A COMPARISON OF BRIEF TONE AUDIOMETRY WITH OTHER SELECTED AUDITORY TESTS OF COCHLEAR FUNCTION

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Michael Anthony Nerbonne

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Edward J. Hardick
Major professor

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Michael A. Nerbonne

The major purpose of this investigation was to evaluate the performance of a group of individuals with temporary cochlear lesions with four diagnostic tests, the Short Increment Sensitivity Index (SISI), Bekesy audiometry, the Alternate Binaural Loudness Balance (ABLB), and a form of brief tone audiometry (BTA), in order to determine which of these tests was the most sensitive to this type of lesion. In addition, questions were posed concerning the performance of males and females on these four special tests, the possibility of linear integration at threshold and its relationship with recruitment, and the reliability of a temporary threshold shift.

Twenty subjects, ten males and ten females ranging in age from 14 to 39, were selected for the study. Each subject's hearing was required to be

10 dB HL or better bilaterally for the octave frequencies from 250 through 8000 Hz.

Each subject was seen for four separate test sessions. At each session he was given one of the four tests of interest in the study five times, once before exposure to 15 minutes of 110 dB SPL of broad band white noise, and four set times following exposure.

The data were subjected to descriptive and inferential statistical analyses in order to answer the questions originally posed. Analyses of variance, as well as descriptive measures, were employed to resolve the question of whether or not the brief tone testing provided information that was not obtained with the SISI, Bekesy testing, and the ABLB, and to determine if any significant differences in test scores existed between males and females. Pearson Product Moment Correlations were used to investigate the relationship between the integration of energy and recruitment, as well as determining the reliability of the TTS measures obtained.

The following conclusions were drawn: (1) The SISI, ABLB, and BTA are quite sensitive to cochlear lesions caused by exposure to broad band white noise, whereas Bekesy testing is not; (2) BTA can be utilized clinically as a tool to detect the presence of a cochlear lesion; (3) The normal integration of energy at threshold over time is linear above a minimal intensity level; (4) Males and females do not differ in their performance on any of the special tests employed in this study; (5) The amount of recruitment and the degree of temporal integration are not highly related. BTA appears to be testing another aspect of the auditory process than does the ABLB; (6) The amount of TTS experienced at several different exposures, as well as the recovery of hearing, is reasonably reliable; (7) There is evidence that the amount of TTS experienced and the rate of recovery is different in males and females, with males experiencing more TTS and females recovering from TTS at a more rapid rate.

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CHAPTER I

Introduction

When confronted with a client suffering from a hearing loss of unknown origin and degree, the clinical audiologist will routinely employ conventional pure tone testing, speech audiometry, and various special tests in an attempt to assess the amount of loss present and its probable location(s) within the auditory system. In attempting to identify the site of lesion, the audiologist has to determine whether or not the lesion is contained within the external or middle ear, the cochlea, the VIII th nerve, the brain stem and higher order auditory pathways, or any combination of these general areas. In most cases it is possible to pinpoint with a reasonable amount of certainty the point(s) of breakdown in the hearing mechanism; but in a significant number of cases evaluated audiometrically, this information remains uncertain. This is particularly true of lesions contained within and medial to the cochlea.

Those tests which have been designed specifically to detect the presence of cochlear pathology and which have received the greatest acceptance include the following:

1. Pure tone air and bone conduction testing.
2. Short Increment Sensitivity Index (SISI), introduced by Jerger, Shedd, and Harford[1] in 1959.
3. Alternate Binaural Loudness Balance (ABLB), developed originally by E. P. Fowler, Sr.[2] and later modified by Jerger and Harford.[3]
4. Monaural Loudness Balance (MLB), by Scott Reger.[4]
5. Bekesy audiometry, introduced by Georg von Bekesy[5] and later modified for clinical use by Jerger.[6]

These tests provide valuable information relative to the state of the cochlea in many cases, but in some instances they do not provide sufficient evidence for determining whether or not cochlear pathology is present.

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[1]J. Jerger, J. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," Archives of Otolaryngology, 69 (1959), 200-211.

[2]E. P. Fowler, "Marked Deafened Areas in Normal Ears," Archives of Otolaryngology, 8 (1928), 151-155.

[3]J. Jerger and E. Harford, "Alternate and Simultaneous Binaural Balancing of Pure Tones," Journal of Speech and Hearing Research, 3 (1960), 15-30.

[4]Scott Reger, "Differences in Loudness Response of the Normal and Hard of Hearing Ear at Intensity Levels Slightly Above the Threshold," Annals of Otology, Rhinology, and Laryngology, 45 (1936), 1029-1039.

[5]Georg von Bekesy, "A New Audiometer," Acta-Otolaryngology, 35 (1947), 411-422.

[6]J. Jerger, "Bekesy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), 275-287.

A procedure introduced in recent years, which involves the integration of the energy contained within a pure tone as a function of the duration of the signal, has shown promise as a possible tool to detect pathology within the cochlea. With this in mind, it was the intent of this study to determine the role which this procedure, termed brief tone audiometry (BTA), might play in assisting the audiologist in the detection of cochlear pathology.

Purpose of the Study

The primary purpose of this study was to determine whether brief tone audiometry would provide information regarding the condition of the cochlea in cases known to possess a temporary malfunction within this structure which could not be obtained with the tests currently employed in diagnostic audiology. Specifically, the study was concerned with examining the possibility that results obtained with brief tone audiometry might provide more conclusive evidence of a cochlear lesion than any one of the other three diagnostic tests evaluated in this study, the SISI, Bekesy, or ABLB.

The major null hypothesis tested in this study was:

Ho_1: There is no significant difference in the capacity of the SISI, Bekesy audiometry, the

ABLB, and brief tone audiometry (BTA) to detect a cochlear lesion caused by exposure to a fatiguing stimulus.

In addition, four null hypotheses of secondary interest were tested. These were as follows:

Ho_2: There is no significant relationship between the presence of recruitment, as measured by the ABLB, and abnormal integration of energy at threshold, which was evaluated by BTA.

Ho_3: There are no significant differences in the test scores obtained with males and females.

Ho_4: The amount of temporary threshold shift experienced by each subject and each test group is not reliable for the four separate test sessions.

Because of the nature of the data, the final null hypothesis of interest could not be tested inferentially but the data were presented and evaluated. This hypothesis was that:

Ho_5: The function for the integration of energy at threshold as a function of signal duration is not a linear one.

Importance of the Study

It has been shown by several individuals that the SISI is capable of identifying cochlear pathology. The same can be said for the work done with the ABLB and with the research carried out on the MLB. The Bekesy audiometric procedure has also been shown to be successful in detecting cochlear pathology, as well as non-cochlear hearing losses, in such a manner that information is obtained concerning both the amount of hearing loss and site of lesion.

It should be pointed out, however, that none of these tests is so conclusive that it can predict with complete accuracy the presence or absence of cochlear pathology. Indeed, there are many instances when information obtained from all of these tests on a particular case is so conflicting that an accurate diagnosis as to the presence or absence of cochlear pathology is impossible.

Since the work of Hughes,[1] Miller,[2] and Garner,[3] there has been considerable interest in the integration of energy by the ear, both normal and pathological, at threshold as a function of the duration of the signal. More recent research has shown that individuals with medically confirmed cochlear pathology are not capable of adequately integrating all of the additional energy

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[1]J. Hughes, "The Threshold of Audition for Short Periods of Stimulation," Procedings of the Royal Society (London), B133 (1946), 486-490.

[2]G. Miller, "The Perception of Short Bursts of Noise," Journal of the Acoustical Society of America, 20 (1948), 160-170.

[3]W. Garner, "The Effects of Frequency Spectrum on Temporal Integration of Energy in the Ear," Journal of the Acoustical Society of America, 19 (1947), 808-815.

available due to the increase in duration of the test signal, say from 20 to 200 msec. In fact, there is an indication that brief tone audiometry may be more sensitive in detecting particular cases of cochlear pathology than other widely used tests designed to do so, such as the ABLB.

It seemed important, therefore, that the potential of brief tone audiometry to provide additional information in pinpointing a cochlear lesion should be investigated.

Definition of Terms

Normal Hearing- Pure tone air and bone conduction thresholds from 250-8000 Hz of 10 dB HL or better (1964 ISO standard) bilaterally, with no air-bone gap of more than 5 dB at any frequency.

Cochlear Lesion- Dorland's Medical Dictionary[1] defines a lesion as "any pathological or traumatic discontinuity of tissue or loss of function of a part." In keeping with this definition, a cochlear lesion was used in this study to imply any loss of function contained within a space bordered by the medial portion of the

[1]*Dorland's Illustrated Medical Dictionary*, (Philadelphia: W. B. Saunders Company, 1965), p. 812.

oval window and the spiral ganglia of the auditory system.

Temporary Threshold Shift (TTS)- A temporary reduction in the hearing sensitivity of an individual following exposure to a given signal which returns to its original level of functioning over time.

Temporal Integration of Energy- The capacity to utilize additional acoustic energy provided by an increased signal duration to improve threshold.

Limitations of the Study

It has been pointed out by various individuals, such as W. Dixon Ward,[1] that the temporary hearing loss which is induced by exposure to a fatiguing stimulus is not identical to a typical permanent hearing loss found within the cochlea. It was not, however, the purpose of this study to generalize the results obtained from temporary hearing losses to permanent losses of the cochlea. As stated earlier, the primary interest was in determining the ability of each of the four special tests utilized in the study to detect a lesion within the

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[1] W. Dixon Ward, "Auditory Fatigue and Masking," in Modern Developments in Audiology, ed. by J. Jerger (New York: Academic Press, 1963), p. 279.

cochlea and to provide accurate information for the differential diagnosis of a cochlear malfunction.

In connection with this, all subjects were required to have normal hearing, as indicated by conventional pure tone audiometry. This was done to eliminate the possibility of pathology existing within areas of the auditory mechanism. After exposure to the fatiguing stimulus, the subjects' hearing loss would then be primarily due to a breakdown within the cochlea, a condition which was necessary to answer the chief question of interest in this research.

CHAPTER II

REVIEW OF THE LITERATURE

The following discussion will present a review of the literature relevant to this investigation. Specifically, the discussion will include the literature concerned with (1) the diagnosis of lesions contained within the cochlea, using the four special tests of interest in this study, and (2) the audiological and physiological characteristics of the temporary hearing loss caused by exposure to intense sound.

Diagnostic Tests

SISI

According to Newby,[1] a period existed during the late 1940's and early 1950's when difference limen (DL) testing for intensity was quite popular as a means for detecting the presence of recruitment. Among those making contributions in the development of difference

[1]Hayes Newby, Audiology (New York: Appleton, Century, Crofts, 1964), 170.

limen tests were Luscher and Zwislocki,[1] Denes and Naunton,[2] and Jerger.[3, 4] However, the DL was eventually found to be inadequate in accurately separating pathological ears from normal ears and was finally abandoned.

In 1959 a procedure, which was based on a modification of DL testing, was introduced by Jerger, Shedd, and Harford[5] for detecting the existence of pathology within the cochlea. This test, labeled the Short Increment Sensitivity Index (SISI), consisted of the regular insertion of short amplitude increments of constant magnitude which were superimposed over a continuous tone with a constant amplitude. The subject's task was to respond each time he detected one of these

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[1]E. Luscher and J. Zwislocki, "A Simple Method for Indirect Monaural Determination of the Recruitment Phenomenon (Difference Limen in Intensity in Different Types of Deafness)," Acta-Otolaryngolica Supplement, 78 (1949), 156-168.

[2]P. Denes and R. F. Naunton, "The Clinical Detection of Auditory Recruitment," Journal of Laryngology and Otology, 64 (1950), 375-398.

[3]James Jerger, "A Difference Limen Recruitment Test and Its Diagnostic Significance," Laryngoscope, 62 (1952), 1316-1332.

[4]James Jerger, "D L Difference Test," Archives of Otolaryngology, 57 (1953), 490-500.

[5]J. Jerger, J. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," Archives of Otolaryngology, 69 (1959), 200-211.

brief increases in the loudness of the signal presented to him.

Generally, Jerger and his associates found that those individuals with medically confirmed cochlear pathology heard most or all of the increments, whereas normal hearers heard few, if any. Specifically, it was reported that normal hearers, those with conductive hearing losses, and those with VIII th nerve involvement would score between 0-15 percent on the SISI (negative), while scores between 60-100 percent (positive) would be obtained in patients with cochlear pathology.

While widely accepted as a tool for determining whether or not a cochlear lesion exists, several studies have shown that not all individuals with medically confirmed cochlear pathology will yield positive SISI scores.

Using 29 cases of Meniere's disease, Harrison[1] found that at 4000 Hz eight cases did not receive positive scores for the SISI. At 1000 Hz he also found that fifteen of these same 29 cases had scores which were

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[1] R. J. Harrison, "Audiological Manifestations of Meniere's Disease," (unpublished Ph.D. dissertation, Northwestern University, 1962), 100.

either negative or questionable. Harford,[1] in a report of 54 cases with Meniere's disease, reported that at 1000 Hz eleven negative or questionable SISI scores resulted, and at 4000 Hz five scores out of the total were not positive. Likewise, Yantis and Decker,[2] using 42 cochlear cases, found that at 1000 Hz six individuals did not yield positive SISI scores.

It is apparent, therefore, that while the SISI does seem to be capable of detecting a majority of confirmed cochlear lesions, it is unable to provide accurate information regarding the state of the cochlea in a significant number of cases where pathology is known to exist in this structure of the ear.

The ability of the SISI to aid in the differential diagnosis of retrocochlear pathology has also been investigated. By using the SISI to determine whether or not a lesion exists within the cochlea, information is gained concerning the possibility of retrocochlear pathology through a process of elimination.

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[1]E. Harford, Chapter 18 - Clinical Application and Significance of the SISI Test," in Sensorineural Hearing Processes and Disorders, ed. by A. Bruce Graham, (Boston: Little, Brown, and Company, 1967), 227.

[2]P. Yantis and R. Decker, "On the Short Increment Sensitivity Index (SISI Test)," Journal of Speech and Hearing Disorders, 29 (1964), 231-246.

Brand and Rosenberg[1] gave the SISI at 1000 Hz to four cases with tumors of the VIII th nerve. They found that all four individuals received positive scores. Using eighteen cases labeled retrocochlear, Yantis and Decker[2] found that at 1000 Hz two cases yielded positive SISI scores. Johnson and House[3] examined the performance of 19 cases with VIII th nerve tumors on the SISI. At 1000 Hz three positive scores resulted, while at 4000 Hz nine positive scores were obtained. Johnson,[4] in another investigation of the scores obtained on the SISI with cases of VIII th nerve tumors, administered the SISI to 82 cases at four different frequencies and found that nearly 20 percent received positive scores.

It can be concluded, therefore, that the SISI cannot be depended upon at all times to provide accurate information as to the presence or absence of pathology

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[1]S. Brand and P. Rosenberg, "Problems in Auditory Evaluation for Neurosurgical Diagnosis," Journal of Speech and Hearing Disorders, 28 (1963), 355-361.

[2]Yantis and Decker, "On the SISI Test," 231-246.

[3]E. Johnson and W. House, "Auditory Findings in 53 Cases of Acoustic Neuromas," Archives of Otolaryngology, 80 (1964), 667-677.

[4]E. Johnson, "Auditory Test Results in 110 Surgically Confirmed Retrocochlear Lesions," Journal of Speech and Hearing Disorders, 30 (1965), 307-312.

within the cochlea. As recommended by many individuals, the SISI should be used as one of a battery of tests and never relied upon alone in deciding upon the state of the cochlea. But as will be seen later on in the review of the literature pertaining to the other special tests of interest in this investigation, the other tests themselves do not appear to be any more accurate in predicting a cochlear lesion than is the SISI.

Bekesy Audiometry

In 1947 Georg von Bekesy[1] published a description of an automatic type audiometer in which the intensity of the stimulus was controlled by the subject by manipulating a control key. An audio-oscillator, which produced the stimulus tone, could be programmed to be either continuously changing or fixed in frequency. A motor driven attenuator, controlled by the subject, changed the intensity of the stimulus tone and recorded these changes directly on an audiogram with an attached recording pen.

Bekesy proposed two diagnostic contributions of the automated pure tone procedure in his original study. First, threshold recording as a continuous function of

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[1]Georg von Bekesy, "A New Audiometer," Acta-Otolaryngology, 35 (1947), 411-422.

frequency would permit testing at frequencies not ordinarily testable with conventional audiometers. Secondly, he felt that the tracings obtained would allow for the examination of a kind of difference limen, which he felt to be of diagnostic significance in differentiating hearing disorders.

Many studies were carried out immediately after Bekesy's initial article. Perhaps the most significant investigation pertaining to Bekesy audiometry was done by Jerger.[1] Using 434 adult subjects seen at the Northwestern University clinics for a period of three years, he collected both continuously variable and fixed-frequency tracings with pulsed and continuous signals. He was able to place all of these tracings into one of four general types, each dependent upon the type of hearing loss involved. Type I tracings indicated normal hearing or lesions of the middle or outer ear and was characterized by an interweaving of the interrupted and continuous signal tracings. Type II tracings were indicative of cochlear lesions, with the continuous tracing falling 5-20 dB below the interrupted, usually at frequencies above 1000 Hz.

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[1]J. Jerger, "Bekesy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), 275-287.

Type III and Type IV predominated with patients having VIII th nerve lesions and were characterized by the continuous tracing dramatically below the pulsed tracing in the lower frequencies. This was particularly true of the Type III audiogram.

