primary	90.00	95.62	97.50	65.00	90.00	55.00	90.00	CONTRAL. 33.00
Staggered Spondaic Word Test				HIGH BRAINSTEM N=4		CENTRAL AUDITORY RECEPTION N=15		N=21
KATZ (C-SSW)	50dBSL	30dBSL	50dBSL					
Right ear condition	+2.00	-9.35	-1.03	IPSIL. 53.00		17.00		--
Left ear condition	+2,00	-5.02	2.13	CONTRAL. 4.00		52.00		63.00
				TEMPORAL LOBE RIGHT	LEFT	DEEP PARIETAL RIGHT	LEFT	TEMPORAL LOBE POSTERIOR
LYNN & GILROY	50dBSL	30dBSL	50dBSL	50dBSL	50dBSL	50dBSL	50dBSL	50dBSL
Right alt.	98.80	97.42	94.03	95.00	80.00	90.00	100.00	ALT. IPSI. 93.70
Right simult.	97.30	92.57	88.84	95.00	45.00	90.00	85.00	ALT. COMTRAL70.50
Left alt.	98.70	93.48	92.88	85.00	95.00	85.00	85.00	SIM. IPSI. 77.40
Left simult.	96.40	86.51	86.34	60.00	85.00	55.00	55.00	SIM. CONTRAL42.90

TABLE 11-continued

SYNTHETIC SENTENCE IDENTIFICATION	30dBSL	30dBSL	20dBSL	TEMPORAL LOBE GLIOMA RIGHT	RIGHT & LEFT	BRAINSTEM RIGHT PONTINE GLIOMA
CONTRALATERAL COMPETING MESSAGE						
Right primary	90.00	99.09	97.57	90.00	IPSIL. 95.00	90.00
Left primary	90.00	99.39	97.81	70.00	CONTRAL.80.00	60.00

TEST	NORMAL HEARING	COCHLEAR IMPAIRED			CENTRAL TEMPORAL LOBE RIGHT	BRAINSTEM RIGHT GLIOMA
SSI-ICM	30dBSL	30dBSL	20dBSL		30dBSL	30dBSL
0dBMCR						
Right	90.00	86.66	87.00		90.00	60.00
Left	90.00	90.30	89.56		90.00	10.00
-10dBMCR						
Right	80.00	63.44	--		60.00	20.00
Left	80.00	76.89	--		40.00	Could Not Test

		COCHLEAR			CENTRAL-LESIONS OF THE PONS
RASP	30dBSL	20dBSL	30dBSL	40dBSL	30dBSL
	99.00	79.67	79.37	84.78	40.00

TABLE 11-continued

BINAURAL FUSION	NORMAL	COCHLEAR	COCHLEAR	BRAINSTEM INVOLVEMENT			
	30dBSL	30dBSL	40dBSL	30dBSL			
Right low pass / left high pass	89.00	72.24	82.81	10.00			
Left low pass / Right high pass.	89.00	70.00	79.37	0.00			
				TEMPORAL LOBE		DEEP PARIETAL	
				RIGHT	LEFT	RIGHT	LEFT
MONAURAL LOW-PASS FILTERED	50dBSL Willeford	50dBSL	30dBSL	50dBSL		50dBSL	
Right	87.00	40.26	35.15	54.00	45.00	45.00	50.00
Left	87.00	36.62	41.57	35.00	55.00	40.00	45.00
	Miltenberger						
Right	80.00						
Left	80.00						

normal hearing individuals. The only test demonstrating a large difference is the MLPF, ranging from 35.15% to 40.26%. The difference between ears is 10% or less for all tests with the exception of the SSI-ICM, -10dB MCR condition.

Comparison between the cochlear impaired group and the group with central auditory impairment suggests the following: (1) differences of 5-62% between the two groups with cortical lesions demonstrating dramatically poorer scores for the ear contralateral to the lesion on the CST and the SSW, (2) differences of 0-80% on the SSI-ICM and the RASP for brainstem lesions, (3) differences of 4-39% for central lesion, temporal lobe and brainstem for the SSI-CCM, and (4) no appreciable difference between the cochlear and central dysfunction cases for the MLPF.

The difference scores between normal hearing individuals and cochlear impaired individuals as compared with those of cochlear and central auditory impaired individuals are shown in Table 12.

STATISTICAL ANALYSIS

Central Auditory Test Battery

In order to have a common variable for examination, a three-way analysis of variance was performed for the entire battery of central auditory speech tests (CAB) for which a single presentation level of 30dBSL was used. The

TABLE 12

DIFFERENCE SCORES (D/S) FOR NORMALS/COCHLEAR IMPAIRED AS COMPARED WITH CENTRAL/COCHLEAR IMPAIRED. SCORES ARE IN PERCENT OF DIFFERENCE.

TEST	NORMALS/COCHLEARS		CENTRALS/COCHLEARS: TEMPORAL LOBE Right	TEMPORAL LOBE Left	DEEP PARIETAL Right	DEEP PARIETAL Left	TEMPORAL LOBE POSTERIOR	
COMPETING SENTENCE	35dBSL	25dBSL	35dBSL	35dBSL	35dBSL	35dBSL	35dBSL	
Right primary	+5.31	+7.81	+5.31	50.31	5.31	35.31	IPSIL.	11.31
Left primary	+5.62	+7.50	30.62	5.62	40.62	5.62	CONTRAL.	62.62

SSW - KATZ	50dBSL	30dBSL	HIGH BRAINSTEM N=4		CENTRAL AUDITORY RECEPTION N=11	N=21
Right ear	-0.97	-7.35	IPSIL.	54.03	18.03	--
Left ear	-0.13	-3.02	CONTRAL.	1.87	50.13	60.87

SSW LYNN & GILROY	50dBSL	30dBSL	TEMPORAL LOBE Right 50dBSL	TEMPORAL LOBE Left 50dBSL	DEEP PARIETAL Right 50dBSL	DEEP PARIETAL Left 50dBSL
Right alt.	4.77	1.38	.97	14.03	4.03	+5.97
Right simult.	8.46	4.73	+6.16	43.84	+1.16	3.84
Left alt.	5.82	5.22	7.88	+2.12	7.88	7.88
Left simult.	10.04	9.89	26.34	1.34	31.34	31.34

SSI-CCM	30dBSL	20dBSL	TEMPORAL LOBE RIGHT GLIOMA 30dBSL	TEMPORAL LOBE RIGHT AND LEFT 30dBSL		BRAINSTEM RIGHT PONTINE GLIOMA 30dBSL
Right primary	9.09	7.57	9.09	IPSIL.	4.09	9.09
Left primary	9.39	7.81	29.39	CONTRAL.	19.39	39.39

TABLE 12-continued

TEST	NORMALS/COCHLEARS			CENTRALS/COCHLEARS			
SSI-ICM				RIGHT TEMPORAL LOBE		RIGHT BRAINSTEM GLIOMA	
0dBMCR	30dBSL	20dBSL		30dBSL		30dBSL	
Right	3.34	3.00		+3.34		26.66	
Left	0.30	0.44		0.30		80.30	
-10dBMCR							
Right	16.56	--		3.44		53.44	
Left	3.11	--		36.89		Could not test	
RASP	20dBSL	30dBSL	40dBSL	CENTRAL-LESIONS OF THE PONS			
				30dBSL			
	19.33	19.63	14.22	39.37			
				BRAINSTEM INVOLVEMENT			
BINAURAL FUSION	30dBSL	40dBSL		30dBSL			
Right low pass/ Left high pass.	16.76	6.19		62.24			
Left low pass/ Right high pass.	19.00	9.63		70.00			
MONAURAL LOW-PASS FILTERED	50dBSL	30dBSL		TEMPORAL LOBE		DEEP PARIETAL	
				RIGHT	LEFT	RIGHT	LEFT
				50dBSL		50dBSL	
Right	46.74	51.85		+13.84	+4.84	+4.84	+9.84
Left	50.38	45.43		1.62	+18.38	+3.38	+8.38

three main factors were (1) ear--right and left; (2) test--Competing Sentence Test (CST)--Staggered Spondaic Word Test--Katz' scoring procedure (SWK), Staggered Spondaic Word Test--Lynn and Gilroy's scoring procedure, alternating simultaneous condition (SWL-SIM) and alternating binaural condition (SWL-BIN), Synthetic Sentence Identification Test-Ipsilateral Competing Message, MCR -10dB (SIC-10), Monaural Low-Pass Filtered Speech Test (FST), Synthetic Sentence Identification Test--Ipsilateral Competing Message, MCR 0dB (SIC 0), Binaural Fusion Test (BFT), and Rapid Alternating Speech Test (RAS); and (3) subjects--N-38. These main factors were chosen since they were the only common variables. The data are displayed in Table 13.

The main effects of subjects and tests are shown to be statistically significant at the 0.001 level; ear is significant at the .05 level, with the left ear performing better than the right. The interaction between ear and test is significant at the .05 level.

ANALYSIS OF VARIANCE FOR INDIVIDUAL TESTS

An analysis of variance was performed for each of the subtests which are discussed individually. All observations were obtained in percent correct, except for the SWK, since this test is scored in percent error.

In order to meet the critical assumption of analysis of variance that each set of data is homogeneous

TABLE 13

THREE-WAY ANALYSIS OF VARIANCE FOR CENTRAL AUDITORY SPEECH TEST BATTERY AT 30dBSL

Effect	df	MS	F	p
Ear	1	6254.81250	5.905	0.015**
Test	8	68697.50000	64.581	0.001*
Subject	8	2790.86572	2.635	0.001*
Ear/Test	27	2112.84668	1.995	0.048**
Ear/Subject	27	859.33081	0.811	0.735
Test/Subject	216	1306.50732	1.233	0.062

* $p < .001$

** $p < .05$

with respect to error variance, the original data were transformed from percent correct to arc sine units. Analyses were performed, therefore, on arc sine transforms assuring that the magnitude of the variability in scores was not due to the variability of the data (Ferguson, 1971).

Competing Sentence Test

A three-way ANOVA was performed to examine the effects of right and left ears using presentation levels of 35dBSL and 25dBSL, and 32 subjects. As can be seen from the data in Table 14, there are no statistically significant effects except for the factor of subjects at the 0.001 level. There are no statistically significant interaction effects at either the .001 or .05 level.

Staggered Spondaic Word Test

A three-way ANOVA on the SSW test using Katz' scoring procedure was performed on the factors of right and left ears--presentation levels of 30dBSL and 50dBSL and subjects N=26. Test data appear in Table 15. This analysis shows that (1) presentation level was significant at the .001 level with a mean score of -8.4% at 30dBSL and a mean score of -0.3% at 50dBSL; (2) ear was significant at the .05 level, with the right ear obtaining a mean score of -6.7% and the left ear a mean score of -2.0%; and (3) subjects were statistically different at the .05 level. The interaction effect of ear and subject was significant at the .05 level.

TABLE 14

THREE-WAY ANALYSIS OF VARIANCE FOR THE COMPETING SENTENCE TEST

Effect	df	MS	F	p
Ear	1	0.00400	0.150	0.703
Level	1	0.05631	2.111	0.153
Subject	31	0.09931	3.723	0.001*
Ear/Level	1	0.01328	0.498	0.507
Ear/Subject	31	0.04212	1.579	0.105
Level/Subject	31	1.01464	0.549	0.950

*$p < .001$

TABLE 15

THREE-WAY ANALYSIS OF VARIANCE FOR STAGGERED SPONDAIC WORD TEST-KATZ' SCORING PROCEDURE

Effect	df	MS	F	p
Ear	1	0.05914	5.333	0.028**
Level	1	0.16800	15.149	0.001*
Subject	25	0.03157	2.847	0.006**
Ear/Level	1	0.00170	0.153	0.701
Ear/Subject	25	0.03266	2.945	0.005**
Level/Subject	25	0.01282	1.156	0.360

*p < .001

**p < .05

A four-way ANOVA was performed on the SSW test using Lynn and Gilroy's scoring procedure. The factors examined included alternating simultaneous and binaural simultaneous conditions; right and left ears; presentation levels of 30dBSL and 50dBSL; and subjects N=26. The data are set forth in Table 16. The main factors of condition, level, and subject were all significant at the .001 level. Subjects performed better in the alternating condition than in the simultaneous condition, with respective mean scores of 96.0% and 89.16%. They scored better at the 30dBSL, with a mean of 94.81%, compared with that of 91.27% at 50dBSL. The effect of ear was significant at the .05 level in which the right ear performed better than the left, at 94.23%, compared with 91.97% for the left. The interaction effect between ear and subjects was significant at the .001 level, with the right ear performing better than the left.

