

A STUDY OF AUDITORY DIFFERENTIAL
SENSITIVITY TO INTENSITY IN CHILDREN
AND ADULTS

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This is to certify that the

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ABSTRACT

A STUDY OF AUDITORY DIFFERENTIAL SENSITIVITY TO INTENSITY IN CHILDREN AND ADULTS

by Robert M. Screen

The purpose of this research was two-fold. The first purpose was to determine if the Short Increment Sensitivity Index (SISI) Test as now used in diagnostic audiology could be employed with children five years of age and above. The second purpose was to compare the size of the intensity difference-limen (DL) in adults and children by using the quantal psychophysical method.

Seventy-two subjects in six age groups were selected for this study. One group was composed of twelve adults. The other groups consisted of twelve five-year old, twelve seven-year old, twelve nine-year old, twelve eleven-year old, and twelve thirteen-year old children. Each group consisted of 50 per cent males, and was equally divided into either an "Average IQ" or a "High IQ" category.

The intelligence quotients of the adult subjects were determined by administering an abbreviated form of the Wechsler Adult Intelligence Scale (WAIS). The intelligence quotients of the children were determined by administering Form A of the Peabody Picture Vocabulary Test. The scores

achieved by adults and children were employed to place each subject into the average or high IQ category.

Each subject was given a conventional pure tone hearing evaluation in a commercial, sound-treated room. Pure tone auditory thresholds were obtained for the frequencies 500, 1000, and 4000 Hz by air conduction, and 500 and 4000 Hz by bone conduction.

Once the subject's auditory threshold had been determined with conventional audiometry, the SISI test was then administered. The test was presented at 4000 Hz at a 20 dB sensation level. At this frequency and sensation level, each subject was tested with the increments of 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, and 2.0 dB. The order in which the increments were presented was randomized. After the seventh increment presentation, an increment was selected to repeat the test at a level closest to the subject's 50 per cent score in order to ascertain reliability.

The Method of Least Squares was used to calculate each subject's DL from the derived data. The significance of differences among mean DLs and mean SISI scores at the 1 dB increment was determined with three-dimensional analyses of variance. Duncan's New Multiple Range Test was applied to both analyses in order to make individual comparisons among means. Reliability was determined by employing a correlation coefficient and the standard error of measurement (SE_m).

The following conclusions were drawn: (1) Children nine, eleven, and thirteen years of age could be tested with the Short Increment Sensitivity Index (SISI) Test, and when situations warrant it, this test should be used more frequently with children of these age levels; (2) A modification should be made of the original SISI test instructions when employing the test with five and seven-year old children; (3) Greater care should be taken with the conditioning procedure when the SISI test is employed with five and seven-year old children; (4) The sex of a subject apparently does not affect his ability to perform on the Short Increment Sensitivity Index (SISI) Test; (5) Children and adults with IQ scores higher than 90 can perform on the Short Increment Sensitivity Index (SISI) Test; (6) The criterion score for a clinically positive SISI score for children five years of age and above should be 80 per cent; (7) The DL values obtained when using the procedure in this study do not appear different from the DL values reported in the literature using other methods, and the quantal procedure is thus recommended for DL testing; (8) Above the age of five, there are no statistically significant differences in DLs as a function of age when using the quantal psychophysical method; (9) The sex of a child or adult apparently does not affect his ability to perform on the DL test procedure used in this study;

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(10) Children and adults with IQ scores higher than 90 seem to perform adequately on the DL test used in this study and produce reliable DL results.

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By

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CHAPTER I

INTRODUCTION

It has become evident that in recent years, while there have been significant advances made in differential diagnosis in audiology, very little has been done in this area with children. This research is concerned with one of the tests used in differential diagnosis in audiology, the Short Increment Sensitivity Index (SISI) Test, and in determining whether or not this test, as currently administered, can also be successfully employed with children.

It has been pointed out by a number of investigators that there are certain kinds of hearing losses that are apparently accompanied by a very keen differential sensitivity to intensity. The employment of difference-limen (DL) tests, therefore, has contributed to a determination of the site of lesion in hearing losses. The Short Increment Sensitivity Index (SISI) Test employs one of the techniques of DL testing--the quantal psychophysical method. Yet, there seems to be no report in the literature of the values of the difference-limen (DL) for normal hearers obtained with the quantal psychophysical method. Even where difference-limen values have been found with normal hearing adults, the variations in these values were

so great that investigators found it difficult to evaluate the results.¹ The relationship of the difference-limen for adults and children, as well as a comparison of their performance on the SISI test as currently administered, were important concerns of this research.

Purpose of the Study

The major purpose of this investigation was to determine if the Short Increment Sensitivity Index (SISI) Test as currently employed in diagnostic audiology can be employed with children from the ages of five through thirteen. Specifically, this research was concerned with the increment amplitude now employed in the administration of the SISI test, and the size of the difference-limen (DL) for intensity using the quantal psychophysical method. A question posed was whether the presently used increment amplitude of 1 dB presented at a 20 dB sensation level can be used with children with normal hearing, and produce results similar to those of adults with normal hearing.

Another major concern of this research was the comparison of the difference-limen (DL) in adults and children using the quantal psychophysical method. The literature has stressed the contribution made by DL testing

¹Lauritz Lund-Iversen, "An Investigation on the Difference-Limen Determined by the Method of Lüscher-Zwislocki in Normal Hearing and in Various Forms of Deafness," Acta Oto-Laryngologica, 42 (1952), pp. 219-223.

to a determination of the site of lesion in hearing losses. Yet, the literature does not show evidence of systematic research with any specific DL procedure for adults or children. A question posed, therefore, was whether the DLs of children with normal hearing differed significantly from the DLs of adults with normal hearing. This research also investigated whether there was any relationship between IQ scores at a given age level and a subject's DL score as well as his performance on the SISI test at the 1 dB increment. Consideration was also given as to whether or not the sex of a subject affected his performance on the DL test and the SISI test using a 1 dB increment.

A final goal, of which this research is just a beginning, is to determine if acoustically handicapped children will respond to both the SISI test and the DL procedure used in this study. Before such a goal can be accomplished, however, it should be determined whether or not these procedures are feasible with a normal hearing population of children. A review of the literature indicates an obvious dearth of information in this regard.

In order to gain information concerning the above questions, the following null hypotheses were formulated:

1. There is no significant difference between the responses of normal hearing adults and children between five through thirteen years of age to the 1 dB increment currently employed in the Short Increment Sensitivity Index (SISI) Test.

2. There is no significant difference in the difference-limen (DL) of normal hearing adults and that of children between five through thirteen years of age.
3. There is no significant difference in the DL and SISI scores obtained employing the 1 dB increment between subjects who have an average intelligence quotient and those who have a high intelligence quotient for each of the six age levels tested.
4. There is no significant difference in the DL and SISI scores obtained employing the 1 dB increment between male and female subjects at each of the six age levels tested.

Importance of the Study

A review of the literature reveals that the great majority of research studies concerning standardized audiometric procedures have utilized adults as samples. The response of children to conventional pure-tone audiometry has been studied and reported extensively in the literature, as well as the response of children to unconventional audiometric procedures. With regard to special tests used in differential diagnosis, however, very little, and in some cases nothing at all, is reported concerning the response of children to these procedures. Among the special tests used in differential diagnosis, Bekesy audiometry with children has been investigated most frequently in recent years, and this has not been done systematically. In this same regard, almost nothing is reported concerning the use of the SISI test with children. Further, there is a paucity of information regarding the difference-limen (DL) for children, since most studies concerned with difference-limen

data have used adults as subjects. In 1952, Jerger¹ reported the DL for 39 normal ears for a 15 dB sensation level, but the quantal psychophysical method was not used in establishing the DL in his study, and there is no specific reference to the ages of the subjects. In the 1959 study by Jerger, et. al.,² at which time the SISI procedure was first reported in the literature, there was no concern for the DL per se, but only with finding an increment size which would successfully dichotomize normal ears from ears with cochlear pathology.

Since 1960, the SISI test has been a valuable clinical tool in helping the audiologist to localize the site of damage to the cochlea. Indeed, children as well as adults suffer hearing problems caused by damage to the cochlea. It is unfortunate, however, that attempts have not been made to utilize it in differential diagnosis of children. It would seem, however, that as a clinical tool for localizing the site of damage to the cochlea, the SISI test would certainly be as important for children as it is for adults. A parallel can be drawn in this regard to the DL values for normal hearing children and adults, then

¹James F. Jerger, "A Difference-Limen Test and its Diagnostic Significance," Laryngoscope, 62 (1952), pp. 1316-1332.

²James F. Jerger, Joyce Lassman Shedd, and Earl Harford, "On the Detection of Extremely Small Changes in Sound Intensity," AMA Archives of Otolaryngology, 69 (1959), pp. 200-211.

these values would begin to have more meaning when compared to those of the hearing impaired. Only with this kind of concerted research effort can we ascertain the diagnostic significance of DL values.

Definition of Terms

The following definitions are used in this investigation.

The Short Increment Sensitivity Index (SISI) Test.--

A test which differentiates between patients with normal hearing or middle ear lesions, sensory, or VIIIth nerve disorders. The patient is presented with the desired continuous discrete frequency at a 20 dB sensation level. Every five seconds the intensity is increased 1 dB for 0.2 second. Whenever the patient hears the intensity increase, he pushes the signal key. Twenty increases are presented in a series. The test is scored in terms of the percentage of the number of intensity increases that are perceived.

The Quantal Psychophysical Method.--One of the variations of the Constant Methods. It derives from an hypothesis by Stevens, Morgan, and Volkman¹ that increments on a sensory-response continuum are not essentially

¹S. S. Stevens, C. T. Morgan, and J. Volkman, "Theory of the Neural Quantum in the Discrimination of Loudness and Pitch," The American Journal of Psychology, 54 (1941), pp. 315-335.

continuous but occur in small units or quanta. The detection of a change in making comparative judgments depends upon this unit or quantum. The standard stimulus S_s arouses a given number of quanta of neural activity. It also provides varying amounts of a surplus that is not sufficient in itself to arouse one more quantum, but in conjunction with an increment in the stimulus S , it may arouse one more quantum. As the surplus or residual excitation varies, it requires a stimulus change of varying amounts to complete the extra quantum and thus give rise to a reportable change.

Difference-Limen (DL) for Intensity.--In any sensory process a difference-limen is defined as a "just noticeable difference" (jnd) in whatever aspect of the sensation is under investigation. The DL for intensity is the amount of change in intensity required to produce a jnd in loudness.

Sensation Level.--Indicates the number of decibels that a sound is above the threshold of audibility of a specific ear.

Average IQ.--In this study average IQs are defined as intelligence quotients from 90 to 109 obtained with the Peabody Picture Vocabulary test or the Wechsler Adult Intelligence Scale (WAIS).

High IQ.--In this study, an intelligence quotient of 125 or higher obtained with the PPVT, or an intelligence quotient of 120 and above obtained with the WAIS.

Conventional Audiometry.--Indicates the use of a pure-tone audiometer in order to obtain a person's hearing threshold for specific frequencies. In this study, the procedure was to have the subject listen for pure tones through earphones and he was asked to indicate when he heard the tone by depressing a signal key, and taking his hand off the key when the tone disappeared.

Limitations of the Study

Several limitations were introduced into the study in order to make it practicable. First, it was felt that the children, in order to qualify as subjects, should demonstrate the ability to respond to conventional audiometry. Certainly, if the child could not respond to conventional audiometry he would not be able to respond to the task required to obtain his DL and SISI scores. Therefore, if the investigator was unable to obtain a reasonable auditory threshold by a conventional pure tone test, the child did not qualify as a subject.

A second limitation was that all subjects were required to have normal hearing, as indicated by conventional audiometry. This was done to eliminate clinical variables, such as contralateralization, which may arise when testing an individual with pathological hearing.

Another limitation was imposed by the desire to establish a clear relationship between intellectual ability

and the ability to perform the task required for this study. In other words, children having an IQ score between 110 and 124, and below 90, did not qualify for this study. Also, adults having an IQ score between 110 and 119, and below 90, did not qualify for the study.

A final limitation was imposed by the physical parameters actually involved in the SISI and DL tasks, i.e., the frequency, sensation level, and the increment magnitudes investigated. This study confined itself to an investigation of the SISI scores at 4000 Hz and at a 20 dB sensation level. In order to compute the DL, the increment magnitudes investigated were 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, and 2.0 dB. The selection of 4000 Hz and the 20 dB sensation level was made for two reasons. First, the investigator wanted to approximate, as closely as possible, the manner in which this test is given clinically so that some comparison of results could be made. In the second place, time would not permit the investigation of SISI scores at more frequencies and sensation levels, although it is hopeful that future research will study responses at other frequencies and sensation levels. The particular increment magnitudes studied were also selected because the investigator wanted a basis of comparison with the increment magnitudes that had been investigated previously with adults.

CHAPTER II

REVIEW OF THE LITERATURE

The review of the literature concerning this study will include the pertinent investigations of differential sensitivity to intensity change. Specifically, the discussion of these investigations will view (1) the manner in which the difference-limen (DL) is measured, (2) the psychophysical methods employed, and (3) some of the reported results of these investigations with normal hearers. A further concern of this chapter will be the research employing the Short Increment Sensitivity Index (SISI) Test with normal hearing subjects. Both concerns of this chapter should provide a general overview and a firm groundwork for the understanding of the present study for two important reasons. First, an investigation of the literature in this area reveals a dearth of information showing the results of the SISI test with children. Secondly, little is apparently known of the normal DL, either with adults or children, when the quantal psychophysical method is used.¹

¹Letter from James Jerger, Director of Research, Houston Speech and Hearing Center, Houston, Texas, Dec. 4, 1967.

Methods Employed in DL Measurements

The smallest detectable change in the intensity of a tone determines the intensive differential sensitivity of the ear. Stevens and Davis¹ state that this sensitivity may be strictly defined as the reciprocal of the just-noticeable change, or DL (difference-limen).

