VALIDITY AND RELIABILITY OF BÉKÉSY AUDIOMETRY WITH PRESCHOOL AGE CHILDREN

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ABSTRACT

VALIDITY AND RELIABILITY
OF
BÉKÉSY AUDIOMETRY
WITH
PRESCHOOL AGE CHILDREN

by F. Harry Tokay

The major purposes of this study were to determine the validity and reliability of audiometric thresholds, obtained from Békésy audiometry, for children three, four and five years of age.

Sixty preschool children, ages three through five years were selected for this study. The subjects were chosen such that twenty children were in each of the three age groups. There were an equal number of male and female subjects in each group. Further, half of the subjects in each group had average intelligence and half had above average intelligence quotients.

The subject's intelligence quotient was determined by administering the Peabody Picture Vocabulary Test, and the resulting scores were employed to place each subject into the average or high IQ category. The average IQ category consisted of subjects scoring between 90 and 110, and the high IQ category consisted of subjects scoring 120 and higher.

Each subject was given a conventional pure tone hearing evaluation in a commercial, sound-treated room. Pure tone auditory thresholds were obtained for the ear on the cerebrally dominant side of the head. Play audiometric testing techniques were employed to obtain the thresholds at 250, 500, 1000, 2000, 4000 and 6000 Hz.

Immediately following the pure tone testing a Békésy audiometric hearing test was administered. A continuous tone was employed and presented at a speed of one octave per minute, and an attenuation rate of 2.5 dB per second. Test results were obtained for the frequency range from 250 to 6000 Hz by this technique.

A retest session was conducted one week after the initial testing period. During this session only the Békésy audiometric test was re-administered to each subject. The purpose of this re-evaluation was to obtain reliability data.

The data were subjected to statistical analysis in order to determine validity, reliability and difference between mean audiometric thresholds. Validity was examined by obtaining correlations between the Békésy audiometric results and the conventional audiometric results. The reliability of the audiometric thresholds was determined by employing measures of both absolute and relative consistency. The significance of difference among mean audiometric thresholds as a function of age, sex and IQ were determined with three-dimensional analyses of variance. Criterion values were the thresholds in dB for the frequencies 500, 1000 and 2000 Hz.

The following conclusions were drawn: (1) Five year old children with average or above average intelligence, when properly conditioned, can be tested with Békésy audiometry and produce valid, reliable auditory threshold tracings. (2) Four year old children do not perform very consistently with Békésy audiometry. Some children this age will trace a Békésy audiometric threshold that is valid, whereas, other children will trace thresholds that are not a very true representation of their actual auditory threshold. (3) Typically, three year old children, as presently conditioned, are not candidates for Békésy audiometry. (4) There is no apparent difference between the average intelligence or above average intelligence four and five year old children and their ability to take the Békésy audiometric test; however, it does affect the three year old child's ability.

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CHAPTER I

INTRODUCTION

Although the science of audiology is very young, many special tests and procedures for measuring auditory thresholds have been developed. During their development, however, researchers concerned with the standardization of these procedures generally utilized samples of adults and did not usually involve children.[1] This fact was also very evident in the development and research of the Békésy audiometer. The studies which have involved the standardization of the Békésy audiometer technique, including the different methods of determining thresholds, the advisability of having the stimulus completely disappear or remain "barely audible," and the speed of signal attenuation have all been conducted with adults. There are no reported studies related to these matters that have been conducted with children. Research concerning Békésy audiometry and its use with children has been conducted and reported; however, the usual study looks at the relationship between Békésy results and conventionally obtained results, and only with children of school age or older. Apparently,

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[1]D. Robert Frisina, "Measurement of Hearing in Children," Modern Developments in Audiology, ed. J. Jerger, (Academic Press, Inc., 1963), 127.

little has been done with preschool age children, and further, very few studies concerning differential diagnosis have been conducted even with school-age children. There is an obvious dearth of information concerning Békésy audiometry and its employment with children.

Purpose of the Study

The major purpose of this investigation was to determine if Békésy audiometry could be employed with preschool-age children. Specifically, this study was concerned with children three, four, and five years of age.

This research was concerned with the validity of the audiometric thresholds obtained from Békésy audiometry. The question was posed whether the Békésy audiometric results compared with those audiometric thresholds obtained with conventional techniques. The reliability of the audiometric thresholds obtained with a Békésy audiometer was another concern. There was a question posed as to whether Békésy audiometric thresholds obtained in a retest situation one week after the first Békésy test was administered, correlated highly with the initial results. This research also investigated whether there was any difference between children with an average IQ score and children with a high IQ score, at a given age level, and their ability to function with Békésy audiometry. Consideration was also given to whether or not the sex of a subject affected ability to perform the Békésy audiometric task. The mean number of traced excursions, for each age group of subjects, was also investigated. The concern was whether the number of traced excursions per Békésy audiogram was the same for all three, four, and five year old subjects.

A final goal, of which this research is just a beginning, is to determine if acoustically handicapped preschool children can be evaluated with a Békésy audiometer. However, before that can be done, the basic feasibility with "normal" preschool children must have been determined.

Importance of the Study

In reviewing the literature written in the new field of audiology it can be seen that many studies concerning auditory research have been conducted. This same review will also bare the fact that most research concerning the standardized audiometric procedures has utilized samples of adults. Some work has been done with children, and generally it has revealed that a child's ability to perform in a valid manner on the many special tests and procedures of measurement will vary from one test to another. Certain audiometric procedures employed for testing children, such as conventional pure tone audiometry, have been studied and reviewed rather extensively; however, little has been done concerning the procedures such as Békésy audiometry.

According to Frisina,[2] "Békésy audiometric threshold procedures have not been systematically studied in subjects other than adults."

In recent years the Békésy audiometer has become a valuable clinical tool to aid the audiologist in classifying middle ear, cochlear, VIIIth nerve lesions, and pseudohypoacusis. Children also suffer from many of these kinds of hearing problems. However, the research concerning the Békésy audiometer has not attempted to utilize it in differential diagnosis of children. Having a clinical tool available to help determine a site of lesion in children must certainly be as important as having such equipment and tests subserve for adults.

It would seem that with the great need to diagnose accurately the hearing problems of younger children, audiologists would attempt to make use of every available technique. Once the applicability of Békésy audiometry to normal children is known, studies can be made with hearing-impaired children with known etiologies in an attempt to determine whether the classifications established on an adult population can be applied to them. Because there is this need to improve our diagnostic procedures with children, and because there have been very few studies written about Békésy audiometry and preschool-

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[2] Ibid.

age children, this study is proposed. It is proposed to determine if employment of Békésy audiometry is feasible with preschool children as young as three years of age.

Definition of Terms

The following definitions are employed in this investigation:

1. Validity.--the degree to which a test actually measures what it purports to measure. The criterion measure for determining the validity of the Békésy tests will be the auditory threshold obtained by conventional audiometry.

2. Reliability.--indicates the stability or consistency of a test. For our immediate purpose the reliability of the measuring instrument will be obtained by test-retest methods.

3. Average IQ.--an intelligence quotient from 90 to 110 obtained by any intelligence test which has a Mean of 100 and a S.D. of 15. An example of a test that could be employed is the Peabody Picture Vocabulary Test.