Synthetic Sentence Identification Test-Contralateral Competing Message

The three-way ANOVA for the SSI-CCM had three main effects--ear-right receiving the primary message and left receiving the competition, left receiving the primary message and right receiving the competition; presentation level-30dBSL and 20dBSL; and subjects-N=32. The data appear in Table 17. The main factor of level is significant at the .05 level in which performance is better at 30dBSL than at 20dBSL. Subjects are shown to be

TABLE 16

FOUR-WAY ANALYSIS OF VARIANCE FOR STAGGERED SPONDAIC WORD TEST-LYNN AND GILROY'S SCORING PROCEDURE

Effect	df	MS	F	p
Condition	1	3.35528	101.690	0.001*
Ear	1	0.41604	12.609	0.002**
Level	1	1.02437	31.043	0.001*
Subject	25	0.46081	13.966	0.001*
Condition/Ear	1	0.02461	0.746	0.600
Condition/Level	1	0.10473	3.174	0.804
Condition/Subject	25	0.04495	1.362	0.222
Ear/Level	1	0.18115	5.490	0.026**
Ear/Subject	25	0.13594	4.120	0.001*
Level/Subject	25	0.05900	1.788	0.076
Condition/Ear/Level	1	0.00976	0.296	0.598
Condition/Ear/Subject	25	0.04035	1.223	0.309
Condition/Level/Subject	25	0.02079	0.630	0.872
Ear/Level/Subject	25	0.04887	1.481	0.166

*$p < .001$

**$p < .05$

TABLE 17

THREE-WAY ANALYSIS OF VARIANCE FOR THE SYNTHETIC SENTENCE IDENTIFICATION TEST-CONTRALATERAL COMPETING MESSAGE

Effect	df	MS	F	p
Ear	1	0.00100	0.217	0.649
Level	1	0.03274	7.109	0.012**
Subject	31	0.04915	10.674	0.001*
Ear/Level	1	0.00024	0.052	0.816
Ear/Subject	31	0.00828	1.797	0.054
Level/Subject	31	0.03819	8.293	0.001*

*$p < .001$
**$p < .05$

statistically different at the .001 level; interaction effect of subject and level is significant at the .001 level.

<u>Synthetic Sentence Identification Test-Ipsilateral Competing Message</u>

Analysis of variance for the SSI-ICM had three main effects--message competition ratios of 0 and -10dB; ear, right and left; and subjects N=29. These data are presented in Table 18. The data indicate that OdB MCR, compared with -10dB MCR, is a significant factor at the .001 level with the mean score at ODB MCR (30dBSL presentation level) 90.22% and the mean score at -10dB MCR (30dBSL presentation level) 71.36%. This difference is not unexpected, however, since the -10dB MCR level represents a more difficult task than the OdB MCR condition. The left ear performance is significantly better than the right ear performance at the .05 level, confirming the observation that ear is significant. The interaction between MCR and ear as well as that of subject and ear is significant at the .05 level.

<u>Monaural Low-Pass Filtered Speech</u>

The analysis of variance for the monaural low-pass filtered speech test can be seen in Table 19. There was no significant score difference between ears in terms of poor performance for both and no significant difference in terms of presentation level. The only statistically

TABLE 18

THREE-WAY ANALYSIS OF VARIANCE FOR THE SYNTHETIC SENTENCE IDENTIFICATION TEST-IPSILATERAL COMPETING MESSAGE

Effect	df	MS	F	p
Message-to-competition ratio (MCR)	1	7.05249	109.666	0.001*
Ear	1	0.69621	10.826	0.003**
Subject	28	0.13294	2.067	0.030**
MCR/Ear	1	0.62099	9.656	0.004**
MCR/Subject	28	0.07946	1.236	0.289
Ear/Subject	28	0.12356	1.921	0.045**

*$p < .001$
**$p < .05$

TABLE 19

THREE-WAY ANALYSIS OF VARIANCE FOR THE MONAURAL LOW-PASS FILTERED SPEECH TEST

Effect	df	MS	F	p
Ear	1	0.01236	0.174	0.683
Level	1	0.01987	0.279	0.607
Subject	29	0.60762	8.543	0.001*
Ear/Level	1	0.73404	10.320	0.003**
Ear/Subject	29	0.14232	2.001	0.033**
Level/Subject	29	0.16041	2.255	0.016**

*$p < .001$
**$p < .05$

significant main factor was subject at the .001 level. Interaction effects of ear and level, ear and subject, and level and subject, however, all became statistically significant at the .05 level.

Binaural Fusion Test

A three-way ANOVA for the BFT was performed. Factors included ear--right and left; sensation level--30dBSL and 40dBSL; and subjects--N=32 (see Table 20). The analysis confirms that level is a significant factor at .001 level in performance by the cochlear impaired subjects, with better scores obtained at 40dBSL than at 30dBSL--82.05%, compared with 73.45%. Subjects are statistically significant at the .001 level; interaction between ear and subject is significant at that level, with right ear performance better than the left.

Rapid Alternating Speech Test

A two-way analysis of variance was performed for the RASP. The main effect of sensation level, whether using the two levels of 30dBSL and 40dBSL or the three levels of 20dBSL, 30dBSL, and 40dBSL was statistically nonsignificant. The effect of subject was significant at the .001 level. Data are displayed in Table 21.

Summary

In summary, (1) the main effect of subject is shown to be statistically significant for all subtests individually as well as for the central auditory test

TABLE 20

THREE-WAY ANALYSIS OF VARIANCE FOR THE BINAURAL FUSION TEST

Effect	df	MS	F	p
Ear	1	0.25627	2.996	0.090
Level	1	1.38118	16.147	0.001*
Subject	31	0.38823	4.539	0.001*
Ear/Level	1	0.00191	0.022	0.877
Ear/Subject	31	0.55044	6.435	0.001*
Level/Subject	31	0.06009	0.702	0.835

*$p < .001$

TABLE 21

TWO-WAY ANALYSIS OF VARIANCE FOR THE RAPID ALTERNATING SPEECH TEST

Effect	df	MS	F	p
Level	1	0.00933	0.143	0.709
Subject	29	0.29081	4.452	0.001*
Level/Subject	29	0.06532	-----	-----

*$p < .001$

battery in its entirety; (2) the main effect of level is statistically significant for the SSW test, for both Katz' and Lynn and Gilroy's scoring procedures, for the SSI-CCM and the BFT; (3) there is a significant ear effect for the SSW test and the SSI-ICM, with the right ear performing better than the left using Lynn and Gilroy's scoring procedures for the SSW; a more negative score on the right than the left ear using Katz' scoring procedure for the SSW; and the left ear performing better than the right on the SSI-ICM; (4) the interaction effect of ear and subject is statistically significant for the SSW test, using both scoring procedures, the SSI-CCM, the SSI-ICM, BFT, and the MLPF speech test.

CHAPTER V

DISCUSSION

The main purpose of this study has been to explore the effect of cochlear dysfunction on central auditory speech test performance. The first major finding is that cochlear dysfunction does affect central auditory speech test performance. The ability of the cochlea to receive acoustic information and code it into appropriate patterns of neural activity determines the intelligibility of speech. The acoustic patterns provide cues to the perception of speech. The redundancy of these cues permit speech perception to occur even under difficult conditions. Impairment of the peripheral cochlear hearing system, results in reduction of available information for analysis.

To date there is limited information reported as to how cochlear hearing losses per se influence the perception of speech sounds. It has been shown, however, that tuning curves of the primary auditory nerve fibers widen after permanent damage to the hair cells. This widening contributes to impaired frequency discrimination. The question arises as to whether this is due to impaired spectral resolution in the place analyzer or the increase in masking of the temporal analyzer (Møller, 1972).

Linguistic feature analysis takes place in the dominant hemisphere, most frequently the left. Signals arising from a damaged cochlea are already distorted due to peripheral dysfunction. Those types of degradation providing the most linguistic cues will be the least affected by damage to the cochlea.

Dichotic tasks, in this study, showed less effect than monotic tasks, as measured by test performance. More information, thereby providing increased cues, presumably is arriving at the cortical level due to the acoustic input from both ears.

Degradation involving filtering appeared to be more affected than those involving the separation of messages. Filtering reduces spectral redundancy associated with the frequency characteristic of the signal, suggesting that damage to the cochlea interferes with adequate processing of acoustic cues. Despite cochlear involvement, messages degraded by competition provide greater linguistic contrasts than filtered or time-altered speech, thereby reducing the dependency upon the acoustic signal.

The degree of the effect of cochlear dysfunction varies depending upon (1) the choice of the individual test, (2) the presentation level of the test, (3) the undistorted speech discrimination scores of the cochlear impaired individual, and (4) the audiogram configuration.

Choice of Test

The arbitrary selection of a test can affect performance in relation to (1) the type of central auditory test used: dichotic or monotic; (2) the type of speech material used: sentences, spondaic words, or monosyllabic words; (3) the nature of the task: identification or repetition; and (4) the type of degradation used.

Dichotic tests appear to be less affected by cochlear dysfunction than the monotic tests. Further consideration suggests that the central auditory tests used in this study, namely, the Competing Sentence Test, the Synthetic Sentence Test-Contralateral Competing Message, the Synthetic Sentence Test-Ipsilateral Competing Message, the Staggered Spondaic Word Test, the Binaural Fusion Test, the Rapid Alternating Speech Test, and the Monaural Low-Pass Filtered Speech Test, range in their difficulty and are more dependent upon the nature of the task, the type of material and/or the degradation rather than on the presentation mode itself.

The type of material used in the above subtests included sentences, spondaic words, and monosyllabic PB words, with sentences being the most intelligible and spondaic words somewhat less intelligible, and finally with PB words being the most difficult, the latter apparently due to the fewer number of cues available for discrimination. The slope of the articulation function for these three types of material demonstrates these differences. The slope for spondaic words resembles that of sentences, with a rapid rise of intelligibility as a function of intensity and an average slope for selected spondees of 10% per dB over the range between 20 and 80 percent. The slope is less steep for the PB word lists. For example, the NU #6 CNC word lists show a rise in scores for normals from 32% to 74.7% to 91.6% to 97.6% at OdBSL, 8dBSL, 16dBSL, and 24dBSL re SRT, respectively. Sensorineural hearing impaired subjects demonstrate a rise in scores from 19.6% to 51.2% to 73.6% to 87.4% at OdBSL, 8dBSL, 16dBSL, and 24dBSL re SRT, respectively (Tillman and Olsen, 1979). The steeper functions obtained for sentences as compared to monosyllabic words is due to the additional length of the test items and therefore provide an increased number of cues to the listener (Olsen and Matkin, 1979).

The sentences themselves vary from test to test in the mean number of syllables per sentence as well as in their contextual and syntactical difficulty. For example, the SSI-CCM and ICM tests contain an average of 9.0 syllables per sentence; the RASP List A-8.6, List B-8.2, and List C-9.4 syllables per sentence; and the CST-List 1A, 1B, 2A and 2B range from 7.0 to 7.7 syllables per sentence. The competing sentence test consists of simple, natural English sentences that involve message perception; the SSI-CCM and ICM are third word approximations to sentences and the RASP sentences involve message perception made more difficult by the low predictability of their syntax. By selecting central auditory speech tests that employ material that is easily intelligible, either spondaic words or sentences, the effect of cochlear impairment on test performance can be minimized.

The nature of the task also has an effect on performance in that identification is easier than repetition; repetition of sentences is easier than spondaic words, and spondaic words are more intelligible than monosyllabic PB words. The identification tasks used were synthetic sentences in a 10-item closed-message set. The repetition tasks given in order of increasing difficulty, involved open-message sets of sentences, spondees, and monosyllabic words. Closed-message sets limit the number of alternatives available, and, therefore provide an easier task for cochlear impaired subject than the open-set paradigms (Goetzinger, 1978).

The type of degradation used has relevance in terms of performance. Those tasks degraded by filtering decrease spectral cues while these degraded by alternation of stimuli decrease temporal cues. The cochlear impaired individual has a reduction in both spectral and temporal cues imposed by the hearing loss itself, and is unable to compensate for them sufficiently to perform well on filtered or alternating tasks.