According to Dallos and Carhart,² the work of Fechner some hundred years ago paved the road to the appreciation of the difference-limen (DL) for intensity change as a psychophysical indicator of the listener's experience in the loudness domain. A great deal of research has been devoted to such tasks as: (1) testing the validity of E. H. Weber's original concept that the DL is proportional to presentation level; (2) ascertaining whether loudness increase can be considered a simple cumulation of the subjective magnitudes of the DL's; and (3) clarifying the effects on the DL of modifying the stimulus frequency, the presentation level, and the pattern for modulating the intensity fluctuation of the stimulus. This work has yielded a general understanding of the nature of the differential sensitivity to intensity change in the normal

¹S. S. Stevens and Hallowell Davis, Hearing: Its Psychology and Physiology (New York: John Wiley and Sons, Inc., 1938), p. 136.

²Peter J. Dallos and Raymond Carhart, "Cumulation of DL's for Intensity Change at Low Sensation Levels," Journal of the Acoustical Society of America, 35 (1963), pp. 848-855.

ear. It has also led experimental psychologists to view meticulous measurement of DL's as an unproductive and somewhat spurious approach to defining the basic phenomenon of the loudness experience.

One of the major concerns of most investigators of differential sensitivity to intensity change is the manner in which the difference-limen (DL) is measured. H. C. Montgomery¹ states that in measuring differential intensity sensitivity a number of different factors which may influence the results must be taken into account. As is the case with nearly all psychophysical measurements, account must be taken of variations among individuals who may be used as subjects. The physical characteristics of the sound used as a stimulus, such as the frequency, intensity, and harmonic composition for a musical tone, must be specified. Furthermore, Montgomery states that the following elements are influential upon the results of testing differential sensitivity to intensity change: monaural versus binaural observation, duration of tones, transition between tones, number of comparisons, control of instant of presentations, and the type of judgment required.

¹H. C. Montgomery, "Influence of Experimental Technique on the Measurement of Differential Intensity Sensitivity of the Ear," Journal of the Acoustical Society of America, 7 (1935), pp. 39-43.

Dimmick and Olson¹ are critical of Montgomery's claim that differences in the technique of measuring differential sensitivity are directly reflected in wide divergencies of the results. While they appear to agree with his conclusion, they are dissatisfied that Montgomery's considerations of "type of judgment" in his own experiments makes no mention of the standard psychophysical methods. In other words, they feel that Montgomery's measurements of the detection of changes produced by the observer himself even defy simple naming, and they do not believe that any uniformity or stability of results can be expected until a standard procedure is adopted. Support for this point of view is found in Jerger,² who states that the size of the DL is extremely dependent on the method by which it is measured. For this reason, the absolute sizes of the DLs can be compared only if they have been obtained by the same method.

Lüscher and Zwislocki³ employed a DL test that was administered at a sensation level of 40 dB. It involved

¹Forrest L. Dimmick and Ruth M. Olson, "The Intensive Difference Limen in Audition," Journal of the Acoustical Society of America, 12 (1941), pp. 517-525.

²James F. Jerger, "DL Difference Test," AMA Archives of Otolaryngology, 57 (1953), pp. 490-500.

³E. Lüscher and J. Zwislocki, "A Simple Method for Indirect Monaural Determination of the Recruitment Phenomenon (Difference Limen in Intensity in Different Types of Deafness)," Acta Oto-laryngology Supplement, 78 (1949), pp. 156-168.

the presentation of a tone that "wobulated" in intensity, that is, it varied in intensity so the patient heard intensity beats. The examiner then reduced the wobulation gradually until the patient reported the tone sounded "steady." The amount of intensity variation occurring at the point at which the patient signaled the tone was no longer fluctuating is his DL.

Denes and Naunton¹ differed from Lüscher and Zwislocki in that no attempt was made to interpret the absolute size of the DL. Denes and Naunton were interested, however, in the difference in the value of the DLs at two sensation levels. Their technique involved a comparison of the size of a patient's DL at sensation levels of 4 and 44 dB. In determining the size of the DL at each sensation level they used two separate tones of the same frequency, one tone held constant in intensity and the other varied. These tones were presented to the patient's ear alternately with an interval of silence between the two. In the beginning the tones were of equal intensity, but as the test progressed, one tone was varied until the patient reported he could detect a difference in intensity between the tones. The DL was defined as the intensity difference between the

¹P. Denes and R. F. Naunton, "The Clinical Detection of Auditory Recruitment," Journal of Laryngology and Otology, 64 (1950), pp. 375-398.

two tones when the variable tone is just perceptibly "louder than" or "softer than" the fixed tone.

Dimmick and Olson¹ gave their subjects a period of training in loudness judgments with the psychophysical method of limits. After the training period, the psychophysical method of constant stimuli was followed in which seven stimulus intensities were compared with the standard in random order. The judgments of loudness difference between the two tones was not based on change within a continuous stimulus, but on the perception of difference in intensity of two separate tones.

Knudsen² used as a source of sound a telephone receiver actuated by a current from a vacuum tube oscillator. The intensity or the pitch could be changed periodically, once a second or so, by automatically changing the resistance in the oscillating circuit. The method of observation, then, was to change ΔE or ΔN continuously until the threshold of perception of fluctuation was reached. Separate observations usually checked within 10 per cent.

¹Dimmick and Olson, "Intensive Difference-Limen," pp. 519-520.

²Vern O. Knudsen, "The Sensibility of the Ear to Small Differences of Intensity and Frequency," Physical Review, 21 (1923), pp. 84-102.

Lidén and Nilsson¹ used the method for determination of difference-limen proposed by Lüscher and Zwislocki. The method was tried with normal individuals as well as with patients suffering from various forms of deafness. The variations in the values of difference-limen found, however, were so great that it was difficult to evaluate the results.

In Jerger's² original difference-limen test, a 15 dB sensation level was chosen. This was done because investigation showed that levels below 15 dB were too low for accurate judgment by normal hearing subjects; therefore, 15 dB was chosen as the sensation level at which to test.

In the test administration the subject was given a steady tone, which was gradually changed to a beating tone. He was to raise his fingers as soon as he heard the beat. As soon as he signaled, the beat was taken out, and a re-trial was done. It was done three or four times in this manner to make sure the patient did not make any mistakes. After two practice trials, the test was begun. There were three or four trials made at each frequency. The mean value of the trials was taken as the difference-limen, or DL for that frequency. Frequencies tested in order were

¹Gunnar Lidén and Gunnar Nilsson, "Differential Audiometry," Acta Oto-laryngologica, 38 (1950), pp. 521-527.

²James F. Jerger, "A Difference-Limen Recruitment Test and Its Diagnostic Significance," Laryngoscope, 62 (1952), pp. 1313-1332.

1000, 2000, 4000, 500, and 250 Hz, so as to maintain consistency with common audiometric procedure.

Jerger¹ later developed a test procedure in which the DL was measured at two levels above threshold according to the Denes and Naunton method, but in which these DLs were actually obtained by the Lüscher technique. In this method, two DLs were obtained: one at 10 dB, the other at 40 dB above the patient's threshold. These DLs were measured in the following manner. When the patient's threshold at a given frequency had been determined audiometrically, the hearing loss dial of the audiometer was set to a level 10 dB above threshold. Then, with the tone "continuously on," the periodic variation was gradually introduced until the subject signaled his awareness of an intensity beat. The average of three to five trials was recorded as the patient's DL at the frequency under test. This procedure was then repeated at a level 40 dB above the patient's threshold. The difference between the two DLs (DL at 10 dB minus DL at 40 dB) was recorded as the "DL Difference" for the frequency under test.

¹Jerger, "DL Difference Test," pp. 493-494.

The Short Increment Sensitivity
Index (SISI) Test

The procedure of particular concern for this study was introduced by Jerger, Shedd and Harford¹ in 1959. These authors pointed out that while there was disagreement among early investigators in their attempts to explain the observations of abnormally acute differential sensitivity in terms of the loudness recruitment phenomenon, this did not alter the significance of the observation that certain patients (generally those with loudness recruitment) were often able to detect smaller intensity changes than normal ears at comparable levels above threshold. Recognizing that a patient's intensity difference-limen might be entirely normal when defined by a methodology not involving sustained stimulation (e.g., the method of constant stimulus differences), the authors supposed that patients with cochlear lesions might manifest behavior simulating abnormally keen differential sensitivity only when the measurement is performed in a particular and unique manner.

The task, then, was that of designing a new procedure with two goals in mind: (1) to employ a stimulus whose temporal pattern would not require a beating judgment; (2) to make the test procedure as objective as possible by limiting the number of decisions required of the tester.

¹James F. Jerger, Joyce Lassman Shedd, and Earl Harford, "On the Detection of Extremely Small Changes in Sound Intensity," AMA Archives of Otolaryngology, Vol. 69 (Feb., 1959), pp. 200-211.

To meet these goals, the basic temporal pattern used in the quantal psychophysical method was adopted. In this method, short amplitude increments are superimposed on a signal of constant amplitude at relatively widely spaced intervals. The patient's task is to respond whenever he hears a momentary change in the loudness of the signal. The tester's task is merely to record the presence or absence of a response to the presentations of each increment. The method is characterized by (1) use of relatively sustained stimulation over time; (2) a simplification of the patient's task be complete avoidance of a "beating" judgment; and (3) simplification and objectification of the tester's role in the procedure.

In the present test sequence an increment occurred once every five seconds. Each increment rose to a maximum amplitude in 50 msec., remained at maximum amplitude for 200 msec., then decayed to the steady-state level in 50 msec. Thus, the duration of the increment was exactly 1 dB.

The initial design of the procedure was guided by the desire to construct a task so difficult that subjects with normal differential sensitivity could not perform it with any degree of success. To this end, an increment magnitude of 1 dB and a presentation level 10 dB above the subject's threshold were initially chosen. Subsequent experience suggested, however, that 10 dB may have been unnecessarily low. Even at levels of 30 to 40 dB, the task is sufficiently difficult, and the extreme faintness of the 10 dB tone makes the procedure somewhat frustrating for patients with a conductive loss. In view of these considerations, a sensation level of 20 dB was later adopted. The difference between results obtained at the two levels was found to be minimal.

All results have been expressed in terms of the percentage of 1 dB increments to which a correct response was made. The resultant score is termed a "short-increment sensitivity index" (SISI). Thus, a Patient who responded to 10 of the 20 increments received a SISI score of 50%, etc.¹

Results of the above investigation reveal that, in general, purely conductive losses yield very low scores, while losses presumed to be localized in the sensory structure of the inner ear tend to show very high scores.

¹Ibid., p. 203.

In order to draw a specific dichotomy regarding characteristic responses on the SISI test, it would be important, indeed, to know what kinds of responses are made by normal hearers to this procedure. Further, such a consideration is necessary because of inter- and intra-subject variability which could exist among normal hearing subjects and thereby affect conclusions about the responses to the SISI test of a patient with a pathologic ear.

Jerger¹ presented a general discussion of the SISI test as one of a battery of useful techniques in otologic diagnosis. He mentioned that his experience indicated scores between 0 and 20 per cent for those with normal hearing, with conductive losses, and with VIIIth nerve involvement, and scores between 60 per cent and 100 per cent (at frequencies above 4000 Hz) for patients with cochlear pathology.

Yantis and Decker² administered the SISI test to normal hearers at 500, 1000, 2000, and 4000 Hz, and at intensity increments of 1, 2, 3, and 4 dB. These authors also found the mean scores to be below 20 per cent. The mean SISI scores become progressively greater with increased

¹James F. Jerger, "Hearing Tests in Otologic Diagnosis," AMA, 4 (1962), pp. 139-145.

²Phillip A. Yantis and Robert L. Decker, "On the Short Increment Sensitivity Index (SISI Test)," Journal of Speech and Hearing Disorders, 29 (1964), pp. 231-246.

intensity of the automatic tone pulse, and the average normal ear is least sensitive to the 1 dB increment. At 4000 Hz, however, the range of scores was found to be 0 - 85 per cent; seven of the 25 subjects tested scored higher than 20 per cent at this frequency. The authors concluded that their data indicate that an intensity of 1 dB at the sensation level (20 dB) employed in the SISI test is sufficiently small in amplitude to make this increment size relatively difficult to detect by the normal ear, at least as compared to increments of 2, 3, and 4 dB. However, sensitivity to amplitudes even of this small size tends to increase in the average normal ear with increasing frequency.

Hanley and Utting¹ investigated the SISI scores of normal hearers at 4000 Hz, and at increment magnitudes of 1 dB, 0.75 dB, and 0.50 dB. For the 1 dB increment the mean SISI score for normals was 42 per cent, with one-third of the 45 subjects scoring as high as 60 per cent. For the 0.75 dB increment, the mean SISI score for normals was only 15 per cent and with only two of the 48 subjects scoring as high as 60 per cent. Even for the 0.50 dB increment the mean SISI score for normals was 5.4 per cent. The authors suggest that if a SISI score of 60 per cent or

¹Clair N. Hanley and Jack F. Utting, "An Examination of the Normal Hearer's Response to the SISI," Journal of Speech and Hearing Disorders, 29 (1964), pp. 231-246.

higher is to be accepted as indicative of cochlear pathology, the use of a 0.75 dB increment rather than a 1 dB increment might more definitely isolate cochlear involvement from other types of pathology.

Owens¹ introduced another variable in studying the normal hearer's response to the SISI test. He studied the effect of changing the sensation level at which the test is administered. Owen's concern was not the mean score nor the range of scores at different sensation levels, but only determination of the lowest presentation level at which subjects could score 60 per cent or higher. At a 20 dB sensation level only one of the 27 normal hearing subjects was able to meet the 60 per cent criterion and only at one frequency, 4000 Hz. At this sensation level there was characteristically no response. At 40 dB sensation level, three subjects were able to achieve a score of 60 per cent or better at 500 Hz, four subjects at 1000 Hz, and one subject at 4000 Hz. According to his data found for normal hearers, Owens concluded that a 25 dB sensation level may be employed for the SISI test with good assurance that a positive score will indicate cochlear involvement.

¹Elmer Owens, "The SISI Test and VIIIth Nerve Versus Cochlear Involvement," Journal of Speech and Hearing Disorders, 30 (1965), pp. 252-262.