4. High IQ.--an intelligence quotient of 120 or higher, obtained with any intelligence test which has a Mean of 100 and a S.D. of 15.

5. Hughson-Westlake Technique.--a technique for obtaining pure tone thresholds as described by Carhart and Jerger.[3] The fundamental feature of this method is that minimum audibility is measured only by progressively increasing the stimulus intensity. In other words, presentations always progress from levels where the sound is inaudible to the first level where perception of the stimulus occurs.

6. Play audiometry.--is used in this context to mean any "game-like" procedure employed to obtain a child's response to a pure tone. It can be the use of activities, such as rings and a peg, where the child places a ring on the peg every time he hears a pure tone, or it can be the use of special instrumentation, such as a pediacoumeter.

7. Conventional audiometry.--the employment of a pure tone audiometer, i.e., portable audiometer, to obtain an audiometric threshold. The subject listens for pure tones through earphones and is asked to indicate by some overt behavior when

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[3] Raymond 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.

he hears the tone. Play audiometry can be considered a form of conventional audiometry.

8. Békésy audiometry.--in this context it is the process of obtaining an audiometric threshold with an automatic-type audiometer. Essentially, it has a beat frequency oscillator which is capable of producing pure tones from 100 to 10,000 Hz. The oscillator is connected to a motor driven shaft, and if started at 100 Hz, the frequency sweeps upward until 10,000 Hz is reached. The intensity is also variable, and is controlled by a hand-switch which is held by the subject. The subject is told that when he hears a tone he should press the button and when the sound disappears he should release the button. There is an ink pen connected electronically to the handswitch, which in turn, traces along an audiogram blank at a position which indicates the intensity of the stimulus being presented. When the button is pressed the intensity of the stimulus decreases and when the button is released the stimulus intensity increases.

Limitations of the Study

Several limitations were built into the study, most of which occurred because of facilitative purposes; that is, they were introduced in order to make the study feasible. The first of these limitations involves the child's ability to perform with conventional audiometry. If the examiner could not obtain a pure tone threshold by conventional techniques, the child was not accepted for study, the reasoning being that if a child could not respond to the task of conventional audiometry, then he certainly would not be able to function with the more abstract task of Békésy audiometry. Therefore, if the examiner was unable to obtain an auditory threshold by conventional pure tone test techniques, the child did not qualify as a subject.

Another limitation was that the child must have normal hearing, as indicated by conventional audiometry. This was done to eliminate the clinical variables, such as contralateralization, which arise when testing any individual with a pathological hearing problem.

Children who had intelligence quotients falling within the range of 110 to 119 or below 90 imposed another limitation. In order to have a reasonably distinct dichotomy of "intellectual ability," the investigator chose to study those children who were average (90 to 110 IQ) and those who were above average (120 IQ and above). Therefore, those children having an IQ between 110 and 119, and below 90, did not qualify for this study.

A variable that might possibly affect a child's ability to perform with Békésy audiometry is that of individual differences in personality characteristics. Some children are quite obviously extroverts in nature and adjust quite easily in new or different environments. On the other hand, some children are introverts and don't adjust to new and different environments very easily. There might well be a difference between the aggressive, gregarious child and the child who hides behind mother, and ability to take the Békésy audiometric test. It was not within the confines of this study to examine such effects; however, it was hoped that they would be minimized by random sampling.

Another limitation imposed was the possible determination of whether or not a child might be able to be conditioned to function with Békésy audiometry. It is known that not all young children can immediately respond adequately to conventional audiometry; however, after several sessions of "play therapy" we find that many children can be conditioned to respond to pure tones. Perhaps the same thing might be true for Békésy audiometry. That will have to wait for future investigation, although it was controlled in this study by not accepting any child who could not immediately respond to conventional audiometry. It was also controlled by giving each participating subject an opportunity for practice. If there was an apparent significant improvement noted during a subject's second test with Békésy audiometry, the subject was called back a third time, and the statistical analysis was made between his second and third Békésy audiograms. The first audiogram was discarded and not used.

Organization of the Report

Chapter I is organized to provide an introduction to the problem of employing Békésy audiometry with preschool age children. The problem to be investigated was broadly defined and limited.

Chapter II consists of a comprehensive review of the literature pertaining to the areas concerned in this investigation. These areas include the previous research done with Békésy audiometry and an investigation of the basic information available in the area of child audiometry.

Chapter III concerns an explanation of the subject selection method, a discussion of the equipment employed, and a detailed description of the procedures conducted during this study.

Chapter IV presents an analysis of the data obtained during the course of this study. It affords specific results and a discussion of the questions originally posed.

Chapter V is organized to present a summary of the research, a listing of the conclusions, and an enumeration of recommendations for further research.

CHAPTER II

REVIEW OF THE LITERATURE

The review of pertinent literature concerning this study will include the research done with Békésy audiometry and an investigation of information in the area of child audiometry. Specifically, the discussion of Békésy audiometry will include research on its general employment in pure tone testing, its use in differential diagnosis, and also the research that has been done with children. The broad area of child audiometry will necessitate a look at conventional pure tone testing with children, a review of the expected incidence of hearing loss in the childhood population, and a thorough coverage of the research concerning Békésy audiometry with children.

CONVENTIONAL PURE TONE TESTING OF CHILDREN

Incidence

Our present-day American society is abundant with Federal, State and Local agencies which make special services available to the handicapped child. The foundation for these programs was laid in 1935, when Congress passed the Social Security Act, Title V, parts one and two.[4] The early programs resulting from this act provided help that was generally aimed at the orthopedically handicapped; however, during the 1950's people with other kinds of disabilities also began to seek assistance. The number of children with hearing impairment who were receiving medical services through crippled children services increased from 12,509 in 1950 to 22,974 in 1960.[5] A report prepared by the National Committee on Child Health discloses that today roughly 5% of school children may be found to have hearing loss sufficient to warrant treatment.[6] The report goes on to state that 1.5 to 3.0% of the total school population actually have hearing defects severe enough to require special educational help and, further, that about 0.1% of school-age children can be classified as deaf.

Another prominent source of information concerning the incidence of hearing loss in children is the reports that come directly from various hospital speech and hearing clinics. Reports coming from these clinics are generally quite concise and usually afford a breakdown concerning

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[4]Donald A. Harrington, "Fifty Years of Work with Children," Hearing News, 30 (1962), pp. 7-8.

[5]Ibid.

[6]Committee on Child Health, Services for Children with Hearing Impairment (New York: The American Public Health Association, Inc., 1956), p. 14.

the etiological aspects of hearing loss. Kinney[7] offers such a report on the analysis of 3,622 children which encompassed a testing period of fifteen years. His findings were that 10% of the hearing-impaired population had very little usable hearing, 64.2% of this population suffered conductive losses, and that 35.8% had sensorineural type losses. Reviewing this, one notes that there is a rather high incidence of conductive loss, as compared to sensorineural losses, and it certainly raises the question as to why much of this conductive problem could not be eliminated with proper screening programs. A further breakdown of the incidence of hearing loss in children would indicate that there is no significant sex difference in children with perceptive deafness.[8] It would also reveal that only 2% of the childhood hearing handicapped population suffer nonorganic losses.[9]

The seriousness of hearing loss in children and what ramifications it may have, is dramatically evidenced in a study by Pauls and Hardy.[10] They investigated 572 infants

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[7]Charles E. Kinney, "Hearing Impairments in Children," <u>Laryngoscope</u>, 63 (1953), pp. 220-226.