In the distribution of the four Bekesy types with cases of known etiology, however, Jerger's data contained several instances where cases with medically confirmed cochlear pathology traced types other than Type II. Also, cases with pathologies confirmed not to exist in the cochlea traced Type II Bekesy audiograms.

In 1961 Jerger and Herer[1] identified a fifth type of tracing obtained with the Bekesy audiometer. The Type V tracing was considered indicative of functional hearing impairment, and was generally characterized by the tracing for the continuous tone being above the interrupted tone tracing.

An investigation was carried out by Owens[2] to evaluate further the implications of Bekesy audiometry

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[1]J. Jerger and G. Herer, "Unexpected Dividend in Bekesy Audiometry," Journal of Speech and Hearing Disorders, 26 (1961), 390-391.

[2]E. Owens, "Bekesy Tracings and Site of Lesion," Journal of Speech and Hearing Disorders, 29 (1964), 456-468.

for predicting site of lesion. Using a sample of 92 cases of cochlear pathology, 20 with retrocochlear pathology and 2 with both cochlear and retrocochlear lesions, he obtained Bekesy tracings for both continuously variable and fixed-frequency signals. Owens found that 21 out of the 92 subjects with cochlear lesion traced Type I audiograms, indicative of normal hearing or conductive pathology.

In evaluating the results obtained from 41 cases of acoustic neuromas with several auditory tests, Johnson and House[1] found nine instances where Type II Bekesy tracings were obtained.

These studies point out the fact that while Bekesy audiometry is a beneficial tool for the clinical audiologist, there are many cases where misleading results concerning the cochlea are obtained.

ABLB

In 1928 Fowler[2] identified and labeled the phenomenon of auditory recruitment in "nerve-type deafness" and later developed a test to differentiate

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[1]E. Johnson and W. House, "Auditory Findings in 53 Cases of Acoustic Neuromas," Archives of Otolaryngology, 80 (1964), 667-677.

[2]E. P. Fowler, "Marked Deafened Areas in Normal Ears," Archives of Otolaryngology, 8 (1928), 151-155.

this type of hearing loss from conductive losses on the basis of the presence or absence of recruitment. The method proposed by Fowler[1] is known as the Alternate Binaural Loudness Balance test (ABLB). Additional research has been carried out with the ABLB, with an investigation by Jerger and Harford[2] showing that the ABLB is the tool of choice in testing the loudness function in normal and abnormal ears.

Investigations by several researchers have shown, however, that the results obtained with the ABLB can be misleading. Anderson and Barr[3] found that in examining the results obtained with the ABLB on 18 cases of unilateral ossicular fixation, moderate recruitment was indicated. Jerger,[4] using data obtained in the past with middle ear, cochlear, and VIII th nerve pathologies, felt that in 25 out of 100 cases of cochlear pathology

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[1]E. P. Fowler, "Measuring the Sensation of Loudness," Archives of Otolaryngology, 26 (1937), 514-521.

[2]J. Jerger and E. Harford, "Alternate and Simultaneous Binaural Balancing of Pure Tones," Journal of Speech and Hearing Research, 3 (1960), 15-30.

[3]H. Anderson and B. Barr, "Conductive Recruitment," International Audiology, 7 (1968), 48-54.

[4]J. Jerger, "Hearing Tests in Otologic Diagnosis," ASHA, 4 (1962), 134-145.

the ABLB will not indicate recruitment and that this same test would, in 18 cases out of 100 with VIII th nerve lesions, yield results predicting cochlear pathology. Johnson and House[1] in looking at the auditory findings of 31 acoustic neuromas with the ABLB, found that 8 cases had partial or complete recruitment. Likewise, Brand and Rosenberg[2] reported on two case studies where the ABLB results indicated the presence of cochlear pathology, but where tumors were later surgically removed.

Clearly, the presence of recruitment as measured by the ABLB does not always mean that cochlear pathology is present.

Brief Tone Audiometry

According to Dallos and Olsen,[3] since the work of Hughes there has been a definite increase in interest in the integration of energy by the ear at threshold as a

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[1]Johnson and House, "Acoustic Neuromas," 667-677.

[2]S. Brand and P. Rosenberg, "Problems in Auditory Evaluation for Neurosurgical Diagnosis," Journal of Speech and Hearing Disorders, 28 (1963), 355-361.

[3]P. Dallos and W. Olsen, "Integration of Energy at Threshold with Gradual Rise-Fall Tone Pips," Journal of the Acoustical Society of America, 36 (1964), 743-751.

function of the duration of the signal. Work done in this area has involved both normal and impaired hearing subjects in an effort to describe accurately the normal integration of energy and to determine if the information gained in altering the duration of the test signal could be used in the differential diagnosis of auditory lesions.

Integration at Threshold by Normal Listeners

Using 6 normal hearing subjects, Garner[1] found a linear relationship for a limited range of durations between the intensity and duration of 1000 and 4000 Hz signals at threshold. Garner found that this relationship did not hold for very short or long duration tones, and not at all for a 250 Hz tone.

In investigating the duration-intensity relationship as a function of frequency, Miskolczy-Fodor[2] found a near perfect relationship between time and intensity changes at 1000 and 4000 Hz, with a shift of slightly more than 9 dB occurring with a log unit change in the duration of the signal. For frequencies below 1000 Hz

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[1]W. Garner, "Auditory Thresholds of Short Tones as a Function of Repetition Rates," Journal of the Acoustical Society of America, 19 (1947), 600-608.

[2]F. Miskolczy-Fodor, "Relations between Loudness and Duration of Tonal Pulses: Response of Normal Ears to Pure Tones Longer than Click Pitch Threshold," Journal of the Acoustical Society of America, 31 (1959), 1128-1134.

(250, 125, and 60 Hz), the strength of the duration-intensity relationship became less as the frequency of the test signal was lowered.

Goldstein and Kramer's[1] results with 48 normal hearing adults also indicated a near-perfect relation between time and intensity as the duration of a 1000 Hz tone was increased from 20 to 200 msec. They also discovered that thresholds continued to become better as the duration of the signal was increased beyond 200 msec and found that the duration-intensity curve was steeper for women than for men.

The results obtained with normal hearers by Olsen and Carhart,[2] as well as by Dallos and Olsen,[3] have also indicated that there is perfect integration of energy at 250, 1000, and 4000 Hz above a minimum critical intensity level. In addition, Olsen and Carhart found no differences in the performances of males and females with this task, showed that test-retest reliability was

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[1]R. Goldstein and R. Kramer, "Factors Affecting Thresholds for Short Tones," Journal of Speech and Hearing Research, 3 (1960), 249-256.

[2]W. Olsen and R. Carhart, "Integration of Acoustic Power at Threshold by Normal Hearers," Journal of the Acoustical Society of America, 40 (1966), 591-599.

[3]Dallos and Olsen, "Integration of Energy at Threshold with Gradual Rise-Fall Tone Pips," 743-751.

very high, and demonstrated that their data conformed closely to the model proposed by Garner and Miller[1] for describing the change in auditory threshold as a function of stimulus duration. This model is based on the fact that there is a minimal intensity, I_0, that is not an effective stimulus, but that the auditory system will integrate with perfect linearity all energy above this point as a function of time. This model, as expressed by Garner and Miller, is as follows:

$$t(I-I_0)=C$$

where t is time, I is the over-all power of the signal in watts/centimeter squared, I_0 refers to that portion of the stimulus intensity that does not contribute to integration for the ear, and C is the resultant energy constant.

Harris,[2] however, did not find perfect temporal integration of energy in normal hearers. Because the ear does not use intensities much below threshold, Harris chose to compute the duration of his signals between the 6 dB

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[1]W. Garner, and G. Miller, "The Masked Threshold of Pure Tones as a Function of Duration," Journal of Experimental Psychology, 37 (1947), 293-303.

[2]J. D. Harris, "Peak Versus Total Energy in Thresholds for Very Short Tones," Acta-Otolaryngology, 47 (1957), 134-140.

down points on the stimulus envelope. With this criterion, he found a duration-intensity function of 6.4 dB for every decade change in the signal duration.

Integration at Threshold by Pathological Hearers

Miskoczy-Fodor[1] has shown that in cases where cochlear pathology is present, specifically lesions within the Organ of Corti, the intensity required to reach threshold for a given signal does not increase, with shortened stimulus duration, to the same degree that it does in the normal ear.

Jerger[2] attempted to determine whether the same duration-intensity function that Miskolczy-Fodor described would be present in cases with normal hearing who were exposed to 110 dB SPL of thermal noise for two minutes and then administered a brief tone procedure at 4000 Hz. The pre-exposure time-intensity relationship proved to be linear as the duration of the signal was changed from 5 to 50 msec. The post-exposure thresholds obtained as these

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[1] F. Miskolczy-Fodor, "Monaural Loudness Balance Test and Determination of Recruitment Degrees with Short Sound Impulses," Acta-Otolaryngology, 43 (1953), 573-595.

[2] J. Jerger, "Influence of Stimulus Duration on the Pure Tone Threshold During Recovery From Auditory Fatigue," Journal of the Acoustical Society of America, 27 (1955), 121-124.

two durations indicated, however, that a breakdown occurred in the normal time-intensity relationship which was similar to that obtained by Miskolczy-Fodor with cases of cochlear pathology.

Harris, Haines, and Meyers[1] studied the slope of integration and recruitment in a group of 25 defective ears and were unable to confirm Miskolczy-Fodor's opinion that integration data will in all cases permit the separation of conductive and cochlear impairments, or that recruitment and abnormal integration of energy were always present together. They found cases exhibiting both, or only one, or neither one of these auditory parameters in cochlear lesions. The authors felt, however, that the information obtained with brief tone audiometry, when used with other information obtained with various other auditory tests, could be of significant value in determining whether or not a lesion is present in the inner ear. In fact, the data from several subjects in this study indicated that the slope of integration might provide information relative to the type of pathology contained within the cochlea, thus possibly

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[1] J. D. Harris, H. Haines, and C. Myers, "Brief Tone Audiometry," Archives of Otolaryngology, 67 (1958), 699-713.

being able to separate one type of cochlear pathology from another.

Using subjects with hearing varying from normal to severely impaired sensorineural losses, Elliott[1] found a strong inverse relationship between threshold for a 1000 msec tone and the amount of shift seen as the duration of the tone was shortened to 3 msec. In other words, the greater the hearing loss, the less will the subject's threshold be shifted by reducing the duration of the test signal.

The purpose of an investigation by Sanders and Honig[2] was to gather data related to the slope of integration in the normal and pathological ear. Using 10 normal hearers and 14 cases with cochlear pathologies, the authors concluded that (1) cochlear lesions can be differentiated from the normal ear by brief tone audiometry; (2) brief tone audiometry may be capable of detecting sub-clinical pathology, which is not detected by conventional audiometry; (3) brief tone audiometry may

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[1]E. Elliott, "Tonal Threshold for Short Duration Stimuli as Related to Subject Hearing Level," Journal of the Acoustical Society of America, 35 (1963), 578-580.

[2]J. Sanders and E. Honig, "Brief Tone Audiometry," Archives of Otolaryngology, 85 (1967), 84-91.

also be capable of differentiating between cochlear and retrocochlear pathology; (4) abnormal energy integration and recruitment do not always appear together in cochlear lesions, a conclusion which does not, of course, agree with the findings of Miskolczy-Fodor; (5) the degree of abnormality in energy integration tends to be proportional to the degree of hearing loss present; (6) brief tone audiometry does not appear to distinguish between various types of cochlear lesions.

Wright[1] evaluated the utility of a conventional Bekesy audiometer as a clinical procedure for integration of energy, and employed a case with a unilateral cochlear hearing loss as a subject. He concluded that the threshold data obtained were capable of distinguishing between the two ears. Wright also suggested that threshold-duration functions may be more sensitive in detecting hair cell pathology than are the conventional recruitment measures used presently.

In 1968 Wright and Canella[1] looked at the differential effect of conductive hearing loss on the

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[1]H. Wright, "Clinical Measurement of Temporal Auditory Summation," Journal of Speech and Hearing Research, 11 (1968), 109-127.

[2]H. Wright and F. Cannella, "Differential Effect of Conductive Hearing Loss on the Threshold-Duration Function," Journal of Speech and Hearing Research, 12 (1969), 607-615.

threshold-duration function. It was concluded that conductive hearing losses have no apparent effect on normal integration of energy, and that in mixed-type hearing losses only the sensorineural component contributes to an abnormal threshold-duration function. The authors therefore felt that the threshold-duration function shows promise as another source of information for the differential diagnosis of auditory disorders.

Temporal integration of energy functions in 10 individuals with surgically confirmed VIII th nerve tumors and 10 patients with cochlear pathology were obtained by Sanders, et al.[2] The results indicated that cochlear pathology could be easily distinguished from retrocochlear pathology on the basis of temporal integration, since VIII th nerve cases fell within the normal range on the brief tone test.

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[1]H. Wright and F. Cannella, "Differential Effect of Conductive Hearing Loss on the Threshold-Duration Function," Journal of Speech and Hearing Research, 12 (1969), 607-615.

[2]J. Sanders, A. Josey, and F. Kemker, "Temporal Integration of Energy in VIII th Nerve Tumor Patients," To be published in Journal of Speech and Hearing Research, 1970.

TTS in Normal Hearers

According to Rudmose,[1] the effects of noise upon hearing have been investigated for many years. As early as 1880 the effects of railroad noise upon hearing were reported, and others as early as 1890 investigated the problem of occupational deafness among boilermakers. Since that time the area of auditory fatigue, both temporary and permanent in its effect on hearing, has continued to receive a vast amount of attention from researchers.

Because of the enormous quantity of information dealing with temporary threshold shift, Ward[2] has developed a summary of those relations between noise and TTS which seem well established at this time. These include the following:

1. The growth of TTS in dB is nearly linear in the logarithm of time. However, when TTS reaches 40 dB or more, recovery may become linear in time.

2. Noises whose maximum energy is in low frequencies will produce less TTS than those whose energy is at higher frequencies.

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[1]W. Rudmose, "Hearing Loss Resulting From Noise Exposure," in The Handbook of Noise Control, ed. by C. Harris (New York: McGraw Hill, 1957), 71.

[2]W. Dixon Ward, "Effects of Noise on Hearing Thresholds," in Noise as a Public Health Hazard, ASHA Reports, No. 4 (1969), 40-48.

3. The maximum effect from a noise that has energy concentrated in a narrow frequency range will be found half an octave to an octave above that range rather than at it.

4. TTS increases linearly with the average noise level, beginning at about 80 dB SPL, at least up to 130 dB or so.

5. An intermittent noise is much less able to produce TTS than a steady one.

6. Neither growth nor recovery of TTS is influenced by drugs, medications, time of day, hypnosis, good thoughts, or extrasensory thoughts. The locus of the physiological deficit associated with TTS thus seems to be extremely peripheral--at the hair cells of the cochlea, to be specific.

Ward[1] points out, however, that a dearth of information exists on the physiological state of the auditory mechanism, specifically the cochlea, during a noise-induced temporary threshold shift. He reports that the studies that have dealt with this topic have revealed pertinent information concerning the presence of pitch, loudness, and timbre changes in suprathreshold stimuli presented following the cessation of a fatiguing stimulus. These features can, of course, be directly related to diplacusis, recruitment, and distortion; Ward cautions, however, that it would be unwise to

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[1] W. Dixon Ward, "Auditory Fatigue and Masking," in Modern Developments in Audiology, ed. by J. Jerger (New York: Academic Press, 1957), 278.

assume that the physiological basis of TTS is the same as that of a permanent loss.

Beck[1] has shown, through histochemical preparation, the reaction of the external hair cells of the Organ of Corti to acoustic stimuli. There is a reduction of ribonucleic acid and albumins in the medial portions of the hair cells and a definite shift of metabolic substances from the nucleus to the cell plasma. These changes are reversible and the inner hair cells show them at a higher intensity level of traumatizing noise.

Ward[2] states that Wustenfied has reported, as has a World Health Organization report on noise,[3] that exposure to high frequency tones resulted in the swelling of nuclei in the hair cells of the basal area of the cochlea. This was also true for apical hair cells when a low frequency fatiguing tone was used. Wustenfied found that this was only true of the outer hair cells.

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[1]C. Beck, "Minute Metabolic Reactions in the Sensory Cells of Corti's Organs After Pure Tone Sound," Archive fuer Ohren- Nasen-und Kehlkopfheilkunde, 175 (1959), 374-378.

[2]Ward, "Auditory Fatigue and Masking," 279.

[3]World Health Organization, "Noise: An Occupational Hazard and Public Nuisance," WHO Chronicle, 20 (1966), 191-203.

Some evidence exists concerning the performance of individuals with a TTS on several special audiometric tests. O'Neill,[1] using 100 dB SPL of broad band white noise for 30 minutes as his fatiguing stimulus, administered loudness balance tests before and after exposure to 16 normal hearing subjects and did not find any evidence of recruitment. A study by Harris, Haines, and Myers[2] with normal listeners does not support this finding. They found a straight line type of recruitment following auditory fatigue.

Hickling[3] gave a battery of special tests, consisting of the SISI, ABLB, and Bekesy tests, at 4000 Hz to 14 normal hearing subjects before and after exposure to a 2.4-4.8 KHz noise band for 10 minutes at SPL's up to 108 dB. He concluded that the ABLB was the only test to give consistent positive results in post-exposure testing.

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[1] J. O'Neill, "The Effects of Exposure to White Noise on Individual Test Scores: Loudness Balance and Intelligibility Tests," Report Project Number NM 001 064.01.29, U.S. Naval School of Aviation Medicine, Pensacola, Fla.

[2] J. D. Harris, H. Haines, and C. Myers, "Loudness Perception for Pure Tones and for Speech," Archives of Otolaryngology, 55 (1952), 107-133.