One of the more recent investigations of the response of normal hearers to the SISI test was done by Blegvad.¹ In this study the test was presented at 250, 1000, and 4000 Hz, and at 10 dB, 20 dB, and 40 dB sensation levels. At each individual frequency and sensation level the subjects were tested with increments of 0.50, 1.0, 1.50, 2.0, 2.5, 3.0, 3.5, and 4.0 dB. The order in which the different frequencies and sensation levels were presented was randomized, as was the order of the different increment magnitudes. The results of Blegvad's study indicate that at low sensation levels scores increase with frequency. At 40 dB sensation level the scores are grossly independent of frequency. As a result, the increase in score with sensation level is most marked at low frequency. The data in Blegvad's study agree quite closely with that of Yantis and Decker,² both for the 1 dB and 2 dB increments. On the other hand, Blegvad's values are significantly lower than those obtained by Hanley and Utting.³ This applies to the mean score of 1 dB, as well as to the number of subjects with scores that are equal to or greater

¹B. Blegvad, "The SISI Test in Normal Listeners," Acta Oto-laryngologica, 62 (1966), pp. 201-212.

²Yantis and Decker, "On the Short Increment," p. 235.

³Hanley and Utting, "Normal Hearer's Response," p. 62.

than 60 per cent. In these studies the test was always presented at a 20 dB sensation level. There is only fair agreement with the Owens¹ study with regard to the number of subjects scoring 60 per cent or higher. At a 40 dB sensation level there was a tendency for Owens' subjects to score better at 1000 Hz than at 4000 Hz, which was the opposite case in the Blevgad study. The author concluded that his data allow him to confirm Jerger's statement that scores for 1 dB increments are generally below 20 per cent, but in agreement with Yantis and Decker he found that about four subjects were able to score higher at 4000 Hz, and two subjects had scores equal to or greater than 60 per cent. For 1.50 dB increments the number of subjects with positive scores increased to 14, and the mean scores increased from 10 per cent to 40 per cent. Blevgad believed that although the results of his study might have been influenced by a certain practice effect, they do tend to imply that even minor changes of increment magnitude will cause substantial changes in SISI scores.

Sanders and Simpson² tested the proposal of Hanley and Utting that the SISI test should employ an increment

¹Owens, "The SISI Test," p. 226.

²Jay W. Sanders and Mary E. Simpson, "The Effect of Increment Size on Short Increment Sensitivity Index Scores," Journal of Speech and Hearing Research, 9 (1966), pp. 297-304.

magnitude of 0.75 dB rather than the 1.0 dB increment originally proposed by Jerger, Shedd, and Harford. The SISI test was given with three increment magnitudes, 1.0 dB, 0.75 dB, and 0.50 dB, to a group of normal hearing subjects and to a group of subjects with cochlear lesion hearing loss. The findings of this study disagreed with the results of Hanley and Utting. The mean scores obtained with the 0.75 and 0.50 dB increments in the two studies were not significantly different at the 5% level. At the 0.50 dB increment the mean score reported by Hanley and Utting was 5.4% and 1.8% by Sanders and Simpson. At the 1.0 dB increment, however, the mean score reported by Hanley and Utting was 42.4% as compared to 19.4% by Sanders and Simpson. The mean scores reported at the 0.75 dB increment were 15.5% by Hanley and Utting and 9.2% by Sanders and Simpson.

The major conclusion of this study was that the SISI test should be continued with the 1.0 dB increment magnitude originally proposed. The test results indicate that the 1.0 dB increment is large enough to reveal cochlear pathology when it exists, yet small enough to prevent spuriously high scores in ears with normal cochlear structures. Moreover, the findings presented in this study suggest the possibility that the SISI test with the 1.0 dB increment might have sufficient sensitivity to detect

the presence of subliminal cochlear pathology in at least some ears having pure-tone thresholds within normal limits.

The investigations just discussed are some of the more pertinent ones with regard to the normal hearer's response to the SISI test. They do indicate some intra-subject variability which does not appear to be significant. In general, however, they tend to agree with Jerger's original statements regarding the parameters of increment magnitude, sensation level, and the resultant SISI score with normal hearers. On the other hand, these studies are also evidence of the lack of information on this procedure with children, which again demonstrates the need for systematic research in this area.

The review of the literature thus far has established a relationship between the SISI scores for normal and pathologic ears, to the extent that normals, for the most part, are not expected to achieve "positive" SISI scores using this procedure. This research, then, would like to know what would be this relationship if the SISI test were administered to children. It is also apparent that the investigations of the SISI test thus far discussed have not been concerned with the DL per se, but rather with finding an increment size which would successfully dichotomize normal ears from ears with cochlear pathology. Thus, another question becomes of important concern: what is the relationship between normal and pathologic ears that

can be seen from the actual DL values reported in the literature? And, of course, this research would like to know in what way the DL values of children compare with those of adults, and what is the significance of this comparison.

Findings of DL Measurements

A number of writers have claimed that increased differential sensitivity (decreased DL size) occurs when there is pathology of the cochlea, and therefore, that measurement of the intensity DL in clinical situations can serve as a major diagnostic indicator. Most evidence tends to support this contention, though some investigators have argued the opposite. According to Dallos and Carhart,¹ this consequent uncertainty has encouraged otologists and clinical audiologists to treat the intensity DL as a subject for arguments rather than as a phenomenon which can be explored to practical advantage.

There are discrepancies from one study to another in the size of the DLs reported in the literature. It should be remembered, however, that experimental conditions, variations among subjects, and differences in psychophysical method all influence the absolute size of the just noticeable difference (jnd). Because of the number of factors

¹Dallos and Carhart, "Cumulation of DLs," p. 850.

that influence the measurement of intensity change, some discrepancies would occur even if the psychophysical method were standardized from one study to another.

Hirsh, Palva, and Goodman¹ cite a study by Doerfler who compared the differential sensitivity of a group of normal subjects with that of a group of patients with sensorineural deafness, the latter group consisting of many types of hearing loss that were non-conductive and presumably including both recruiting and nonrecruiting ears. He employed the sinusoidal modulation of Riesz by putting two tones together, and showed that the DL for patients was always between 0.5 and 0.1 dB lower than that of the normal subjects.

Montgomery² showed that the DL for one normal subject in a two-tone comparison was 0.8 dB for a 1000 Hz, 40 dB tone when the two tones were separated by an interval of 0.5 second. When this interval was eliminated, the DL decreased to 0.6 dB. When more than one two-tone comparison was allowed, the DL decreased to 0.4 dB. When the subject himself controlled a switch that turned one or the other tone on, the DL went down to 0.2 dB. This study by Montgomery is a demonstration of the dependence of the difference-limen upon experimental technique.

¹Montgomery, "Influence of Experimental Technique," pp. 42-43.

²Jerger, "A Difference-Limen," pp. 1321-1325.

Jerger¹ obtained the DL for 39 normal ears at a 15 dB sensation level. The figures listed by Jerger are average DLs for each of the frequencies tested. At 250 Hz the average DL was 2.0 dB; at 500 Hz, 1.8 dB; at 1000 Hz, 1.7 dB; 2000 Hz, 1.7 dB; and at 4000 Hz, 1.6 dB. A comparison of these DLs is made with those with pathologic ears. For those patients with conductive losses, the average DL at 250 Hz was 2.0 dB; at 500 Hz, 2.0 dB; 1000 Hz, 1.9 dB; 2000 Hz, 1.9 dB; and 4000 Hz, 1.8 dB. As for the sensorineural group, all cases showing a sensorineural component were included, whether there was a conductive component or not. The DLs exhibited by these cases, at the frequencies at which there was a sensorineural component, were divided into three categories: abnormally small DLs, normal DLs, and abnormally large DLs. At 250 Hz, the average DL for the abnormally small DL was 1.0 dB; the normal DL was 2.0 dB, and the abnormally large DL was 4.2 dB; at 500 Hz, the DL values were 0.9 dB, 1.8 dB, and 4.2 dB; at 1000 Hz the DL values were 0.9 dB, 1.8 dB, and 3.6 dB; at 2000 Hz, the DLs were 0.9 dB, 1.8 dB, and 4.3 dB; at 4000 Hz the DLs were 0.9 dB, 1.6 dB, and 3.3 dB. The ages of the subjects used to obtain these values, and the values stated by Montgomery, were not specified.

¹Jerger, "A Difference-Limen," pp. 1321-1325.

The author states that these findings show that in pure conductive hearing loss the DL is normal, indicating the absence of recruitment, but in sensorineural loss the DL may be abnormally small, indicating recruitment, or normal, indicating the absence of recruitment. It was pointed out further that a small number of cases tested showed abnormally large difference limens. In each one of these cases there was sufficient concomitant evidence to lead to the tentative conclusion that the patient's apparent hearing loss was not on a peripheral organic basis. No specific conclusions regarding this apparent relationship were drawn.

Harris¹ used the forced-choice method in studying the intensity difference-limen. Two tones, each 0.5 second in duration were presented monaurally, with a 40-msec. rise-fall time, and a 0.5 second inter-stimulus interval. The subject was requested to press a silent microswitch whenever he felt his physiological noise level was low and he was in a maximally receptive attitudinal condition. He was forced to judge the second tone "louder" or "softer." If in doubt, he was allowed to press the switch at liberty until a judgment was forthcoming. Each variable was presented 75 times, over a period of months to wash out

¹J. Donald Harris, "Loudness Discrimination," JSHD Monograph Supplement, 11 (1963), p. 6.

incidental factors. Each $DL_{75\%}$ was thus derived from a total of 900 judgments. The frequency 1000 Hz was studied with four normal hearing subjects at sensation levels of 5, 10, 20, 40, 60, and 80 dB. The results of this study indicated that under optimal conditions the human ear can yield a $DL_{75\%}$ of the order of 0.5 dB and less over a major portion of the auditory area, and is thus almost completely independent of frequency and loudness.

Stevens and Davis¹ cite the experiments of Riesz in measuring differential sensitivity to intensity. Riesz presented his tones monaurally by means of a special moving coil receiver designed to be especially free of distortion. The receiver was connected to the outputs of two oscillators in such a way that both oscillators activated the receiver simultaneously and produced beats when the frequencies of the two impressed tones were close together. First, the tone from one oscillator was presented at a definite sensation level, and then the intensity of the tone from the other oscillator was increased, from a point near zero, until the observer was just able to detect a beat. From the intensities of sound needed to obtain this beat, the intensity at the maximum and at the minimum of the beat could be calculated. The difference between the maximum and the minimum was taken as defining the DL.

¹Stevens and Davis, Hearing, p. 137.

The size of the DL was found to be a function of the rate of the fluctuations in intensity. A representative curve showing the size of the relative DL as a function of the rate at which the beats were presented is shown by the author.¹ It is characterized by a broad minimum in the neighborhood of 3 cycles, and this rate was adopted for the experimental determination of the DL for intensity.

Average curves giving the size of the relative DL as a function of intensity (sensation level), with frequency as a parameter, are also presented by the author.² At a given frequency the relative difference-limen approaches a constant value for intensities above 50 dB, but increases rapidly as the intensity is reduced toward the auditory threshold.

The author presents another curve³ that shows the behavior of the relative DL as a function of frequency for different values of the parameter intensity. The relative DL is a minimum at a frequency of about 2500 Hz, although the minimum is less sharply pronounced at high intensities than at low. The region of the greatest differential

¹Ibid.

²Ibid., p. 138.

³Ibid., p. 139.

sensitivity of the ear corresponds to the frequency range of greatest absolute sensitivity.

The values for the DL in Riesz' study are not cited, but they can be plotted from the above-mentioned curves in Stevens and Davis.¹ Although there are variations in these studies, the reasons which have been previously stated, there does seem to be a basic similarity that unites all these studies, and this similarity can be summed up in the following conclusions:

1. The differential sensitivity of the ear increases with the intensity at the same time as its dependence upon the frequency decreases.
2. Differential sensitivity is a minimum as a function of frequency at about 2500 Hz. The minimum is less sharply pronounced at high intensities than it is at low intensities.
3. At any given frequency the differential sensitivity approaches a constant value for high intensities but increases rapidly as the intensity is reduced toward the auditory threshold.

Summary

It is evident that the literature does contain reports on the methods of DL measurements and their findings.

¹Ibid., pp. 137-139.

Nevertheless, the audiologist is still confronted with a major problem when he looks at these findings with DL measurements and attempts to interpret them clinically. For example, what is the significance of a normal DL of 1.8 dB at 400 Hz, and how much would this DL vary with psychophysical method, with frequency, and sensation level? An even more important concern is the comparison of this DL with that of a pathologic ear. If some systematic work is not done in this area, there is no way of knowing how to interpret results obtained from DL measurements. Indeed, these measurements would have little significance. Another concern for the audiologist is the relationship of the DL for children to that of adults. Certainly, the audiologist's role with children cannot be de-emphasized, and children suffer the same kinds of hearing problems as do adults. Unfortunately, however, there is little evidence of extensive work on DL measurements with children. It can be said that standardization of methods used to obtain DL measurements is needed in order to give the results of these measurements greater significance clinically. In other words, extensive work should be done employing particular psychophysical methods. In this way, some basis would be established for classifying a DL as normal or abnormal, as small or large.

The SISI test also suffers from a lack of systematic investigations of the responses of children. This seems

unfortunate for two reasons. First, at the present time the SISI test has gained considerable use as an important diagnostic instrument in audiology. Both in the United States and Europe, different makes of SISI equipment are now available. Secondly, all audiologists are well aware of the need for improving diagnostic measures used with children. It is not enough to assume that, on the basis of past experience with conventional audiometry and other special tests of hearing, children cannot be expected to perform well on the SISI test. Because the SISI test is an important diagnostic instrument, the capacity of its employment with children should be thoroughly investigated. Audiologists should know at what ages children can and cannot be expected to perform on this test. Additional data on the effects of a child's Intelligence Quotient (IQ) and sex on his performance would give a more complete picture to the investigation of children's responses to the SISI test.