[8]Steen Johnson, "Clinical Aspects of High Tone Perceptive Deafness in Children," <u>Acta Oto-Laryngologica</u>, 44 (1954), pp. 24-43.

[9]G. J. Leshin, "Childhood Nonorganic Hearing Loss," <u>Journal of Speech and Hearing Disorders</u>, 25 (1960), pp. 290-292.

[10]M. D. Pauls and W. G. Hardy, "Hearing Impairment in Preschool-Age Children," <u>Laryngoscope</u>, 63(1953), pp. 534-544.

and preschool-age children who had communication problems. It was found that only one-fifth of these children had normal auditory function and the remaining four-fifths had impaired hearing. Such evidence certainly indicates that more must be done in the area of preventive medicine with children. This need has been recognized and presented to the American Speech and Hearing Association by its own "Subcommittee on Hearing Problems in Children."[11] Surely our profession can be the catalyst needed for improving the training of personnel and providing better clinical services.

Conditioning

Clinical experience will reveal the fact that many children can be taken into the hearing-testing situation and function quite well when simply asked to "please raise your hand when you hear the sound;" however, many other children don't grasp the concept of the task so readily and, therefore, need a conditioning period. Miller[12] states that one of the most efficient "reward-motivators" is praise.

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[11] C. B. Avery, et al., "Report of Subcommittee on Hearing Problems in Children," JSHD Monograph Supplement, 5 (1959).

[12] Alfred L. Miller, "The Use of Reward Techniques in Testing Young Children's Hearing," Hearing News, 30 (1962), pp. 5-7.

This can be offered verbally or can simply be a clap of the clinician's hands accompanied with a smile. It can be seen that such reward-conditioning techniques are employed very successfully in all forms of play audiometry. Zwislocki[13] offers that conditioning takes place with simple repetition or practice. He found that thresholds improve significantly with practice and positive feedback, and that improvement is very rapid and may be accomplished in a rather short period of time. It was also stated that thresholds seem to improve most at the low frequencies. This would seem to indicate, then, that audiologists should probably test the hesitant child at 125 or 250 Hz and allow him to practice responding to a sufficiently loud sound.

Another problem often encountered in testing children is the task of getting the child to wear headphones. Many children refuse to wear them and subsequently delay the evaluation period significantly. A technique to solve this problem has been reported by Thorne.[14] He uses a bone oscillator and allows the child to "feel" the sound vibrating on his hand. When the child appears to be comfortable with this, the audiologist then moves the oscil-

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[13] J. Zwislocki, et al., "On the Effect of Practice and Motivation on the Threshold of Audibility," Journal of Acoustical Society of America, 30 (1958), pp. 254-262.

[14] Bert Thorne, "Conditioning Children for Pure Tone Testing," Journal of Speech and Hearing Disorders, 27 (1962), pp. 84-85.

lator up the child's arm, very slowly, toward his head. Once this is accomplished, the bone conduction headband is placed on the child and he is tested at a few frequencies. Then the audiologist can easily, and more quickly, do the same thing with the air conduction headphones. While these simple conditioning techniques work with the hesitant child, they do not generally apply to the immature or very young child. This latter group of children requires more elaborate methods and is most successfully tested with play audiometry.

The entire function of play audiometry can probably be best defined as the employment of high-probability behavior, i.e., response to a jumping puppet, to induce or to increase low-probability behavior (voluntary response to pure tone). Normally it is not too difficult to get a child to stack a few blocks, beat a drum, or place marbles in a box; however, it is frequently arduous to get a child to respond to pure tones. Audiologists, therefore, often structure play activities as useful operant conditioners during the hearing testing situation. Lloyd[15] discusses two approaches to operant conditioning and labels them "conditioned orientation reflex" and "tangible reinforcer methods." His conditioned orientation reflex reinforces

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[15] Lyle L. Lloyd, "Behavioral Audiometry Viewed as an Operant Procedure," Journal of Speech and Hearing Disorders, 31 (1966), pp. 128-136.

a localization response and does not require the child to make a "hand raising" or "button pushing" response to receive visual reinforcement. Rather, if the child looks at the appropriate loudspeaker during an auditory signal presentation, an animal or doll located near that speaker is illuminated as a method of visual reinforcement. His tangible reinforcer method is simply the process of rewarding the child with some edible item for his response to a sound. It might be added that a sage audiologist should attempt to determine which tangible reinforcer would work most effectively for each subject rather than using some arbitrarily predetermined reinforcer.

Another conditioning technique which is employed by audiologists at the John Tracy Clinic is described in an article by Lowell, *et al.*[16] The technique involves teaching a child to make a simple motor response with a toy to an audiometric tone. Initially the child is taught to respond to the sound of a drum, which he can see, hear, and feel. When the child has been successfully conditioned to place a ring on a peg, put an object on a form board, or perform some other simple motor response with a toy in response to a beat of the drum, an auditory tone is substituted. Generally the transition from drum-beat to

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[16] E. L. Lowell, *et al.*, "Evaluation of Pure Tone Audiometry with Preschool Age Children," *Journal of Speech and Hearing Disorders*, 21 (1956), pp. 292-302.

auditory stimuli is quite rapid. The report stated that this technique was successfully employed with deaf children from 3.6 years of age and older, and with normal hearing children 2.6 years of age and older.

A variation of pure tone audiometry for children, which is probably the most classic in the literature, was designed by Dix and Hallpike.[17] In their procedure the child learns that when he hears a tone and pushes a button, a light will go on and illuminate a picture within a doll-house. Of course, the system was wired in such a way that the only time a light could go on was when a pure tone was being emitted. This "Peep-Show" test was said to be very effective for children under six years of age.

O'Neill, Oyer, and Hillis[18] have studied children and found that a testing technique should include a pre-test play period. It was indicated that observation during this semistructured activity provided the audiologist an opportunity to gain rapport with the child, to view the child's reactions to gross sounds, to help the child develop an awareness of sound and its relation with the testing activities to follow, and also, to help the audiologist

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[17] M. R. Dix and C. S. Hallpike, "The Peep Show," British Medical Journal, (Nov., 1947), pp. 719-723.

[18] John J. O'Neill, Herbert J. Oyer, and James W. Hillis, "Audiometric Procedures Used with Children," Journal of Speech and Hearing Disorders, 26 (1961), pp. 61-66.

select a testing procedure which they believed would be most effective in evaluating the child. They tested 58 children, having a mean age of 65.5 months, with a Pedia-coumeter and found that 84% could be successfully evaluated. Their criteria of a successful evaluation were that the child's responses were very consistent, earphones could be used in testing, and it was possible to obtain both air and bone condution audiogram for each ear.