[3] S. Hickling, "Hearing Test Patterns in Noise Induced Temporary Hearing Loss," Journal of Auditory Research, 7 (1967), 63-76.

Employing 12 normal hearing adults as subjects, Jerger[1] exposed their test ears for two minutes to 110 dB SPL of thermal noise, and then administered a test of temporal integration with a 4000 Hz test tone. It was concluded that a disturbance of the time-intensity relationship for threshold was evident which was similar to that seen in other studies utilizing cases with cochlear lesions.

Because of the evidence that TTS is a hair cell lesion and that temporal integration, or brief tone audiometry, may be very sensitive to hair cell pathology, this study was formulated and carried out.

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[1] J. Jerger, "Influence of Stimulus Duration on the Pure Tone Threshold During Recovery from Auditory Fatigue," 121-124.

CHAPTER III

EXPERIMENTAL PROCEDURES

Information concerning the selection and grouping of subjects, equipment and tests to be employed during the study, and the test procedures utilized will be included in this chapter. Briefly, 20 male and female subjects with normal hearing were evaluated with four different diagnostic tests before and after exposure to broad band white noise, with performances on each of these tests being monitered over time following the cessation of the fatiguing stimulus.

Subjects

Twenty subjects, 10 males and 10 females, ranging in age from 14 to 39, participated in the study. In order to qualify, each subject was required to have pure tone air and bone conduction thresholds of 10 dB HL (1964 ISO standard) or better bilaterally for the following frequencies: 250, 500, 1000, 2000, 4000, and 8000 Hz. In addition, the presence of an air-bone gap of 10 dB or more at any one or more of the test frequencies from 250-4000 Hz and/or a history of prolonged exposure to high intensity level noise served to eliminate anyone from the study sample.

Equipment

The instrumentation utilized for this study is included in the following list:

Artificial Ear (Bruel and Kjaer, Model 4152)
Sound Level Meter (Bruel and Kjaer, Model 2203)
Octave Filter Set (Bruel and Kjaer, Model 1613)
Condensor Microphone (Bruel and Kjaer, Model 4131)
Condensor Microphone (Bruel and Kjaer, Model 4132)
Earphones (Telephonics, Model TDH-39)
Earphone Cushions (Model MX-41/AR)
Artificial Mastoid (Beltone, Model M5A)
Artificial Mastoid Amplifier (Beltone, Model M5A)
Microphone Amplifier (Bruel and Kjaer, Model 2601)
Bone Vibrator (Radioear, Model B-70A White Dot)
Clinical Pure Tone Audiometer (Beltone, Model 15C)
Bekesy Audiometer (Grason-Stadler, Model E-800)
SISI Adapter (Stowe, Model 1259)
Noise Generator (Beltone, Model NB 102)
Electronic Switch (Grason-Stadler, Model 829E)
Wave Form Generator (Tektronix, Model 162)
Pulse Generators (Tektronix, Model 161)
Electronic Counter (Bekman, Model 6148)

Timer (Westclox, Model L-31)

Commercial Test Room (Industrial Acoustics Company, Inc., Series 1600 ACT)

Oscilloscope (Tektronix, Model 564B)

Oscilloscope Camera Attachment (Tektronix, Model C-12)

Camera (Polaroid)

All equipment employed during testing, with the exception of the earphones, bone vibrator, and calibration equipment were located in the control room of the suite, while the earphones and vibrator, as well as the calibration equipment, were located in the adjoining test room. Figure 1 is a schematic diagram of the control and test rooms, as well as the relative position of the equipment used during testing.

The ambient noise level of the test room was measured with the sound level meter on the linear scale and was found to have an over-all intensity level of 58.5 dB SPL. An octave band analysis was also carried out in the test room, with the octave band with a center frequency of 31.5 Hz containing the greatest amount of acoustical energy (44 dB SPL). Ambient noise levels for the octave bands from 125 to 31,500 Hz did not exceed 20 dB SPL.

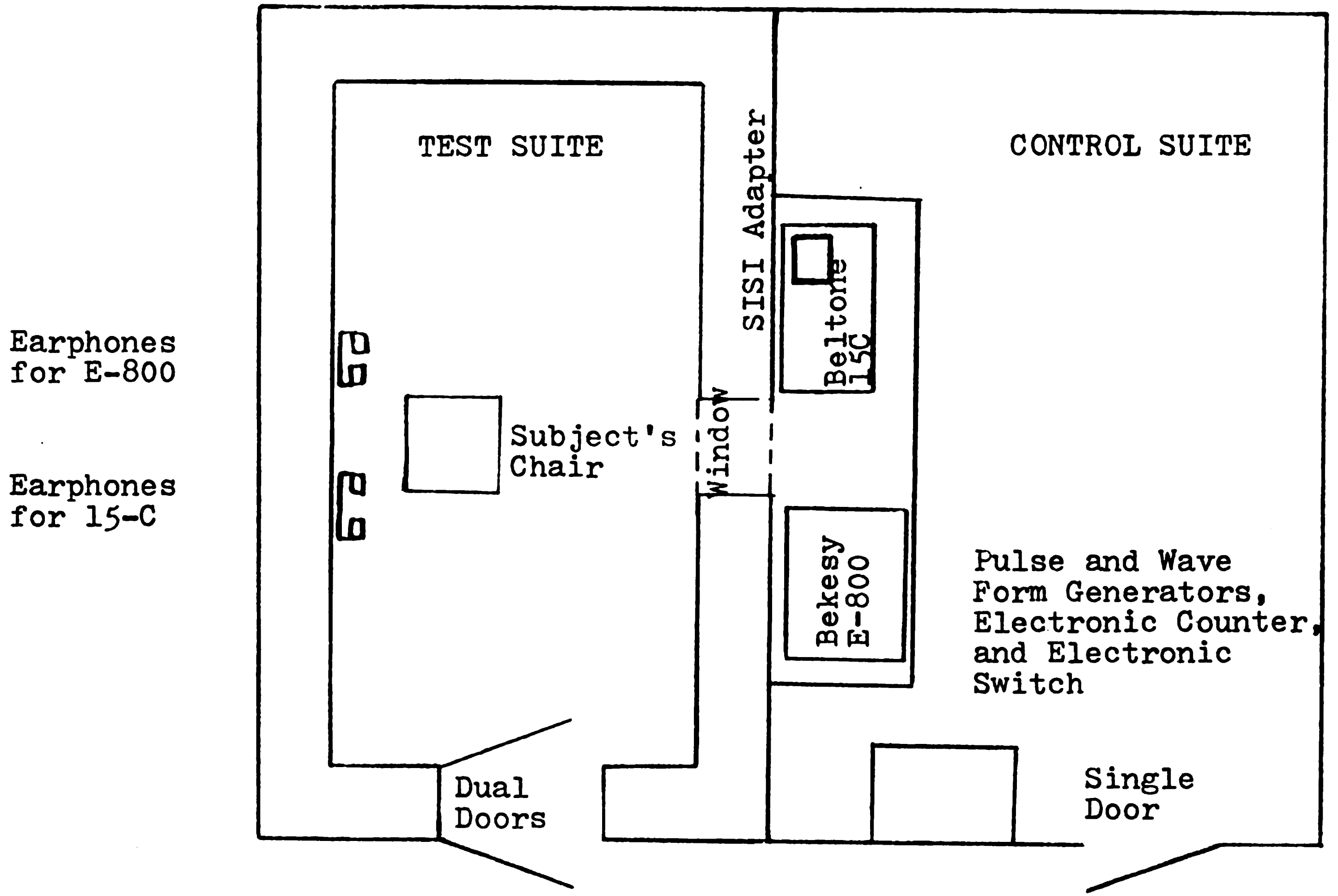

Figure 1.--Schematic representation of test and control rooms, including the relative position of pertinent equipment.

Instrumentation and Calibration

Pure Tone Testing

Pure tone air and bone conduction testing was done with a Beltone, Model 15C audiometer, which drove either a matched pair of TDH-39 earphones contained within MX41/AR cushions or a hearing aid-type bone conduction vibrator, the Radioear B-70A White Dot. For those subjects whose thresholds were better than 0 dB HL (1964 ISO standard) at any frequency, an external auxillary attenuator was utilized which reduced the minimum output of the audiometer from 0 to -20 dB HL.

Calibration of the air conduction system was carried out with a Bruel and Kjaer (B&K) sound level meter, which was used in conjunction with a B&K octave filter set and a B&K artificial ear assembly. A B&K voltmeter and the Beltone artificial mastoid assembly were employed in checking the accuracy and stability of the bone conduction system. Both air and bone conduction signals were calibrated on each test day according to the procedures outlined by the American Standards Association[1]

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[1] "American Standard Specifications for Audiometers for General Diagnostic Purposes," American Standard Association, Inc. (1960), p. 9.

and the Operating Manual for the Beltone Artificial Mastoid.[1]

SISI Testing

A Stowe SISI adapter was utilized in conjunction with the Beltone 15C for the presentation of the SISI. The manufacturer's specifications on this plug-in unit state that it permits an intensity increment of controlled magnitude with a 50 msec rise-decay time, a peak intensity duration of 200 msec, and total stimulus duration of 300 msec.[2] These dimensions are identical to those described by Jerger, Shedd, and Harford.[3] In attempting to verify the manufacturer's specifications of the Stowe adapter, by means of a Tektronix oscilloscope and a Polaroid camera attachment, it was determined that the desired 50 msec rise and 200 msec peak intensity durations were present in the increment produced, but that only a 25 msec decay time was produced. After

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[1]Operating Manual for the Beltone Artificial Mastoid, M5 Series, (Chicago, Ill.: Beltone Electronics Corp.).

[2]Instruction Manual for the SISI Adapter, Model 1259, (Northbrook, Ill.: Gordon Stowe and Associates).

[3]J. Jerger, J. Shedd, and E Harford, "On the Detection of Extremely Small Changes in Sound Intensity," Archives of Otolaryngology, 69 (1959), 200-211.

unsuccessfully attempting to modify the adapter so that the desired decay time could be obtained, it was decided to accept the adapter's present dimensions as being adequate. These dimensions were inspected prior to the study, midway, and at its conclusion and were found to remain stable over time.

A Beltone noise generator was used to generate 20 dB of effective narrow band masking at 4000 Hz, and this signal was presented to the non-test ear during all SISI testing via a TDH-39 earphone.

The SISI system was calibrated each test day, using the artificial ear assembly employed in conjunction with the sound level meter and the associated octave band filter network discribed earlier. With the earphone placed over the artificial ear and the SISI stimulus turned on at the desired intensity level, the increment intensities were read and measured from the sound level meter.

Bekesy Testing

A Grason-Stadler Bekesy audiometer, Model E-800, was used in obtaining fixed-frequency Bekesy tracings. By means of the oscilloscope and camera combination mentioned previously, it was possible to determine that the interrupted signal produced by the Bekesy in the study met the manufacturer's specifications of 25 msec rise-decay times, approximately 2.5 interruptions per second, a 2.5 dB per second attenuation rate, and a one octave per minute chart speed. As with the SISI, the Bekesy's signal was inspected before the study was initiated, midway through the collection of the data, and at its completion and was found to remain stable at all times.

The Bekesy audiometer's frequency and intensity parameters were calibrated each test day, both internally as described in the E-800's manual, and externally by monitoring its intensity output with a standard air conduction calibration assembly.

ABLB Testing

In obtaining a signal for the ABLB that was similar to that recommended by Jerger and Harford,[1] it was necessary to couple a Bekesy E-800 audiometer with a Grason-Stadler electronic switch, Model 829E. The signal produced by the E-800 was split, and separate but identical signals entered each of the two channels of the electronic switch, which then altered the stimuli in such a manner that 50 msec rise-decay times, 400 msec peak

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[1]J. Jerger and E. Harford, "Alternate and Simultaneous Binaural Balancing of Pure Tones," Journal of Speech and Hearing Research, 3 (1960), 15-30.

intensity duration, and 500 msec total duration signals were produced in an alternating fashion. These two pulsing signals were then returned to the E-800, one to the "Stim In" jack and the other to the "Alternate In" jack. The two signals were then transduced by two TDH-39 earphones.

The ABLB signals were also visually inspected with an oscilloscope and camera attachment to insure their stability over time.

The ABLB system was calibrated before each test session. Both signals were adjusted through the gain controls of the electronic switch so that with a 60 dB HL input from the E-800, the SPL reading on the sound level meter for each signal was within $\pm$ 0.1 dB of the ISO standard for 4000 Hz. To facilitate calibration, a 10 dB attenuation pad was installed between Channel B of the electronic switch and the "Alternate In" jack of the E-800.

Brief Tone Testing

A Bekesy audiometer, modified by a network of external equipment, served as the central piece of equipment in the circuitry employed in brief-tone threshold testing. Figure 2 is a simplified block design of the apparatus employed.

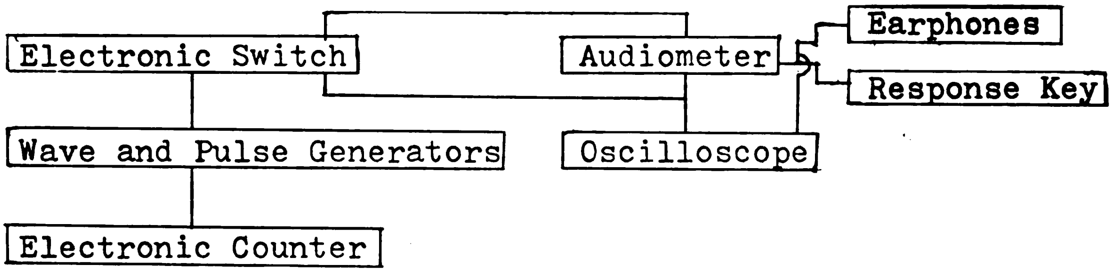

Figure 2. Simplified block design of the equipment used in brief tone audiometry.

The output of the E-800 was routed from the "Oscillator Output" jack in the rear of the audiometer to a Grason-Stadler electronic switch, Model 829E. This switch, in conjunction with a Tektronix wave form generator, Type 162, and two Tektronix pulse generators, Type 161, served to control the total duration, rise-decay time, and repetition rate of the stimuli utilized in the study. The attenuation and frequency of the stimuli were still controlled internally by the E-800, whose stimulus control was in the "Stim On" position.

Upon exiting from the switch, the signal was then returned to the Bekesy by means of the "Stim In" jack located in its front panel and was delivered to the right ear of the subject via a TDH-39 earphone. The subject used the response key normally used for the Bekesy to alter the intensity of the test signal between just heard and just not heard points, as in conventional Bekesy testing, with the excursions being recorded automatically by the Bekesy pen. Because all testing was done at 4000 Hz, the cam of the Bekesy was changed from its normal sweep frequency position to one that kept the oscillator at that frequency.

A Bekman, Model 6148, electronic counter was used to measure the interval of time between the signals produced by the two pulse generators. To monitor the wave form and repetition rate of the stimulus, a Tektronix oscilloscope, Model 564B, was used periodically. With this apparatus, the stimulus parameters were checked at the terminals of the earphone and between the output of the electronic switch and the Bekesy audiometer.

Durations of 33.33, 213.33, and 413.33 msec were used, all having rise-decay times of 10 msec and repetition rates of one per second. Total duration was defined as the amount of time that the stimulus is on, including rise-decay and peak duration times. Peak duration was used to indicate the time that the test signal is at peak amplitude, while rise-decay time refers to the time required by the stimulus to rise or decay between peak amplitude and complete off. According to the equation derived by Dallos and

Olsen,[1] the above stimuli had equivalent durations of 20, 200, and 400 msec. The formula used to compute their equivalent durations was $t = 2r/3 + P$, where t refers to time, r is the rise or decay time (if equivalent) and P is the peak duration of the signal. Table 1 is a summary of the stimulus dimensions used in this study.

TABLE 1.--Stimulus parameters for brief tone testing (in msec).

Rise-Decay Time	Peak Duration	Total Duration	Equivalent Duration
1. 10	13.33	33.33	20
2. 10	193.33	213.33	200
3. 10	393.33	413.33	400

The instrumentation utilized for brief tone testing was calibrated before each test session. With an input of 60 dB HL from the Bekesy, an output reading within ± 0.1 dB of the ISO standard at 4000 Hz was obtained from a sound level meter, via the earphone, through gain adjustments within either the audiometer or the electronic switch.

[1]P. Dallos and W. Olsen, "Integration of Energy at Threshold with Gradual Rise-Fall Tone Pips," Journal of the Acoustical Society of America, 36 (1964), 743-751.

Fatiguing Stimulus

A stimulus consisting of 110 dB SPL of broad band white noise, presented to the right ear through TDH-39 earphones for 15 minutes, was used to produce a temporary threshold shift in the 20 subjects. It was produced by a noise generator contained within the Bekesy audiometer and was calibrated with a sound level meter before each test session so that an SPL reading of 110 dB was obtained on the linear scale. Figure 3 is a graphic representation of the energy contained in the fatiguing stimulus at octave intervals.