CHAPTER III

EXPERIMENTAL PROCEDURES

This chapter presents information regarding the selection of subjects, their assignment to categories by age, sex, and intelligence quotient, and a discussion of the testing procedures employed. In brief, a total of 72 subjects were used in the study. Twelve of the subjects were adults, 50 per cent of whom were males. These subjects were equally divided into average and high IQ groups. The remaining 60 subjects were children, ranging in age from five to thirteen years. These subjects were divided into five groups, consisting of twelve five, seven, nine, eleven and thirteen-year olds. Each group was equally divided according to sex, and was further equally divided into average and high IQ groups. All subjects were administered a conventional pure tone hearing test and the Short Increment Sensitivity Index (SISI) Test, administered at seven intensity increments.

Subjects

Two groups of subjects participated in the study. One group was composed of twelve adults, ranging in age from 19 to 21 years, with a mean age of 19.9 years.

Subjects were equally divided as to sex, and were also equally divided with reference to IQ into "Average IQ" or "High IQ" categories. A second group of subjects was composed of 60 children, ranging in age from five years to thirteen years, eleven months. They were sub-divided into five equal sized age groups (5 years-0 months to 5 years-11 months, 7 years-0 months to 7 years-11 months, 9 years-0 months to 9 years-11 months, 11 years-0 months to 11 years-11 months, and 13 years-0 months to 13 years-11 months of age) and each group consisted of a 50 per cent male and a 50 per cent female population. These subjects were similarly divided into either an "Average IQ" or "High IQ" category.

In order to obtain IQ scores for the children, the investigator administered Form A of the Peabody Picture Vocabulary Test. This test was used because it can be administered easily and quickly, and it has good demonstrated validity. Scores from the PPVT were used to place subjects into an average or high IQ category. The average IQ category consisted of those subjects scoring between 90 and 109, and the high category consisted of subjects scoring 125 and higher. Those subjects whose scores fell between 110 and 125, as well as those whose scores were below 90, were not accepted for the study. If any other intelligence test information was available, i.e., from the subject's school folder, it was used as a validity check on the PPVT results.

Such information was available on eight of the 5-year old subjects who met the IQ criteria for the study. None of the eight subjects had to be rejected because of a significant discrepancy between the test scores. These eight subjects had previously been evaluated with the Wechsler Pre-School and Primary Scale of Intelligence (WPPSI).

To determine the IQ scores of adult subjects, the investigator administered an abbreviated form of the Wechsler Adult Intelligence Scale (WAIS), which will be discussed later in this chapter. This abbreviated form of the WAIS was selected because it permits an accurate estimate of the Full Scale score in 35 to 40 minutes of testing. For the adult age group in this study, the abbreviated form of the WAIS which was used has demonstrated a correlation of 0.96 with the Full Scale score. Scores from the WAIS were also used to place subjects into an average or high IQ category. The average IQ category consisted of subjects scoring between 90 and 109, and the high IQ category consisted of subjects scoring 120 and above. Those subjects whose scores fell between 110 and 119, as well as those whose scores were below 90, were not accepted for the study. No other intelligence test information was available on these subjects. The mean IQ score for each group of subjects is illustrated in Table 1.

TABLE 1.--Mean IQ scores for each group of subjects

	AVERAGE IQ Group		HIGH IQ Group	
	Male	Female	Male	Female
5 years	107	106	133	129
7 years	104	103	138	139
9 years	98	102	138	133
11 years	102	96	133	132
13 years	106	103	134	127
ADULTS	96	96	154	134

The subjects were obtained from various sources. Twenty per cent of the children were obtained from the Michigan State University Laboratory Preschool and the Spartan Nursery of Michigan State University. The remaining 80 per cent of the subjects were children of professors and other graduate students living in the University community. Some of the children in this 80 per cent category were obtained from the investigator's friends who taught in the Wainwright and Pleasant View Schools of Lansing, Michigan. Even though there were sixty children employed in this study, a larger number had to be contacted. Some of the children did not fit into either of the IQ categories desired for the study, and a few did not meet the criteria for normal hearing. No child had to be eliminated from the study because he could not attend to the task, i.e., taking the earphones off or refusing to participate.

The adult subjects were undergraduate students at Michigan State University and young adults outside the

college population who were contacted through friends and acquaintances of the investigator. As was the case with the children, a large number of adult subjects had to be contacted even though only twelve were needed for the study. It was difficult to find undergraduate students who scored in the "Average IQ" category on the WAIS. This was true even of so-called "average" students who had been recommended to the investigator by graduate assistants and graduate advisors in the dormitories. Therefore, a non-college population had to be used in order to fulfill this category. In addition, several of these subjects did not meet the hearing criteria and had to be eliminated from the study.

A subject was not included in the study if he revealed an auditory threshold which indicated an average loss (500, 1000, and 4000 Hz) of 10 dB or greater (1964 ISO standard). Likewise, any subject whose conventional pure tone test showed an air-bone gap was excluded from the study. The pure tone test was administered at frequencies of 500, 1000, and 4000 Hz for air conduction testing, and at frequencies of 500 and 4000 Hz for bone conduction testing.

Equipment and Standardized Tests

The equipment listed below includes the major instruments employed for this study.

Clinical Audiometer (Beltone, model 15-C)

Earphones (Telephonics, model TDH - 39)

Earphone cushions (model MX - 41/ AR)

Bone Vibrator (Radioear, Model B70-A)

SISI Adapter (Stowe, model 1259)

Sound Level Meter (Bruel and Kjaer, model 2203)

Artificial Ear (Bruel and Kjaer, model 4152)

Artificial Mastoid (Beltone, model M5B)

Oscilloscope (Model 502A with Polaroid Camera attachment)

Commercial Test Room (Industrial Acoustics Company, Inc., model 10-1052)

Peabody Picture Vocabulary Test

Wechsler Adult Intelligence Test

The sound-treated room and all audiometric equipment were located in the Speech and Hearing Clinic in the Michigan State University Auditorium building. The ambient noise of the sound-treated room had been previously measured with the sound level meter on the C scale. This noise level was found to be 42 decibels SPL. Also, an octave analysis of the ambient noise level in the sound-treated room had been done previously, and the results indicated that the greatest amount of ambient noise (40 dB average) was found in the octave bands below 100 Hz. For those octave bands from 100 to 8000 Hz, the ambient noise level averaged 14 dB SPL.

The SISI adapter was located in an adjoining test room which communicates with the sound-treated room by a window and a two-way electronic communications system. This adapter was designed as a "plug-in" unit for the pure tone audiometer to allow the administration of the SISI test. With this self-contained unit, extensive and permanent modifications of the audiometer circuit are not necessary for the administration of the test.¹ The audiometer used with the SISI adapter in this study was the Beltone, model 15-C. The testing rooms and equipment were situated as schematically diagrammed in Figure 1.

According to the manufacturer's specifications, the Stowe SISI Adapter permits an intensity increment of controlled magnitude with a 50 msec. rise-decay time, a duration of 200 msec at peak intensity, and a total duration of 300 msec. These were the specifications of the SISI stimulus described by Jerger, Shedd, and Harford.¹ Upon measuring these increments for this study, this particular adapter was found to provide an increment with a 50 msec rise-time and a 25 msec decay-time. The duration at peak intensity was 200 msec, and the total duration was 275 msec. These measurements were made at regular intervals with an Oscilloscope, model 502A, with a Polaroid camera

¹Instruction Manual for the SISI Adapter, Model 1259 (Northbrook, Illinois: Gordon N. Stowe and Associates).

²Jerger, Shedd, and Harford, "On the Detection," p. 202.

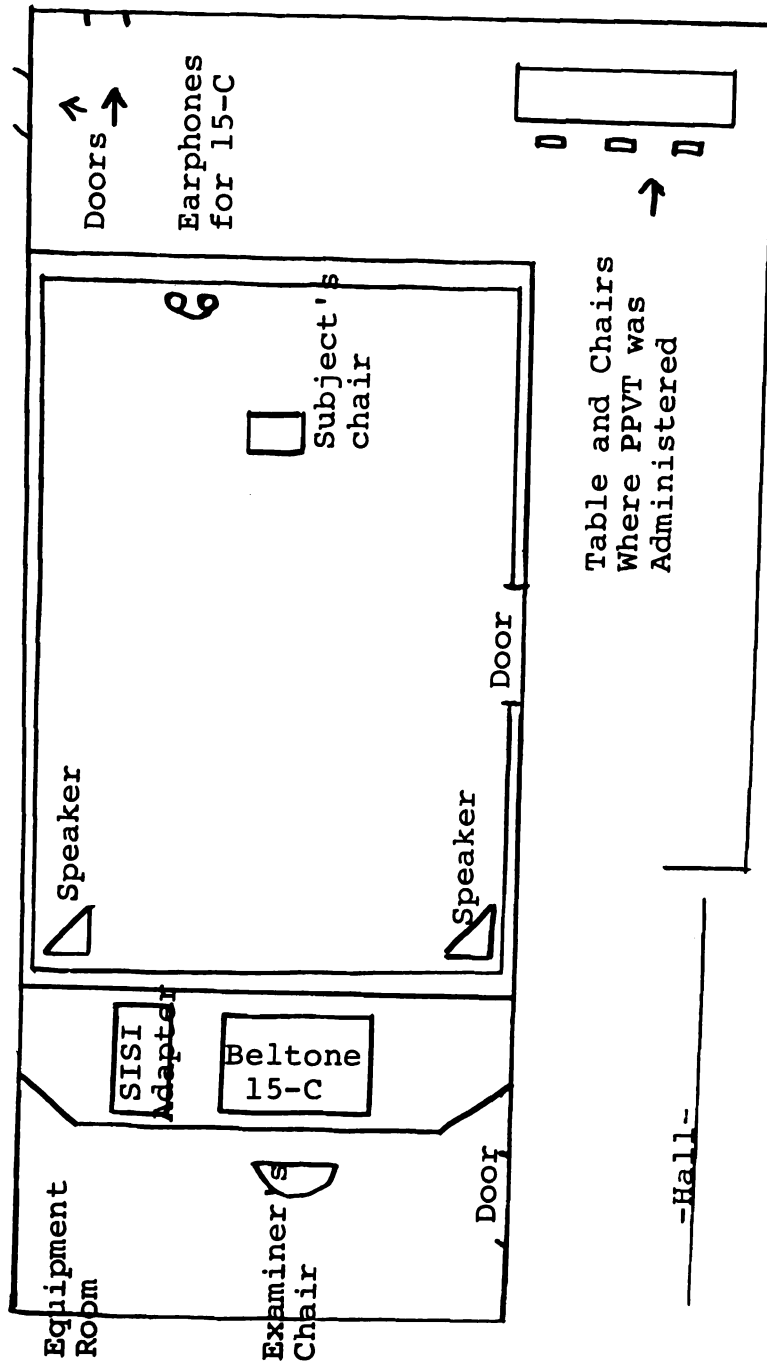


Figure 1.--Schematic diagram of the testing rooms and placement of equipment.

attachment. Initially, the equipment did not produce a signal that would meet the specifications required for this study. After a number of instrumental modifications and a series of measurements, the above-stated specifications were reached. Once these specifications were obtained, three additional measurements were made; one at the beginning of the study, one at the mid-point of the study, and a final measurement at the end of the study. It was found that these increment magnitudes remained the same throughout the study.

Calibration of the SISI stimulus was made each day of testing. This was done by placing the earphone over the artificial ear assembly, which was attached to the sound level meter. With the SISI stimulus turned on, the increment magnitudes were read and measured from the sound level meter. Calibration of the air conduction stimulus from the Beltone 15-C was also done each day subjects were seen. This was done by connecting the earphone to the artificial ear assembly, which in turn was connected to the sound level meter. The Beltone 15-C audiometer was then set to produce a 60 dB signal, and the output was measured at octave intervals between 250 and 8000 Hz. The earphone used in this study was a TDH-39 earphone in an MX 41/ AR cushion. Only one earphone was used in the study, and the same earphone was used for all subjects. The earphone covering the opposite ear was employed to keep the headset

in place on the subject's head.

Peabody Picture Vocabulary Test

The Peabody Picture Vocabulary Test is an intelligence test designed to give an estimate of a subject's verbal intelligence.¹ The materials consist of 150 plates contained in a spiral-bound booklet, each plate containing four pictures. The test has been standardized to provide norms for ages two years-six months through eighteen years. Two equivalent forms of the test, A and B, are available, each with a separate table of norms.

Various validity results are presented in the manual. Some of the tests with which the PPVT has been correlated are the Stanford Binet, Columbia Test of Mental Maturity, Wechsler Intelligence Scale for Children, and the California Test of Mental Maturity. As presented in the manual, these correlations are 0.88, 0.82, 0.86, and 0.82.

The Wechsler Adult Intelligence Scale (WAIS)

The Wechsler Adult Intelligence Scale (WAIS) is designed to measure adult intelligence. It is an extension and modification of the Wechsler-Bellevue Intelligence

¹Lloyd M. Dunn, Expanded Manual for the Peabody Picture Vocabulary Test (Minneapolis: American Guidance Service, Inc., 1965), p. 25.

Scale, Form 1.¹ The WAIS consists of eleven tests. Six of these are grouped into the Verbal Scale; the remaining five comprise the Performance Scale; all eleven tests are combined to make the Full Scale. The Verbal tests are: Information, Comprehension, Arithmetic, Similarities, Digit Span, and Vocabulary. The Performance tests are: Digit Symbol, Picture Completion, Block Design, Picture Arrangement, and Object Assembly.

The Abbreviated WAIS

There are many instances when users of the WAIS would want a reasonably accurate estimate of a subject's IQ without giving all eleven sub-tests of the Scale. Doppelt² investigated the effectiveness of a sub-group of tests in predicting the Full Scale Score, which is the sum of scores on the eleven tests. One of the major problems was the decision as to the number and type of sub-tests to be included in the predictor group. This decision, to some extent, was arbitrary. It was decided to select the group of four sub-tests which correlated highest with the Full Scale Score. Although the prediction of the Full Scale

¹David Wechsler, Manual for the Wechsler Adult Intelligence Scale (New York: The Psychological Corporation, 1955), p. 4.