The variations on the theme of play audiometry with children have been many. One such variation has been suggested by Empey,[19] who stated that the audiologist should relate the pure tones to some object with which the child is familiar. For example, the child might listen for a boat whistle; and to help condition the child attend to less intensity you could have him listen how the boat whistle becomes smaller as the boat leaves the dock. Along this same theme Bloomer[20] suggests that audiologists use pictures of various animals with which the child is familiar and relate the sound to them. An audiologist could show the child a picture of a dog when presenting a low frequency tone or the picture of a bird when a high frequency tone

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[19] Margaret Empey, "Pure Tone Audiometry with Young Children," Volta Review, 55 (1953), pp. 439-442.

[20] Harlan Bloomer, "Simple Method of Testing Hearing of Small Children," Journal of Speech and Hearing Disorders, 7 (1942), pp. 311-312.

was employed. It was believed that such relationships provided the child with some meaning for the pure tone sound. Shimizu and Nakamura[21] used a slide projector with a multitude of slides that young children would enjoy. The child was conditioned that a picture would appear on the screen every time he pushed a button when he heard a sound. This technique has variety in that the slides can cover many topics or depict several short stories.

The diversities in methods of conditioning children with play audiometry are as numerous as there are creative audiologists. For example, in Japan, Ishisawa[22] constructed an elaborate electric locomotive with which to condition and test young children. Green[23] electrically wired a toy puppy so that he would take several steps on a board and then bark four times when the child responded correctly to a pure tone. A fact that all of the various techniques have in common is that the audiologist is using some form of operant conditioning to induce the child to respond to a pure tone. The child is positively rewarded for some

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[21] Hirosh Shimizu and Fumio Nakamura, "Pure-Tone Audiometry in Children: Lantern-Slide Test," Annals of Otology, Rhinology, and Laryngology, 66 (1957), pp. 392-398.

[22] H. Ishisawa, "A Study on Play Audiometry," dsh Abstracts, 2 (1962), p. 201.

[23] Davis S. Green, "The Pup Show: A Simple Inexpensive Modification of the Peep-Show," Journal of Speech and Hearing Disorders, 23 (1958), pp. 118-120.

specific behavior he has performed, which in this case is usually a response to a pure tone.

Play audiometry can also be used to determine a child's speech reception threshold. Generally the audiologist has either small toy animals, or pictures of them, and then makes a game of listening by saying something like, "point to the squirrel," or "put the rabbit on the floor." Keaster[24] uses such a technique; however, she warned that the words to be employed must have common usage for the child's age. Lerman[25] employed a picture identification test to evaluate hearing-impaired children. He learned that hearing-impaired children as young as four years of age could be successfully evaluated with this approach. The authors of articles about speech audiometry with young children also frequently advise audiologists to use only five or six pictures or toy animals at one time, and too frequently, offer substitutes for these during the testing session.[26]

In concluding this section it should be stated that

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[24] Jacqueline Keaster, "A Quantitative Method of Testing the Hearing of Young Children," Journal of Speech and Hearing Disorders, 12 (1947), pp. 159-160.

[25] Lerman, Ross, and McLauchlin, "A Picture Identification Test for Hearing-Impaired Children," Journal of Auditory Research, 5 (1965), pp. 273-279.

[26] Ruth E. Bender, "A Child's Hearing," Maico Audiological Library Series, 3 (Report 2).

the age at which play audiometry can be successfully conducted with children varies. Barr[27] evaluated children between the ages of two and six years, and did find success as a function of age. There was 100% success in obtaining auditory thresholds for children six years of age, 92% success with five year olds, 88% success with four year olds, 71% success at three years of age, 55% for the two and one-half year olds, and only 14% success for those between two and two and one-half years. The conclusion was that children over two and one-half years of age could function satisfactorily with play audiometry; however, those children younger than that were rarely tested successfully. These same kinds of results were obtained by Haug and Guilford,[28] who present a description of a solenoid-released jack-in-the-box device, the Pediacoumeter, which is used as an accessory to the audiometer for measuring pure tone thresholds of children. They evaluated the hearing of 968 preschool children between one and six years of age. The results indicated that successful-complete pure tone audiograms were obtained from 96% of the five year

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[27]Bengt Barr, "Pure Tone Audiometry for Pre-School Children," Acta Oto-Laryngologica: Supplementum, 121 (1955), pp. 5-82.

[28]Haug and Guilford, "Hearing Testing on the Very Young Child: Follow-Up Report on Testing the Hearing of 968 Preschool Patients with Pediacoumeter," Transactions of the AAOO, 64 (1960), pp. 269-271.

old children, 94% of the four year old children, 82% at three years of age, 47% at two years of age, and only 12% for the one year old children. Here again it can be seen that success in obtaining a complete auditory threshold is a function of age.

Special Hearing Tests

Some young children cannot readily be conditioned to respond to pure tones, and subsequently, special techniques such as electroencephalography are employed. Because auditory stimulation seems to produce some rather characteristic electrical activity in the brain, which can be measured, audiologists occasionally use this to test the hearing of young children.[29] They observe the fluctuations of brain waves during the presentation of auditory stimuli, and thus hearing thresholds are determined. Price and Goldstein[30] researched this concept and found that there is good agreement between the results of behavioral audiometry and results of EEA when used with children.

Another special test which has been frequently employed

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[29] R. E. Marcus, "Hearing and Speech Problems in Children: Observation and Uses of Electroencephalography," Archives of Otolaryngology, 53 (1951), pp. 134-146.

[30] Lloyd L. Price and Robert Goldstein, "Average Evoked Responses for Measuring Auditory Sensitivity in Children," Journal of Speech and Hearing Disorders, 31 (1966), pp. 248-256.

to determine the hearing thresholds of young children is electrodermal response (EDR).[31] Hardy and Bordley[32] have used this technique successfully with children as young as four months of age. They do caution, however, that some central nervous system disorders such as cerebral palsy may make it impossible to use EDR. Some other special tests which have been suggested, but which will need more research before regular employment with children, are the cochleagram (electrode in the round window) and plesiosectional tomography (X-ray of the cochlear area).[33]

BÉKÉSY AUDIOMETRY

General Employment of the Békésy Audiometer

In an attempt to devise a more standardized and objective method of determining auditory sensitivity, Georg von Békésy invented a self-administering and self-recording audiometer. The presentation of frequencies is controlled by the instrument, and the intensity is changed in an orderly,

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[31] Helmer R. Myklebust, "Differential Diagnosis of Deafness in Young Children," Journal of Exceptional Children, 17 (1951), pp. 97-101.

[32] Wm. G. Hardy and John E. Bordley, "Special Techniques in Testing the Hearing of Children," Journal of Speech and Hearing Disorders, 16 (1951), pp. 123-131.