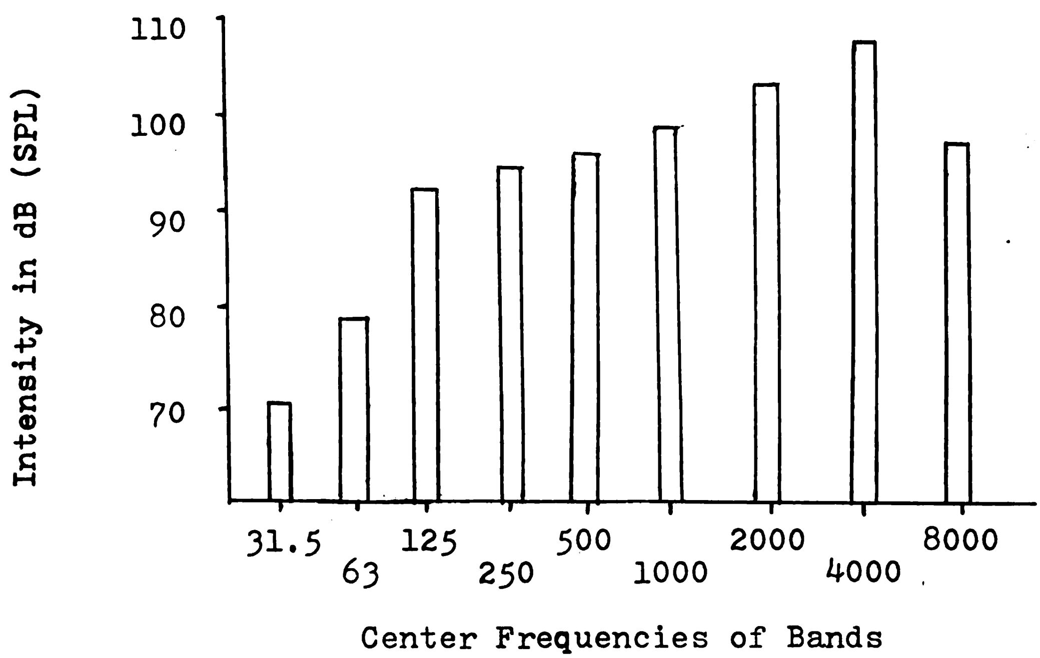

Figure 3.--Octave band analysis of white noise employed to produce TTS.

Procedure

Initially every subject was required to pass a pure tone screening examination to establish the presence of normal hearing. In order to qualify as a normal hearer, each subject had to pass a pure tone screening examination, as described earlier, and to have a negative history of excessive noise exposure.

After meeting the requirements for the study, each subject was then seen for four different test sessions, with a minimum of five days being required between each session. On each session the following procedures were carried out:

1. Pure tone air and bone conduction thresholds were obtained bilaterally for the following frequencies: 250, 500, 1000, 2000, and 4000 Hz. An air conduction threshold was also obtained at 8000 Hz.

2. One of the four special tests of interest was then administered to the right ear of each subject.

3. Upon the completion of the special test administered, the subjects right ear was then exposed to 110 dB SPL of broad band white noise for 15 minutes, via a TDH-39 earphone.

4. After cessation of the fatiguing stimulus, each subject's threshold at 4000 Hz in the fatigued

ear was obtained with the Beltone 15C at 1, 9, 19, and 29 minutes post-exposure, and the same special test given prior to exposure was also administered at 2, 10, 20, and 30 minutes post-exposure.

The sequence of test administration was set up in a rotating fashion to minimize any ordering effects. Subject 1 was administered the SISI at the first test session, followed by Bekesy testing at the second session, and the ABLB and brief tone audiometry at the third and fourth sessions. Subject 2, however, was given Bekesy testing at the first session, the ABLB at the second, and brief tone audiometry and the SISI at the third and fourth sessions. Subject 3, then, was tested with the ABLB initially, and so on for the entire 20 subjects.

SISI Testing

After the subject's pure tone thresholds had been established, the initial SISI was given in the right ear following the procedural outline suggested by Jerger,[1] except that 20 dB of effective masking was simultaneously presented in the non-test ear during testing, both prior to and following noise exposure. Conditioning done prior

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[1]J. Jerger, J. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," 200-211.

to the actual test consisted of three signal presentations of 5, 4, 3, 2, and 1 dB increments at a 20 dB sensation level (SL). The subject was given the following instructions prior to conditioning:

> You will hear a steady tone which will last for approximately five minutes. During this time you may hear little jumps in the loudness of this tone. Each time you hear this little jump in loudness, regardless of its size, push this button. If you think you heard a jump, but you're not sure, don't do anything.
>
> You will also hear a masking stimulus in the opposite ear, which sounds much like steam. Ignore this signal and only listen for the short increases in loudness in the test ear.

All SISI testing was done at 4000 Hz at a 20 dB SL and followed the general test schedule outlined earlier for all four special tests of interest in the study.

Bekesy Testing

Fixed-frequency Bekesy testing was carried out at 4000, 1000, and 250 Hz, in that order, for both pulsed and continuous stimuli. An attenuation rate of 2.5 dB per second, a pulse rate of 2.5 pulses per second, and a chart speed of one octave per second were utilized during testing.

The following instructions were given to each subject prior to testing:

> When I put these earphones on, you are going to hear a beeping sound in your ear. As long as you

> don't do anything, the sound will keep getting louder. But you can make it fade away by holding down this switch. When you let up on the switch, the sound will get louder again. Now, here is what I want you to do. Listen very carefully, and as soon as you hear the beeping sound, hold this switch down until you can't hear it any more. As soon as the beeping sound is gone, let up on the switch until it comes back. Then, as soon as you hear it again, hold the switch down until it goes away again, and so forth. The idea is to keep going back and forth from where you can just hear the beeping sound to where you can just not hear it any more. Never let the sound get very loud and never let it stay away too long. Hold this switch down as soon as you hear the sound, then let it up as soon as the sound is gone.[1]

Each subject was then allowed to trace their threshold for 30 seconds at 4000 Hz and 250 Hz with the pulsed signal. Then the following instructions were introduced.

> Now we are going to do the same thing again, but this time the sound will be steady instead of beeping on and off. Your job is still the same. Hold the switch down as soon as you hear the steady sound, and let it up as soon as the steady sound goes away.[2]

Practice with the continuous signal was carried out for 30 seconds at 4000 Hz and 250 Hz. Following practice sessions with both pulsed and continuous signals, the Bekesy testing was administered according to the testing schedule outlined earlier. All testing began with 4000 Hz, followed by 1000 Hz and 250 Hz, with each

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[1]J. Jerger, "Bekesy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), 275-287.

[2]Ibid.

subject tracing his threshold for a minimum of 10 excursions or one minute, whichever occurred first. The pulsed signal was always presented first.

ABLB Testing

All ABLB testing was done at 4000 Hz, using a 2.5 dB per second attenuation rate, a one pulse per second pulse rate for each signal, and a one octave per minute chart speed. The test stimuli were presented to the subjects at 20 and 40 dB SL's. The reference tone, with a set intensity of either 20 or 40 dB SL, was always presented to the left ear, while the intensity of the signal in the right ear was controlled by the subject. Four loudness balances, with two ascending and two descending approaches, were obtained at each sensation level. Each loudness balance consisted of at least 10 excursions or a minimum of one full minute, whichever occurred first.

The following instructions were given before ABLB testing:

> Tones of the same frequency but different intensities will be presented to both ears in a pulsing fashion. Your task is to continuously adjust the loudness of the stimulus in your right ear so that it is equal in loudness to the stimulus in the left ear. To make the signal in your right ear softer, press this switch and hold it down; to make the signal louder once again, release the switch. You are to balance the loudness of the two signals

until the test is completed. Remember not to allow the variable stimulus to become too loud or too soft when compared to the reference tone.

To give the subjects adequate practice, they were required to make an ascending and descending loudness balance at each sensation level before actual testing began. In the formal ABLB testing, each subject began with a descending loudness balance, and then an ascending balance, with the reference tone at a 40 dB SL. Then an ascending balance, followed by a descending balance, was traced at a 20 dB SL. The subjects then balanced the two signals at a 40 dB SL, first in an ascending manner and then from a descending approach. Finally, loudness balances were obtained at a 20 dB SL, with a descending balance being done first, followed by an ascending balance.

This procedure was carried out according to the general outline of test administration described earlier.

Brief Tone Testing

For brief tone testing with the E-800, a 2.5 dB per second attenuation rate was used, as was a one pulse per second presentation rate and a one octave per minute chart speed. All threshold tracings were done at 4000 Hz, with the 20 msec equivalent duration signal being presented first, followed by the 200 and 400 msec equivalent duration tones. Threshold tracings were obtained for a minimum of 10 excursions or one minute, whichever occurred first.

Instructions given for brief tone testing were as follows:

> When I put these earphones on, you are going to hear a beeping sound in your ear. As long as you don't do anything, the sound will keep getting louder. But you can make it fade away by holding down this switch. When you let up on the switch, the sound will get louder again. Now, here is what I want you to do. Listen very carefully, and as soon as you hear the beeping sound, hold this switch down until you can't hear it anymore. As soon as the beeping sound is gone, let up on the switch until it comes back. Then, as soon as you hear it again, hold the switch down until it goes away again. The idea is to keep going back and forth from where you can just hear the beeping sound to where you can just not hear it any more. Never let the sound get very loud and never let it stay away too long. Hold this switch down as soon as you hear the sound, then let it up as soon as the sound is gone.

Practice for this test included tracing at threshold for 60 seconds with the 200 msec and 20 msec equivalent duration stimuli. All testing was done according to the test schedule outlined previously.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter will include an explanation of the manner in which the criterion values were obtained, as well as a presentation of the results of the study relative to the hypotheses which were tested. This will be followed by a general discussion of the findings and their implications, and a brief summary of the results of the study.

Procedures for Determining Test Scores

SISI

Only one score was used, of course, to represent performance on the SISI at a given test time, this being the percentage of twenty 1 dB increments heard at a 20 dB sensation level.

Bekesy

All threshold testing for fixed-frequency Bekesy tracings was carried out for either ten excursions or one minute, whichever occurred first. To determine the auditory thresholds, a mid-point technique was employed. This technique involved averaging the peaks of the excursions of a tracing which were more than 2 dB but not more than 15 dB in length; all other excursions were not used in the computation of thresholds because it was felt that excursions of this nature were not an accurate indication of a subject's acuity. Inclusion of these excursions would therefore result in unrealistic thresholds.

Six scores were derived to represent a subject's performance on the Bekesy. To obtain these scores, the mean thresholds for each frequency were computed for both pulsed and continuous signals at two separate points in the tracings: the initial five excursions and the final five acceptable excursions of a tracing. This is illustrated below.

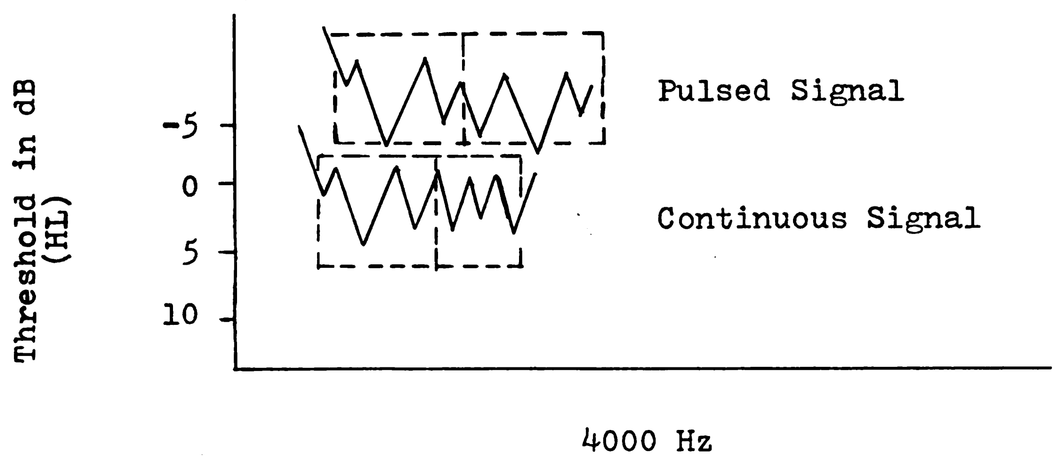

Figure 4.--Illustration of method employed to determine auditory thresholds from Bekesy audiograms.

In this manner four raw scores were obtained at each frequency. To determine the dB difference between the pulsed and continuous stimuli, the score derived from the first five excursions of the interrupted signal was subtracted from the corresponding first five excursions of the continuous signal. Likewise, a dB difference score was obtained for the last five excursions of the two stimuli. This was done for each test frequency, resulting in a total of six dB difference scores which were used to represent a subject's performance with Bekesy testing.

ABLB

All balancing was done for a total of ten acceptable excursions or one minute, whichever occurred first. The midpoint technique described for determining Bekesy thresholds was utilized for computing the balance levels obtained at the 20 and 40 dB sensation levels. All ten excursions, or the number of acceptable excursions completed during one minute, were used to compute a single measure of the balance.

Four separate balances were performed at each sensation level, and these measures were then averaged so that a single intensity level for each sensation level was formed. To obtain a measure of recruitment each subject's threshold at 4000 Hz, which was obtained just prior to the administration of the ABLB, was subtracted from the averaged intensity level for balances at the 40 dB sensation level. This resulted in one score at each presentation time which represented a subject's performance on the ABLB.

Brief Tone Audiometry

The subjects traced their thresholds for three signals of different duration for a total of ten acceptable excursions or one minute, whichever occurred first. The threshold for each duration was calculated by computing the midpoint of these excursions, and in this manner three separate scores were obtained for each test administration time.

All statistical computations for the study were obtained using a Control Data Corporation 3600 Digital Computer. Means, standard deviations, and correlations were obtained employing the program "Calculations of Basic Statistics on the Bastat Routine."[1] Work related to the analyses of variance utilized the program

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[1]Michigan State University, Agricultural Experiment Station, "Calculation of Basic Statistics on the BASTAT Routine," STAT Series Description #5, (March, 1966).

"Analysis of Variance with Equal Frequencies in Each Cell."[1]

In order that the data could be presented in a more efficient manner, the following coding system was employed in describing the test scores obtained:

SISI--The percentage score obtained with the Short Increment Sensitivity Index.

$Bekesy_1$--The dB difference between the average of the first five excursions of the pulsed signal and the first five excursions of the continuous signal at 4000 Hz with Bekesy testing.

$Bekesy_2$--The dB difference between the average of the last five excursions of the pulsed signal and the last five excursions of the continuous signal at 4000 Hz in Bekesy testing.

$Bekesy_3$--The dB difference between the average of the first five excursions of the pulsed signal and the first five excursions of the continuous signal at 1000 Hz in Bekesy testing.

$Bekesy_4$--The dB difference between the average of the last five excursions of the pulsed signal and the last five excursions of the continuous signal at 1000 Hz in Bekesy testing.

$Bekesy_5$--The dB difference between the average of the first five excursions of the pulsed signal and the first five excursions of the continuous signal at 250 Hz in Bekesy testing.

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[1]Michigan State University, Agricultural Experiment Station, "Analysis of Variance with Equal Frequencies in Each Cell," STAT Series Description # 14, (March, 1966).

$Bekesy_6$--The dB difference between the average of the last five excursions of the pulsed signal and the last five excursions of the continuous signal at 250 Hz with Bekesy testing.

ABLB--The dB difference between the average balance at a 40 dB sensation level and the threshold obtained one minute prior to the balance with the Alternate Binaural Loudness Balance.

BTA_1--The dB difference between the thresholds traced at 4000 Hz with 20 and 200 msec signal durations in brief tone audiometry.

BTA_2--The dB difference between the thresholds traced at 4000 Hz with 20 and 400 msec signal durations in brief tone audiometry.

Sensitivity to a Cochlear Malfunction

To evaluate the capacity of the four special tests under investigation to detect the presence of cochlear malfunctioning, it was necessary to examine the test results as a function of two parameters: time and amount of temporary threshold shift (TTS). In doing so, that test which indicated a breakdown in the normal functioning of the cochlea for the longest period of time following exposure could be determined, as well as the test which yielded the most positive results as the amount of TTS was minimized. Even though there is a definite correlation between TTS and the amount of time elapsed since the cessation of the fatiguing stimulus, this relationship is not a perfect one. It was necessary, therefore, that both of these measures should serve as criteria in determining which of the four special tests was the most sensitive to cochlear abnormalities caused by exposure to a fatiguing stimulus.

Analysis Over Time

Table 2 contains the mean scores of the test measures as a function of time. Inspection of the data reveals that the results of the SISI, according to Jerger's[1] classification, indicate the possibility of a cochlear lesion at all four post-exposure time intervals. Of the six measures obtained with the Bekesy, only the $Bekesy_2$ dB difference score indicated the possibility of any cochlear abnormalities, that occurring only at the ten minute post-exposure test time. The other test times for this frequency (4000 Hz) did show increases in the dB difference between the pulsed and continuous signals, but they did not exceed the 5 dB minimum established by Jerger[2] as indicating a cochlear malfunction. The ABLB results indicate a cochlear lesion at all post-exposure

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[1] J. Jerger, J. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," Archives of Otolaryngology, 69 (1959), 200-211.

[2] J. Jerger, "Bekesy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), 275-287.

TABLE 2.--Mean scores and standard deviations (SD in parentheses) of the 10 scores as a function of time.