Filtered speech provides only limited format frequency changes for identification of low frequency consonant and vowel sounds, and, therefore, taxes and perception of high frequency consonant sounds (Dempsey, 1977). The cues available are not sufficient to enable the subject to compensate for the cochlear defect. Alternation of continuous speech reaches the listener's ears in segments, thereby eliminating the cues available when segments of the speech waveform run together (Green, 1976). Competing messages or separation of messages do not involve a reduction of spectral or temporal cues but rather provide additional cues and increased predictability enabling the cochlear impaired subject to compensate for internal distortion.

Presentation Level

The level of stimulus presentation is another variable that has an effect on the performance of the cochlear impaired subject. Statistically significant differences were found between the presentation levels for the SSI-CCM and for the BFT. On the SSI-CCM subjects performed better at the 30dBSL than at the 20dBSL. For the BFT, subjects performed better at the 40dBSL as compared with the 30dBSL. In both these cases it seems that the amount of spectral cues being provided at the lower sensation levels were not sufficient to enable the cochlear impaired individual to perform optimally. It is reasonable to assume that an increase in presentation level of the SSI-ICM at -10dBMCR from 30dBSL to 40dBSL would have resulted in improved test scores. Olsen and Matkin (1979) suggest that presentation level is a critical variable. In individuals with high frequency sensorineural hearing loss an increase in speech presentation level so that they exceed the pure tone thresholds at 2000Hz results in increased speech discrimination scores. They consider this as support for the contribution of acoustic energy in speech in the 2000Hz frequency region for correct recognition of monosyllabic words.

Presentation level also was a significant factor in relation to the SSW test. According to Katz' scoring procedure a mean score of -8.4% was obtained at 30dBSL while a score of -0.3% was obtained at 50dBSL. Both these scores, however, were negative for central auditory pathology. The only test yielding significantly better scores at a lower presentation level was the SSW as scored using the Lynn and Gilroy procedure. The reason for this remains unclear. Comparison between mean scores was 94.81% at 30dBSL and 91.97% at 50dBSL, indicating that although the higher level yielded better scores, the subjects as a group scored within normal limits at both levels.

Undistorted speech discrimination abilities

A review of the undistorted speech discrimination abilities for each cochlear impaired subject for PB min and PB max scores obtained using PI-PB functions indicated that for the PB max, six ears scored 80% or poorer, three had poorer right ear pure tone audiograms while three had symmetrical hearing losses; for the left ear, four scored 80% or poorer, with two having poorer left ear thresholds and two symmetrical hearing losses. The PB min indicated that 15 right ears scored 80% or poorer while 13 left ears scored 80% or poorer.

The PB scores appear to be related to central auditory speech performance results. In those individuals where speech discrimination abilities were at their poorest at the lowest presentation level (30dBSL), central auditory speech test results obtained at 30dBSL presentation level reflected these poor scores. Consideration should be given to presenting the central auditory speech tests at the level of the PB max so as to obtain optimal performance by the cochlear impaired subject.

Analysis (ANOVA) of the entire central auditory speech test battery at the 30dBSL presentation level revealed significant ear effect at the .05 level with the left ear performing better than the right. Inspection of the pure tone thresholds for the frequencies of 250-8000Hz, indicated that the left ear was more sensitive than the right in 12 of the 18 subjects. The remaining 15 individuals had symmetrical hearing. For undistorted speech discrimination abilities, left ear discrimination was better in 10 of 16 subjects with the remaining 17 subjects having equal discrimination abilities at the 30dBSL re P.T.A. It appears that the significant ear effect in this population was due to the better hearing and speech discrimination abilities of the left ear as compared with the right ear, rather than to an inherent quality of the tests. Examination of the individual subtests suggested significantly better left ear performance than right on the SSI-ICM, -10dBMCR. It is believed that this was partially due to the better hearing for the left ear among this group. Another possible explanation was the test order presentation for the task with the right ear in all instances being the first to receive the initial series of sentences. The degree of (1) the effect of practice, (2) adjusting to the difficulty of the test and/or (3) changes in test strategy on the SSI-ICM scores remains unknown.

Audiogram Configuration

A breakdown of the 33 cochlear impaired audiograms revealed 15 sloping, 9 flat, 6 unilateral-asymmetric, two trough-shaped configurations and one unclassifiable type pattern. The audiogram configuration did not appear to affect performance on the SSI-CCM, the CST, or the RASP. Performance on the MLPF speech task was poor for the majority of individuals regardless of audiogram configuration.

A breakdown of the 15 sloping configurations included five mild, six moderate and four severely sloping curves. The SSI-ICM, -10dBMCR condition appeared to be affected most by this type of configuration, with 10 of 12 individuals performing poorly on this task. It appears that the intensity of the presentation level was insufficient to provide enough acoustic energy in the higher frequency regions to permit optimal performance. On the other hand, the BFT, at 40dBSL did not appear to be affected by the sloping audiogram configuration. This may have been due to the way in which the presentation level was derived. Since the level of presentation was based on the pure tone thresholds at 500Hz and 2000Hz, it therefore provided adequate intensity in the higher frequency regions allowing optimal performance by the cochlear impaired subjects.

For the majority of the individuals with sloping audiogram configurations, the SSW scores, Katz' procedure, were over-corrected. Over-corrected scores are frequently obtained by individuals with cochlear losses.

Of the nine flat audiogram configurations, six were mild and three were moderate. Once again, the SSI-CCM and the CST showed no measurable influence on the performance of this group. The SSW test results did not reveal any unusual test pattern. On the RASP, three individuals with mild flat configurations performed poorly, whereas the remaining six subjects having mild or moderate degrees of loss performed normally. The BFT results indicated that two of the three individuals with moderate and the one subject with a mild flat configuration failed the task. All individuals with flat audiogram configurations failed the SSI-ICM, at the -10dBMCR condition.

The unilateral hearing loss group appeared to do well on all subtests except the BFT, with three of the six subjects failing this task. The two individuals with trough-shaped audiograms did well on all subtests except for one individual who failed the SSI-ICM, -10dBMCR condition in the right ear. The one "other" or unclassifiable configuration did well on all subtests.

Comparison between sloping and flat configurations suggests poorer performance by individuals with flat audiogram configurations on the BFT at both 30 and 40dBSL, the SSI-ICM right ear at MCR 0 and -10dB, and on the RASP at 40dBSL. Performance on the SSI-CCM at 20dBSL and for the CST at 25dBSL, left ear was somewhat poorer for those with flat as compared to sloping configurations.

Poorer performance by individuals with sloping configurations was noted on the SSW test, Katz' scoring procedure at 50dBSL for right and left ears, at 30dBSL for the left ear and for Lynn and Gilroy's scoring procedure at 30dBSL for the right and left alternating and simultaneous conditions, the RASP at 30dBSL, and the SSI at MCR at -10dB for the left.

On the whole, flat audiogram configurations did more poorly as a group than other configurations. Two possible explanations include (1) an upward spread of masking from the low frequency sounds which resulted in decreased discriminability, and (2) insufficient intensity to discriminate the sounds. Audiogram configuration, and not degree of hearing loss, appeared to affect overall performance with flat configurations yielding the poorest scores.

The second major purpose of this study centered on determining which central tests are maximally affected by concomitant cochlear disorder. The cochlear dysfunction effect appears to be greater for those tasks designed to challenge the lower levels in the central auditory system, namely, brainstem integrity, than for those used to assess the higher levels involving cortical integrity. Those tests maximally affected by concomitant cochlear disorder were (1) monotic tests, where repetition had a greater effect on performance than did identification and (2) filtered tests, in which filtering the signal had a greater effect on performance than did competing message tasks. Factors apparently contributing to the poor performance obtained on the monotic low-pass filtered speech test included the open-response paradigm utilizing monosyllabic words complicated by the low-pass filtering, a type of degradation for which cochlear impaired subjects appear to have great difficulty compensating.

The SSI-ICM is a monotic identification test using a competing message. At an MCR of -10dB the competing message is more intense than the primary message. During the presentation of this task, the right ear always received the items before the left. The cochlear impaired subjects performed significantly poorer on the right ear than the left, with the mean percent correct of 63.44 for the right, as compared with 76.89% for the left. The relation of practice to improve test performance by the cochlear impaired for this task should be considered. These results suggest that practice on this task may contribute to optimal performance by cochlear impaired subjects. Whether increasing the presentation level from 30 to 40dBSL re P.T.A. would have influenced the scores significantly remains unclear.

The rapid alternating speech test, a dichotic repetition task, also was affected to a great extent by the cochlear impairment. The alternation of continuous speech eliminates temporal cues available when segments of the speech waveform run together. The cochlear dysfunction itself causes a reduction in the temporal cues being received.

The central auditory speech tests that are minimally affected by concomitant cochlear dysfunction were the dichotic competing message tasks which involved the individual's ability to separate messages. The SSI-CCM, an identification task using sentences, was the least affected followed by the competing sentence test which combines the use of sentences with a repetition task, followed by performance on the SSW test, a repetition task using spondaic words.

The binaural fusion test, a dichotic test involving resynthesis, was minimally affected by the cochlear dysfunction at the 40dBSL presentation level.

Inspection of the data suggests that the level of performance on the central auditory speech tests is related to the level of the auditory site for which the tests were intended. The level of performance was highest for those tests designed primarily for the evaluation of cortical lesions including temporal lobe lesions, deep parietal lobe lesions, interhemispheric dysfunction, and vascular and degenerative lesions; that is the SSI-CCM, the CST, and the SSW.

The lower the site of the auditory lesion for which the tests were intended, the poorer the test performance. The RASP, which is intended for assessing (1) binaural integration functions believed to be mediated in the pons, especially the caudal region and (2) for assessing breakdown in brainstem processing yielded poorer performance scores than all other tests of cortical integrity. The SSI-ICM, which is primarily intended for assessing low brainstem lesions also yielded poor performance scores.

<u>Other variables</u>

Variables examined that did not appear to affect the performance by the cochlear impaired subjects on the central auditory speech tests included: (1) symmetry between ears, (2) degree of hearing loss, (3) etiology, (4) age, (5) sex, and (6) test order presentation.

Of the 33 cochlear impaired subjects, 15 had symmetrical hearing losses: of the 18 individuals demonstrating asymmetrical losses, 12 had poorer thresholds in the right while six had poorer hearing in the left ear. Failure to perform well on dichotic and/or monotic tasks did not appear to be influenced by symmetrical or the lack of symmetrical audiogram configurations.

The degree of hearing loss as measured by pure tone audiometry did not appear to affect overall performance. The combined effects of audiogram configuration and undistorted speech discrimination abilities seemed to affect test performance rather than the degree of hearing loss itself.

The effect of etiology on central auditory speech test performance was explored. Breakdown by etiology included eight congenital hearing losses, eight with endolymphatic hydrops, nine with acoustic trauma, four with noise-induced hearing losses, two with viral disorder, and two with ototoxic loss. All etiological groups scored well on the SSI-CCM and the CST, while all scored poorly on the MLPF speech task. Etiology did not seem to affect performance on the SSI-ICM, with all groups experiencing difficulty with the task. Performance on the SSW and the RASP did not differentiate among the groups. Scores on the BFT indicated good performance by the acoustic trauma and congenital etiologies, whereas the endolymphatic hydrops group experienced some difficulty. In summary, performance on the individual subtests did not appear to distinguish among the various etiologic groups in any consistent manner.

The age range of subjects was 18 to 58 years with a mean age of 43.06 years; there were 15 females between 18 and 58 years and a mean age of 42.96 years; and 18 males between 27 and 57 years, and a mean of 43.27 years. Central auditory speech test performance did not appear to be significantly influenced by either the age or the sex of the subject.

Seven different test order presentations were used. No specific test order appeared to influence overall performance on the test battery. However, as previously mentioned, the SSI-ICM, -10dBMCR condition was always presented to the right ear first, which appeared to be related to performance on this task.

Comparison to other studies

This study supports the statement by Calearo and Antonelli (1968) that the use of sentences for the evaluation of central auditory functioning is possible despite tone deficits. Central auditory tasks using sentence material were minimally affected by the peripheral cochlear dysfunction as compared with monosyllabic words.