[33] Philip E. Rosenberg, "Misdiagnosis of Children with Auditory Problems," Journal of Speech and Hearing Disorders, 31 (1966), pp. 279-282.

standardized manner by the subject. This audiometer eliminates many of the problems of conventional audiometry in that the testing skill of the audiologist is limited to instructing the patient how to take the test and how to operate the control switch.[34]

Threshold determinations are made by a subject pressing a control-switch when he hears the sound and releasing the control-switch when the sound disappears. The stimulus intensity is increased if the control-switch is not pressed. An ink pen traces the position of the hearing loss attenuator on an audiogram blank. Normally the audiologist initiates the test at about 100 Hz, and the frequency of the oscillator is continuously changed from 100 to 10,000 Hz. The subject's threshold is mapped as a continuous function of frequency. As threshold judgments are being made, the frequency is slowly changing, and therefore, the subject recognizes both a loudness change and a pitch change.

Several studies have been concerned with the correlation of thresholds between conventional pure tone audiometry and Békésy audiometry. Corso[35] tested 105 subjects with

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[34]Scott N. Reger, "Clinical and Research Version of the Békésy Audiometer," The Laryngoscope, 62 (1952), p. 1334.

[35]John F. Corso, "Effect of Testing Methods on Hearing Thresholds," AMA Archives of Otolaryngology, 63 (1956), pp. 78-91.

both techniques and found that the results were generally correlated. One purpose of that study was to ascertain which method of determining a Békésy threshold (midpoint vs peak technique) produced a threshold most like that of the conventional results. It was found that the "peak" technique revealed results most closely correlated with the conventional audiogram; however, it must be pointed out that Corso had his subjects keep the tone "barely audible" during the entire Békésy audiometric test. The specific results of the "peak" technique were that the mean correlation for octave frequencies between 250 and 8000 Hz was 0.53; however, for the frequencies above 1000 Hz the correlation was much higher, approximately 0.70. These correlations appear to be rather low, especially when comparing the mean thresholds obtained with both the Békésy and conventional test. The mean thresholds at 500, 1000 and 2000 Hz, obtained with the Békésy audiometric test, were respectively 14.0, 4.6 and 6.9 dB, and the mean thresholds at those same frequencies obtained with the conventional test were 12.7, 6.3 and 5.8 dB. It should be pointed out that perhaps a correlation was an inadequate measure, and that a standard error of measurement might have been more appropriate.

Another comparison of the auditory thresholds as measured by conventional pure tone and Békésy audiometry was conducted by Burns and Hinchcliffe.[36] They utilized twenty subjects, between twenty and fifty-eight years of age who did not reveal any gross otologic abnormalities. During the Békésy audiometric test the subjects were instructed to push the button until the tone disappeared. The results of this study indicated that thresholds obtained by both conventional and Békésy audiometry are relatively consistent with one another. The mean difference, when averaged for octave frequencies between 500 and 6000 Hz, was 1.5 dB. In most instances the Békésy audiometric threshold was slightly better than the conventionally obtained threshold. It was also shown that when the subject allows the Békésy tone to disappear completely before releasing the button, the most valid threshold is obtained from the "midpoint curve." The authors stated that if the midpoint technique was employed, the Békésy audiometer could be used satisfactorily in place of conventional audiometry.

While the studies cited above did indicate that the results of Békésy audiometry do closely resemble those of conventional audiometry, there was disagreement between employment of the "tone barely audible" and "tone to inaudibility" technique of selecting the auditory threshold.

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[36]W. Burns and R. Hinchcliffe, "Comparison of the Auditory Threshold as Measured by Individual Pure Tone and by Békésy Audiometry," Journal of the Acoustical Society of America, 29 (1957), pp. 1274-1377.

This specific problem was investigated by Stream and McConnell.[37] They instructed half of their forty-two subjects to keep the Békésy tone audible and half of the subjects to allow the tone to become inaudible. Results of this study denote that the method of instruction does make a difference in the threshold obtained, and it was specifically stated that the "tone to inaudibility" technique produced the most valid threshold. When employing an attenuation rate of 2.5 dB per second, mean thresholds obtained for the audible technique were 7.5 dB at 250 Hz, -0.3 dB at 1000 Hz, and 9.0 dB at 2000 Hz. However, for the "inaudible" technique the respective mean thresholds were 3.5 dB, -3.1 dB, and 4.9 dB. These findings appeared to be independent of the amount of previous experience the listener had in the area of audiometry.

Another variation in the method of obtaining an auditory threshold with Békésy testing is the difference between the results of an ascending technique and a descending technique when administered at a single frequency. Research concerning this problem was conducted by Price.[38] It was found that there was no significant difference between the

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[37] R. W. Stream and Freeman McConnell, "A Comparison of Two Methods of Administration in Békésy-Type Audiometry," Journal of Auditory Research, 1 (1961), pp. 236-271.

[38] Lloyd L. Price, "Threshold Testing with Békésy Audiometry," Journal of Speech and Hearing Research, 6 (1963), pp. 64-69.

thresholds procured by these two methods. This same study also concerned itself with auditory thresholds as obtained by employing both the "fast" (5.0 dB/sec. rate of attenuation) and "slow" (2.5 dB/sec. rate of attenuation) speeds of the Békésy audiometer. It was clear that a midpoint mean of the "slow" speed sweep-frequency tracing appeared to be in best agreement with ascending and descending thresholds.

Corso[39] conducted a study to determine the effect of testing time and signal attenuation. Adult subjects were tested at the rate of one, two, and four minutes per octave, and the rate of signal attenuation was 0.5, 1.0 and 2.0 dB per second. The results from this study showed that (a) testing time and attenuation rate have no effect on mean threshold values at 1000 Hz, (b) attenuation rate has a significant effect on overall threshold variability, i.e., area enclosed within an envelope of the tracing peaks and (c) attenuation rate does have a significant effect on test-retest reliability. It was interesting to note how the area within the envelope (measured in dB-distance traced) increased as a function of attenuation rate. The mean variability score was a distance of 6.46 dB at 0.5 dB/sec. attenuation rate, 7.24 dB distance at 1.0 dB/sec.

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[39] John F. Corso, "Evaluation of Operating Conditions and a Békésy-Type Audiometer," AMA Archives of Otolaryngology, 61 (1955), pp. 649-653.

attenuation rate, and a distance of 8.77 dB at an attenuation rate of 2.0 dB/sec. The effect of attenuation rate on test-retest reliability was also interesting. The test-retest reliability coefficient was .94 for a rate of 0.5 dB/sec.; however, the correlation was only .68 at 1.0 dB/sec. attenuation rate and .56 at the slow rate of 2.0 dB/sec. It was concluded that optimal performance by adults on the Békésy is attained with an attenuation rate of 0.5 dB per second when combined with a total testing time of 5, 10, or 20 minutes.

One of the most significant articles concerning Békésy audiometry was written by Jerger.[40] In his writing Jerger discussed the results obtained from 434 adult subjects whose thresholds were determined with both a continuous and an interrupted pure tone. The findings revealed four basic types of tracings, each dependent upon the type of hearing loss involved.