²Jerome E. Doppelt, "Estimating the Full Scale Score on the Wechsler Adult Intelligence Scale from Scores on Four Subtests," Journal of Consulting Psychology, Vol. 20, No. 1 (1956), pp. 63-66.

Score was the goal, it was felt that the best approach would be to select the two verbal sub-tests which were most highly correlated with total Verbal Score and the two performance measures which were the best predictors of the total Performance Score.¹ The four subtests selected were Arithmetic, Vocabulary, Block Design, and Picture Arrangement. The selection of these tests was also based on the data obtained in the national standardization of the WAIS.

In order to obtain the subject's IQ, a simplified regression equation was presented in which the sum of scaled scores on the four selected subtests is multiplied by 2.5, which is the coefficient of the predicting variable in the regression equation. A constant is then added to this figure, depending upon the subject's age. For the age group used in this study, the constant was 10. This abbreviated form permits an estimate of Full Scale Score after 35 to 40 minutes of testing.

The author warned that in making any prediction one should always have some idea of the error involved.² In his study the standard deviation of Full Scale Scores was about 25 and the correlation coefficient between the sum of the four selected tests and the Full Scale Score

¹Ibid., p. 63.

²Ibid., p. 65.

was approximately 0.96. Consequently, the standard error of estimate in predicting Full Scale Score from the four tests is about seven scaled score points, which is equivalent to 4.2 IQ points. Thus, an estimated Full Scale Score would be within seven scaled score points of the actual score about 68 out of 100 times.

Procedure

The adult subjects were seen first in the study. The investigator made appointments to meet each subject either in a residence hall classroom or a classroom at the Michigan State University Auditorium building. The non-college subjects were seen in their homes or in the Auditorium building. At this time, a subject was administered the abbreviated form of the Wechsler Adult Intelligence Scale (WAIS).

Once the IQ had been determined, the subject came to the sound-treated room in the Speech and Hearing Clinic, and a pure tone hearing evaluation was administered. The examiner determined thresholds for the frequencies 500, 1000, and 4000 Hz by air conduction, and 500 and 4000 Hz by bone conduction. These thresholds were determined by the method of Carhart and Jerger.¹

¹Raymond Carhart and James F. Jerger, "Preferred Method for Clinical Determination of Pure-Tone Thresholds," Journal of Speech and Hearing Disorders, 24 (1959), pp. 330-345.

Once the subject's auditory threshold was obtained by conventional audiometry, the SISI test was administered. The instructions and test procedure of Jerger¹ were essentially the same, with one exception. The familiarization run which precedes the actual SISI testing consisted of five 5 dB increments and five 3 dB increments. The investigator believed, as did Hanley and Utting,² that ten increments would help the subject to settle down and become more familiar with the procedure, and reducing the familiarization increment from 5 dB to 3 dB might not present much contrast to the smaller increments of the test run. The subject was then given the following instructions:

You will hear a steady sound through the earphone for about two minutes. The sound will be very faint. During the time it is on you may occasionally hear a little jump in loudness. Whenever you are positive that you have heard one of these short loudness jumps, press the button which you have in your hand. If you think you heard a jump but you are not certain, then do not press the button. Only press it when you are sure you heard a jump in loudness.³

The test was presented at 4000 Hz and at a 20 dB sensation level. It was given in only one ear, and the ear chosen was the better of the two ears at 4000 Hz, as determined by the pure tone hearing test. At this frequency and sensation level, the subject was tested with

¹Jerger, Shedd, and Harford, "On the Detection," p. 203.

²Hanley and Utting, "An Examination of the Normal," p. 60.

³Jerger, Shedd, and Harford, "On the Detection," p. 203.

increments of 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, and 2.0 dB. The order in which the increments were presented was randomized according to a table of random numbers.¹ Following each of the test runs at each increment, the subject was allowed a one minute rest period before beginning a run at another increment. This was done to avoid fatiguing the subject, and to keep him alert to the presentations at each increment. Randomization was also employed to reduce the practice effect. After the seventh increment presentation, an increment was selected to repeat the test at a level closest to the subject's 50 per cent score for a reliability check. Even with the reliability check, no subject required more than 45 minutes to complete the test.

Thirty-two of the children were administered Form A of the Peabody Picture Vocabulary Test in their homes prior to coming to the Auditorium building for the hearing test. The remaining twenty-eight children were administered the test at a small table outside the sound-treated audiometric test room. Only 10 to 15 minutes were required to give this untimed test. The scale is administered only over a critical range of items for a particular subject. The starting point, basal and ceiling, vary from testee to testee.² The starting points are listed in the manual,

¹Hubert M. Blalock, Jr., Social Statistics (New York: McGraw Hill Book Company, Inc., 1960), pp. 437-440.

²Dunn, Manual for the Peabody, p. 5.

and they vary as a function of age and assumed ability. From the indicated starting point the examiner works forward until the subject makes his first error. In the event that eight correct responses have not been made to this point, the examiner goes back immediately to the starting point and works backward consecutively until a total of eight consecutive correct responses have been obtained. This is the basal score. To obtain the ceiling score, the examiner continues testing forward until the subject makes six errors in eight consecutive presentations. The last item presented is considered as the subject's ceiling. The test is discontinued when a basal and ceiling have been established. In order to determine the subject's intelligence quotient, the sum of the incorrect responses is subtracted from the ceiling score. This gives the raw score which is used to obtain the IQ score from the tables in the manual.¹

After the Peabody test had been given, a conventional pure tone hearing evaluation was administered. As with the adults, auditory thresholds were determined for the frequencies 500, 1000 and 4000 Hz by air conduction, and 500 and 4000 Hz by bone conduction. These thresholds were also determined by the method of Carhart and Jerger.²

¹Ibid., pp. 8-10.

²Carhart and Jerger, "Preferred Method," pp. 330-345.

Once the subject's auditory threshold had been determined with conventional audiometry, the SISI test was administered. The procedure was essentially the same as that used with adults, including the use of five 5 dB increments and five 3 dB increments in the familiarization run. There was a slight deviation in the manner in which instructions were stated, however, so as to make the task clear for the children. The subjects were given the following instructions:

Now you will listen for tones that are just a bit different from the first tones you heard. This time you will hear a steady tone in your ear for a few minutes. It will sound much like the tone you heard in the first test. While the tone is on, however, you will begin to hear a little jump in loudness. I want you to listen very carefully for the jump in loudness (the examiner often demonstrated this verbally). When you are sure that you heard the jump in loudness, press the button you have in your hand. Remember, press the button only when you are certain that you heard the tone jump. If you are not sure, do not press the button.

There was one other deviation in the previously outlined procedures as they applied to the children. After the fourth increment run the child was allowed to come out of the sound-treated room and take a ten minute break before resuming the experiment. They were motivated to continue by rewards which the investigator placed in their sight, even though most of them admitted they were tired at the half-way point. Nevertheless, none of the children refused to continue the experiment, and the elapsed time required to complete the task for any child did not exceed one hour.

The Quantal Theory

The quantal theory derives from the assumption that the basic neural processes mediating a discrimination are of an all-or-none character. The advantage of a quantal theory of sensory discrimination lies not solely in the fact that it makes explicit the role of neural processes that are all-or-none, but also in the fact that it enables us to predict the form and the slope of certain psychometric functions. Instead of psychometric functions resembling the probability integral, there are rectilinear functions. Instead of curves of unpredictable slope, there are lines whose slopes are proportional to the differential sensitivity of the observer. Instead of failure of even the smallest stimulus-increments to produce perceptions of increase, a critical value is found below which no increment is ever perceived.¹ The theoretical argument for the quantal theory is as follows.

It is assumed that the neural structures initially involved in the perception of a sensory continuum are divided into functionally distinct units. Bekesy² thought of these units as single afferent fibers, but the evidence indicates that the functional units are larger than fibers,

¹S. S. Stevens, C. T. Morgan, and J. Volkman, "Theory of the Neural Quantum in the Discrimination of Loudness and Pitch," The American Journal of Psychology, 54 (1941), pp. 315-335.

²Stevens and Davis, Hearing, p. 147.

and that they are probably centrally located. A stimulus of a given magnitude excites, at a particular instant, a certain number of these quantal units, and, in order for an increment to be noticeable, it must excite at least one additional quantum. That is the basic picture; but here enter some additional considerations. The stimulus which excites a certain number of quanta will ordinarily do so with little to spare; it will excite these quanta and leave a small "surplus" insufficient to excite some additional quantum. This surplus stimulation will contribute, along with the increment ΔI , to bring into activity the added quantum needed for discrimination. Consequently, at any instant, the size of the increment necessary to add another quantum to the total number excited must depend upon the amount of "left-over" stimulation.

The frequency with which a given stimulus-increment will excite an additional quantum depends upon the frequency with which the surplus stimulation exceeds a certain crucial amount, and this occurs a proportion of the time which is dependent directly upon the amount to be exceeded. From these considerations, it follows that, if the increment is added instantaneously to the stimulus, it will be perceived a certain fraction of the time, and this fraction is directly proportional to the size of the increment itself.

This argument can be rendered more precise with the aid of mathematics. As already stated, it is assumed that

at a given moment a steady stimulus excites completely a certain number of quanta and leaves a small surplus, p , which goes part way toward exciting the quantum next in line; and that the stimulus increment, ΔI , which is required to complete the excitation of this quantum, is smaller when the surplus, p , is larger. The size of a quantum can be measured in terms of the increment, Q , which will just succeed always in exciting it. Then the ΔI just sufficient to complement the surplus, p , and thereby excite an additional quantum is given by the equation, $\Delta I = Q - p$.¹

An example of the psychometric function is shown by the graph in Fig. 2. This graph is a plot of the equation, $R = (\Delta I/Q - 1) \times 100$,² where R represents the percentage of the increments which an 0 should be able to detect, and R varies between zero and 100. This equation is derived from the assumption that the addition of two quanta is required for a discrimination. In the plot shown, the value of Q is used as the unit for measuring the stimulus increment. In these units the slope of the straight psychometric function is exactly determined. Furthermore, when a discrimination requires the addition of two quanta, it is noted that stimulus increments of less than one quantum are never detected, whereas those greater than two quanta are always detected.

¹Stevens, Morgan, and Volkmann, "Theory of Neural Quantum," p. 318.

²Ibid.

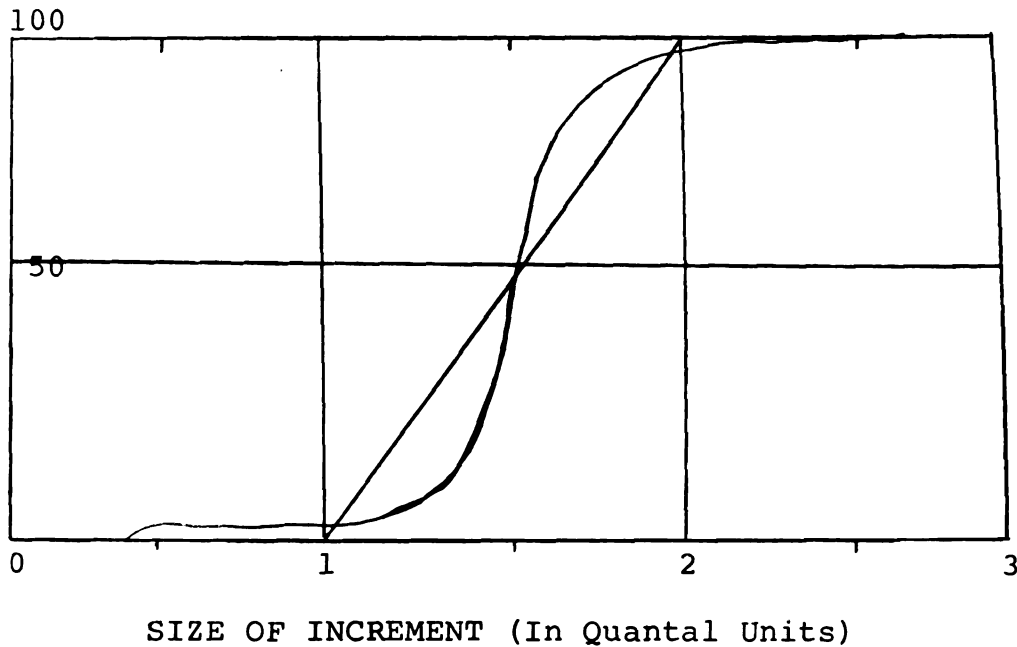


Figure 2.--The Quantal and Phi-Gamma Functions. The straight line shows the results expected on the basis of the quantal theory. It is the graph of the equation $R = (\Delta I/Q - 1) \times 100$. The S-shaped curve was constructed by fitting the phi-function of gamma to the rectilinear quantal function.¹

According to classical theory, the convention then is to define as the difference-limen that increment which is noticed 50 per cent of the time. It is sometimes argued that when the difference-limen is small, the slope of the psychometric function must be steep (its b must be high); but precisely what slope is to be expected, the theory is unable to disclose.

¹Ibid., p. 319.

Analysis of the Data

The data derived from each subject's DL were computed according to the formula from the Method of Least Squares.¹ A desk calculator was used for the computations. After the computations were made, the DL data were plotted on a composite graphy, using the line of best fit according to the principle of least squares. The line of best fit according to the principle of least squares is that line from which the sum of the squares of the residuals is a minimum. A residual is a discrepancy between an obtained Y value and the Y value that could be predicted from its corresponding X on the basis of the equation which is being used. According to Blalock,² y_p may be used to indicate that the Y value has been predicted from a least-squares equation. The least-squares line, therefore, will be the best estimate of the true regression if the regression actually is linear.

In order to determine the significance of differences among the variables in the principal comparisons (Ho_1 , Ho_2 , Ho_3 , and Ho_4), a "Three-Dimensional Design" analysis of variance was employed. The actual analysis of

¹J. P. Guilford, Psychometric Methods (New York: McGraw-Hill Book Company, Inc., 1954), p. 64.