Korsan-Bengtsen (1973), reporting on the effects of peripheral hearing loss on a battery of Swedish distorted speech tests, noted a difference in performance based on etiology, with congenital hearing loss subjects scoring similar to normal hearing subjects, and significantly better than the acquired sensorineural hearing loss group. The current study did not find a significant difference in performance among the various etiologic groups. This may be explained on the basis of (1) inherent differences between the Swedish and English languages, (2) choice of the type of degradation used, and (3) the difference in composition between the acquired etiologic groups.

Roeser, Johns, and Price (1976) reported on the difference between normal hearing individuals and those with bilaterally symmetrical sensorineural hearing loss on two dichotic listening tasks. Their findings suggest significantly poorer performance by the hearing loss subjects as compared to normal hearing individuals on the dichotic digit task and CV nonsense syllable test. There was a difference of 24% between the normals and the peripheral hearing loss group on dichotic digit test and an 18% difference between the groups on the CV nonsense syllable test. The authors noted that performance and degree of hearing loss were related with the mean number of correctly repeated stimuli decreasing significantly on both tests as the degree of hearing loss increased. They related the overall level of performance to the monaural speech discrimination scores but suggested that this relationship needed further study.

In the current study the degrees of hearing loss did not significantly affect performance on the central auditory speech test battery; however, monaural undistorted speech discrimination scores did have an appreciable effect on performance. This difference may be attributed to (1) choice of central auditory test, (2) presentation level of the tests, and (3) audiogram configuration. Roeser et al (1976) used a dichotic digit task and a CV nonsense syllable task, both of which resulted in decreased scores for normal hearing subjects as well as for sensorineural hearing loss subjects. The tests were presented at only one level of 30dBSL re S.R.T. No attempt was made to control for audiogram configuration. All three of these variables have been demonstrated to affect central auditory speech test performance in the present study.

Winkelaar and Lewis (1977) included in their study one case with bilateral sensorineural hearing loss, mild to profound sloping audiogram configuration, mixed cochlear and central pathology. The central dysfunction was due to a tumor deep in the left thalamic region. This case demonstrated abnormal scores on the CST of 70% with the right ear receiving the competing message and of 60% with the left ear receiving the competing message, an abnormal score of 50% on the RASP, and an abnormal score in the right ear of 30% error on the SSW test.

Comparison of these scores to mean scores obtained in this study, suggest difference scores of 25.31% for the right and 35.62% for the left ear for the CST; 29.37% for the RASP; and 28% for the SSW test. These difference scores support the suggestion that central auditory speech tests can be used to differentiate between concomitant peripheral and central dysfunction.

Miltenberger, Dawson, and Raica (1978) using a central auditory test battery including the CST, MLPF, BFT, and RASP, reported on findings with 70 sensorineural hearing loss subjects. Sixteen of the 70 (22.85%) scored within normal limits on the entire test battery. Of the remaining 54 subjects, 43 failed the MLPF task. Twelve of the 70 subjects (17.14%) failed the CST; 17 subjects (24.28%) failed the BFT, and 15 subjects (21.42%) failed the RASP.

Comparison with the present study is not possible for the following reasons (1) pure tone audometric results indicated hearing well within normal limits at 250-2000Hz, with varying degrees of hearing loss at 4000-8000Hz; (2) actual scores obtained by the individual subjects or the subjects as a group were not included; neither mean scores nor a range of scores were presented; (3) degree of hearing loss was not included, (4) audiogram configuration data were not included, (5) undistorted speech discrimination scores as well as PB max scores were not included, and (6) level of presentation of the test stimuli was not included. Despite all these differences, it was interesting to note that the twelve individuals (17.14%) who failed the CST was much larger than the number who failed the CST in the present study; 1 of 33 (3.12%), at the 25dBSL presentation level and 4 (12.12%) at the 35dBSL presentation level. The reason for this remains unclear especially since pure tone audiometric results from the Miltenberger et al study were so much better than those in the present study.

Interpretation of central auditory speech test scores

The question arises as to the interpretation of central auditory speech test scores with the cochlear impaired individual. Comparison of scores between individuals with normal peripheral hearing and those with cochlear impairments on each of the central auditory subtests suggests the following:

1. For the SSI-CCM, at the standard presentation level of 30dBSL, none of the 33 subjects failed, while at 20dBSL one of the 33 (3.03%) failed. One individual would have scored at non-standard level.

2. For the CST, at the standard presentation level, four of the 33 subjects (12.12%) failed and would have been misdiagnosed; however, at 25dBSL only one individual failed.

3. For the SSW, Katz' scoring procedure, using half-lists, three of the 33 subjects (9.09%) would have failed at 30dBSL while at 50dBSL, six of 26 (23.07%) would have failed.

4. Using Lynn and Gilroy's scoring procedure for the SSW, eight of 33 (24.24%) would have failed at 30dBSL while nine of 26 (27.27%) would have failed at 50dBSL.

5. For the RASP test, nine or 32 (28.12%) at 30dBSL and 11 of 31 (35.48%) at 40dBSL would have performed

below reported norms.

6. For the BFT using Willeford's norms, 21 of 33 (63.63%) failed at 30dBSL, while 17 or 32 (53.12%) failed at 40dBSL.

Using Miltenberger's norms, at 30dBSL, 16 of 33 (48.48%) as compared with six of 32 (18.75%) at 40dBSL would have failed.

7. For the SSI-ICM at OdBMCR, 30dBSL eight of 33 (24.24%) as compared with three of 16 (18.75%) at 20dBSL would have failed while at -10db MCR, 20 of 25 (80%) would have failed.

8. For the MLPF at 50dBSL, using Willeford's norms, 28 of 32 (93.33%) as compared with 33 of 33 (100%) at 30dBSL would have failed.

Failure on these tests is interpreted as consistent with a diagnosis of central auditory disturbance.

Based on the mean scores obtained for the central auditory speech tests by the cochlear impaired individuals as compared with normal hearing subjects and those with central auditory dysfunction, a table of difference scores is suggested. The concept of difference scores is not new. It was used by Goetzinger (1972) in comparing performance between the W-22 word lists and the Rush-Hughes word lists to evaluate central auditory functioning. Use of the D/S table is suggested as an attempt to reduce the number of false positives (i.e., cochlear impaired individuals who would have failed the central auditory speech tests) and whose performance therefore would have been consistent with a diagnosis of central auditory disorder.

CHAPTER VI

SUMMARY, FINDINGS, RECOMMENDATIONS, AND IMPLICATIONS FOR FUTURE RESEARCH

The major purpose of this study was to explore the effect of cochlear dysfunction on central auditory speech test performance. Thirty-three subjects, 15 males and 18 females, ranging in age from 18-58 years of age, all with sensorineural hearing loss medically diagnosed to have cochlear site of lesions, were evaluated using a central auditory speech test battery consisting of the following tests: the Competing Sentence Test, the Synthetic Sentence Identification Test-Contralateral Competing Message, the Synthetic Sentence Identification Test-Ipsilateral Competing Message, the Staggered Spondaic Word Test, the Binaural Fusion Test, the Rapid Alternating Speech Test, and the Monaural Low-Pass Filtered Speech Test.

Summary of Findings

1. Cochlear dysfunction has an effect on central auditory speech test performance. The degree of the effect varies with the following: (a) choice of test, (b) presentation level of the test, (c) the undistorted speech discrimination scores of the cochlear impaired subject, (d) the audiogram configuration, and (e) presentation mode of the test.

2. The level of performance on the central auditory speech tests is related to the level of the auditory site

for which the tests are intended. (a) The level of performance was highest for those tests designed primarily for the evaluation of cortical functioning; that is the SSI-CCM, the CST, and the SSW test. (b) The lower the level of the auditory lesion for which the tests are intended, the poorer the level of performance; these tests include the BFT, the RASP, the SSI-ICM, and the MLPF.

3. The central auditory speech tests which were minimally affected by concomitant cochlear disorder were (a) the CST, (b) the SSI-CCM, and (c) the SSW test. Identification and repetition tasks involving sentence material or spondiac words minimized the effect of cochlear dysfunction.

4. The cochlear impaired subjects as a group are able to perform within the range of normal according to reported norms for the following tests with some qualifying conditions: (a) the CST, (b) the SSI-CCM, (c) the SSI-ICM, MCR OdB condition, right and left ears; MCR - 10dB condition, left ear only, (d) the SSW test, Katz' scoring procedure, (e) the BFT at the 40dBSL presentation level, and (f) the RASP at the 40dBSL presentation level.

5. All tests, with the exception of the CST, demonstrated a wide range of variability in performance.

6. Abnormal test performance by the cochlear impaired subjects on the CST, the SSI-CCM, and the SSW should be considered a reflection of the central auditory system dysfunction and not the peripheral cochlear system.

7. Abnormal performance on the SSI-ICM, 0dB MCR and -10dB MCR conditions, the RASP, and the BFT, as currently administered cannot be interpreted as reflecting central auditory system disturbance; however, normal performance on these tasks will help rule out central auditory dysfunction.

Recommendations

1. Tests should be administered at the level of PB max.

2. On the basis of these test results and comparison with existing data, the SSW test should be administered in its entirety, rather than half-lists, and scored according to Katz' procedures in order to obtain the most complete information with regard to central auditory functioning. The use of half-lists with the cochlear impaired subjects appears to yield more severely over-corrected categories than when full lists are used. In addition, the value of the response biases in determining site of lesion is lost if half-lists are used.

3. Any cochlear impaired subject with pure tone thresholds no greater than 60dBSL in combination with an undistorted PB max of 60% or better, and between the ages of 18 and 58 years, may be considered a candidate for central auditory speech testing using the proposed battery.

4. Practice items should be presented prior to the SSI-ICM and the RASP tests.

5. Based on those investigated in this study, the

following central auditory speech test battery is recommended: (a) the competing sentence test, at presentation level of 35dBSL re P.T.A., (b) the SSI-CCM at MCR -40dBHL where thresholds permit at a presentation level of 30dBSL, (c) the SSW test, 160 items, using Katz' scoring procedures at a presentation level of 50dBSL where thresholds permit, (d) the binaural fusion test at a presentation level of 40dBSL re the 500Hz and 2000Hz pure tone air conduction thresholds.

6. The following tests may be used with certain modifications: (a) Rapid Alternating Speech Test. Performance equivalent to that of subjects with normal peripheral hearing will help rule out brainstem pathology; failure on the test cannot be interpreted with confidence as positive for brainstem pathology; (b) Synthetic Sentence Identification Test-Ipsilateral Competing Message. The use of the SSI-ICM at OdBMCR is possible; but unless the central auditory pathology is extensive and the individual scores abnormal at the OdBMCR condition, the SSI-ICM will not contribute additional diagnostic information. Interpretation of abnormal scoring by the cochlear impaired individual as signifying brainstem pathology at the -10dBMCR condition is not possible. The use of practice items is suggested in view of the better performance by the cochlear impaired subjects on the SSI-ICM, -10dBMCR condition for the left ear, which was always presented after the right ear in this study; (c) Monaural low-pass filtered speech.

This procedure should not be used in its present form with cochlear impaired subjects because mean scores on this test are poorer than those obtained by individuals with central auditory impairment and, therefore, have no diagnostic significance.

7. It is suggested that difference scores be used to compare the performance of the cochlear subjects to normal hearing individuals and to individuals with central auditory impairments as an aid in interpreting subject performance on the central auditory test battery.

8. In addition to central auditory speech test results, results obtained from a peripheral battery of test procedures (i.e., Bekesy audiometry, SISI, tone decay tests, recruitment tests, and acoustic impedance measurements) should be considered in the evaluation of the cochlear impaired subject. Frequently, this test battery will provide additional information which will be useful in arriving at an accurate diagnosis.

Implications for future research

1. The results of this study should be compared with the performance of a group of individuals with cochlear dysfunction and concomitant central auditory dysfunction.

2. The effect of practice items on overall central auditory speech test performance by the cochlear impaired subjects should be explored further.

3. The use of additional central auditory speech

tests using sentence identification or repetition tasks with other types of degradation on a cochlear impaired population should be explored: these should include time-compression and filtering.

4. Test performance by the cochlear impaired subjects on central auditory speech tests should be compared to results obtained using electrophysiolgic techniques, including ABR (auditory brain response).

5. The use of the difference score table should be further explored and refined with populations having cochlear dysfunction, central auditory dysfunction, and a combination of the two pathologies.