Test Measure	Test Time in Minutes: Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
SISI	12.5% (15.3)	84.0% (13.8)	76.8% (23.4)	74.8% (24.6)	62.3% (24.9)
$Bekesy_1$	2.1 dB (2.0)	2.4 dB (2.2)	2.9 dB (2.2)	3.8 dB (2.1)	3.0 dB (2.3)
$Bekesy_2$	1.9 dB (3.3)	3.8 dB (3.6)	5.7 dB (3.7)	4.7 dB (3.8)	4.0 dB (3.6)
$Bekesy_3$	-0.4 dB (2.5)	-0.2 dB (2.7)	-0.5 dB (3.1)	0.8 dB (2.8)	-0.5 dB (2.6)
$Bekesy_4$	0.5 dB (2.3)	0.7 dB (2.6)	0.6 dB (3.3)	0.5 dB (2.4)	0.8 dB (2.1)
$Bekesy_5$	-0.5 dB (2.3)	-1.3 dB (2.3)	-0.0 dB (2.7)	-0.4 dB (3.0)	-0.9 dB (3.2)
$Bekesy_6$	1.9 dB (2.9)	-0.4 dB (2.0)	-0.1 dB (1.9)	-0.8 dB (3.5)	-0.9 dB (2.1)
ABLB	41.1 dB (7.5)	27.3 dB (9.3)	31.5 dB (9.1)	33.3 dB (10.5)	35.8 dB (8.8)
BTA_1	7.4 dB (1.4)	5.9 dB (1.5)	5.2 dB (1.9)	4.7 dB (1.3)	4.9 dB (1.4)
BTA_2	7.7 dB (1.8)	7.5 dB (1.4)	6.1 dB (2.1)	5.5 dB (1.9)	5.2 dB (1.2)

test times except the score obtained at the 30 minute post-exposure test time, which does not exceed the $\pm$ 5 dB range generally allowed for a margin of error. The results of brief tone audiometry tend to predict a cochlear lesion at all post-exposure test times, since the dB difference scores obtained at BTA_1 and BTA_2 are reduced at each post-exposure test time. Closer examination also reveals that the dB difference scores are less at the 30 minute post-exposure test time than at the 2 minute test time, indicating a definite ability of brief tone audiometric procedures to detect cochlear malfunctions of this type which have only minimal involvement.

An attempt was made to examine what interaction, if any, took place between time and test scores when the test scores are classified on the basis of the magnitude of the score, such as Type I or II Bekesy audiogram tracings, etc. Tables 3 through 7 illustrate the results of this classification as a function of test administration time for the SISI, ABLB, and Bekesy testing. Because no categories of abnormal integration have been established as yet, this type of analysis could not be performed with the data obtained through brief tone testing. The classification of the data for the SISI and Bekesy

TABLE 3.--Distribution of SISI, Bekesy, and ABLB results after classification at the pre-exposure test time.

Bekesy Type	ABLB No Recruitment SISI -	?	+	ABLB Partial Recruitment SISI -	?	+	ABLB Complete Recruitment SISI -	?	+	Total
I	9	4	0	1	1	0	0	0	0	15
II	4	0	0	0	1	0	0	0	0	5
Total	13	4	0	1	2	0	0	0	0	20

TABLE 4.--Distribution of SISI, Bekesy, and ABLB results after classification at the 2 minute post-exposure test time.

Bekesy Type	ABLB No Recruitment SISI -	?	+	ABLB Partial Recruitment SISI -	?	+	ABLB Complete Recruitment SISI -	?	+	Total
I	0	0	3	0	0	6	0	0	1	10
II	0	0	1	0	2	6	0	0	1	10
Total	0	0	4	0	2	12	0	0	2	20

TABLE 5.--Distribution of SISI, Bekesy, and ABLB results after classification at the 10 minute post-exposure test time.

Bekesy Type	ABLB No Recruitment SISI -	?	+	ABLB Partial Recruitment SISI -	?	+	ABLB Complete Recruitment SISI -	?	+	Total
I	0	0	2	0	0	6	0	0	0	8
II	0	2	2	1	0	7	0	0	0	12
Total	0	2	4	1	0	13	0	0	0	20

TABLE 6.--Distribution of SISI, Bekesy, and ABLB results after classification at the 20 minute post-exposure test time.

Bekesy Type	ABLB No Recruitment SISI -	?	+	ABLB Partial Recruitment SISI -	?	+	ABLB Complete Recruitment SISI -	?	+	Total
I	0	1	4	1	0	6	0	0	1	13
II	0	0	2	0	1	3	0	0	1	7
Total	0	1	6	1	1	9	0	0	2	20

TABLE 7.--Distribution of SISI, Bekesy, and ABLB results after classification at the 30 minute post-exposure test time.

Bekesy Type	ABLB No Recruitment SISI -	?	+	ABLB Partial Recruitment SISI -	?	+	ABLB Complete Recruitment SISI -	?	+	Total
I	0	2	4	0	2	3	0	0	0	11
II	0	2	3	0	0	4	0	0	0	9
Total	0	4	7	0	2	7	0	0	0	20

testing was based on the norms established by Jerger and his associates.[1, 2] Negative SISI scores ranged from 0-15 percent, questionable from 20-55 percent, and positive from 60-100 percent. The Type I Bekesy was characterized by interweaving pulsed and continuous tracings, whereas the continuous tracing was at least 5 dB poorer than the pulsed tracing at the higher frequencies in the Type II. Scores of the ABLB were categorized according to the magnitude of the dB difference score obtained between the

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[1]J. Jerger, J. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," 200-211.

[2]J. Jerger, "Bekesy Audiometry in Analysis of Auditory Disorders," 275-287.

40 dB balance and threshold. As a result, scores of more than 35 dB were classified as having no recruitment, scores of 20 to 35 dB as partial recruitment, and scores of less than 20 dB as complete recruitment.

Observation of these data reveals that those individuals who had partial or complete recruitment, as measured by the ABLB, tended also to have positive SISI scores at the post-exposure test administration times. It should be pointed out that in most cases, those individuals who showed no recruitment at the post-exposure test times received positive SISI scores. Analysis of the Bekesy types over time indicates, with the exception of the 10 minute test administration time, a tendency for the 20 tracing types to be equally distributed between types I and II at all post-exposure test times. Those subjects with positive SISI scores and partial or complete recruitment traced Type I audiograms with approximately the same frequency as they did Type II. Apparently the presence of positive SISI scores and recruitment does not allow one to predict with any high degree of accuracy what type of Bekesy tracing will be obtained in the fatigued ear.

If the decibel difference scores which were obtained in post-exposure brief tone testing were compared to the pre-exposure scores and were found to be significantly different, this would indicate the possibility of abnormal integration of energy at threshold. Accepting this, such an analysis of the data obtained indicates that in 13 instances during post-exposure testing results were obtained with BTA_1 implying the possibility of abnormal energy integration when negative or questionable SISI scores were obtained. Likewise, there were 19 occasions during the four post-exposure test times where an indication of abnormal integration was evident with BTA_1 but where no evidence of recruitment was discovered. This also occurred 33 times when $Bekesy_2$ was analyzed with BTA_1. If the results of the SISI and ABLB were used together to predict the presence of a cochlear lesion, there would be seven instances where they both indicated no cochlear involvement, but where BTA_1 did. This information tends to imply that BTA is, in a significant number of cases, more sensitive to cochlear lesions produced by exposure to noise than is any of the other tests employed in this investigation.

To evaluate further the sensitivity of the diagnostic tests of interest over time, as well as examining any test score differences attributable to the sex of the subjects and any sex-time interaction, 10 two-way analysis of variance designs were employed. In doing this it was then possible to systematically ascertain the effects which time, sex, and any sex-time interactions might have on any of the special test measures obtained on the subjects in this study.

The first measures evaluated in this manner were SISI scores. A summary of this analysis is presented in Table 8. Inspection of this summary reveals that the only factor showing statistical significance, at the 0.01 level of confidence, was time.[1] Neither sex of the subjects nor sex-time interaction was significant variables. The analysis of variance, however, does not provide specific information relative to the difference between means, only that a significant difference exists or does not exist for a specific variable.

Therefore, in order to further evaluate the factor of time with the SISI, the data were subjected to multiple comparisons using Duncan's New Multiple Range

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[1]Because of the nature of the data, the degrees of freedom were derived according to a procedure suggested by Greenhouse and Geisser in Psychometrika, 24 (1959), p. 112. This procedure results in a more conservative alpha level for the ANOVA than is ordinarily the case. All degrees of freedom derived for the ANOVA's done in this study were computed based on this method.

TABLE 8.--Summary of analysis of variance comparing performance on the SISI as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	342.25	1	342.25	0.22
Subjects: Sex	27842.50	18	1546.81	- - -
Times	66288.50	4	16572.13	79.23*
Sex x Times	671.50	4	167.88	0.80
Times x Subjects: Sex	15060.00	72	209.17	- - -
TOTAL	110204.75	99	- - -	- - -

*Significant beyond the 0.01 level.

Test.[1] The results of this test are shown in Table 9, utilizing the 0.01 level of significance.

An examination of this analysis reveals the following significant differences: (1) the pre-exposure mean differs significantly from all four post-exposure means; (2) the mean of the 30 minute post-exposure test time is significantly different from the 2 and 10 minute post-exposure test times; and (3) the differences between the 2, 10, and 20 minute post-exposure test scores are not significant. It is apparent, therefore, that over

[1]Allen L. Edwards, Experimental Design in Psychological Research (New York: Holt, Rinehart and Winston, 1960), 136-157.

TABLE 9.--Duncan's New Multiple Range Test applied to the differences between SISI means as a function of time.

		Test Administration Times				
		Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
Time and Means		12.5%	84.0%	76.8%	74.8%	62.3%
Pre-exp	12.5%		71.5*	64.3*	62.3*	49.8*
$Post_2$	84.0%			7.2	9.2	21.7*
$Post_{10}$	76.8%				2.0	14.5*
$Post_{20}$	74.8%					12.5

*Significant at the 0.01 level

time the SISI was highly sensitive to the cochlear lesion produced by the fatiguing stimulus, even 30 minutes after its cessation.

The six test measures obtained with Bekesy audiometric procedures were also subjected to analyses of variance. Summaries of these tests are presented in Tables 10 through 15.

As can be seen in the above summaries, the variables of interest were not significant for any of the six measures obtained with Bekesy testing. Because of this, the Bekesy's ability to detect this type of cochlear lesion is consequently questionable. Because no significant

TABLE 10.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the initial portions of the pulsed and continuous signals at 4000 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	2.56	1	2.56	0.40
Subjects: Sex	115.09	18	6.39	- - -
Times	32.22	4	8.05	1.80
Sex x Times	36.85	4	9.21	2.16
Times x Subjects: Sex	307.67	72	4.27	- - -
TOTAL	494.39	99	- - -	- - -

*Significant beyond the 0.01 level.

TABLE 11.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the final portions of the pulsed and continuous signals at 4000 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	16.48	1	16.48	0.46
Subjects: Sex	642.38	18	35.69	- - -
Times	154.29	4	38.57	4.78
Sex x Times	45.35	4	11.34	1.41
Times x Subjects: Sex	581.38	72	8.07	- - -
TOTAL	1439.87	99	- - -	- - -

*Significant beyond the 0.01 level.

TABLE 12.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the initial portions of the pulsed and continuous signals at 1000 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	3.96	1	3.96	0.26
Subjects: Sex	275.66	18	15.31	---
Times	24.27	4	6.07	1.04
Sex x Times	56.34	4	14.09	2.41
Times x Subjects: Sex	420.31	72	5.84	---
TOTAL	780.55	99	---	---

*Significant beyond the 0.01 level.

TABLE 13.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the final portions of the pulsed and continuous signals at 1000 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	18.15	1	18.15	1.02
Subjects: Sex	319.20	18	17.73	- - -
Times	2.11	4	0.53	0.12
Sex x Times	21.35	4	5.34	1.22
Times x Subjects: Sex	314.31	72	4.37	- - -
TOTAL	675.11	99	- - -	- - -

*Significant beyond the 0.01 level.

TABLE 14.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the initial portions of the pulsed and continuous signals at 250 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	14.98	1	14.98	1.30
Subjects: Sex	206.60	18	11.48	- - -
Times	18.47	4	4.62	0.74
Sex x Times	65.84	4	16.46	2.62
Times x Subjects: Sex	452.20	72	6.28	- - -
TOTAL	758.08	99	- - -	- - -

*Significant beyond the 0.01 level.

TABLE 15.--Summary of analysis of variance comparing performance with Bekesy audiometry on the dB difference between the final portions of the pulsed and continuous signals at 250 Hz as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	0.28	1	0.28	0.02
Subjects: Sex	232.80	18	12.93	- - -
Times	102.33	4	25.58	4.56
Sex x Times	23.88	4	5.97	1.06
Times x Subjects: Sex	403.62	72	5.61	- - -
TOTAL	762.91	99	- - -	- - -

*Significant beyond the 0.01 level.

F's were revealed with the analysis of variance procedure, no further testing related to any sex, time, or sex-time interaction influences was attempted with Bekesy results.

As with the SISI and Bekesy data, the results of the ABLB were also evaluated by means of an analysis of variance. A summary of this statistical analysis is given in Table 16.

TABLE 16.--Summary of analysis of variance comparing performance on the ABLB as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	13.32	1	13.32	0.04
Subjects: Sex	6720.00	18	373.33	- - -
Time	2219.04	4	554.76	26.73*
Sex x Time	28.31	4	7.08	0.34
Time x Subjects: Sex	1494.49	72	20.76	- - -
TOTAL	10475.16	99	- - -	- - -

*Significant beyond the 0.01 level.

The results presented in this table indicate that the factor of time was the only variable analyzed which was statistically significant. So that the variable of time could be more extensively analyzed, the Duncan New

Multiple Range Test was employed once again. The results of this test are included in Table 17.

TABLE 17.--Duncan's New Multiple Range Test applied to the differences between ABLB means as a function of time.

		Test Administration Times				
		Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
Time and Means		41.5dB	27.3dB	31.5dB	33.3dB	35.8dB
Pre-exp	41.5dB		14.2*	10.0*	8.2*	5.7*
$Post_2$	27.3dB			4.2*	6.0*	8.5*
$Post_{10}$	31.5dB				1.8	4.3
$Post_{20}$	33.3dB					2.5

*Significant beyond the 0.01 level.

Inspection of this table reveals the following differences: (1) the pre-exposure mean is significantly different from the means of all four post-exposure test times; (2) the 2 minute post-exposure test mean is significantly different from the means of the other three post-exposure test times; (3) the means of the 10, 20, and 30 minute post-exposure test times are not statistically different. Apparently the ABLB, like the SISI, was quite sensitive to the temporary cochlear lesion which was present.

The results of brief tone audiometry were also analyzed by an analysis of variance, and Table 18 summarizes the influence which the variables of sex, time, and the sex-time interaction had on the dB difference between thresholds obtained with 20 and 200 msec equivalent duration signals.

TABLE 18.--Summary of analysis of variance comparing performance with brief tone audiometry on the dB difference between thresholds obtained with 20 and 200 msec equivalent duration signals as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	0.25	1	0.25	0.08
Subjects: Sex	59.13	18	3.28	- - -
Time	94.25	4	23.56	11.22*
Sex x Time	8.41	4	2.10	1.00
Time x Subjects: Sex	151.43	72	2.10	- - -
TOTAL	313.47	99	- - -	- - -

*Significant beyond the 0.01 level.

As Table 18 indicates, the only variable of significance at the 0.01 level was time. The Duncan New Multiple Range Test was once again utilized in analyzing the differences between mean for the variable of time, and these results are shown in Table 19.

TABLE 19.--Duncan's New Multiple Range Test applied to the differences between means with brief tone audiometry dB difference scores obtained with 20 and 200 msec equivalent duration signals as a function of time.

		Test Administration Times				
		Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
Times and Means		7.4dB	5.9dB	5.2dB	4.7dB	4.9dB
Pre-exp	7.4dB		1.5*	2.2*	2.7*	2.5*
$Post_2$	5.9dB			0.7	1.2	1.0
$Post_{10}$	5.2dB				0.5	0.3
$Post_{20}$	4.7dB					0.2

*Significant beyond the 0.01 level.

The results of Table 19 indicate the following differences: (1) the pre-exposure mean is significantly different from the means of all four post-exposure test times; (2) the means of the four post-exposure times are not significantly different from each other. The brief tone testing procedure is therefore felt to also be capable of detecting a cochlear lesion of this type with the same degree of success as do the SISI and ABLB.

Table 20 shows the influence which the factors of sex, time, and the sex-time interaction had on the dB difference between 20 and 400 msec equivalent duration signals employed in BTA, as measured by an analysis of variance procedure.

TABLE 20.--Summary of analysis of variance comparing performance with brief tone audiometry on the dB difference between thresholds obtained with 20 and 400 msec equivalent duration signals as a function of sex and time.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Sex	2.89	1	2.89	0.48
Subjects: Sex	108.88	18	6.05	- - -
Time	105.66	4	26.41	12.08*
Sex x Time	5.06	4	1.27	0.59
Time x Subjects: Sex	157.44	72	2.19	- - -
TOTAL	379.92	99	- - -	- - -

*Significant beyond the 0.01 level.

From the results of this analysis, it is apparent that the variable of time had a significant influence on test results, while sex and any sex-time interaction did not. Further evaluation of this variable was carried out with the Duncan New Multiple Range Test, and the results are included in Table 21.

The following differences were detected from the above results: (1) the pre-exposure mean is significantly different from the means at 10, 20, and 30 minute test

TABLE 21.--Duncan's New Multiple Range Test applied to the differences between means with brief tone audiometry dB difference scores obtained with 20 and 400 msec equivalent duration signals as a function of time.

		Test Administration Times				
		Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
Times and Means		7.7dB	7.5dB	6.1dB	5.5dB	5.2dB
Pre-exp	7.7dB		0.2	1.6*	2.2*	2.5*
$Post_2$	7.5dB			1.4*	2.0*	2.3*
$Post_{10}$	6.1dB				0.6	0.9
$Post_{20}$	5.5dB					0.3

*Significant beyond the 0.01 level.

times; (2) the mean of the 2 minute post-exposure test time is significantly different from the other post-exposure test time means; (3) the means of the 10, 20, and 30 minute post-exposure test times are not significantly different from each other. Here again, the results obtained with BTA allow one to predict the presence of a cochlear lesion, even 30 minutes after cessation of the fatiguing stimulus.