²Blalock, Social Statistics, p. 284.

variance was conducted on a Control Data Corporation 3600 Digital Computer. The F-ratio was used in testing the significance of the variations. Specifically, two different three-way analyses were computed; one with the DL score as the dependent variable, and the other with the SISI score at the 1 dB increment as the dependent variable. The source of variation for each of these analyses, was age, sex, and IQ.

After having tested the DL means and the SISI means for each age group by an analysis of variance, Duncan's New Multiple Range Test was applied to determine specifically which means differed when a significant F was obtained. The test itself was conducted on a Control Data Corporation 3600 Digital Computer, employing the program, "Calculation of Basic Statistics on the BASTAT Routine."¹

The mean DL scores for the variables of sex and IQ were computed for each of the six age levels studied. An examination of the variability around these means was made by computing the standard deviation at each age level for the variables of sex and IQ. Likewise, the mean SISI scores at the 1 dB increment and their standard deviations were computed for the variables of sex and IQ, at each of the six age levels. The means were computed on a Control

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

Data Corporation 3600 Digital Computer. The standard deviations were computed on a desk calculator.

The ranges of the SISI scores at the 1 dB increment were tabulated at each age level for the variables of sex and IQ. These ranges provided a comparison with previous research at the 1 dB increment employing normal hearing adults. Moreover, careful investigation of these ranges opened the possibility for a re-evaluation of the diagnostic criteria previously established for the normal hearer's response to the SISI test at the 1 dB increment.

During the DL experiment, an increment was selected to repeat the test at a level closest to the subject's 50 per cent score in order to ascertain reliability. A Pearson Product-Moment correlation coefficient was computed on this test-retest data, and a standard error of measurement (SE_m) was computed for the test-retest scores. A desk calculator was used for these calculations.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter is divided into four sections. The first two sections are devoted to the presentation of the results of the study relative to the hypotheses which were tested. The third section presents reliability data relative to the SISI test procedure used in this study. The fourth section presents a general discussion of the results.

The Intensity Difference- Limen (DL)

In order to gain information concerning the questions originally posed for this study, four null hypotheses were formulated. A re-statement of these hypotheses would be appropriate at this time:

1. There is no significant difference between the responses of normal hearing adults and children between five through thirteen years of age to the 1 dB increment currently employed in the Short Increment Sensitivity Index (SISI) Test.
2. There is no significant difference in the difference-limen (DL) of normal hearing adults and that of children between five through thirteen years of age.
3. There is no difference in the DL and SISI scores obtained employing the 1 dB increment between subjects who have an average intelligence quotient and those who have a high intelligence quotient for each of the six age levels tested.

4. There is no difference in the DL and SISI scores obtained employing the 1 dB increment between male and female subjects at each of the six age levels tested.

Each subject's difference-limen (DL) was computed according to the procedures outlined by Guilford¹ and previously discussed on page 57. In addition, the DL was computed for each age group. The line of best fit was obtained by mathematically locating two points following the procedures outlined in Blalock.² Figures 3 through 8 show the psychometric function derived from the application of the quantal method. Each graph presents the mean response at each increment for each age level. The resultant DL, therefore, is the mean DL for that particular age level.

Examination of Figures 3 through 8 indicates some discrepancies between the visual display of the mean DLs and the mean DLs shown in Table 2. These discrepancies, for the age groups over five years, are minor, and are caused by the mathematical manipulation required in order to plot the line of best fit. The mean DL for each age group may be calculated one of two ways. By means of the first method, the slope and Y-intercept of the line of best fit for each subject are used to find the DL for that

¹J. P. Guilford, Psychometric Methods (New York: McGraw-Hill Book Company, Inc., 1954), p. 63.

²Hubert M. Blalock, Jr., Social Statistics (New York: McGraw-Hill Book Company, Inc., 1960), p. 284.

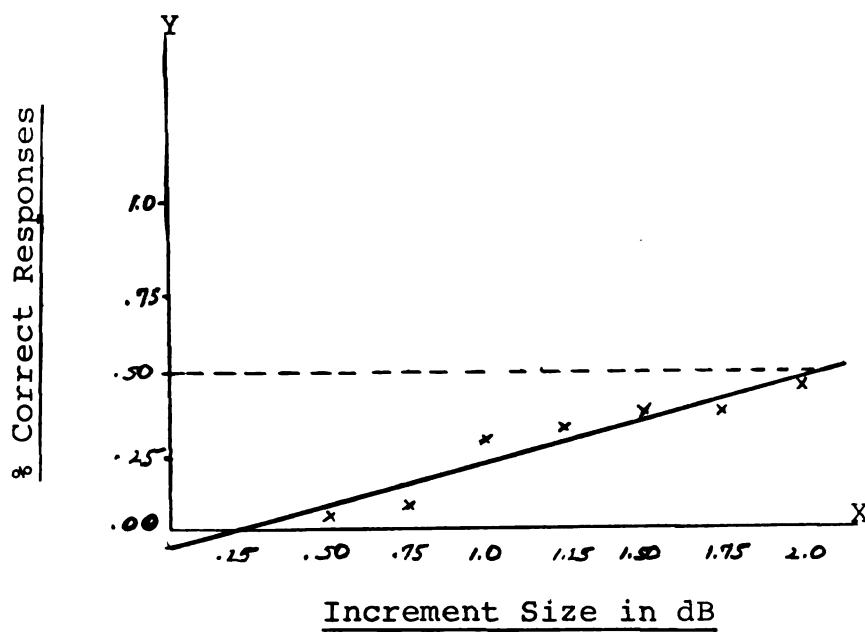


Figure 3.--The mean percentage response at each dB increment level and the mean DL for 5-year old subjects.

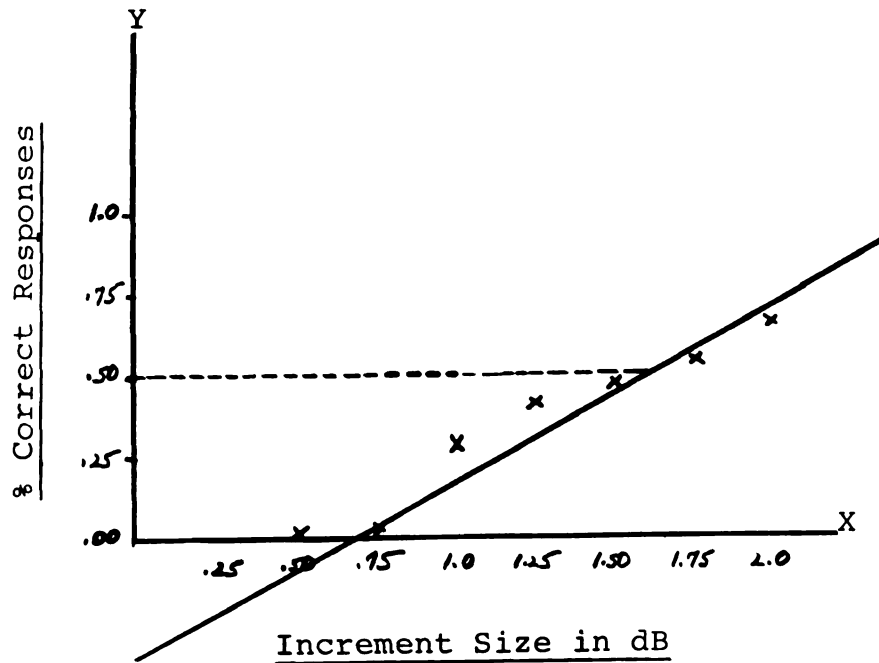


Figure 4.--The mean percentage response at each dB increment level and the mean DL for 7-year old subjects.

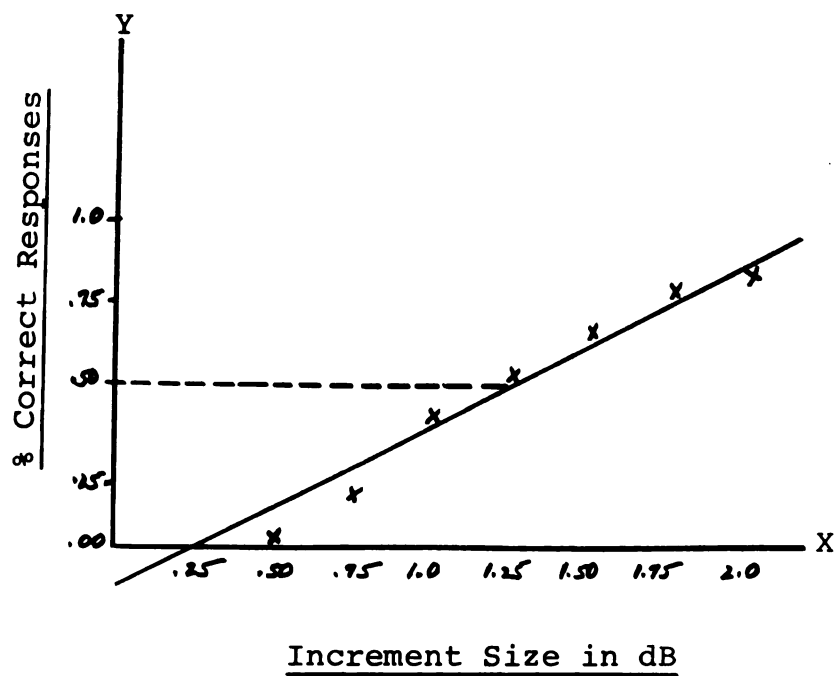


Figure 5.--The mean percentage response at each dB increment level and the mean DL for 9-year old subjects.

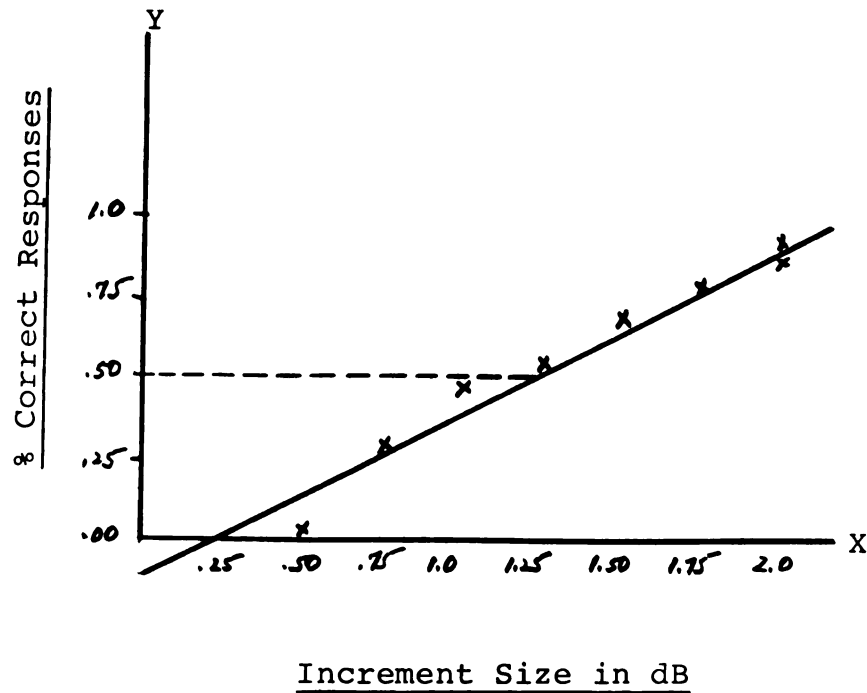


Figure 6.--The mean percentage response at each dB increment level and the mean DL for 11-year old subjects.

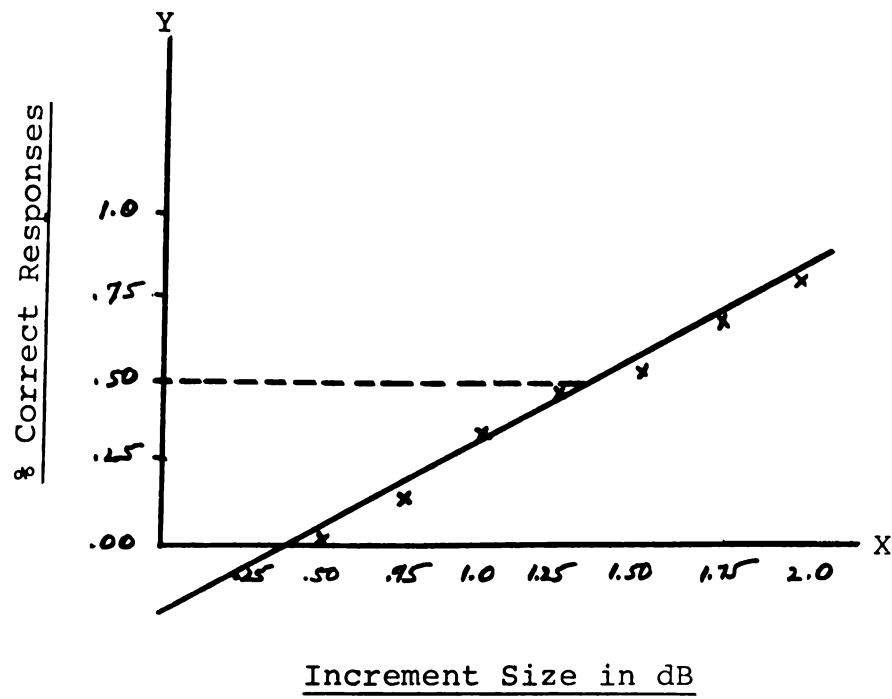


Figure 7.--The mean percentage response at each dB increment level and the mean DL for 13-year old subjects.