An audiogram revealing a Type I tracing has the tracings of the continuous and interrupted pure tones interweaving throughout the frequencies and has an average trace-width of about 10 dB. Tracing widths of as small as 3 dB and as wide as 20 dB are not uncommon. A Type II tracing reveals that the response to the continuous pure tone drops below

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[40] James F. Jerger, "Békésy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), pp. 275-287.

the response to the interrupted pure tone at high frequencies. It was stated that this gap seldom exceeds 20 dB, and usually does not appear below 1000 Hz. The width or amplitude of the continuous tracing is generally quite small; about 3 to 5 dB. A Type III tracing reveals an audiogram where the continuous tracing diverges from the interrupted tracing at a very low frequency (100 to 500 Hz) and shows a rather precipitous drop. It is not uncommon to see the continuous tracing break away and drop to a level as much as 40 to 50 dB below the interrupted tracing. A Type IV tracing reveals the continuous responses dropping below the interrupted responses, usually about 10 dB, at the low frequencies and then following the interrupted tracing rather consistently through all the frequencies tested. The site of lesion is determined by the type of Békésy tracing and is grouped as follows.[41]

Békésy Audiogram	Site of Lesion
Type I	Middle Ear or Central Nervous System
Type II	Cochlear
Type III	VIIIth Nerve
Type IV	VIIIth Nerve

More recently investigations discussed in the literature have presented a new Békésy tracing which results in an audiogram where the responses to the interrupted tone

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[41] *Ibid.*

follow below the continuous tracing. This new tracing is called a "Type V" and is generally indicative of a functional hearing loss.[42] At the Veterans Administration Clinic in Washington, D.C., Stein[43] tested thirty subjects and found that the Békésy audiometer can be of definite value in isolating a functional hearing loss. He found that seventeen of the thirty cases (57%) of functional hearing loss recorded the Type V Békésy pattern. Furthermore, nine of the remaining thirteen subjects with functional hearing loss recorded Békésy patterns that could not be classified as one of the five types of Békésy tracings. Of the total thirty subjects, then, twenty-six or approximately 87% recorded either Type V or unclassifiable Békésy tracings. The study also indicated, however, that there are no readily identifiable characteristics of the Type V pattern on which to base estimates of the subject's true level of hearing.

A number of researchers have looked at some of the parameters of fixed-frequency Békésy audiometry in patients

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[42] James F. Jerger and G. Herer, "Unexpected Dividend in Békésy Audiometry," Journal of Speech and Hearing Disorders, 26 (1961), pp. 390-391.

[43] Laszlo Stein, "Some Observations on Type V Békésy Tracings," Journal of Speech and Hearing Research, 6 (1963), pp. 339-348.

with acoustic neurinoma. Dallos, Tillman,[44] and Bilger[45] have investigated this area and reported that a Type III tracing can be obtained with a fixed-frequency presentation. They stated that it is the amount of off-time (no sound) between stimulus presentations that is the critical variable. It was found that with off-time of 25 msec and less, a subject suffering acoustic neurinoma could not maintain a stable threshold tracing regardless of the amount of time the stimulus was presented. The tone would decay for the subject and before he could perceive the stimulus again, it would have to be increased in intensity. However, with off-times equal to or greater than 50 msec, stable thresholds could usually be maintained, and in fact, threshold improvement was directly related to the inter-stimulus interval.

One article that cautions the audiologist concerning the clinical utility of Békésy audiometry in suggesting the presence of VIIIth nerve lesions is written by Robertson.[46]

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[44] P. J. Dallos and T. W. Tillman, "The Effects of Parameter Variations in Békésy Audiometry in a Patient with Acoustic Neurinoma," Journal of Speech and Hearing Research 9 (1966), pp. 557-572.

[45] Robert C. Bilger, "Some Parameters of Fixed-Frequency Békésy Audiometry," Journal of Speech and Hearing Research, 8 (1965), pp. 85-89.

[46] D. G. Robertson, "Use of Békésy Findings in Auditory Diagnosis," Journal of Speech and Hearing Disorders, 29 (1964), pp. 36-46.

He offers a plea that audiologists confine their Békésy audiometric findings to a statement pertaining to lesion site rather than to cause of the pathology suggested by auditory tests. His experience indicates that a number of neural syndromes in addition to VIIIth nerve tumors can yield the Békésy neural pattern.

Many varied uses for the Békésy audiometer have been employed since its introduction. Watson and Voots[47] report on the use of the Békésy audiometer in the performance of the Stenger test. They added a simple attenuator arrangement which allowed the examiner to vary the intensity of the test tone on the supposedly poor ear while the subject was tracing his Békésy audiometric threshold on the good ear. Results demonstrated different types of Békésy-Stenger tracings, and it was concluded that the test appeared to have a high clinical dependability. Another variation on the use of Békésy audiometry was an attempt to relate Békésy audiometric tracings to personality and electro-physiological measures. Shepard and Goldstein[48] conducted tests on forty subjects in order to determine if

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[47] J. W. Watson and R. J. Voots, "A Report of the Use of the Békésy Audiometer in the Performance of the Stenger Test," Journal of Speech and Hearing Disorders, 29 (1964), pp. 36-46.

[48] D. C. Shepard and Robert Goldstein, "Relation of Békésy Tracings to Personality and Electrophysiologic Measures," Journal of Speech and Hearing Research, 9 (1966), pp. 385-411.

such a relationship existed; however, the results did not reveal any positive evidence.

Békésy Audiometry with Children

The literature does contain some writing concerning the employment of Békésy audiometry with children; however, there is a definite dearth of this information. A study which is frequently quoted in the literature was conducted by Price and Falck.[49] They used the Békésy audiometer and tested fifty-four male and female subjects whose ages ranged from six to eleven years. The Békésy audiometric test was administered under both the pulsed and continuous tone condition. Each subject was also given an I.Q. test with either the Ammons and Ammons Full Range Vocabulary Test, Peabody Picture Vocabulary Test, or the Wechsler Intelligence Scale for Children. Generally, their results indicated that most children with a mental age of seven years or more produced clinically useful results, and that children with high I.Q.'s performed better on the Békésy Audiometric test than those with lower I.Q.'s. It should be pointed out, however, that while the authors talked about "clinically useful results," they did not explain

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[49] Lloyd L. Price and V. T. Falck, "Békésy Audiometry with Children," Journal of Speech and Hearing Research, 6 (1963), pp. 129-133.

specifically what this meant. It was also noted that they indicated all children with a chronological age of seven years had clinically useful results; however, they did not indicate their I.Q. or mental age levels. Because the distribution of intelligence scores of their population was obviously skewed in the direction of high I.Q., and because they did not offer a breakdown of age vs I.Q., it is unclear if any dull-normal or retarded seven year old children performed the Békésy audiometric task. Concerning the younger children, it is important to note that they were able to obtain "clinically useful" audiograms from 66% of the six year olds tested.

Rudmose[50] cites a study conducted in Richardson, Texas, where 513 school-aged children were tested with an automatic Békésy-type audiometer. The results of that study revealed that the acceptability of an audiogram increased with the age of the child. Specifically, 25% of the first grade children tested had nonacceptable audiograms, 17% of the second grade children had nonacceptable audiograms, and 7.5% of the third grade children tested fell into that category. The exact meaning of these figures is rather unclear, however, in that the author did not define the term "nonacceptable audiogram." Ambiguity also arises when

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[50] W. Rudmose, "Automatic Audiometry," Modern Developments in Audiology, ed. J. Jerger, (New York: Academic Press, Inc., 1963), p. 57.

one considers the fact that the children were isolated from others taking the test by only a three-sided booth. The report indicated that when a child was in this booth, he could peek around and observe neighbors taking the test, and also, the ambient noise of the school environment was not attenuated significantly. Taking all this into consideration, it would still appear that a child's ability to function with the Békésy audiometer probably increases with age.