TTS-Test Score

As well as inspecting the relationship of time and test score to determine the capacity of each of the four special tests evaluated here to detect a cochlear malfunction, it was felt that examination of the relationship between the amount of TTS experienced and the corresponding test scores would be of interest in attempting to resolve this question. The rationale for looking at the relationship between these two variables is based on the fact that the more sensitive tests of a cochlear lesion would detect such a condition when there was only minimal involvement. The purpose here, then was to determine which test yielded results indicative of a cochlear lesion at the lowest levels of TTS.

Table 22 represents the classification of the test scores obtained on the SISI, ABLB, and Bekesy audiometry as a function of the amount of TTS present when the test scores were obtained. As discussed previously, the analysis of the results of brief tone audiometry in this manner was not possible, since an attempt has not been made thus far to classify the results of temporal integration in pathological cases.

Inspection of this table reveals that all three tests seem to perform equally well when the amount of TTS present is in the range of 5 to 10 dB. Above this point, however, the SISI tends to indicate the presence of a cochlear lesion more consistently than does either the ABLB or Bekesy testing.

TABLE 22.--Distribution of SISI, Bekesy, and ABLB post-exposure test results after classification as a function of the amount of TTS present.

Amount of TTS in dB	SISI			BEKESY		ABLB Recruitment		
	-	?	+	I	II	N	F	C
0	0	1	0	0	0	0	0	0
5	0	2	3	4	4	3	1	0
10	2	6	5	7	3	5	6	0
15	1	1	12	9	5	10	7	0
20	0	2	13	7	11	3	15	0
25	0	2	8	7	4	2	7	1
30	0	0	10	4	5	3	10	0
35	0	0	7	4	3	1	1	1
40	0	0	0	1	1	1	0	1
45	0	0	0	1	0	0	1	1
50	0	0	0	0	0	0	0	0

To further evaluate the relationship between the amount of TTS and the resulting test scores, Pearson Product Moment Correlations were obtained between the amount of TTS present and the test scores of each test at the corresponding point in time. These correlations are provided in Appendix C. Only two of the computed correlations were significant at the 0.05 level, those occurring with the amount of TTS present at the 30 minute post-exposure test time and the resulting test scores on the SISI and ABLB. Both Bekesy testing and BTA did not correlate significantly with TTS at any point. The magnitudes of all of the correlations obtained would tend to indicate that only a minor relationship exists between the amount of TTS present and the resulting score on any of the four tests.

On the basis of the results presented concerning test scores as a function of time and amount of TTS, it is apparent that the SISI, ABLB, and BTA all seem quite sensitive to this type of cochlear lesion, while Bekesy testing does not appear as sensitive.

Linearity of the Integration Function

Initially the threshold data obtained for the three signal durations used in the study were plotted and analyzed in dB re Audiometric 0. Figure 5 is a graphic representation of these data.

Inspection of this figure reveals that the slope of integration at the pre-exposure test time is, when compared to the post-exposure functions, different. Because the pre-exposure slope is steeper and the post-exposure integration slopes more compressed, the magnitude of the dB shifts which occurred after the fatiguing stimuli were much greater for the 200 and 400 msec signals than for the 20 msec signal. This tendency for the duration-intensity function to become compressed is an indication that the integration of energy in the post-exposure test times is abnormal relative to the pre-exposure function.

The thresholds at the pre-exposure test time were then converted to sound pressure level readings (SPL), and Table 23 contains the results of this conversion. From these data it is apparent that a 7.4 dB difference exists between the mean thresholds obtained with the 20 and 200 msec signals. This compares reasonably well with the results obtained with normal hearers by Olsen and Carhart[1] for the same durations and frequency.

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[1]W. Olsen and R. Carhart, "Integration of Acoustic Power at Threshold by Normal Hearers," Journal of the Acoustical Society of America, 40 (1966), 591-599.

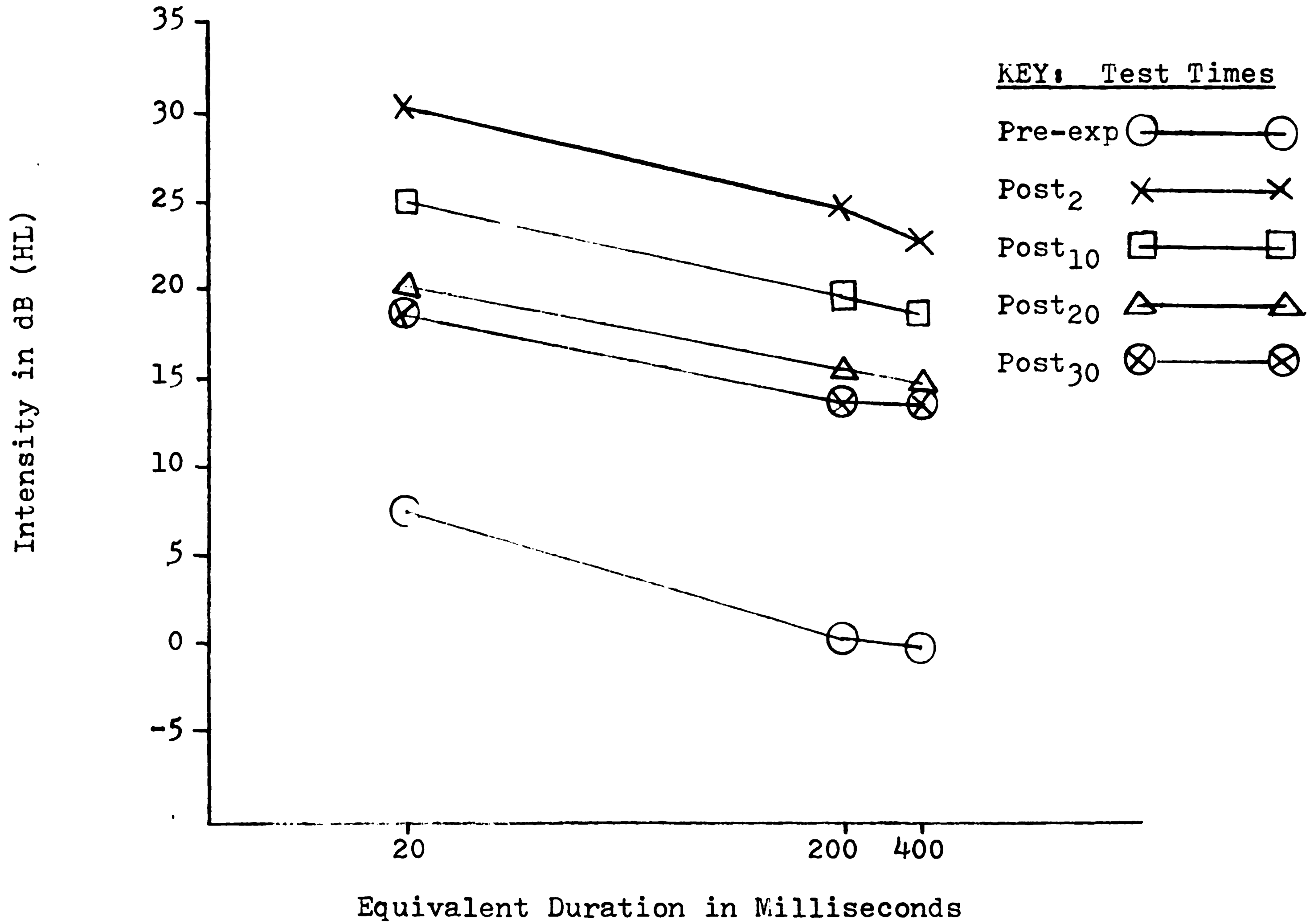

Figure 5.--Mean threshold values as a function of time and stimulus duration.

TABLE 23.--Mean intensity levels at threshold during pre-exposure brief tone audiometric testing. Means are expressed in dB re 0.0002 Microbar. Standard deviations also in dB.

	Equivalent Duration of Stimuli		
	20	200	400
Mean	16.9	9.5	9.1
Standard Deviation	5.5	5.5	5.0

A major question to be answered with the data concerns whether or not the normal slope of the integration of energy is linear over time. The results presented earlier in Figure 5 and Table 28 show that the duration-intensity function for the 20 subjects at the pre-exposure test time is not linear. In other words, for every log unit change in the duration of the signal, there is not a corresponding 10 dB shift in threshold. As can be seen, this shift is actually 7.4 dB for the data obtained in this study.

In analyzing the slope of integration, however, Garner and Miller[1] feel that only intensities above a certain level will contribute in eliciting threshold. The equation $t\ (I-I_0) = C$, based on the Garner and Miller

[1]W. Garner, and G. Miller, "The Masked Threshold of Pure Tones as a Function of Duration," Journal of Experimental Psychology, 37 (1947), 293-303.

hypothesis of the integration of acoustical energy, provides a means of determining the integration function of energy above this critical level. In this formula t represents signal duration, I the power of the signal in watts, and I_0 the energy which is not utilized in eliciting threshold. I_0 in this study was computed by transforming the data presented by Olsen and Carhart by means of a simple proportion equation, which was

$$\frac{I_{200-OC}}{I_{0-OC}} = \frac{I_{200-N}}{I_{0-N}}$$

where I_{200-OC} was the intensity in watts at threshold reported by Olsen and Carhart for a 4000 Hz tone with a 200 msec equivalent duration, I_{0-OC} was their computed intensity level in watts which was not an effective stimulus for the ear, I_{200-N} was the intensity in watts at threshold for a 200 msec tone at 4000 Hz in this study, and I_0 was the component being solved for. The value computed for I_0 was then used as the I_0 for the data obtained in this study. Solving for I_0 in this manner, a value of 6.2 watts/cm^2 was obtained.

Figure 6 displays the effective intensity ($I-I_0$) at threshold as a function of the signal durations employed in this study, as well as a plotting of the same function obtained by Olsen and Carhart with their data.

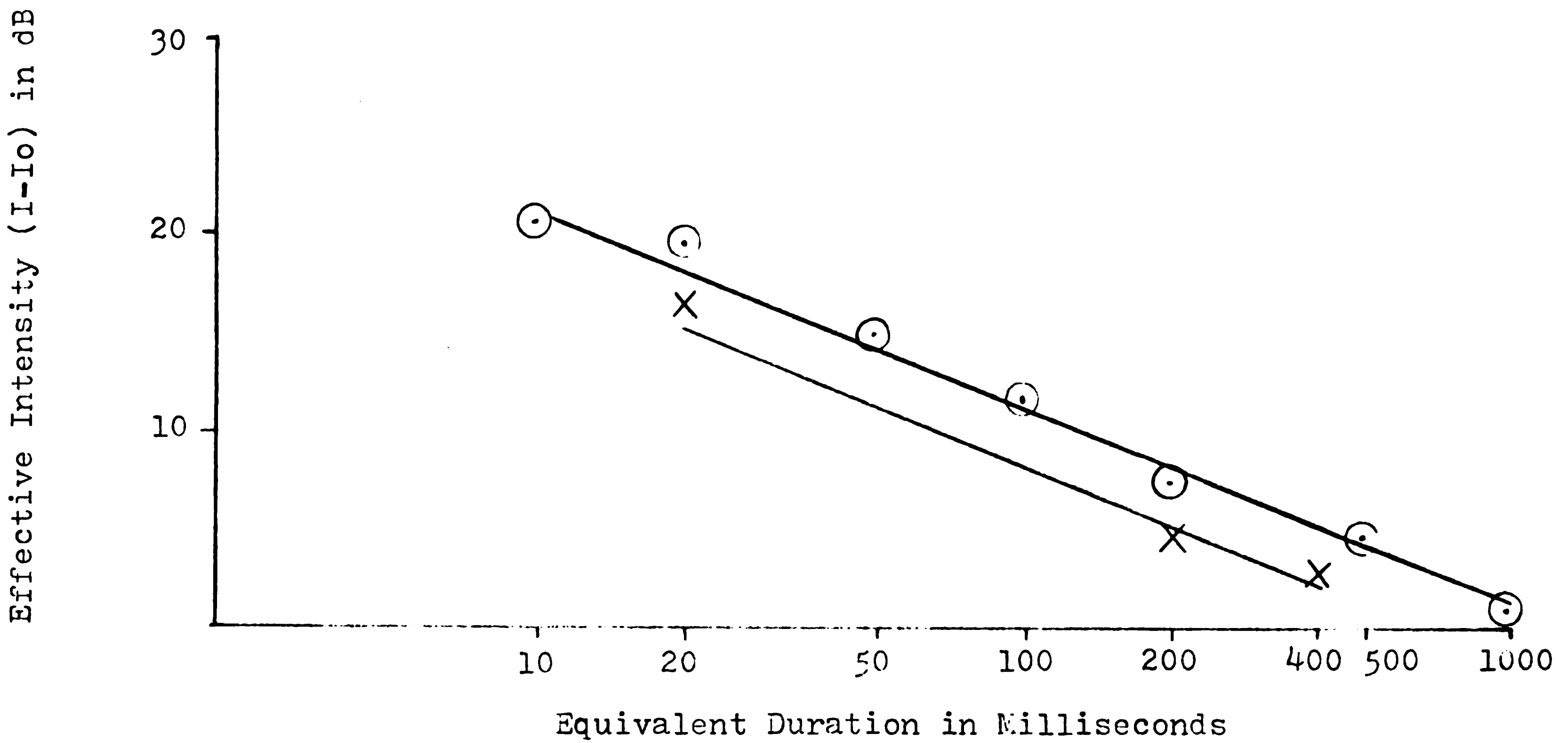

Figure 6.--Effective intensity (I-Io) at threshold as a function of stimulus duration. Io value in dB for each stimulus has arbitrarily been set to 0 dB. O: Olsen-Carhart data points. X: Data of present study.

The lines drawn through the data are a hypothetical representation of what the slope of integration would be according to the model of Garner and Miller. This model calls for a 3 dB alteration in threshold for every doubling or halving of the signal duration.

The displacement of the data for this study toward the abscissa of approximately 2-3 dB is due simply to slight differences in acuity between the two groups of subjects. Taking into account the fact that only three points have been plotted from this study, it is still apparent that the data points conform reasonably well to the function representing the Garner and Miller model, as do the data of Olsen and Carhart. On the basis of this information, one can conclude that the data generally agree with the model of Garner and Miller, and that this lends further support to the notion that only energy above a certain critical magnitude is integrated in a linear fashion.

Recruitment and Abnormal Integration

In investigating the integration of energy in pathological ears, a number of studies have considered the relationship between the presence of recruitment and abnormal integration. Some, such as Miskolczy-Fodor,[1] have concluded that the presence of an abnormal integration function strongly suggests the presence of recruitment, whereas others, such as Harris, et al.,[2] have not found this to be true in a number of cases. Because some question does exist on this topic, Pearson Product Moment Correlations were obtained between the dB difference scores obtained in BTA testing and the dB difference score used to represent performance on the ABLB. The results of these correlations are given in Appendix D. Even though a significant correlation does exist at the pre-exposure test time, the post-exposure scores of the two tests do not correlate well at all. These weak correlations, then, would tend to indicate a minimal amount of predictability of one of these tests based on the score of the other.

Amount of TTS and Its Reliability

The mean amount of TTS experienced at four post-exposure times for each of four test sessions, as

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[1]F. Miskolczy-Fodor, "Monaural Loudness Balance Test and Determination of Recruitment Degrees with Short Sound Impulses," Acta-Otolaryngology, 43 (1953), 573-595.

[2]J. Harris, H. Haines, and C. Myers, "Brief Tone Audiometry," Archives of Otolaryngology, 67 (1958), 699-713.

well as the corresponding standard deviations, are given in Table 24.

TABLE 24.--Mean amount of TTS in dB of the 20 subjects at each test session and time. The standard deviations at each period are also given and are in parentheses.

Time of TTS Measurement in Minutes	Test Session: SISI	Bekesy	ABLB	BTA
$Post_1$	30.3 (7.2)	28.0 (6.6)	29.2 (6.6)	27.8 (5.8)
$Post_9$	22.5 (8.0)	22.2 (8.1)	21.8 (5.8)	20.3 (6.0)
$Post_{19}$	17.5 (7.7)	16.8 (8.1)	17.8 (6.6)	16.3 (6.1)
$Post_{29}$	13.0 (7.5)	13.8 (7.9)	14.0 (7.5)	13.0 (7.0)

Figure 7 is a graphic representation of these means. As can be seen, the mean amount of TTS experienced at the initial test time is quite similar for the four separate test sessions. Recovery from exposure also is very similar for each session and is never complete at the last evaluation time, which was 29 minutes after cessation of the white noise.