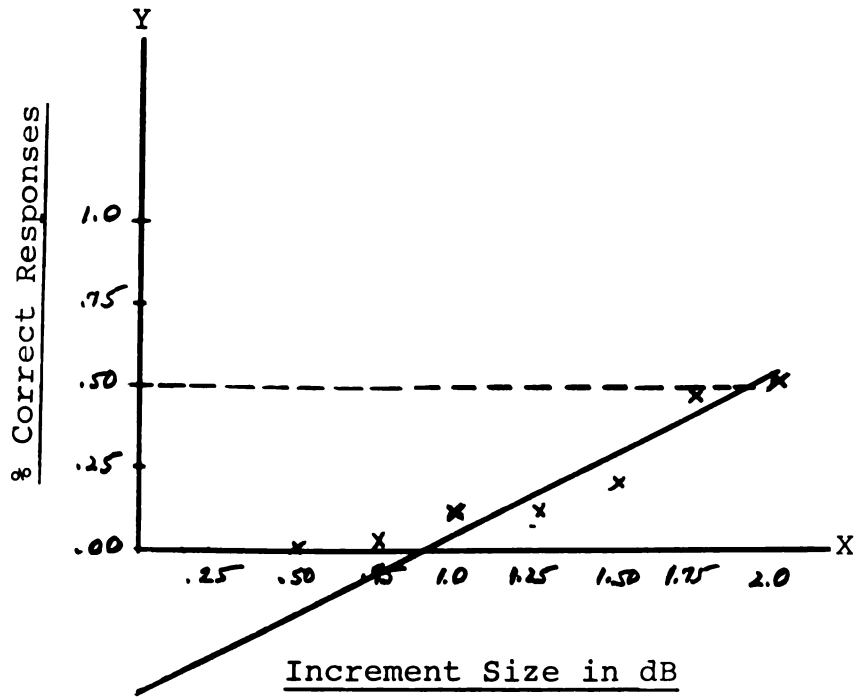


Figure 8.--The mean percentage response at each dB increment level and the mean DL for adult subjects.

subject. Thus, DLs may then be averaged to find the mean DL for that group. Conversely, the slopes and Y-intercepts for all subjects within a group may be averaged and the mean DL calculated from the averaged values. It can be shown mathematically that these two methods are not exactly equivalent, and may, in some cases, yield slightly different values for the mean DL. This may also account for small discrepancies between calculated values of the mean and their graphical representations. In order to show the mean DL values graphically, however, it was necessary to use the second method of calculation. The largest discrepancy appeared with the 5-year old group, and this was caused by the excessively large DL (12.58) on the part of one subject, which affected the mean DL for that group.

The means used in comparing differences of age, sex, and IQ for the DL test are presented in Table 2 along with their respective standard deviations.

Inspection of the mean DLs in Table and in Figures 3 through 8 indicates that the "largest" DLs occur with the five-year old children and with adults. Extreme caution should be used in applying the terms "large" DL or "small" DL in this regard. Such caution is advisable because these terms are difficult to interpret; there is no evidence of other research findings of the normal intensity difference-limen (DL) using the procedure that was used in this study. Until such research is available, then, these terms would tend to have little or no clinical significance.

TABLE 2.--Mean DLs and standard deviations (SD in parentheses) by age, sex, and IQ for the six age levels.

IQ	AGE AND SEX											
	5		7		9		11		13		Adult	
	M	F	M	F	M	F	M	F	M	F	M	F
Low	4.18 (.660)	2.13 (.497)	1.66 (.397)	1.40 (.025)	1.17 (.204)	1.25 (.009)	1.17 (.179)	1.63 (.658)	1.56 (.703)	1.76 (.944)	1.76 (.157)	2.00 (.518)
High	5.26 (.517)	1.63 (.386)	1.54 (.477)	1.79 (.570)	1.24 (.308)	1.33 (.088)	0.99 (.096)	1.29 (.498)	1.27 (.248)	1.37 (.037)	2.13 (.488)	2.14 (.367)
Mean DL by Age	3.30		1.60		1.25		1.27		1.49		2.01	

In order to compare the significance of differences as a function of age, sex, and IQ on the DL Test, a "Three-Dimensional Design" analysis of variance was employed.¹ The data from the experiment were entered in a three-dimensional table. In this instance, it consisted of six rows representing age, two columns representing sex, and two slices representing IQ. Therefore, an A x B x C three-entry table was employed to organize the data for the three-factor experiment computation. The sources of variation for this analysis were age, sex, and IQ. A summary of this analysis is presented in Table 3.

TABLE 3.--Summary of analysis of variance comparing performance on the DL test as a function of age, sex, and IQ.

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Age	36.152	5	7.230	3.695*
Sex	2.229	1	2.229	1.139
IQ	0.011	1	0.011	0.005
Age x Sex	22.620	5	4.524	2.311
Age x IQ	1.069	5	0.213	0.109
Sex x IQ	0.300	1	0.300	0.153
Age x Sex x IQ	1.832	5	0.366	0.180
Within Cells (error)	93.926	48	1.956	---
TOTAL	158.141	71	---	---

*Significant beyond the 0.01 level.

¹E. F. Lindquist, Design and Analysis of Experiment in Psychology and Education (Boston: Houghton Mifflin Co., 1956), pp. 220-253.

Inspection of Table 3 reveals that the only factor showing statistical significance, at the 0.01 level of confidence, was age. Levels within sex, levels within IQ, and interactions, were not significant. The analysis of variance, however, does not show individual comparisons among the means. It is not known, therefore, which means differ from each other and how they differ.

In order to determine which of the differences between means are significant and which are not, the mean DL score for each age level was subjected to multiple comparisons using Duncan's New Multiple Range Test.¹ The results of this test, at the 0.01 level of confidence, are displayed in Table 4.

TABLE 4.--Duncan's New Multiple Range Test applied to the differences between DL means.

	<u>Age Groups</u>				
	5 Yrs	7 Yrs	9 Yrs	11 Yrs	13 Yrs
Age and Means	3.30 dB	1.60 dB	1.25 dB	1.27 dB	1.49 dB
5 Yrs.	3.30 dB				
7 Yrs.	1.60 dB	1.70 dB*			
9 Yrs.	1.25 dB	2.05 dB*	0.35 dB		
11 Yrs.	1.27 dB	2.03 dB*	0.33 dB	0.02 dB	
13 Yrs.	1.49 dB	1.81 dB*	0.11 dB	0.24 dB	0.22 dB
Adults	2.01 dB	1.29 dB	0.41 dB	0.76 dB	0.74 dB
*Significant beyond the 0.01 level.					

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

Inspection of Table 4 reveals the following differences: (1) The mean DL score for five-year olds differed significantly from the mean DL scores of seven, nine, eleven, and thirteen-year old children; (2) The mean DL scores of seven, nine, eleven, and thirteen-year old children did not differ significantly from each other; (3) The mean DL score for adult subjects did not differ significantly from any of the other age groups.

The SISI Score at the 1 dB
Increment

The regular SISI test procedure as suggested by Jerger, Shedd, and Harford¹ was employed throughout this experiment. The response at the 1 dB increment was a major concern in this study. This concern was based largely on the manner in which the SISI test is employed clinically. Further, emphasis has already been given to the dearth of information pertaining to children's responses to the SISI test. In order to make a clinical comparison of children's responses to adults then, it would be important to know what these responses were at the 1 dB increment.

Another factor which is important to the study of responses to the SISI test is the range of SISI scores. Careful inspection of ranges of SISI scores helps to

¹James F. Jerger, Joyce Lassman Shedd, and Earl Harford, "On the Detection of Extremely Small Changes in Sound Intensity," AMA Archives of Otolaryngology, Vol. 69 (Feb., 1959), pp. 200-211.

establish criteria for evaluating responses to the SISI test. Though the literature has revealed cases that refute pathological category based on their percentage SISI score, this does not discount the value of carefully inspecting the ranges of SISI scores for certain groups of subjects. For the most part, clinical observation reveals that grouping cases on the basis of the range of their scores has displayed an accuracy that has to be regarded with importance. The ranges displayed for the six age levels in this study are shown according to the number of subjects scoring at the indicated percentage score levels.

TABLE 5.--Ranges of SISI scores at the 1 dB increment showing percentage score response by number of subjects at each age level

[illegible]

Examination of Table 5 shows that the ranges for the adults in this study are similar to those previously reported in the literature.¹ The highest score among the adults was 35 per cent, and this was scored by only one subject. Six of the twelve subjects scored only 5 per cent. Inspection of the ranges of five- and seven-year olds shows that 11 of these 24 children scored above 30 per cent. Therefore, it would seem that the criteria established by Jerger² (0-30%) for the normal hearer's response to the SISI test at the 1 dB increment should not be applied to these age groups. The ranges of children nine and above give further evidence that other criteria should be employed when referring to the normal hearing response to the 1 dB increment of the SISI test at these age levels. Closer examination of these ranges shows that 31 of the 36 children in these three age groups scored from 25 to 80 per cent, and 21 of these 31 children scored from 25 to 50 per cent. These scores very closely parallel the results of Yantis and Decker,³ who found a range of scores for normal hearing adults to be from zero to 85 per cent, and proposed 80 per cent as the criterion for a positive score.

¹Jerger, Shedd, and Harford, "On the Detection," pp. 200-211.

²Ibid.

³Phillip A. Yantis and Robert L. Decker, "On the Short Increment Sensitivity Index (SISI) Test," Journal of Speech and Hearing Disorders, 29 (1964), pp. 231-246.

In order to get a comparison of SISI scores at the various age levels, the mean SISI scores and standard deviations were computed for each age level by sex and IQ. A display of this comparison is shown in Table 6.

Inspection of Table 6 reveals that the mean percentage SISI scores of children nine and above are higher than the upper limit of the range for the normal hearer's response reported by Jerger.¹ Moreover, the mean percentage SISI score for eleven-year olds is higher than the mean percentage SISI score reported by Hanley and Utting,² which is the highest mean percentage SISI score (42.4%) at the 1 dB increment that has recently been reported in the literature. The trend of these results seems to suggest that the SISI test should be used more frequently with children above the age of nine, and that 80 per cent should be considered as the minimal criterion for a positive score with these age levels.

The mean SISI scores at the 1 dB increment shown in Table 6 were also tested by an analysis of variance. Again, a three-dimensional design³ was computed for the

¹Jerger, Shedd, and Harford, "On the Detection," pp. 200-211.

²C. N. Hanley and J. F. Utting, "An Examination of the Normal Hearer's Response to the SISI," Journal of Speech and Hearing Disorders, 30 (1965), pp. 58-65.

³Lindquist, Design and Analysis, pp. 220-253.

TABLE 6.--Mean percent SISI scores at the 1 dB increment and standard deviations (SD in parentheses) by IQ, sex, and age

IQ	AGE AND SEX											
	5		7		9		11		13		Adult	
	M	F	M	F	M	F	M	F	M	F	M	F
Low	21.6 (16.5)	26.6 (19.2)	28.3 (18.8)	33.3 (4.7)	43.3 (15.4)	31.6 (9.4)	55.0 (18.7)	36.6 (22.2)	43.3 (22.0)	35.0 (22.7)	11.6 (6.23)	18.3 (12.4)
High	30.0 (14.7)	26.6 (9.40)	36.6 (23.2)	11.6 (16.5)	48.3 (8.50)	36.6 (4.70)	50.0 (8.50)	53.3 (17.0)	36.6 (15.4)	23.3 (10.2)	6.60 (2.30)	1.60 (2.30)
Mean SISI Score By Age	26.2		27.5		40.0		48.7		34.5		9.5	

variables of age, sex, and IQ. A summary of this analysis is shown in Table 7.

TABLE 7.--Summary of Analysis of Variance comparing differences of age, sex, and IQ and SISI score for the 1 dB increment

Source of Variance	Sum of Squares	df	Mean Square	F-Statistic
Age	10827.777	5	2165.555	6.403*
Sex	734.722	1	734.722	2.172
IQ	68.055	1	68.055	0.201
Age x Sex	498.611	5	99.722	0.294
Age x IQ	898.611	5	179.722	0.531
Sex x IQ	138.888	1	138.888	0.410
Age x Sex x IQ	1061.111	5	212.222	0.627
Within Cells (error)	16233.333	48	338.194	---
TOTAL	30461.111	71	---	---

*Significant beyond the 0.01 level.

Inspection of Table 7 reveals that the only factor showing statistical significance, at the 0.01 level of confidence, was age. Levels within sex, levels within IQ, and the interactions, were not significant. The analysis of variance computed on the SISI score means at the 1 dB increment gave results similar to the analysis of variance computed on DL means. Both showed significance only with age.

Duncan's New Multiple Range Test was applied to the SISI score means to determine if there were any significant differences between them. The results of this test, at the 0.01 level of confidence, are summarized in Table 8.

TABLE 8.--Duncan's New Multiple Range Test applied to the differences between SISI means at the 1 dB increment

		<u>Age Groups</u>				
		5 Yrs	7 Yrs	9 Yrs	11 Yrs	13 Yrs
Age and Means		26.2%	27.5%	40.0%	48.7%	34.5%
5 Yrs	26.2%					
7 Yrs	27.5%	1.3				
9 Yrs	40.0%	13.8	12.5			
11 Yrs	48.7%	22.5*	21.2	8.7		
13 Yrs	34.5%	8.3	7.0	5.5	14.2	
Adults	9.5%	16.7	18.0	30.5*	39.2*	25.0*

*Significant beyond the 0.01 level.

Examination of Table 8 reveals the following differences: (1) The mean SISI scores for nine, eleven, and thirteen-year old children differed significantly from the means of adults; (2) The mean SISI score of eleven-year olds differed significantly from that of five-year olds; (3) The mean SISI score of adults differed significantly from those of nine and thirteen-year olds; (4) The mean SISI scores of adults and five-year olds differed significantly from that of eleven-year olds.

Reliability

During the course of this study, a re-test was done on the increment magnitude that was closest to the increment of each subject's original 50 per cent score. This was done to ascertain reliability. A Pearson Product-Moment correlation coefficient was computed on this test-retest procedure.¹ The correlation coefficient, however, was applicable only to the DL test procedure, and not to the SISI test at the 1 dB increment. Three of the subjects, all five years of age, would not respond to re-test of the increment because of restlessness and fatigue. The correlation coefficient, therefore, was based on sixty-nine subjects rather than the seventy-two in the original experiment. The correlation was 0.57.