Hardick[51] also concerned himself with the problem of testing children and investigated forty-five male, school-age subjects and their ability to perform with Békésy audiometry. The subjects were categorized into three age levels--ten to eleven years, eight to nine years, and six to seven years--and each was given both a conventional pure tone hearing test and a Békésy hearing test. The results showed that the audiograms obtained by conventional testing yielded more accurate and consistent results than those obtained with the Békésy audiometer. It was also stated that increased similarity in auditory thresholds between the conventional audiometric test and the Békésy audiometric test occurred with increases in age. Lower

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[51] Edward J. Hardick, "A Comparison of the Audiometric Thresholds of Children Obtained with the Békésy Audiometer and Conventional Pure Tone Audiometer," (unpublished Master's Thesis, The Ohio State University, 1955).

auditory thresholds were obtained for both audiometric tests with increases in the ages of subjects, and too, increase in age apparently affected the width of stylus tracing on the Békésy audiogram. A final conclusion drawn was that the Békésy audiometric test may be administered to children ten years of age or older with a fair degree of validity.

Hartley and Seigenthaler[52] also tested children with a Békésy audiometer; however, they investigated fixed-frequency tracings as opposed to sweep-frequency tracings. The results of their study paralleled those mentioned above. They found that, even though the Békésy audiometric test was presented as a fixed-frequency test, the variability of resulting thresholds obtained with the Békésy audiometer was greater than for the conventional test for all subjects, and was generally higher for the younger subjects. And, as indicated in other research, the results revealed that the mean width of excursions was greater for young subjects than for older subjects.

All of the studies concerning children that have been discussed to this point have used normal hearing children as subjects. One study that did involve hearing-impaired children, as well as those who had normal hearing,

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[52]Harold V. Hartley, Jr., and Bruce M. Seigenthaler, "Relationship Between Békésy Fixed-Frequency and Conventional Audiometry with Children," Journal of Auditory Research, 4 (1964), pp. 15-22.

was conducted by Stark.[53] He tested 122 children who ranged in age from five to eleven years, and about half of whom had a sensori-neural hearing loss. The results showed that even though children do suffer some hearing loss, they can still function with Békésy audiometry. Concerning the total subject population, 91% gave "usable" Békésy audiograms, and only one more "failure" was noted within the hearing-impaired group as opposed to the normal hearing group. One other interesting point brought out in this study was that there was no significant difference in excursion widths between tracings of continuous and interrupted tones, although there was a slight tendency for the interrupted tracing to be wider.

While many studies conducted with Békésy audiometry and children have been concerned with normal hearing children, some recent investigations have pertained to nonorganic hearing loss (pseudohypoacusis) in children. Peterson[54] reported data on four cases who showed evidence of nonorganicity, or at least a nonorganic component to the observed hearing loss. The Békésy audiometric tracings of these four cases revealed the classically unique relationship

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[53] Earl W. Stark, "Békésy Audiometry with Normal Hearing and Hearing Impaired Children," Journal of Auditory Research, 5 (1956), pp. 73-83.

[54] John L. Peterson, "Nonorganic Hearing Loss in Children and Békésy Audiometry," Journal of Speech and Hearing Disorders, 28 (1963), pp. 153-158.

between the continuous and interrupted tracings: the continuous tracing indicating better hearing than the interrupted tracing. Each could be easily labelled as a Type V Békésy tracing. Further investigation of pseudohypoacusis in children has been conducted by Rintelmann and Harford,[55] who evaluated ten children with pseudohypoacusis ranging in age from nine to nineteen years. Nine of these children traced patterns on the Békésy audiometer in which the continuous tonal stimuli revealed a better threshold than the interrupted stimuli. It was concluded that the Type V Békésy pattern is essentially a qualitative test warning the clinician to suspect a simulated hearing loss.

Summary

It is important to note that approximately 5% of the childhood population suffers hearing loss. The majority of these children have conductive-type losses, which if discovered, could be medically corrected. Various testing techniques and procedures have noted that the approach to testing generally has to be varied with the age of the child. Preschool age children do not condition to audiometric testing as easily as older children, and therefore,

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[55] Wm. Rintelmann and Earl Harford, "The Detection and Assessment of Pseudohypoacusis Among School-Age Children," Journal of Speech and Hearing Disorders, 28 (1963), pp. 141-152.

play audiometry is frequently used. This type of technique is found to be successful with children as young as two and one-half years of age. While many different devices have been constructed for use in conducting play audiometry, one of the apparently popular techniques is to use a ring and peg game, or blocks and a box, and have the child place a ring on the peg whenever he hears a sound. This same kind of testing technique was employed for this investigation.

Many special hearing tests, such as electroencephalography, electrodermal response, the cochleagram, and plesiosectional tomography, are being researched and tested for possible employment with children. Recently, attempts have also been made to use Békésy audiometry with children. Those investigators involved in this process frequently employ the specific Békésy audiometric techniques that have been found to be successful for testing adults. For example, an attenuation rate of 2.5 dB per second appears to be the optimum rate for testing adults, and therefore, it may also be the most ideal rate to use with children. It is also known that the most valid Békésy audiometric threshold for adults is obtained when the subject is instructed to make the tone completely disappear before releasing the button on the control switch, and when the midline technique is employed to interpret the specific thresholds from the audiogram. This is probably also the best technique to use when evaluating children with the Békésy test. It appears that a continuous tone stimulus is employed more frequently than an interrupted stimulus for testing adults, and therefore, this may also be the best approach to use when testing children. The same factor seems to be true for employing the technique of testing from the low frequencies to the high frequencies. It is routine for most audiologists to begin testing adults with the Békésy audiometer at the low frequencies and have the audiometer sweep to the higher frequencies. It might be assumed, then, that this same procedure will probably work well with children. All of the techniques that have been found to be optimum for testing adults with the Békésy audiometer are generally employed when testing children. This same approach to Békésy audiometric testing was employed for this investigation.

It should be added, however, that while the literature does contain reports of some research concerning Békésy audiometry and children, very little reported attempt has been directed toward testing the preschool age child with this technique. It would seem that as important as hearing is to the social, emotional, and educational growth of the preschool child, every possible evaluation technique should be exploited. Because of the important diagnostic capabilities of Békésy audiometry, the capacity of its employment with young children should be thoroughly investigated.

CHAPTER III

EXPERIMENTAL PROCEDURES

In this chapter information is given 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, sixty male and female children, three, four, and five years of age, were divided equally into average and high IQ groups. They were given both a conventional pure tone hearing test and a Békésy hearing evaluation. The conventional pure tone test was employed as a criterion measure against which to judge the results of the Békésy audiometric test to obtain an estimate of validity. To determine reliability of the Békésy audiometric test, a test-retest procedure was employed. The retest session took place one week after the initial test was administered.