6. Qualitative analysis of errors made by individuals with confirmed central auditory lesions, those with cochlear lesions, and those with concomitant cochlear and central dysfunction should be conducted. Based on these findings, modified scoring procedures should be considered.

7. Aside from examining the various types of degradation, an analysis of the acoustic characteristics of the signal should be performed. Such an analysis might lead to an increased understanding of the way in which the disordered auditory system perceives specific acoustic inputs, and thereby might serve to enhance our further understanding of the nature of normal auditory processing.

APPENDICES

APPENDIX A

SEX AND AGE OF THE COCHLEAR IMPAIRED SUBJECTS

SEX AND AGE

FEMALES N=15		MALES N=18	
AGE	CASE	AGE	CASE
18 Years	#23	27 years	#18
28	#2	27	#24
29	#6	28	#21
32	#12	28	#27
35	#29	30	#33
40	#1	43	#22
43	#5	44	#9
45	#10	45	#30
48	#28	45	#31
49	#3	47	#32
50	#20	48	#7
54	#25	48	#8
57	#11	49	#16
57	#15	52	#26
58	#4	53	#17
		53	#19
		55	#14
		57	#13

MEAN: 42.86 years
RANGE: 18-58 years

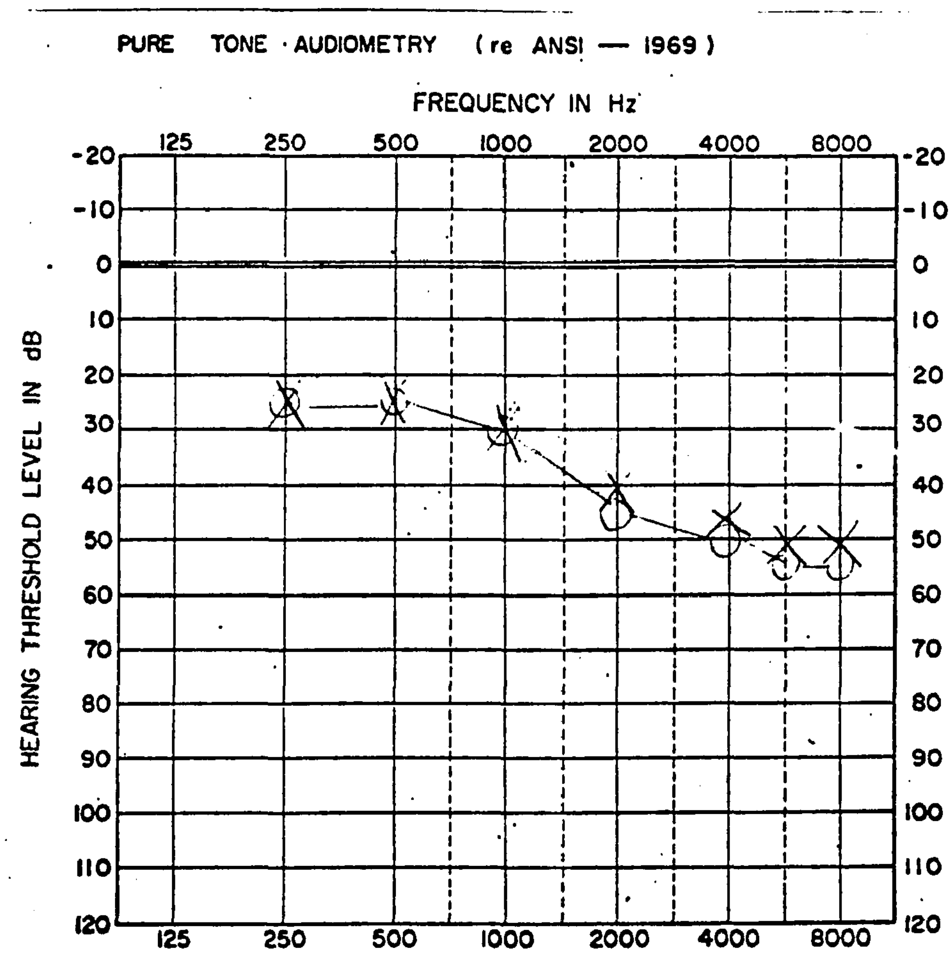
MEAN: 43.27 years
RANGE: 27-57 years

TOTAL MEAN: 43.06 years
TOTAL RANGE: 18-58 years

APPENDIX B

COMPOSITE AUDIOGRAM FOR THE THIRTY-THREE COCHLEAR IMPAIRED SUBJECTS

COMPOSITE AUDIOGRAM FOR 33
COCHLEAR IMPAIRED SUBJECTS



APPENDIX C

AIR CONDUCTION THRESHOLDS FOR THE THIRTY-THREE COCHLEAR IMPAIRED SUBJECTS, IN db RE: AUDIOMETRIC ZERO (ANSI 1969)

AIR CONDUCTION THRESHOLDS FOR THE 33 COCHLEAR IMPAIRED SUBJECTS

	FREQUENCY IN Hz: Right Ear							FREQUENCY IN Hz: Left Ear						
#	250	500	1000	2000	4000	6000	8000	250	500	1K	2K	4K	6K	8K
4	20	20	30	50	60	60	65	10	20	35	45	50	55	60
2	10	10	30	40	30	35	35	10	10	30	40	35	40	40
9	10	10	20	30	45	50	70	10	10	20	35	50	65	70
11	20	20	35	40	45	55	65	25	25	45	50	60	55	65
19	30	45	50	60	45	50	80	20	20	40	55	50	40	35
21	10	15	10	50	70	50	30	20	15	15	25	15	50	40
14	20	20	30	50	60	65	65	10	20	30	55	70	80	65
15	10	15	20	35	40	50	45	10	15	25	60	55	65	70
18	25	30	30	60	60	55	60	25	25	35	70	65	50	45
8	15	25	20	45	65	75	60	10	10	15	10	60	50	60
17	5	5	15	60	80	85	70	15	15	20	55	75	65	60
22	10	15	25	85	85	90	80	20	20	20	70	70	75	75
26	25	20	25	60	95	85	70	30	20	20	25	70	70	80
13	15	10	10	35	55	60	55	20	10	15	45	70	80	75
33	25	35	30	35	50	90	(NR)	0	5	5	10	20	30	60
23	45	30	25	25	40	35	45	20	15	0	5	5	30	15
3	55	50	40	45	35	30	35	20	15	10	15	15	20	5
10	55	50	50	55	55	50	50	20	10	10	15	30	30	15
7	60	70	70	65	60	65	60	10	15	15	5	5	15	40
24	15	10	5	0	0	5	0	70	65	60	55	40	45	55
16	10	15	25	30	50	60	70	10	20	25	35	60	65	60
32	20	15	15	10	20	30	20	30	25	10	10	30	60	50

	FREQUENCY IN Hz: Right Ear							FREQUENCY IN Hz: Left Ear						
#	250	500	1000	2000	4000	6000	8000	250	500	1K	2K	4K	6K	8K
29	40	45	50	60	60	70	60	20	35	30	30	35	35	40
6	30	30	10	30	40	45	60	30	20	15	30	40	60	60
30	20	25	15	25	60	50	60	10	20	10	30	40	35	35
20	20	20	25	40	55	45	60	20	20	20	40	55	45	60
5	30	35	40	45	40	35	30	25	30	35	40	40	35	20
28	25	30	45	45	70	75	80	25	35	45	45	60	65	70
25	45	45	45	50	65	65	60	50	50	55	55	70	70	65
27	45	50	55	60	50	70	65	45	45	50	55	60	65	80
1	50	40	55	55	20	0	10	35	50	65	50	20	10	5
12	35	50	60	50	30	20	10	40	55	65	70	55	25	10
31	25	10	10	10	30	35	45	40	15	10	20	75	75	70

APPENDIX D

PI-PB FUNCTION SCORES FOR THE

THIRTY-THREE COCHLEAR IMPAIRED

SUBJECTS

PI - PB FUNCTIONS: TEST SCORES AND MEAN

	RIGHT EAR					LEFT EAR				
CASE	60db	70db	80db	90db	MEAN	60db	70db	80db	90db	MEAN
2	92	72	88	84	84.0	88	72	80	90	82.5
4	56	76	-	56	62.66	72	80	56	-	69.33
9	84	84	88	-	85.33	100	100	100	-	100
11	-	80	100	100	93.33	0	80	92	96	89.33
8	76	72	84	88	82.18	76	88	88	100	88.0
14	-	92	92	92	92.0	-	92	96	100	96.0
18	-	88	88	96	90.66	-	92	88	92	90.66
21	76	84	76	80	79.0	96	88	100	100	96.0
15	92	92	96	88	92.0	56	64	68	68	64.0
19	-	76	80	92	82.66	-	84	96	88	88.33
13	88	88	92	-	89.33	72	88	76	-	78.66
17	68	88	76	84	79.0	44	68	92	92	74.0
22	-	36	56	44	45.33	-	76	88	88	84.0
26	-	68	88	92	82.66	-	76	88	88	84.0
16	96	100	100	100	99.0	100	100	100	88	84.0
24	100	100	100	100	100	-	-	36	68	52.0
7	-	-	28	56	42.9	100	96	100	92	97.0
3	100	100	100	88	97.0	96	100	100	88	96.0
10	-	56	64	64	61.3	100	100	100	100	100
23	84	96	100	100	95.0	100	100	100	100	100
33	-	100	100	100	100	100	100	100	100	100
5	-	56	60	72	62.66	-	80	72	72	74.66
6	100	100	96	96	98.0	96	92	92	92	93.0
20	76	88	92	92	87.0	94	92	92	92	92.5
29	-	84	88	88	86.66	-	88	84	84	85.33

	RIGHT EAR				LEFT EAR			
	60DB	70DB	80DB	90DB	60DB	70DB	80DB	90DB
#30	96%	96%	96%	97%	100%	100%	100%	100%
#32	100%		96%	98%	100%		96%	98%
#25		80%	84%	86.66%		88%	88%	89.33%
#27		88%	84%	86.0%		96%	88%	90.06%
#28	64%	64%	60%	62.88%	92%	88%	80%	86.66%
#12		96%	100%	98%		80%	88%	84%
# 1			100%	100%		100%	100%	100%
#31	100%		100%	100%	96%		96%	96%

MEAN RE: 86.65

SD = 14.81

MEAN LE: 85.57

SD = 11.60

TOTAL: 86.11

APPENDIX E

INDIVIDUAL RAW SCORES OBTAINED FOR EACH CENTRAL AUDITORY SPEECH TEST

COMPETING SENTENCE TEST: NORMS 80 - 100%

	35SL		25SL			35SL		25SL	
CASE	RE	LE	RE	LE	CASE	RE	LE	RE	LE
#23	100	100	100	100	#18	100	100	100	100
# 2	100	100	100	80	#24	70*	80*	0*	90*
# 6	100	70	100	80	#21	100	100	100	100
#12	100	100	90	100	#27	100	80	90	100
#29	50	70	90	60	#33	100	100	100	100
# 1	100	100	100	100	#22	60	90	80	100
# 5	100	90	100	100	# 9	100	90	100	90
#10	60	100	90	100	#30	100	100	100	100
#28	100	100	100	100	#31	100	100	100	100
# 3	100	100	100	100	#32	100	100	100	100
#20	100	100	100	100	# 7	80	100	100	90
#25	100	100	100	100	# 8	100	100	100	100
#11	100	90	90	100	#16	100	100	100	100
#15	100	80	100	90	#26	100	100	100	100
# 4	100	100	100	100	#17	100	100	100	100
					#19	100	100	100	100
					#14	100	100	100	100
					#13	100	100	100	100