The correlation coefficient, however, does not provide a measure of a subject's absolute consistency, or absolute variability in performance from test to re-test. This absolute consistency is a major concern of the audiologist, and it may be expressed by the standard error of measurement (SE_m). The standard error of measurement may be defined as an estimate of the standard deviation that would be obtained for a series of measurements of the

¹Allen L. Edwards, Statistical Methods for the Behavioral Sciences (New York: Rinehart and Company, Inc., 1960), pp. 145-148.

individual.¹ The standard error of measurement for the test-retest scores in this study was 8.59 per cent. This means that for slightly more than two-thirds of the obtained scores (about 68 per cent), retest scores were within ± 8.59 per cent of the initial SISI score.

Discussion

The results of statistical analyses of the DL test tend to support some observations that were noted during the experiment. For the most part, nine, eleven, and thirteen-year old children responded to the procedure well. They demonstrated an understanding of the procedure, and they attended to the task consistently. The seven-year olds, as a group, were less consistent, as some were more difficult to condition to respond to the increment magnitudes than others. The majority of the five-year olds, on the other hand, were erratic in their responses. They were difficult to condition and their attention wandered frequently. Even though they cooperated by remaining with the task to its conclusion, they appeared restless and bored toward the end, and many of them were curious to know how long it would be before the task would end.

¹Robert L. Ebel, Measuring Educational Achievement (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965), pp. 332-333.

A perusal of the literature indicated that the DL values obtained by other psychophysical methods do not appear to be significantly different from the DL values obtained by the quantal method used in this study. The greatest difference occurs with the mean DL of the five-year old group, but it should be remembered, however, that the mean DL for five-year olds was strongly affected by the DL (12.58) of one subject. It would seem, therefore, that some five-year olds can be tested with the DL procedure used in this study. These observations tend to indicate that the quantal method of obtaining DL measurements can be employed with children between five and thirteen years of age. When employing the procedure with five and seven-year olds, however, a modification of instructions might be recommended to make sure that these subjects understand the procedure clearly. A second suggestion for improving the performance of these children would be to employ greater care in familiarizing them with the conditioning procedure. It would seem that this would improve the consistency of their responses. It was noted during the experiment that five and seven-year olds appeared to respond more consistently to the task after a rest period. Shorter work periods might be suggested, therefore, as another way in which the performance of these children might be improved. Finally, rewards could be used to motivate these children and provide additional incentive

for them to attend to the task to its conclusion. Rewards were employed with all children during this research, and it is believed that they contributed to the fact that all of the five and seven-year olds remained with the task to its conclusion.

The above-mentioned suggestions for improving the performance of five and seven-year olds on the DL procedure used in this study would also apply to improving the performance of these children on the SISI test at the 1 dB increment, which is used clinically. Since five and seven-year olds are much more likely to be inconsistent in their response behavior, it would seem that revising the instructions to make them more lucid, taking greater care to familiarize the subjects with the conditioning procedure, working in shorter periods of time, and presenting rewards for motivation, would tend to decrease the possibility that these children give spuriously high or low SISI scores at the 1 dB increment. An example of revised instructions is shown in Chapter III of this study. During the experiment, the investigator did not have to repeat instructions to a child of any IQ level in any age group. Inconsistent response patterns noted were apparently due to factors already discussed. It was also noted that at no time during the experiment did a child at any age level complain that he did not understand the task.

The ranges of SISI test scores at the 1 dB increment provide some observations that would tend to have clinical importance. First, it seems apparent that when referring to children nine years of age and above, the criterion for a positive SISI score at the 1 dB increment should be 80 per cent, as proposed by Yantis and Decker.¹ Second, children nine and above do tend to show more sensitivity to small changes in intensity than do adults, and this is further support for employing the 80 per cent criterion. Finally, children nine and above do show the ability to respond well to the SISI test, and it is believed that the test should be used more frequently in clinical situations with children at these age levels. If the test is to be employed with five and seven-year old children, the previously stated suggestions for improving their performance on the SISI test should be carefully considered.

Summary

In reviewing the statistical information presented in this chapter, it can be seen that one of the null hypotheses cited earlier can be rejected, whereas three of them cannot be rejected.

¹Yantis and Decker, "On the Short Increment," pp. 231-246.

Specifically, Ho_1 was concerned with the responses to the SISI test at the 1 dB increment made by adults and children between five and thirteen years of age. This null hypothesis was rejected. There was a difference, and upon statistical inspection it was found that nine, eleven, and thirteen-year old subjects gave SISI scores that were significantly different from adults. Moreover, some of the SISI scores differed significantly from each other. The scores of adults differed significantly from those of nine and thirteen-year olds, and the scores of adults and five-year olds differed significantly from those of eleven-year olds.

The second null hypothesis (Ho_2) was concerned with the differences between adults and children five through thirteen years of age and their responses on the difference-limen (DL) test. The results indicated that there were significant differences between five-year olds and all the other children's age groups. Nevertheless, there were no significant differences between the DL of adults and that of the children, and the null hypothesis could not be rejected.

The third null hypothesis (Ho_3) was concerned with the difference in response to the DL test and the SISI test at the 1 dB increment by bright and average subjects at the six age levels studied. The results indicated no

significant differences to either of these procedures as a result of differences in intelligence quotients and the null hypothesis was not rejected.

The final null hypothesis (H_{0_4}) was concerned with the difference in the response to the DL test and the SISI test at the 1 dB increment by male and female subjects at the six age levels studied. The results indicated no significant differences to either of these procedures as a result of differences in sex, and the null hypothesis was not rejected.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATION

The purpose of this research was essentially two-fold. The first purpose was to determine if the Short Increment Sensitivity Index (SISI) Test as now used in diagnostic audiology could be employed with children five years of age and older. A question posed was whether the presently used increment of 1 dB presented at a 20 dB sensation level could be used with normal hearing children and produce results similar to those of adults with normal hearing. Questions were also posed concerning the effect of age, intelligence, and sex on the performance on the SISI test. The second purpose of the research was to compare the size of the intensity difference-limen (DL) in adults and children using the quantal psychophysical method. Consideration was also given to the effect of age, intelligence, and sex on the size of the difference-limen (DL) for intensity using the quantal psychophysical method.

Summary

Seventy-two subjects in six age groups were selected for this study. One group was composed of twelve adults. The sixty remaining subjects were children of five, seven,

nine, eleven, and thirteen years of age. These subjects were sub-divided so that twelve children were in each of the age groups. All groups consisted of a fifty per cent male and a fifty per cent female population, and were equally divided into either an "Average IQ" or a "High IQ" category.

Each subject's auditory threshold was determined with conventional audiometry for the frequencies 500, 1000, and 4000 Hz by air conduction, and 500, and 4000 Hz by bone conduction. Once the subject's auditory threshold had been determined with conventional audiometry, the SISI test was then administered. The test was presented at 4000 Hz and at a 20 dB sensation level. At this frequency and sensation level, the subject was tested with increments of 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, and 2.0 dB. The order in which the increments were presented was randomized according to a table of random numbers.

The results of this study indicated that there is a significant difference in the ability to respond to the 1 dB increment on the SISI test as a function of age. The results relative to the effect of sex and intelligence on performance on the SISI test at the 1 dB increment revealed no significant differences. The results also indicated that the performance of five-year olds on the DL test was significantly different from the performance of seven, nine, eleven, and thirteen-year olds. The performance of

adults on the DL test did not provide any significant differences between adults and any of the other age groups studied. No significant differences were revealed regarding the effect of sex and intelligence quotient on performance on the DL test.

Conclusions

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

1. That children nine, eleven, and thirteen years of age can be tested with the Short Increment Sensitivity Index (SISI) Test, and that when situations warrant it, this test should be used more frequently with children of these age levels.

2. That a modification should be made of the original SISI test instructions when employing the test with five and seven-year old children.

3. That greater care should be taken with the conditioning procedure when the SISI test is employed with five and seven-year old children.

4. That the sex of a child or adult apparently does not affect his ability to perform on the Short Increment Sensitivity Index (SISI) Test.

5. That children and adults with IQ scores higher than 90 can perform on the Short Increment Sensitivity Index (SISI) Test.

6. That 80 per cent should be employed as the criterion for a clinically positive SISI score for children five and above.

7. That the DL values obtained using the procedure in this study do not appear grossly different from the DL values reported in the literature using other methods, and the quantal procedure is thus a recommended procedure for DL testing.

8. That above the age of five, there is no statistically significant difference in DLs as a function of age using the quantal psychophysical method.

9. That the sex of a child or adult apparently does not affect his ability to perform on the DL test procedure used in this study.

10. That children and adults with IQ scores higher than 90 would seem to perform adequately on the DL test used in this study and produce reliable DL results.

Recommendations for Further Research

More information should be obtained on the normal DL using the quantal method by expanding some of the parameters that were used in this study. Specifically, 0.50 dB could be eliminated because of the large number of 0 per cent responses at this increment, and additional increments above 2.0 dB could be explored. A further suggestion would be to use finer divisions along the intensity scale

rather than the divisions of 0.25 dB that were used in this study.

This study on the Short Increment Sensitivity Index (SISI) Test with children should be expanded to include other frequencies and sensation levels. Parameters other than 4000 Hz and the 20 dB sensation level have been reported in the literature using normal hearing adults. A better comparison of hearing sensitivity is possible, therefore, if additional parameters are also explored with normal hearing children.

The procedure used in this study for obtaining the intensity difference-limen (DL) should be replicated using larger samples of children and adults. Consideration should be given to wider age ranges and to IQ levels that were not investigated in this study.

Since this study indicated that children nine, eleven, and thirteen years of age can respond to the Short Increment Sensitivity Index (SISI) Test, additional research should be conducted to compare the responses of children at these same age levels with cochlear and retro-cochlear lesions, with those of adults who also suffer these lesions. Any additional evidence to aid in differential diagnosis with children is certainly desirable.

Once more knowledge of the normal DL is obtained using the procedure in this study, then research can be

conducted on children and adults with cochlear and retrocochlear lesions for a comparison of results. It is only with this kind of comparison that a DL score can meaningfully carry the clinical label of "normal" or "abnormal" DL.

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APPENDIX A

COMPUTED DL VALUES PER SUBJECT

<u>Subject</u>	<u>Age</u>	<u>DL</u>
1	5	1.89
2	"	1.33
3	"	12.58
4	"	3.62
5	"	3.82
6	"	5.11
7	"	1.29
8	"	1.43
9	"	2.17
10	"	1.43
11	"	2.42
12	"	2.54
13	7	1.16
14	"	2.22
15	"	1.26
16	"	2.12
17	"	1.67
18	"	1.19
19	"	1.06
20	"	1.87
21	"	2.45
22	"	1.37
23	"	1.41
24	"	1.43
25	9	1.09
26	"	.96
27	"	1.67
28	"	.92
29	"	1.18
30	"	1.42
31	"	1.21
32	"	1.42
33	"	1.36
34	"	1.25
35	"	1.25
36	"	1.27

<u>Subject</u>	<u>Age</u>	<u>DL</u>
37	11	.92
38	"	1.13
39	"	.93
40	"	.92
41	"	1.31
42	"	1.29
43	"	.98
44	"	.91
45	"	2.00
46	"	1.42
47	"	.95
48	"	2.52
49	13	1.07
50	"	1.12
51	"	1.62
52	"	1.26
53	"	.90
54	"	2.54
55	"	1.36
56	"	1.42
57	"	1.33
58	"	.95
59	"	1.26
60	"	3.09
61	Adults	2.81
62	"	1.91
63	"	1.68
64	"	1.55
65	"	1.83
66	"	1.92
67	"	2.25
68	"	1.65
69	"	2.53
70	"	2.72
71	"	1.76
72	"	1.52

APPENDIX B

SISI SCORES AT THE 1 DB INCREMENT PER SUBJECT

<u>Subject</u>	<u>Age</u>	<u>SISI Score (%)</u>	<u>Subject</u>	<u>Age</u>	<u>SISI Score (%)</u>
1	5	45	37	11	50
2	"	35	38	"	40
3	"	10	39	"	60
4	"	0	40	"	80
5	"	40	41	"	50
6	"	25	42	"	35
7	"	20	43	"	60
8	"	40	44	"	70
9	"	20	45	"	30
10	"	45	46	"	50
11	"	35	47	"	55
12	"	0	48	"	5
13	7	60	49	13	50
14	"	5	50	"	45
15	"	45	51	"	15
16	"	15	52	"	55
17	"	15	53	"	65
18	"	55	54	"	10
19	"	35	55	"	25
20	"	0	56	"	10
21	"	0	57	"	35
22	"	30	58	"	65
23	"	40	59	"	30
24	"	30	60	"	10
25	9	45	61	Adults	5
26	"	60	62	"	10
27	"	40	63	"	5
28	"	65	64	"	20
29	"	30	65	"	5
30	"	35	66	"	10
31	"	40	67	"	0
32	"	40	68	"	5
33	"	30	69	"	0
34	"	25	70	"	5
35	"	25	71	"	15
36	"	45	72	"	35

APPENDIX C

INTELLIGENCE QUOTIENT SCORES PER SUBJECT

<u>Subject</u>	<u>Age</u>	<u>IQ</u>	<u>Subject</u>	<u>Age</u>	<u>IQ</u>
1	5	127	37	11	130
2	"	141	38	"	125
3	"	131	39	"	145
4	"	107	40	"	94
5	"	107	41	"	106
6	"	107	42	"	106
7	"	127	43	"	136
8	"	125	44	"	130
9	"	135	45	"	131
10	"	109	46	"	91
11	"	105	47	"	98
12	"	105	48	"	100
13	7	142	49	13	136
14	"	142	50	"	141
15	"	130	51	"	135
16	"	100	52	"	107
17	"	107	53	"	104
18	"	107	54	"	109
19	"	141	55	"	128
20	"	135	56	"	125
21	"	143	57	"	128
22	"	107	58	"	105
23	"	108	59	"	105
24	"	95	60	"	100
25	9	129	61	Adults	172
26	"	143	62	"	130
27	"	144	63	"	162
28	"	91	64	"	92
29	"	109	65	"	100
30	"	96	66	"	97
31	"	133	67	"	130
32	"	137	68	"	132
33	"	129	69	"	140
34	"	107	70	"	90
35	"	105	71	"	92
36	"	96	72	"	107