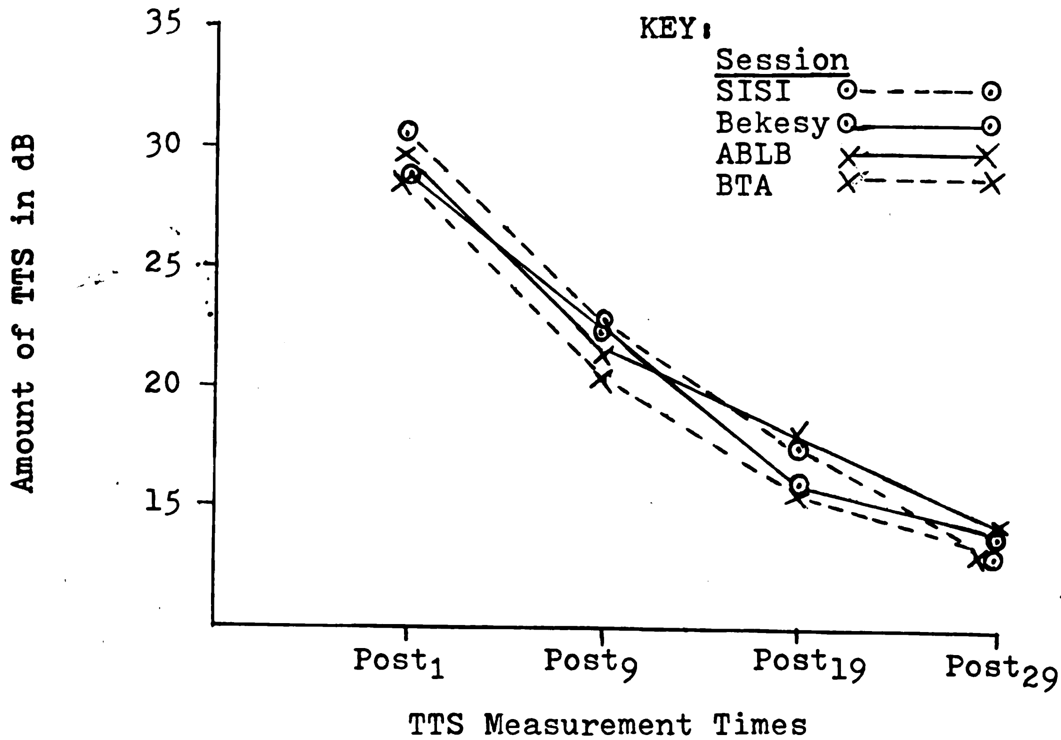

Figure 7.--Graphic representation of the mean amount of TTS experienced as a function of time for all 20 subjects.

The mean amount of TTS experienced by males and females as a function of time is illustrated in Figure 8. Analysis of these data shows a trend for the females to suffer slightly less TTS initially and to recover their hearing more rapidly than did the males.

To determine statistically what the test-retest reliability of the amount of TTS experienced was for all 20 subjects, Pearson Product Moment Correlations were run between the TTS scores obtained during (1) SISI and BTA, and (2) Bekesy and ABLB testing at the four

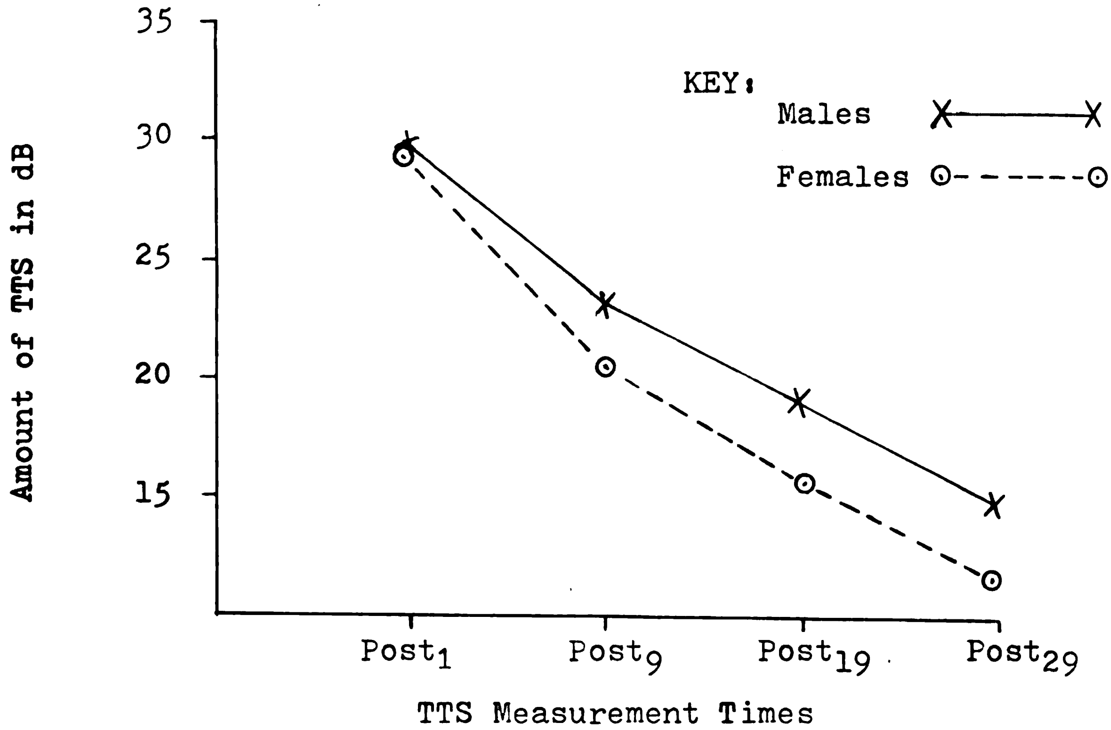

Figure 8.--Graphic representation of the mean amount of TTS experienced by males and females as a function of time.

post-exposure measurement times. The correlations obtained are given in Table 25.

These correlations indicate that both the initial amount of TTS and the rate of recovery from fatigue are significantly related. The initial amount of TTS experienced appears to have the greatest amount of correlation of the four measurement times. On the basis of these results, it is felt that the TTS scores are reasonably reliable from one session to another.

TABLE 25.--Pearson Product Moment Correlations of the amount of TTS experienced at (1) the SISI and brief tone test sessions, and (2) the Bekesy and ABLB test sessions as a function of the four TTS measurement times.

	TTS Measurement Time in Minutes			
Sessions	$Post_1$	$Post_9$	$Post_{19}$	$Post_{29}$
SISI-BTA	0.89*	0.72*	0.71*	0.57*
Bekesy-ABLB	0.69*	0.56*	0.54*	0.67*

*Significant at the 0.05 level

Discussion

As indicated by the results presented, the SISI, ABLB, and BTA were able, in a majority of cases, to appropriately predict the existence of a cochlear lesion. The performance of BTA in detecting this type of lesion can be considered to be at least as adequate as the SISI or ABLB, and the procedure appears to be much more sensitive than Bekesy testing. This is in direct contrast with the results obtained by Hickling[1] in a similar study evaluating the SISI, ABLB, and Bekesy audiometry with

[1]S. Hickling, "Hearing Test Patterns in Noise Induced Temporary Hearing Loss," Journal of Auditory Research, 7 (1967), 63-76.

fatigued ears. In his investigation, Hickling found that the ABLB was the only consistent predictor of a cochlear lesion. The lack of sensitivity on the part of the SISI in his study may be due to the fact that Hickling used a less intense fatiguing stimulus for less time than was employed in this study.

On the basis of the results obtained in this study, as well as other studies concerned with the major question asked in this study, the inclusion of BTA into a routine battery of diagnostic tests would seem warranted in the near future, pending the completion of research intended to gather normative data with various pathologies. It should be pointed out that BTA can be administered to both unilateral and bilateral types of hearing loss, while the ABLB is limited only to patients with unilateral impairments. Thus, BTA is more applicable than the ABLB in a significant number of cases. The procedure employed in this study proved to be a satisfactory one, as did the instrumentation used, which was originally introduced by Wright.[1] The task was an easy one for the subjects and took only three to four minutes from beginning to end.

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[1]H. Wright, "Clinical Measurement of Temporal Auditory Summation," Journal of Speech and Hearing Research, 11 (1968), 109-127.

Some of the equipment that was used, specifically the generators and electronic switch, is not routinely employed in a typical clinical setting, but is generally available because of their utility in other work related to the area of speech and hearing.

The finding that the normal integration of acoustical energy over time is linear above a critical level of input is in direct agreement with the studies done by Olson and Carhart,[1] as well as Dallos and Olsen,[2] who treated their data and described their stimulus parameters in a similar fashion. The presence of linear integration at the pre-exposure test time and abnormal or non-linear integration of energy during post-exposure testing also is consistent with the findings of Jerger,[3] who carried out a similar study on temporal integration with normal hearers who were exposed to a fatiguing stimulus.

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[1]Olsen and Carhart, "Integration of Acoustic Power at Threshold by Normal Hearers," 591-599.

[2]P. Dallos, and W. Olsen, "Integration of Energy at Threshold with Gradual Rise-Fall Tone Pips," Journal of the Acoustical Society of America, 36 (1964), 743-751.

[3]J. Jerger, "Influence of Stimulus Duration on the Pure Tone Threshold During Recovery From Auditory Fatigue," Journal of the Acoustical Society of America, 27 (1955), 121-124.

The lack of a significant relationship between recruitment and abnormal integration lends further support to the conclusions set forth by Harris, et al.,[1] who found several cases exhibiting both recruitment and abnormal integration, several also having neither, and many cases exhibiting either one alone. Sanders and Honig[2] also concluded that abnormal energy integration and recruitment do not always occur together. The absence of a strong relationship between these two auditory functions would imply that perhaps the ABLB and BTA are actually testing aspects of the auditory system which are quite different. In this respect, the utilization of both of these tests to increase the clinical audiologist's diagnostic capabilities is strongly suggested.

The fact that test scores were not significantly influenced by the sex of the subjects is particularly relevant to the area of temporal integration, since conflicting evidence concerning this question has been found. Goldstein and Kramer,[3] for example, found a

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[1]Harris, Haines, and Myers, "Brief Tone Audiometry," 699-713.

[2]J. Sanders and E. Honig, "Brief Tone Audiometry," <u>Archives of Otolaryngology</u>, 85 (1967), 84-91.

[3]R. Goldstein and R. Kramer, "Factors Affecting Thresholds for Short Tones," <u>Journal of Speech and Hearing Research</u>, 3 (1960), 249-256.

significant difference in the performance of the two sexes, with females having a steeper slope of energy integration. Olson and Carhart,[1] on the other hand, found no significant differences at all for the two groups. Perhaps, as Olsen and Carhart point out, the discrepancy between the two studies might be due to the ages of the subjects in the two samples. The subjects in this study ranged in age from 14 to 39, while Olson and Carhart's subjects ages ranged from 18 to 28 and Goldstein and Kramer's from 18 to 76. It is suggested that the steeper integration slope found for females by Goldstein and Kramer may be due in part to a more prevalent presbycusic element in their male sample.

Though it was not a major question to be researched, the amount and reliability of TTS proved to be an interesting one. An examination of the means and simple correlations carried out did, as mentioned earlier, indicate that both the amount of TTS experienced immediately following the fatiguing stimulus and the recovery rate were quite reliable. This is especially apparent for those individuals who experienced either very little or a considerable amount of TTS in their initial test session;

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[1]Olsen and Carhart, "Integration of Acoustic Power at Threshold by Normal Hearers," 591-599.

these individuals continued to experience the same general amount of TTS in following sessions. The range of TTS (20-45 dB) and its test-retest reliability reinforce the already known fact that there is variability in the susceptibility among different individuals to fatiguing stimuli. According to the data obtained in this study with TTS, approximately 20 percent could be considered to be highly susceptible to auditory fatigue.

Another interesting aspect of the TTS data is that even though the females in the study did experience nearly as much fatigue as did the males, they recovered at a faster rate. In a study concerned with this, Ward[1] exposed college-age males and females to the same fatiguing stimulus and found that the males experienced slightly more TTS than did the females and the recovery time of the two groups was similar. Ward felt, however, that the difference in the amount of TTS experienced in the two groups was not significant because of measurement error. However, because of the occurence of a difference attributable in this study, future research in this area appears warranted.

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[1]W. Dixon Ward, "Susceptibility to TTS and the Influence of Gender," Journal of the Acoustical Society of America, 31 (1959), 1138.

Summary

A review of the descriptive and inferential statistical information presented in this chapter has led to the rejection of three null hypotheses and the failure to reject two others.

Specifically, Ho_1 was concerned with evaluating the sensitivity of the four special tests under study in detecting the presence of a cochlear lesion. Two parameters, time and amount of TTS, were analyzed in an attempt to answer this question. The evaluation of test scores over time revealed that the SISI, ABLB, and BTA detected a malfunction in the cochlea at all post-exposure test times, whereas the results of Bekesy testing indicated a cochlear lesion only at one post-exposure test time, that being 10 minutes. This, coupled with the fact that there was a tendency for the SISI and ABLB to detect cochlear pathology more frequently at low levels of TTS than did Bekesy testing, led to the rejection of this null hypothesis.

The question of whether or not recruitment and abnormal integration are directly related was the subject of Ho_2. By correlating the test scores obtained with the two tests of interest, the ABLB and BTA, it was discovered that while a mild correlation existed, no statistically significant relationship was found between the two test measures. On the basis of this, Ho_2 could not be rejected.

Ho_3 involved the possibility of a significant difference in the test scores obtained with males and females. To test this statistically, the data were analyzed by an analysis of variance procedure. Because no significant F's were obtained through such an analysis, it was concluded that Ho_3 could not be rejected.

Ho_4 was concerned with the test-retest reliability of the TTS experienced by the 20 subjects. Simple correlations were used to test this hypothesis and because of the significant r's obtained, it was possible to reject the null hypothesis that TTS was not reliable.

Ho_5, which could not be tested inferentially, dealt with whether or not the normal duration-intensity function was linear. A plotting of the mean thresholds obtained as a function of the duration of the test signal showed initially that a linear function did not exist. However, the data were analyzed according to the Garner-Miller diverted-input hypothesis, and it was shown that above a critical level of energy the auditory system did integrate energy in a linear fashion. Because of this, Ho_5 was rejected.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The basic purpose of this research was to evaluate the performance of a group of individuals with temporary cochlear lesions with four diagnostic tests, the Short increment Sensitivity Index, Bekesy audiometry, the Alternate Binaural Loudness Balance, and a form of brief tone audiometry, in order to determine which of these tests was the most sensitive to this type of lesion. An additional question was posed concerning whether or not the performance of males and females on these tests was significantly different. Concern was also given to the possibility of the linear integration of energy at threshold and its relationship with the auditory phenomenon of recruitment. Finally, attention was given to examining the reliability of the amount of TTS experienced at four different test sessions.

Summary

Twenty subjects, ten males and ten females ranging in age from 14 to 39, were selected for the study.

Each subject's hearing was required to be 10 dB HL or better bilaterally for the octave frequencies from 250 through 8000 Hz in order to be included in the study.

Every subject was seen for four separate test sessions. At each session he was given one of the special tests of interest in the study five different times, once before exposure to fifteen minutes of 110 dB SPL of broad band white noise, and four set times following exposure. All testing was done at 4000 Hz, except that fixed-frequency Bekesy testing was also carried out at 1000 Hz and 250 Hz as well.

The data were subjected to descriptive and inferential statistical analyses in order to answer the questions originally posed. Analyses of variance, as well as descriptive measures, were employed to resolve the question of whether or not the brief tone testing provided information in addition to that obtained with the SISI, Bekesy testing, and the ABLB, as well as determining if any significant differences in test scores existed between males and females. Pearson Product Moment Correlations were used to investigate the relationship between the integration of energy and recruitment, and to determine the reliability of the TTS measures obtained.

The results indicated that three tests, the SISI, ABLB, and BTA, appear to detect a temporary cochlear lesion satisfactorily, while Bekesy testing does not. These same results did not show any difference in the performance of males and females. It was revealed that the normal integration of energy above a critical magnitude does proceed in a linear fashion and the degree of integration is not significantly related to the presence or absence of recruitment. It was also learned that the amount of TTS experienced for four different test sessions is reliable, as is the resulting recovery rate.

Conclusions

Within the limits imposed by the design of the study, the following conclusions appear warranted:

1. The SISI, ABLB, and BTA are quite sensitive to cochlear lesions caused by exposure to broad band white noise, while Bekesy testing is not.

2. BTA can be utilized clinically as a tool to detect the presence of a cochlear lesion.

3. The normal integration of energy at threshold over time is linear above a minimal intensity level.

4. Males and females do not differ in their performance on any of the special tests employed in this study.

5. The amount of recruitment and the degree of temporal integration are not highly related. BTA appears to be testing another aspect of the auditory process than does the ABLB.

6. The amount of TTS experienced at several different exposures, as well as the recovery of hearing, is reasonably reliable.

7. There is evidence that the amount of TTS experienced and the rate of recovery is different in males and females, with males experiencing more TTS and females recovering from TTS at a more rapid rate.

Recommendations for Further Research

A natural extension of this study would be to administer this same battery of tests with a group of individuals who have a permanent hearing loss directly attributable to chronic noise exposure. In this manner a direct comparison of the results obtained in subjects with temporary and permanent noise induced hearing losses could be made. Doing this would also increase the amount of information available concerning the audiological characteristics of individuals with temporary threshold shifts.

The clinical utility of brief tone audiometry should be extensively examined with a large group of subjects representing various conductive, cochlear, retrocochlear, and central lesions so that normative data can be gathered. Representative integration functions for known test signals could possibly be established for various types of lesions, and this information used in the differential diagnosis of pathology within the auditory system.

Further study needs to be conducted on the amount of TTS experienced and the rate of recovery from TTS in males and females. Different fatiguing agents and different test stimuli employed to measure TTS should be utilized, and a variety of post-exposure measurement times should be evaluated with these two groups.