*#24 SL20

SSW CORRECTED EAR SCORES - KATZ' PROCEDURE
SCORES ARE IN PERCENT ERROR

	30dBSL		50dBSL	
Case	Right	Left	Right	Left
23	0	0	0	0
2	1.0	6.0	1.0	1.0
6	2.5	8.5	11.0	4.5
12	-4.0	1.0	2.5	-1.5
29	-5.0	-5.0	-6.0	-7.0
1	5.0	0	2.5[a]	10.0[a]
5	-44.0	-15.0	-7.5	-13.0
10	30.0	0	15.0[a]	5.0[a]
28	-33.5	4.5	-17.5	-7.5
3	5.0	100	0 [a]	6.0[a]
20	-16.0	-19.0	-8.0	-.5
25	-1.0	10.5	11.0	32.0
11	-17.5	-12.5	17.5	2.0
15	-10.0	-43.5	4.5	-22.0
4	-16.5	-17.5	-17.5	-31.5
18	-12.0	-8.0	8.5	-5.5
24	3.2	-20.7	-2.0[a]	-17.0[a]
21	7.5	-19.0	5.0	-6.5
27	-8.5	-7.0	-6.0[a]	3.0[a]
33	0	0	0	0
22	-54.0	-10.0	-41.0	38.0
9	-11.0	7.5	-10.0	20.0
30	-1.5	2.5	-1.5	5.0
31	5.0	5.0	0	-4.0
32	-1.5	-4.0	7.5	0
7	-41.5	7.5	-41.5[a]	5.0[a]
8	-21.5	-1.5	-8.5	-16.5
16	0	0	5.0	2.5
26	-29.5	17.0	-.5	30.0
17	-9.5	-48.5	-11.5	19.5
19	-15.0	-2.5	-0.5[a]	13.5[a]
14	-2.5	12.5	-7.5	11.0
13	-12.5	-15.5	3.0	-8.0

[a] Tests presented at other SL's due to degree of hearing loss; Cases 27, 19, 10 and 1 received SL 40dB; 7 and 24, SL 30dB; and 3, 35dBSL

SSW TEST SCORES - LYNN AND GILROY'S PROCEDURE
SCORES ARE IN PERCENT CORRECT

CASE	30dBSL RIGHT ALT.BIN.	30dBSL RIGHT SIM.BIN	30dBSL LEFT ALT.BIN.	30dBSL LEFT SIM.BIN	50dBSL RIGHT ALT.BIN.	50dBSL RIGHT SIM.BIN	50dBSL LEFT ALT.BIN	50dBSL LEFT SIM.BIN.
23	100	100	100	100	100	100	100	100
2	95	100	100	80	100	90	95	85
6	100	95	90	85	95	75	100	80
12	100	100	100	90	100	95	100	95
29	90	95	95	90	90	90	100	90
1	100	90	100	100	100	95	95	85[a]
5	100	100	100	90	100	80	90	80
10	100	100	55	45	95	95	70	60
28	100	95	95	80	85	70	95	80
3	100	90	100	90	100	100	95	85[a]
20	100	100	100	90	100	100	100	85
25	85	85	80	75	90	80	65	55
11	100	95	90	95	85	80	95	85
15	100	80	100	90	95	80	95	85
4	95	90	100	95	85	50	90	85
18	100	100	100	100	85	90	100	95
24	100	80	100	80	95	85	95	75[a]

[a] Tests presented at other SL's due to degree of hearing loss; Cases 27, 19, 10 and 1 received SL 40db; 7 and 24 SL 30db; and 3, SL 35 db.

CASE	30dBSL RIGHT ALT.BIN	30dBSL RIGHT SIM.BIN	30dBSL LEFT ALT.BIN	30dBSL LEFT SIM.BIN	50dBSL RIGHT ALT.BIN	50dBSL RIGHT SIM.BIN	50dBSL LEFT ALT.BIN	50dBSL LEFT SIM.BIN
21	95	85	95	95	90	75	100	95
27	95	90	95	95	95	90	95	75[a]
33	100	100	100	100	100	100	100	100
22	95	85	70	50	90	80	70	30
9	95	95	100	85	90	70	90	70
30	100	95	100	95	100	95	90	95
31	100	95	100	95	100	100	100	100
32	100	95	100	95	95	90	100	100
7	95	100	100	85	85	95	100	95[a]
8	95	95	85	70	90	95	95	85
16	100	100	100	100	100	90	100	95
26	100	95	65	85	100	90	90	80
17	80	75	95	85	90	85	80	65
19	100	85	95	80	95	90	85	80[a]
14	100	95	95	75	100	85	90	75
13	100	75	85	90	90	80	85	75

[a] Tests presented at other SL's due to degree of hearing loss; Cases 27, 19, 10 and 1 received SL 40db; 7 and 24 SL 30db; and 3, SL 35db.

SYNTHETIC SENTENCE IDENTIFICATION TEST; CONTRALATERAL COMPETING MESSAGE: NORMS 80 - 100% 0 TO -40 MCR. SCORES FOR -40MCR

	30SL		20SL			30SL		20SL	
	RE	LE	RE	LE		RE	LE	RE	LE
#23	100	100	100	100	#18	100	100	100	100
# 2	100	100	100	100	#24	100	100	80	100
# 6	100	100	100	100	#21	100	100	100	100
#12	100	100	100	100	#27	100	100	100	100
#29	80	100	100	100	#33	100	100	100	100
# 1	100	100	100	100	#22	100	100	100	100
# 5	100	100	100	100	# 9	100	100	100	100
#10	100	100	100	--	#30	100	100	100	100
#28	100	90	60	40	#31	100	100	100	100
# 3	100	100	100	100	#32	100	100	100	100
#20	100	100	100	100	# 7	90	100	90	100
#25	100	100	100	100	# 8	100	100	100	100
#16	100	100	100	100	#16	100	90	100	100
#11	100	100	100	100	#26	100	100	100	100
#15	100	100	100	100	#17	100	90	100	100
# 5	100	100	100	100	#19	100	100	100	100
					#14	100	100	100	100
					#13	100	100	90	90

SYNTHETIC SENTENCE IDENTIFICATION TEST: IPSILATERAL COMPETING MESSAGE: NORMS MCR 0 - 80 - 100%, MCR -10 70 - 90% AT 30SL

	RIGHT EAR				LEFT EAR			
	30SL OMCR	30SL -10MCR	20SL OMCR		30SL OMCR	30SL -10MCR	20SL OMCR	
#23	100	70	80		100	90	100	
# 2	80	60	100	(-10) 40SL	100	90	100	
# 6	70	50	100	(+10)	70	70	100	(+10)
#12	100	70	100		100	80	100	(25SL)
#29	90	70	90	(40SL)	80	40	80	
# 1	100	40	100	(40SL)	100	70	100	(30SL)
# 5	70	40	100	(+10)	100	80	80	
#10	60	50	100	(+10)	100	80	100	
#28	30	100 (+10)	60		90	100(+10)	90	
# 3	100	100	90	(-20SL)	90	80	90	
#20	100	60	100		90	70	100	
#25	90	60	100	(+10)	80	50	100	(+10)
#11	100	60	90		80	60	100	
#15	90	70	40	(-20)	90	60	40	(-20)
# 4	90	100 (+10)	60		60	100(+10)	50	

SYNTHETIC SENTENCE IDENTIFICATION TEST; IPSILATERAL COMPETING MESSAGE: NORMS MCR 0 80 - 100%, MCR -10 70 - 90%

	RIGHT EAR			LEFT EAR		
	30SL OMCR	30SL -10MCR	20SL OMCR	30SL OMCR	30SL -10MCR	20SL OMCR
#18	80	50	90(40SL)	90	70	80(40SL)
#24	90	90	90	70	90	100
#21	100	90	100	100	60	100
#27	100	60	100	100	100	100
#33	100	100	100	100	80	100
#22	20	100(+10)	20	70	100(+10)	50
# 9	80	70	100(+10)	90	50	100(+10)
#30	100	50	100	100	90	100
#31	100	70	100	90	70	80
#32	100	50	100	100	90	80
# 7	100	70	30(-20)	90	100	90(-20)
# 8	90	70	90	80	100	100
#13	90	50	70(40SL -10)	90	80	90(-10 40SL)
#26	90	40	90	100	100	100
#17	70	100(+10)	100	100	100(+10)	80
#19	100	60	80	100	70	100
#14	90	40	80	90	60	80
#16	90	80	30(-20)	90	100	80(-20)

BINAURAL FUSION TEST: NORMS - 60 - 100% MILTENBERGER ET AL
75 - 100% WILLEFORD

SCORE REPRESENTS EAR RECEIVING LOW PASS SEGMENT

	30SL RE	30SL LE	40SL RE	40SL LE
#23	10	70	50	70
# 2	100	80	100	100
# 6	90	70	100	70
#12	30	40	90	60
#29	60	90	60	100
# 1	40	90	80	90
# 5	70	40	90	40
#10	0	90	20	90
#28	90	20	90	60
# 3	30	100	70	100
#20	100	50	100	70
#25	50	40	100	50
#11	80	80	90	80
#15	80	90	80	100
# 4	90	90	90	90

	30SL RE	30SL LE	40SL RE	40SL LE
#18	80	90	70	90
#24	70	10	80	40
#21	80	80	90	70
#27	60	40	80	50
#22	100	40	90	70
#33	70	90	90	100
# 9	100	80	100	100
#30	100	70	80	90
#31	100	50	100	60
#32	100	60	90	80
# 7	80	90	50	20
# 8	60	90	80	100
#16	100	90	90	100
#26	100	20	90	60
#17	90	100	80	80
#19	50	90	60	90
#14	100	80	90	100
#13	90	100	80	90

RAPID ALTERNATING SPEECH TEST: NORMS 80 - 100%

	30SL	40SL	20SL		30SL	40SL	20SL
#23	50	70	60	#18	100	90	90
# 2	90	90	80	#24	100	100*	100
# 6	90	100	100	#21	90	80	80*
#12	100*	90	100	#27	90	100	90
#29	50	70	80	#33	100	100	100
# 1	90	90	80*	#22	50	20	40*
# 5	50	70	90*	# 9	80	80	80*
#10	90	60	--	#30	100	90	90
#28	80	60	70	#31	90	100	80
# 3	90	100	100	#32	90	90	100
#20	60	70	70	# 7	100	--	100
#25	80	90	30	# 8	80	40	80
#11	70	50	70	#16	90	100	80
#15	90	100	90*	#26	70	80	60
# 4	60	70	70	#17	60	60	80*
				#19	70	90	80
				#14	50	80	70*
				#13	90	90	70

MONAUAL LOW PASS FILTERED SPEECH TEST: NORMS 74 - 100%, WILLEFORD; 66 - 94%, WILTENBERGER ET AL.

	50SL		30SL			50SL		30SL	
	RE	LE	RE	LE		RE	LE	RE	LE
#23	92	68	36	72	#18	36	24	40	48
# 2	20	12	24	20	#24	96	0	20	0
# 6	72	60	64	64	#21	28	68	60	64
#12	12	12	48	12	#27	16	16	24	32
#29	20	28	24	56	#33	80	84	44	60
# 1	20	20	28	40	#22	32	28	24	60
# 5	32	12	12	16	# 9	16	20	16	20
#10	--	20	72	36	#30	36	56	56	56
#28	24	8	12	32	#31	88	80	44	60
# 3	60	64	68	76	#32	68	48	60	68
#20	44	28	36	56	# 7	--	88	4	64
#25	28	20	32	24	# 8	40	60	32	64
#11	--	--	32	20	#16	24	36	20	48
#15	32	32	0	0	#26	40	48	44	72
# 4	28	32	20	32	#17	20	20	52	40
					#19	16	4	28	36
					#14	36	20	40	28
					#13	52	56	44	60

APPENDIX F

MEAN SCORES OBTAINED BY NORMAL HEARING SUBJECTS ON THE CENTRAL AUDITORY SPEECH TESTS

MEAN SCORES OBTAINED BY NORMALS ON THE
CENTRAL AUDITORY SPEECH TEST BATTERY
N=14 EARS (7 RIGHT, 7 LEFT)

TEST	N	MEAN
PB MAX	14	100%
COMPETING SENTENCE TEST		
Right Primary Message	7	100%
Left Primary Message	7	100%
SSW-TEST (C-SSW)		
Right ear condition	7	0% error
Left ear condition	7	0% error
SSI-CCM MCR 0 to -40dB		
Right primary message	7	100%
Left primary message	7	100%
SSI-ICM MCR 0dB		
Right ear	7	100%
Left ear	7	100%
MCR -10dB		
Right ear	7	85.71%
Left ear	7	87.14%
RAPID ALTERNATING SPEECH	14	100%
BINAURAL FUSION TEST		
Right low pass/ Left high pass	7	82.86%
Left low pass/ Right high pass	7	81.44%
MONAURAL LOW PASS FILTERED SPEECH		
Right	7	82.57%
Left	7	84.00%

APPENDIX G

NUMBER OF COCHLEAR IMPAIRED SUBJECTS WHO PASSED AND FAILED INDIVIDUAL CENTRAL AUDITORY SPEECH TESTS IN RELATION TO PURE TONE AUDIOMETRIC CONFIGURATION