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APPENDIX A

TEST SCORES OF SISI, BEKESY, ABLB, AND BTA TESTING

SISI Test Scores in Percentage

Subject	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
1	50	85	95	75	55
2	00	100	100	95	70
3	00	70	55	40	30
4	10	55	65	60	55
5	00	100	95	90	100
6	10	85	70	65	65
7	00	85	65	60	55
8	10	55	10	05	10
9	30	85	95	100	75
10	20	100	65	75	90
11	00	85	100	100	65
12	40	95	80	95	90
13	00	80	40	40	20
14	00	90	95	90	50
15	15	90	70	90	75
16	00	100	100	90	85
17	00	65	60	60	20
18	35	100	95	100	75
19	05	80	80	95	85
20	25	75	100	70	75

Bekesy$_1$ Test Scores in dB

Subject	Pre-exp	Post$_2$	Post$_{10}$	Post$_{20}$	Post$_{30}$
1	5.5	3.0	3.8	5.9	1.1
2	3.2	3.2	2.9	2.9	4.7
3	3.8	4.7	4.8	8.0	4.2
4	2.4	5.3	1.0	0.3	-1.1
5	0.2	4.1	3.5	3.4	2.2
6	1.6	1.2	3.7	0.1	7.2
7	-2.5	0.0	3.6	6.2	3.8
8	2.7	3.9	3.6	1.8	1.7
9	2.4	-2.6	-3.8	4.5	4.8
10	-0.5	1.8	3.5	3.0	2.7
11	4.4	0.0	2.5	5.9	5.8
12	5.6	3.0	3.0	2.3	4.2
13	2.9	3.0	1.4	3.2	1.4
14	0.5	1.2	3.9	2.8	2.2
15	-0.1	4.3	7.1	6.1	8.3
16	1.3	1.8	3.6	6.3	2.2
17	0.9	5.9	3.8	3.9	1.2
18	0.9	4.8	2.3	2.0	1.2
19	3.8	-1.0	-0.6	1.8	0.9
20	2.8	0.6	4.5	4.7	1.1

Bekesy$_2$ Test Scores in dB

Subject	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
1	3.4	7.3	6.5	3.2	5.6
2	1.5	3.8	3.3	3.5	6.4
3	5.5	3.0	8.4	12.7	4.6
4	-0.1	4.1	6.2	1.1	0.9
5	-0.4	6.5	7.1	3.7	5.0
6	2.7	3.3	6.6	1.9	-1.8
7	-1.6	4.5	6.5	6.4	3.3
8	1.6	4.7	3.9	2.5	4.3
9	-0.6	-7.4	5.5	6.2	4.6
10	-1.8	5.2	3.8	2.4	-3.5
11	2.1	2.9	3.6	3.2	5.6
12	10.0	10.9	12.3	10.6	9.3
13	-1.6	5.6	6.6	2.6	2.2
14	-1.1	1.2	0.9	2.1	3.2
15	7.0	0.2	17.0	14.5	13.9
16	1.2	2.9	1.3	7.6	6.7
17	4.2	8.5	5.0	4.3	3.0
18	-2.1	2.7	2.6	3.1	3.2
19	6.3	1.3	1.3	0.6	2.4
20	2.2	4.6	5.4	1.8	1.3

Bekesy$_3$ Test Scores in dB

Subject	Pre-exp	Post$_2$	Post$_{10}$	Post$_{20}$	Post$_{30}$
1	0.0	2.0	6.6	1.7	-2.5
2	1.4	0.5	0.8	1.1	1.3
3	-0.6	-0.9	3.2	-0.4	1.8
4	-2.7	-6.7	-6.1	-1.1	-8.1
5	3.1	2.2	-0.4	3.2	1.8
6	-0.1	1.6	-3.3	3.2	-2.0
7	-0.1	0.5	-0.7	0.0	-1.5
8	0.6	1.1	-3.4	1.0	-1.9
9	-1.1	-1.8	-1.0	1.8	0.6
10	-2.1	0.3	-0.5	0.1	-1.7
11	4.6	-1.9	-1.0	3.0	0.9
12	0.4	-0.7	-5.7	-1.4	-1.5
13	-1.4	-6.3	1.0	-8.0	-4.1
14	-0.6	2.1	-0.3	3.9	-0.3
15	-5.2	-1.2	-2.0	2.3	3.3
16	-5.2	4.2	2.9	3.3	-2.3
17	-1.7	4.2	4.6	-0.4	1.9
18	-2.3	-0.8	-3.5	4.6	1.3
19	4.2	-1.5	-1.9	-2.7	1.7
20	0.7	-0.8	0.7	0.5	0.5

Bekesy$_4$ Test Scores in dB

Subject	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
1	-0.3	3.4	1.8	1.4	6.8
2	1.2	1.8	0.8	6.4	2.3
3	2.3	0.8	6.4	2.3	4.1
4	-5.1	-5.4	-8.0	-3.3	-1.5
5	4.1	0.9	5.3	7.0	1.0
6	1.9	2.6	3.3	-0.6	-1.7
7	1.6	0.3	-1.0	-2.5	1.0
8	-0.5	1.0	2.9	3.0	2.6
9	0.8	-0.4	-2.9	2.2	0.1
10	2.0	3.7	-1.7	-2.0	0.4
11	0.2	-0.1	2.7	0.9	0.2
12	0.1	0.3	0.2	-1.9	-0.4
13	0.7	-1.7	-0.3	-3.9	-2.2
14	0.6	2.4	1.9	0.2	-1.0
15	-3.6	0.3	2.5	1.2	3.0
16	-2.8	6.5	2.7	0.1	1.8
17	3.1	2.2	-0.2	1.4	2.0
18	-2.3	-1.7	-4.6	-0.1	-0.1
19	3.8	1.8	2.7	1.9	0.5
20	1.4	-4.6	-2.3	1.3	1.1

Bekesy$_5$ Test Scores in dB

Subject	Pre-exp	Post$_2$	Post$_{10}$	Post$_{20}$	Post$_{30}$
1	1.3	-1.7	-5.5	1.0	-2.2
2	0.0	-1.0	-4.9	0.9	-0.5
3	-4.7	-1.2	-1.8	2.3	-3.0
4	0.0	-2.4	-0.1	2.5	-6.1
5	1.4	-1.8	-2.2	-6.8	-2.5
6	2.6	1.9	-2.0	-3.9	-0.6
7	2.0	1.2	-0.8	-1.2	-0.6
8	-1.3	-0.8	0.3	0.8	2.4
9	-1.9	-8.4	-3.0	-6.7	-1.1
10	0.9	-2.3	1.2	6.2	6.7
11	1.6	1.3	2.9	0.4	-2.1
12	-0.2	-0.2	5.4	-1.4	-0.2
13	-5.5	0.5	4.0	-0.9	-1.5
14	-0.6	1.1	-0.7	0.3	-2.6
15	2.9	-1.3	-0.2	-3.4	-0.1
16	-1.9	-0.2	-0.4	0.5	-4.5
17	2.0	-1.6	2.9	0.4	6.5
18	-1.3	-0.5	0.6	2.0	1.5
19	-2.5	-3.2	1.0	-0.8	-3.2
20	-2.3	-4.4	2.8	-0.3	-5.1

Bekesy$_6$ Test Scores in dB

Subject	Pre-exp	Post$_2$	Post$_{10}$	Post$_{20}$	Post$_{30}$
1	3.4	0.0	-1.2	0.7	-2.7
2	1.5	-1.3	1.8	0.7	-2.6
3	5.5	-1.5	-0.5	-2.4	-1.9
4	-0.1	-4.1	-0.1	-2.2	-1.9
5	-0.4	-1.2	1.6	-3.0	-0.2
6	2.7	1.8	-1.6	0.7	-1.4
7	-1.6	3.3	1.4	2.5	0.2
8	1.6	-0.6	0.9	2.3	2.1
9	-0.6	-3.5	-1.4	-9.4	-6.5
10	-1.8	1.3	-1.2	5.4	2.7
11	2.1	0.9	1.8	2.1	0.5
12	10.0	0.2	2.2	3.2	1.4
13	-1.6	1.0	-2.1	-2.3	-1.1
14	-1.1	0.6	-0.1	0.1	-3.1
15	1.8	0.0	1.9	-8.7	-0.1
16	1.2	2.8	-3.1	0.5	0.8
17	4.2	-1.4	0.5	-1.4	1.4
18	2.1	-2.9	-4.8	-2.6	-0.2
19	6.3	-0.4	0.3	-1.8	-3.2
20	2.2	-3.9	2.6	-0.6	-1.9

ABLB Test Scores in dB

Subject	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
1	32.4	31.1	30.5	36.9	37.6
2	42.9	42.2	42.5	44.2	47.9
3	41.6	21.9	36.8	31.6	38.6
4	40.6	21.8	21.6	34.7	30.8
5	40.9	27.1	33.8	26.2	36.6
6	54.3	39.9	47.6	49.3	56.9
7	39.7	23.3	29.2	32.2	38.0
8	40.9	23.7	20.9	24.7	39.9
9	51.9	23.1	37.3	44.2	33.2
10	48.0	23.3	33.4	37.4	39.5
11	38.5	21.4	26.2	22.9	29.0
12	23.7	12.1	20.6	15.5	21.8
13	53.4	53.5	55.9	58.5	51.5
14	31.1	17.1	20.8	15.6	22.3
15	37.8	25.7	21.6	29.1	29.2
16	36.9	29.5	30.2	31.3	32.8
17	44.2	29.2	26.9	23.6	26.1
18	45.3	20.5	30.6	34.8	38.3
19	49.7	36.5	35.2	40.2	36.1
20	36.7	23.2	29.3	33.5	29.0

BTA_1 Test Scores in dB

Subject	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
1	8.1	3.5	5.5	3.3	2.7
2	8.2	5.0	4.1	5.0	6.2
3	6.4	3.7	5.7	4.4	5.8
4	9.1	5.3	5.8	4.1	6.5
5	9.2	8.6	3.2	4.4	1.8
6	7.5	4.8	5.6	6.2	6.8
7	8.0	7.3	8.0	5.7	5.0
8	5.9	3.3	2.7	2.7	3.9
9	7.5	7.3	6.5	6.0	4.0
10	7.1	6.4	4.0	3.4	6.5
11	9.0	6.0	3.5	2.2	2.1
12	5.5	6.0	5.6	5.8	5.3
13	8.3	4.8	2.7	6.0	4.2
14	4.7	6.5	2.1	4.4	4.4
15	5.6	7.3	4.4	5.2	4.3
16	9.5	7.7	6.3	4.2	6.3
17	6.1	7.9	4.6	6.2	5.8
18	6.2	6.0	8.2	4.8	5.2
19	6.3	4.8	8.5	4.2	5.8
20	8.8	4.4	7.1	4.9	4.9

BTA$_2$ Test Scores in dB

Subject	Pre-exp	Post$_2$	Post$_{10}$	Post$_{20}$	Post$_{30}$
1	4.9	4.6	4.7	1.3	3.2
2	7.3	7.4	6.6	6.4	4.4
3	5.6	6.2	6.2	4.5	5.7
4	6.9	8.2	4.9	6.1	6.7
5	8.8	7.0	2.8	3.4	2.9
6	9.1	8.6	8.5	9.3	7.5
7	9.5	8.6	8.7	5.6	4.2
8	5.1	6.4	7.1	2.6	5.6
9	10.6	6.4	6.9	7.0	4.2
10	7.9	7.1	4.2	4.4	6.3
11	10.4	8.0	3.6	3.0	2.7
12	5.9	7.9	9.3	6.4	6.5
13	9.8	6.6	2.5	6.4	5.6
14	4.6	7.6	5.1	6.0	4.5
15	7.7	9.9	4.6	6.0	4.9
16	9.8	10.5	7.1	5.4	6.5
17	6.7	8.2	7.5	8.1	5.0
18	7.4	6.5	8.3	6.8	5.8
19	7.8	6.7	6.8	5.7	6.3
20	8.2	7.7	7.3	5.7	5.0

APPENDIX B

AMOUNT OF TTS EXPERIENCED DURING SISI, BEKESY, ABLB, AND BTA TESTING

Amount of TTS Experienced in dB During SISI Testing

Subject	$Post_1$	$Post_9$	$Post_{19}$	$Post_{29}$
1	25	15	10	05
2	30	25	20	15
3	35	25	15	10
4	20	10	05	00
5	30	25	20	15
6	20	15	10	05
7	35	25	20	15
8	20	15	10	10
9	30	20	20	15
10	30	20	15	15
11	35	25	20	15
12	40	35	30	25
13	20	10	10	05
14	30	20	15	10
15	40	35	30	25
16	35	25	15	10
17	30	20	15	10
18	20	15	10	05
19	40	30	25	20
20	40	40	35	30

Amount of TTS Experienced in dB
During Bekesy Testing

Subject	$Post_1$	$Post_9$	$Post_{19}$	$Post_{29}$
1	30	25	20	20
2	20	15	10	05
3	35	35	25	20
4	25	10	05	05
5	20	15	10	10
6	25	20	15	15
7	30	30	20	15
8	20	15	10	05
9	25	20	15	15
10	20	15	10	05
11	35	25	20	15
12	30	30	20	15
13	20	10	10	05
14	35	25	20	20
15	30	30	25	20
16	25	15	05	05
17	25	20	15	10
18	30	20	15	10
19	35	30	25	25
20	45	40	40	35

Amount of TTS Experienced in dB
During ABLB Testing

Subject	$Post_1$	$Post_9$	$Post_{19}$	$Post_{29}$
1	25	20	20	15
2	30	25	20	15
3	30	15	10	05
4	20	15	10	05
5	25	20	20	15
6	20	15	10	05
7	30	20	10	10
8	20	20	10	05
9	30	20	15	15
10	30	15	15	10
11	30	20	15	10
12	40	30	30	25
13	25	20	15	10
14	35	25	25	20
15	25	25	20	20
16	30	20	15	10
17	25	20	20	15
18	30	20	15	10
19	40	35	30	30
20	45	35	30	30

Amount of TTS Experienced in dB
During BTA Testing

Subject	$Post_1$	$Post_9$	$Post_{19}$	$Post_{29}$
1	25	15	10	10
2	25	15	10	05
3	40	30	25	25
4	20	10	10	05
5	25	15	15	10
6	20	15	10	10
7	35	25	20	15
8	25	15	15	15
9	25	20	20	15
10	20	15	10	05
11	35	25	20	15
12	35	30	25	25
13	25	20	10	10
14	30	25	20	15
15	30	25	20	20
16	30	25	20	15
17	20	15	10	00
18	25	15	10	05
19	30	20	15	15
20	35	30	30	25

APPENDIX C

PEARSON PRODUCT MOMENT CORRELATIONS BETWEEN TEST SCORES AND TTS

Pearson Product Moment Correlations of SISI test scores and the corresponding amount of TTS present at the time each score was obtained.

	Amount of TTS at Each Test Time			
Test Score	TTS_1	TTS_9	TTS_{19}	TTS_{29}
$Post_2$	0.26			
$Post_{10}$		0.37		
$Post_{20}$			0.42	
$Post_{30}$				0.47*

*Significant at the 0.05 level.

Pearson Product Moment Correlations of $Bekesy_1$, $Bekesy_2$, and $Bekesy_3$ test scores and the corresponding amount of TTS present at the time each score was obtained.

Amount of TTS at Each Test Time

Test Score		TTS_1	TTS_9	TTS_{19}	TTS_{29}
	$Post_2$	-0.30			
	$Post_{10}$		0.30		
	$Post_{20}$			0.36	
	$Post_{30}$				0.13
	$Post_2$	-0.11			
	$Post_{10}$		0.30		
	$Post_{20}$			0.20	
	$Post_{30}$				0.11
	$Post_2$	-0.05			
	$Post_{10}$		0.12		
	$Post_{20}$			0.01	
	$Post_{30}$				0.41

*Significant at the 0.05 level.

Pearson Product Moment Corrrlations of Bekesy$_4$, Bekesy$_5$, and Bekesy$_6$ test scores and the corresponding amount of TTS present at the time each score was obtained.

Test Score	Amount of TTS at Each Test Time: TTS_1	TTS_9	TTS_{19}	TTS_{29}
$Post_2$	-0.29			
$Post_{10}$		0.24		
$Post_{20}$			0.18	
$Post_{30}$				0.29
$Post_2$	-0.06			
$Post_{10}$		0.13		
$Post_{20}$			-0.10	
$Post_{30}$				-0.37
$Post_2$	-0.18			
$Post_{10}$		0.42		
$Post_{20}$			-0.13	
$Post_{30}$				-0.40

*Significant at the 0.05 level.

Pearson Product Moment Correlations of ABLB test scores and the corresponding amount of TTS present at the time each score was obtained.

Test Score	Amount of TTS at Each Test Time: TTS_1	TTS_9	TTS_{19}	TTS_{29}
$Post_2$	-0.29			
$Post_{10}$		-0.19		
$Post_{20}$			-0.29	
$Post_{30}$				-0.47*

*Significant at the 0.05 level.

Pearson Product Moment Correlations of BTA test scores and the corresponding amount of TTS present at the time each score was obtained.

		Amount of TTS at Each Test Time			
		TTS_1	TTS_9	TTS_{19}	TTS_{29}
Test Score	$Post_2$	0.09			
	$Post_{10}$		0.14		
	$Post_{20}$			0.01	
	$Post_{30}$				-0.16
	$Post_2$	0.10			
	$Post_{10}$		0.19		
	$Post_{20}$			0.09	
	$Post_{30}$				0.00

*Significant at the 0.05 level.

APPENDIX D

PEARSON PRODUCT MOMENT CORRELATIONS BETWEEN TEST SCORES OF THE ABLB AND BTA

Pearson Product Moment Correlations of the ABLB and BTA test scores over time. The first r given at each time is for ABLB-BTA_1, and the second for ABLB-BTA_2.

Test Time in Minutes

Test Time in Minutes	Pre-exp	$Post_2$	$Post_{10}$	$Post_{20}$	$Post_{30}$
Pre-exp	0.16 0.51*				
$Post_2$		0.14 0.42			
$Post_{10}$			0.01 -0.17		
$Post_{20}$				0.32 0.28	
$Post_{30}$					0.20 0.23

*Significant at the 0.05 level.