TEST CONDITION		MILD SLOPING		MODERATE SLOPING		SEVERE SLOPING		UNILATERAL		MILD FLAT		MODERATE FLAT		TROUGH		OTHER	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
COMPETING SENTENCE																	
35SL	RE	5	0	6	0	3	1	5	1	5	1	3	0	2	0	1	0
	LE	5	0	6	0	4	0	6	0	4	2	3	0	2	0	1	0
25SL	RE	5	0	6	0	4	0	6	0	6	0	3	0	2	0	1	0
	LE	5	0	6	0	4	0	6	0	5	1	3	0	2	0	1	0
SYNTHETIC SENTENCE IDENTIFICATION CCM																	
30SL	RE	5	0	6	0	4	0	6	0	6	0	3	0	2	0	1	0
	LE	5	0	6	0	4	0	6	0	6	0	3	0	2	0	1	0
20SL	RE	5	0	6	0	4	0	6	0	6	0	2	1	2	0	1	0
	LE	5	0	6	0	4	0	6	0	6	0	2	1	2	0	1	0
ICM OMCR																	
30SL	RE	5	0	6	0	2	2	5	1	4	2	2	1	2	0	1	0
	LE	4	1	6	0	3	1	5	1	5	1	3	0	2	0	1	0

TEST CONDITION		MILD SLOPING		MODERATE SLOPING		SEVERE SLOPING		UNILATERAL		MILD FLAT		MODERATE FLAT		TROUGH		OTHER	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
20SL	RE	1	1	4	0	2	1	3	0	2	0	1	1	1	0	1	1
	LE	2	0	4	0	2	1	5	0	3	0	2	0	0	0	1	0
-10MCR 30SL	RE	2	2	3	3	0	2	5	1	1	5	0	2	1	1	1	0
	LE	2	2	3	3	2	0	6	0	4	1	1	1	2	0	1	0
RAPID ALTERN.		RIGHT AND LEFT COMBINED															
30SL		3	2	4	2	1	3	5	1	3	3	3	0	1	0	1	0
40SL		3	2	5	1	2	2	2	2	3	3	2	1	2	0	1	0
20SL		2	2	3	0	0	1	4	1	4	1	1	2	1	0	1	0
STAGGERED SPONDAIC WORD KATZ 30SL	RE	5	0	6	0	4	0	5	1	6	0	3	0	2	0	1	0
	LE	5	0	5	1	3	1	6	0	6	0	3	0	2	0	1	0

TEST CONDITION	MILD SLOPING		MODERATE SLOPING		SEVERE SLOPING		UNILATERAL		MILD FLAT		MODERATE FLAT		TROUGH		OTHER	
	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
50SL RE	4	1	5	0	4	0	2	0	6	0	2	0	1	0	1	0
LE	4	1	4	1	1	3	2	0	6	0	1	1	1	0	1	0
LYNN/GILROY																
30SL RE	5	0	6	0	3	1	6	0	6	0	3	0	2	0	1	0
altern. bin																
simult. bin	5	0	5	1	3	1	5	1	6	0	3	0	2	0	1	0
LE																
altern. bin	5	0	6	0	2	2	5	1	6	0	2	1	2	0	1	0
simult. bin	4	1	3	3	3	1	4	2	6	0	1	2	2	0	1	0
50SL RE	5	0	5	0	4	0	2	0	6	0	2	0	1	0	1	0
altern. bin																
simult. bin	3	2	3	2	2	2	2	0	4	2	0	2	1	0	1	0
LE																
altern. bin	5	0	5	0	2	2	2	0	6	0	1	1	1	0	1	0
simult. bin	4	1	4	1	0	4	2	0	4	2	0	2	1	0	1	0

TEST CONDITION		MILD SLOPING		MODERATE SLOPING		SEVERE SLOPING		UNILATERAL		MILD FLAT		MODERATE FLAT		TROUGH		OTHER	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
MONAURAL FILTERED																	
50SL	RE	0	4	0	6	0	4	3	1	0	6	0	3	0	2	1	0
	LE	0	4	0	6	0	4	2	4	0	6	0	3	0	2	1	0
30SL	RE	0	5	0	6	0	4	0	6	0	6	0	3	0	2	0	1
	LE	0	5	0	6	0	4	1	5	0	6	0	3	0	2	0	1
BINAURAL FUSION 30SL																	
75-100	RE	5	0	4	2	4	0	1	5	4	2	1	2	0	2	1	0
	LE	5	0	6	0	2	2	4	2	1	5	0	3	1	1	0	1
70-100	RE	5	0	5	1	4	0	3	3	6	0	2	1	0	2	1	0
	LE	5	0	6	0	2	2	5	1	4	2	0	3	1	1	0	1
40SL 75-100	RE	5	0	4	2	4	0	2	3	5	1	3	0	2	0	1	0
	LE	5	0	5	1	2	2	3	2	3	3	0	3	1	1	0	1

TEST CONDITION	MILD SLOPING		MODERATE SLOPING		SEVERE SLOPING		UNILATERAL		MILD FLAT		MODERATE FLAT		TROUGH		OTHER	
	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
60-100																
RE	5	0	6	0	4	0	3	2	6	0	3	0	2	0	1	0
LE	5	0	6	0	4	0	4	1	5	1	1	2	2	0	1	0

APPENDIX H

NUMBER OF EARS THAT PASSED OR FAILED TEST PROCEDURE IN RELATION TO TYPE OF AUDITORY DISORDER. CRITERIA ACCORDING TO AUTHORS NORMATIVE DATA

TEST		CONGENITAL		ENDOLYMPHATIC HYDROPS		ACOUSTIC TRAUMA		NOISE INDUCED		OTOTOXICITY		VIRAL	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
COMPETING SENTENCE													
35SL	RE	8	0	5	2	8	1	4	0	2	0	2	0
	LE	7	1	6	1	9	0	4	0	2	0	2	0
25SL	RE	8	0	7	0	9	0	4	0	2	0	2	0
	LE	8	0	6	1	9	0	4	0	2	0	2	0
SYNTHETIC SENTENCE IDENTIFICATION CCM													
30SL	RE	8	0	7	0	9	0	4	0	2	0	2	0
	LE	8	0	7	0	9	0	4	0	2	0	2	0
20SL	RE	8	0	7	0	9	0	3	1	2	0	2	0
	LE	8	0	6	0	9	0	3	0	2	0	2	0
ICM 30SL OMCR	RE	6	2	6	2	8	1	2	1	2	0	2	0
	LE	7	1	6	2	8	1	4	0	2	0	2	0

TEST		CONGENITAL		ENDOLYMPHATIC HYDROPS		ACOUSTIC TRAUMA		NOISE INDUCED		OTOTOXICITY		VIRAL	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
20SL	RE	3	0	4	1	5	1	3	1	1	0	1	0
	LE	4	0	6	1	5	1	4	0	1	0	1	0
30SL -10MCR	RE	3	5	5	2	5	3	1	2	1	1	0	2
	LE	8	0	6	1	6	2	2	1	1	1	0	2
FILTERED MONAURAL													
50SL	RE	0	8	3	3	1	8	0	4	0	2	0	1
	LE	0	8	2	6	1	8	0	4	0	2	0	1
30SL	RE	0	8	0	8	0	8	0	4	0	2	0	2
	LE	1	7	0	8	0	8	0	4	0	2	0	2
BINAURAL FUSION 30SL													
75-100	RE	4	4	3	5	8	1	3	1	1	1	1	1
	LE	4	4	5	3	5	4	3	1	1	1	1	1
60-100	RE	5	3	5	3	9	0	4	0	2	0	1	1
	LE	5	3	6	2	7	2	3	1	1	1	1	1

TEST		CONGENITAL		ENDOLYMPHATIC HYDROPS		ACOUSTIC TRAUMA		NOISE INDUCED		OTOTOXICITY		VIRAL	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
40SL 75-100	RE	6	2	3	4	9	0	4	0	2	0	2	0
	LE	4	4	5	2	6	3	3	1	1	1	1	1
60-100	RE	8	0	5	2	9	0	4	0	2	0	2	0
	LE	7	1	6	1	9	0	4	0	1	1	1	1
RAPID ALT.		RIGHT AND LEFT COMBINED											
30SL		5	2	4	4	7	2	2	2	2	0	1	1
40SL		6	2	2	4	8	1	1	2	2	0	1	1
20SL		5	1	5	2	6	2	1	2	1	0	0	2
STAGGERED SPONDAIC WORD KATZ 30SL	RE	7	1	6	2	8	1	3	1	2	0	2	0
	LE	8	0	8	0	8	1	2	2	2	0	2	0

TEST	CONGENITAL		ENDOLYMPHATIC HYDROPS		ACOUSTIC TRAUMA		NOISE INDUCED		OTOTOXICITY		VIRAL	
	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
50SL RE	5	1	4	0	8	1	4	0	1	0	1	1
LE	6	0	3	1	7	2	3	1	0	1	1	1
LYNN/GILROY 30SL RE	7	0	8	0	9	0	4	0	2	0	2	0
altern. bin simult. bin	8	0	7	1	7	2	3	1	2	0	2	0
LE	7	0	7	1	7	2	4	0	2	0	1	1
altern. bin simult. bin	7	1	5	3	8	1	2	2	2	0	1	1
50SL RE	6	0	5	0	9	0	4	0	1	0	2	0
altern. bin simult. bin	4	2	3	2	5	4	3	1	0	1	0	2
LE	6	0	5	0	8	1	3	1	1	0	1	1
altern. bin simult. bin	5	1	4	1	6	3	1	3	0	1	1	1

APPENDIX I

BREAKDOWN BY ETIOLOGY, CASE, AUDIOGRAM CONFIGURATION, AGE, TEST ORDER, AND SEX

ACOUSTIC TRAUMA HEARING LOSSES
N=9

CASE	AUDIOGRAM CONFIGURATION	AGE	TEST ORDER	SEX
#21	Moderate Sloping	28 years	F Presentation	Male
#30	Mild Flat	45 years	A Presentation	Male
#33	Unilateral	30 years	D Presentation	Male
#26	Severe Sloping	52 years	G Presentation	Male
#22	Severe Sloping	43 years	G Presentation	Male
#15	Moderate Sloping	57 years	C Presentation	Female
#32	Mild Flat	47 years	E Presentation	Male
#13	Severe Sloping	57 years	B Presentation	Male
#16	Mild Sloping	48 years	D Presentation	Male

ENDOLYMPHATIC HYDROPS HEARING LOSSES
N=8

CASE	AUDIOGRAM CONFIGURATION	AGE	TEST ORDER	SEX
#31	Other	45 years	E Presentation	Male
# 7	Unilateral	48 years	E Presentation	Male
# 4	Mild Sloping	58 years	A Presentation	Female
#23	Unilateral	18 years	A Presentation	Female
#24	Unilateral	27 years	F Presentation	Male
#19	Moderate Sloping	53 years	G Presentation	Male
#29	Mild Flat	35 years	D Presentation	Female
#10	Unilateral	45 years	A Presentation	Female

NOISE INDUCED HEARING LOSSES
N=4

CASE	AUDIOGRAM CONFIGURATION	AGE	TEST ORDER	SEX
# 8	Moderate Sloping	48 years	E Presentation	Male
#14	Moderate Sloping	55 years	C Presentation	Male
#17	Severe Sloping	53 years	B Presentation	Male
#28	Moderate Flat	48 years	B Presentation	Female

OTOTOXIC DRUG INDUCED HEARING LOSSES
N=2

CASE	AUDIOGRAM CONFIGURATION	AGE	TEST ORDER	SEX
#27	Moderate Flat	28 years	C Presentation	Male
# 9	Mild Sloping	44 years	A Presentation	Male

VIRAL INDUCED HEARING LOSSES
N=2

#11	Mild Sloping	57 years	F Presentation	Female
#25	Moderate Flat	54 years	G Presentation	Female

APPENDIX J

RANK ORDER OF CENTRAL AUDITORY SPEECH TESTS ACCORDING TO LEVEL OF PERFORMANCE

	TEST	PRESENTATION LEVEL	MEAN SCORE
1.	Synthetic sentence identification-contralateral competing message	30dBSL	RE 99.09 LE 99.39
2.	Competing sentence test	25dBSL	RE 97.81 LE 95.50
3.	Staggered spondaic word test-Katz' procedure	50dBSL	RE -1.03 LE 2.13
4.	Binaural fusion test	40dBSL	RE 82.81 LE 79.37
5.	Staggered spondaic word test-Lynn and Gilroy's procedure	30dBSL	RE alt 97.42 RE sim 92.57 LE alt 93.48 LE sim 86.51
6.	Synthetic sentence identification-ipsilateral competing message	30dBSL, 0dMBCR	RE 86.66 LE 90.30
7.	Rapid alternating speech	40dBSL	84.78
8.	Synthetic sentence identification-ipsilateral competing message	30dBSL, -10dBMCR	RE 63.44 LE 76.89
9.	Monaural low-pass filtered speech	50dBSL	RE 40.26 LE 36.62

APPENDIX K

TEST ITEMS INCLUDED IN EACH OF THE CENTRAL AUDITORY SPEECH TESTS

COMPETING SENTENCE TEST

TEST I.

1. a. I think we'll have rain today.
   b. There was frost on the ground.

2. a. This watch keeps good time.
   b. I was late to work today.

3. a. I'm expecting a phone call.
   b. Please answer the doorbell.

4. a. The bus leaves in five minutes.
   b. It is four blocks to the library.

5. a. My mother is a good cook.
   b. Your brother is a tall boy.

6. a. Please pass the salt and pepper.
   b. The roast beef is very good.

7. a. There is a car behind us.
   b. This road is very slippery.

8. a. Leave the keys in the car.
   b. Fill the tank with gas.

9. a. It's always hot on the Fourth of July.
   b. Christmas will be here very soon.

10. a. We had to repair the car.
    b. You should really take a taxi.

TEST II.

11. a. The ice cream sundae is very good.
    b. We have chocolate and strawberry today.

12. a. Fasten your seat belt.
    b. Get ready for take-off.

13. a. I think you need a band-aid.
    b. You should see a doctor.

14. a. This is the latest style.
    b. That fits you perfectly.

15. a. I will be back after lunch.
    b. You may take this Saturday off.

16. a. I have seen this movie before.
    b. This movie is not like the book.

17. a. Air-mail will get there faster.
    b. Please answer on a postcard.

18. a. I think we have met before.
    b. You probably don't remember me.

19. a. This train is going west.
    b. All the cars are air-conditioned.

20. a. The children are playing baseball.
    b. Football is an exciting game.

STAGGERED SPONDAIC WORD TEST

1.	up	stairs	down	town	2.	out	side	in	law
3.	day	light	lunch	time	4.	wash	tub	black	board
5.	corn	bread	oat	meal	6.	bed	spread	mush	room
7.	flood	gate	flash	light	8.	sea	shore	out	side
9.	meat	sauce	base	ball	10.	black	board	air	mail
11.	house	fly	wood	work	12.	green	bean	home	land
13.	sun	day	shoe	shine	14.	white	walls	dog	house
15.	back	door	play	ground	16.	school	boy	church	bell
17.	snow	white	foot	ball	18.	band	saw	first	aid
19.	blue	jay	black	bird	20.	ice	land	sweet	cream

21.	hair	net	tooth	brush	22.	fruit	juice	cup	cake
23.	ash	tray	tin	can	24.	nite	light	yard	stick
25.	key	chain	suit	case	26.	play	ground	bat	boy
27.	corn	starch	soap	flakes	28.	birth	day	first	place
29.	day	break	lamp	light	30.	door	knob	cow	bell
31.	bird	cage	crows	nest	32.	week	end	work	day
33.	book	shelf	drug	store	34.	wood	work	beach	craft
35.	hand	ball	milk	shake	36.	fish	net	sky	line
37.	for	give	milk	man	38.	sheep	skin	bull	dog
39.	race	horse	street	car	40.	green	house	string	bean

SYNTHETIC SENTENCE IDENTIFICATION TEST

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

BINAURAL FUSION TEST ITEMS

TEST IA		TEST IB	
1.	BAGPIPE	1.	DOVETAIL
2.	WOODCHUCK	2.	SHOELACE
3.	BASEBALL	3.	BEDROOM
4.	BLOODHOUND	4.	EYEBROW
5.	CHURCHBELL	5.	MEATBALL
6.	DAYLIGHT	6.	BLUEJAY
7.	RAINBOW	7.	BIRDNEST
8.	DRUGSTORE	8.	NORTHWEST
9.	BONBON	9.	ALTHOUGH
10.	BUCKWHEAT	10.	PADLOCK

TEST IIA		TEST IIB	
1.	DOORMAT	1.	WIGWAM
2.	FOOTSTOOL	2.	DOLLHOUSE
3.	HORSESHOE	3.	WILDCAT
4.	STAIRWAY	4.	SCARECROW
5.	HOUSEWORK	5.	SOYBEAN
6.	LIFEBOAT	6.	THEREFORE
7.	MISHAP	7.	WHIZBANG
8.	NUTMEG	8.	WORKSHOP
9.	PLATFORM	9.	YARDSTICK
10.	WATCHWORD	10.	BOBWHITE

RAPID ALTERNATING SPEECH TEST

LIST A

1. The fire engine raced down the street.
2. Do you want to go on the picnic?
3. There were many trees around the house.
4. My dog always does what I ask.
5. She is afraid to go home alone.
6. The bird flew out of its cage.
7. The puppy chased the big red ball.
8. The tree branch broke off in the storm.
9. Did you get the tickets for the game?
10. Where did you put the yellow sweater?

LIST B

1. We camped in the woods last night.
2. Would you join me for cokes after school?
3. The mayor was elected yesterday.
4. The secretary gave me the wrong number.
5. There are many kinds of fish in the ocean.
6. The children enjoyed playing at the beach.
7. The horse raced around the track.
8. Put a dozen apples in the sack.
9. There was dew on the grass this morning.
10. Plants will begin to grow in the spring.

LIST C

1. He spilled the gravy on the table.
2. The moon shines brightly in the sky.
3. The officer gave him a ticket for speeding.
4. My father takes me fishing every fall.
5. He fell in the lake and yelled for help.
6. Did the camera flash scare you?
7. She carried the parrot on her shoulder.
8. The garbage man comes on Wednesday.
9. The bird built a nest in the tree.
10. I like to drink cocoa for breakfast.

MONAURAL LOW-PASS FILTERED SPEECH TEST

LIST IA

1. home
2. root
3. hide
4. more
5. lap
6. phone
7. pole
8. mine
9. burn
10. ride
11. jar
12. much
13. kid
14. war
15. have
16. rain
17. curve
18. patch
19. moon
20. car
21. head
22. write
23. hire
24. gone
25. dumb

LIST IB

1. book
2. toad
3. choose
4. shock
5. such
6. bite
7. lot
8. dime
9. talk
10. coat
11. shine
12. bone
13. hot
14. search
15. lash
16. coin
17. lag
18. tire
19. cash
20. luck
21. map
22. neck
23. watch
24. fine
25. wash

LIST IIB

1. wood
2. hash
3. dab
4. work
5. chum
6. hush
7. hate
8. which
9. joke
10. limb
11. weak
12. mire
13. loop
14. jet
15. what
16. chin
17. job
18. turn
19. move
20. word
21. wash
22. vine
23. love
24. bar
25. juice

LIST IIB

1. dock
2. hole
3. wheat
4. shade
5. neat
6. wish
7. pan
8. room
9. tone
10. bug
11. tube
12. bun
13. white
14. pile
15. nose
16. should
17. loan
18. light
19. wire
20. sure
21. wet
22. dish
23. hair
24. well
25. pull

APPENDIX L

N.U. AUDITORY TEST #6 WORD LISTS

List 1A		List 1B		List 2A		List 2B	
1.	burn	26.	size	1.	live	26.	hush
2.	lot	27.	pool	2.	voice	27.	dead
3.	sub	28.	vine	3.	ton	28.	pad
4.	home	29.	chalk	4.	learn	29.	mill
5.	dime	30.	laud	5.	match	30.	merge
6.	which	31.	goose	6.	chair	31.	juice
7.	keen	32.	shout	7.	deep	32.	keg
8.	yes	33.	fat	8.	pike	33.	gin
9.	boat	34.	puff	9.	room	34.	nice
10.	sure	35.	jar	10.	read	35.	numb
11.	hurl	36.	reach	11.	calm	36.	chief
12.	door	37.	rag	12.	book	37.	gaze
13.	kite	38.	mode	13.	dab	38.	young
14.	sell	39.	tip	14.	loaf	39.	keep
15.	nag	40.	page	15.	goal	40.	tool
16.	take	41.	raid	16.	shack	41.	soap
17.	fall	42.	raise	17.	far	42.	hate
18.	week	43.	bean	18.	witch	43.	turn
19.	death	44.	hash	19.	rot	44.	rain
20.	love	45.	limb	20.	pick	45.	shawl
21.	tough	46.	third	21.	fail	46.	bought
22.	gap	47.	jail	22.	said	47.	thought
23.	moon	48.	knock	23.	wag	48.	bite
24.	choice	49.	whip	24.	haze	49.	lore
25.	king	50.	met	25.	white	50.	south

List 3A		List 3B		List 4A		List 4B	
1.	sheep	26.	germ	1.	rose	26.	back
2.	cause	27.	thin	2.	dog	27.	hall
3.	rat	28.	name	3.	time	28.	bath
4.	bar	29.	ditch	4.	such	29.	tire
5.	mouse	30.	tell	5.	have	30.	peg
6.	talk	31.	cool	6.	mob	31.	perch
7.	hire	32.	seize	7.	bone	32.	chain
8.	search	33.	dodge	8.	sail	33.	make
9.	luck	34.	youth	9.	rough	34.	long
10.	cab	35.	hit	10.	dip	35.	wash
11.	rush	36.	late	11.	join	36.	food
12.	five	37.	jug	12.	check	37.	mood
13.	team	38.	wire	13.	wheat	38.	neat
14.	pearl	39.	walk	14.	thumb	39.	tape
15.	soup	40.	date	15.	near	40.	ripe
16.	half	41.	when	16.	lease	41.	hole
17.	chat	42.	ring	17.	yearn	42.	gas
18.	road	43.	cheek	18.	kick	43.	came
19.	pole	44.	note	19.	get	44.	vote
20.	phone	45.	gun	20.	lose	45.	lean
21.	life	46.	beg	21.	kill	46.	red
22.	pain	47.	void	22.	fit	47.	doll
23.	base	48.	shall	23.	judge	48.	shirt
24.	mop	49.	lid	24.	should	49.	sour
25.	mess	50.	good	25.	pass	50.	wife

APPENDIX M

TEST INSTRUCTIONS

TEST INSTRUCTIONS

Competing Sentence Test

Right primary message: You are going to hear two sentences at the same time, one in your right ear, the other in your left ear. Just repeat back the sentence you hear in the right ear; ignore the one in your left.

Left primary message: You are going to hear two sentences at the same time, one in your left ear, the other in your right ear. Just repeat back the sentence you hear in the left ear; ignore the one in your right.

Monaural Low-Pass Filtered Speech

You are going to hear a list of filtered words, some of which will be very difficult for you to understand. The voice will be saying, "You will say", followed by a word, such as cow, horse, or match. Just repeat back the final word. Do the best you can.

Binaural Fusion Test

You are going to hear the voice say the word "ready". Just repeat back the word you hear after the word "ready".

Rapid Alternating Speech Test

You are going to hear a list of sentences. Each sentence will sound like it is copped-up between both ears. Just repeat back the sentences as best you can.

Staggered Spondaic Word Test

You are going to hear a tape with instructions on it. Just follow the instructions. If you do not understand the instructions, we will go back and I shall explain them to you again.

This is the SSW Test, List EC. You are going to hear a group of words presented to one or both of your ears. Just repeat back what you hear. The first four groups are for practice. Are you ready?

Synthetic Sentence Identification Test-Contralateral Competing Message

Read through the group of sentence-like constructions on the card. You will hear one of these sentence-like constructions in one ear, and a continuous story in the other ear. Just tell me the number of the sentence-like construction that you are hearing.

Synthetic Sentence Identification Test-Ipsilateral

Competing Message

Read through the group of sentence-like constructions on the card. You will hear one of these sentence-like constructions in one ear, and a continuous story in the same ear. Just tell me the number of the sentence-like construction that you are hearing.

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