SUBJECTS

The subjects were sixty children ranging in age from three years to five years, eleven months. They were divided into three age groups (3 years-0 months to 3 years-11 months, 4 years-0 months to 4 years-11 months, and 5 years-0 months to 5 years-11 months of age) and each group consisted of a 50% male and a 50% female population. Further, each of these individual groups was divided into either an "Average IQ" or "High IQ" category. The subjects were grouped as displayed in Figure 1.

AGE	INTELLIGENCE				
	Average		High		
Years and Months	Male	Female	Male	Female	Total
3-0 to 3-11	5	5	5	5	20
4-0 to 4-11	5	5	5	5	20
5-0 to 5-11	5	5	5	5	20
Total	15	15	15	15	60

Figure 1.--Categorical grouping of all subjects employed in the investigation.

To determine the subject's IQ, a Peabody Picture Vocabulary Test was administered by the investigator, who has had several courses in psychological testing and considerable practical experience administering various psychological tests.

The PPVT was used because it takes a relatively short time to administer, it is easily given, it has good demonstrated validity, and the materials are interesting for preschool-age children and serve as a good tool for gaining rapport.

The scores from the PPVT were employed to place each subject into an average or high IQ category. The average IQ category consisted of those subjects scoring between 90 and 110, and high IQ category consisted of subjects scoring 120 and higher. Those falling between 110 and 120 as well as those below 90, were not accepted for 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 for approximately 40% of the subjects, and none had to be rejected because of a significant discrepancy between the test scores. An arbitrary limit of five IQ points was set as an indication of a significant difference. No subjects had to be rejected because their other test scores indicated that they did not belong in the IQ categories indicated by the PPVT. The mean IQ score for each group of subjects is illustrated in Table 1.

It is noted that the mean IQ score of the bright, four year old females is 120. This was due to the fact that all of the four year old females in this group had an IQ score of exactly 120.

If, during the conventional audiometric testing procedure, the subject revealed an auditory threshold which indicated an average loss (500, 1000 and 2000 Hz) of 25 dB or greater (1964 ISO standard) the subject was not

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

Age	Average		Bright	
	Male	Female	Male	Female
3 Years	102	102	125	125
4 Years	105	109	127	120
5 Years	101	106	122	122

included in the study. Also, any subject having any middle ear involvement, as determined by an air-bone gap discovered during the conventional pure tone testing, was excluded from the study. While the air conduction test was routinely administered to all subjects at the frequencies of 250, 500, 1000, 2000, 4000, and 6000 Hz, the subjects were screened only with the bone conduction test at 500, 1000, and 2000 Hz. If an air-bone gap appeared at those frequencies, however, the other frequencies were tested to determine the extent of the apparent conductive hearing loss.

The subjects were obtained from various sources. Thirty percent of the subjects were obtained from the Michigan State University Campus Nursery, 20% were from the Michigan State University Speech and Hearing Clinic, and 50% of the subjects were the children of fellow graduate students and friends. While the total number of subjects employed for this study was sixty, a greater number of children had to be contacted. Several children who had begun the testing could not continue because their parents moved from the city. Three children had to be eliminated from the study because of a significant air-bone gap and three, three year old children were not used because they could not be motivated to take the Békésy audiometric test. These three year old children stopped attending to the task, took the earphones off, and refused to participate any further.

EQUIPMENT

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

Békésy audiometer (Grason-Stadler, Model E800)

Portable pure tone audiometer (Beltone, Model 10C)

Speech audiometer (Grason-Stadler, Model 162)

Speakers (Grason-Stadler, Model 162-4)

Earphones (Telephonics, Model TDH39)

Earphone cushions (Model MX41/AR)

Sound level meter (Bruel and Kjaer, Model 2203)

Artificial ear (Bruel and Kjaer, Model 4152)

Commercial test room (Industrial Acoustics Company, Inc., Model 10-1052)

The sound-treated room and all audiometric equipment were located in the basement of the Michigan State University Auditorium building. The portable audiometer, speakers, and earphones employed for testing subjects were situated in the sound-treated room. The ambient noise of the sound treated room was measured with the sound level meter, on the C scale, and was found to be 42 decibels SPL. Also, an octave analysis of the ambient noise level in the sound-treated room was conducted, 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. The Békésy audiometer was located in an adjoining test room, which communicates with the sound-treated room by a window and a two-way electronic communications system which was an integral unit of the speech audiometer. The testing rooms and equipment were situated as schematically diagrammed in Figure 2.

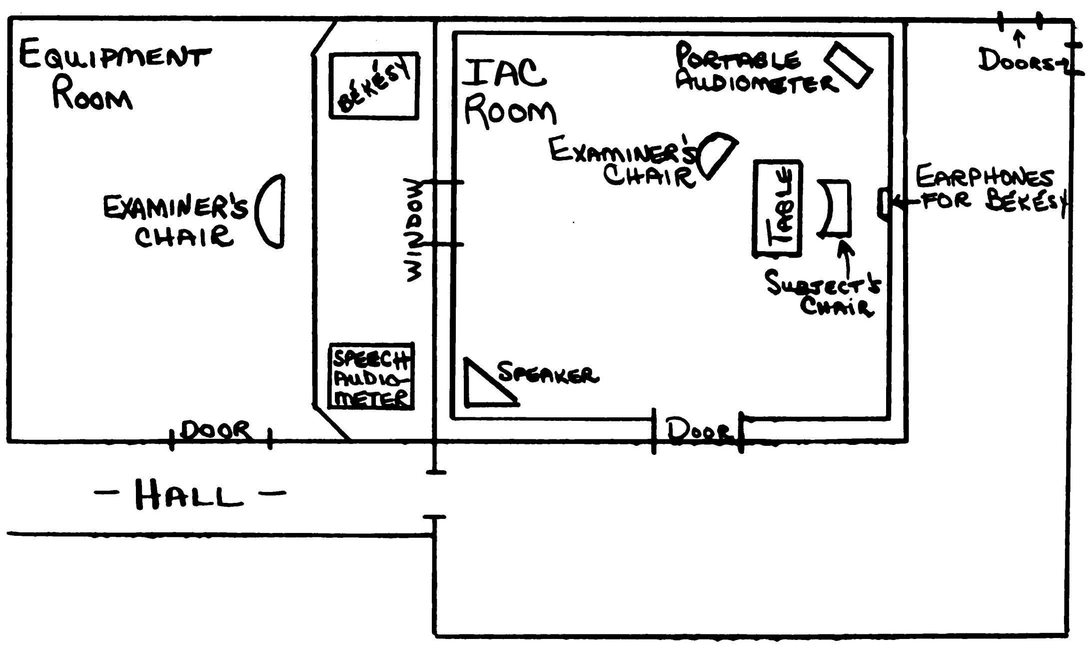

Figure 2.--A schematic diagram of the testing rooms and placement of equipment.

The Békésy audiometer produces a pure tone signal which is generated by a continuously variable beat-frequency oscillator with a range of 100 to 10,000 Hz. The mode of presentation employed for this study was to have the frequency oscillator sweep upward from approximately 125 Hz to approximately 6500 Hz, at the Békésy "slow" speed of one octave per minute and an attenuation rate of 2.5 dB per second. This range was selected because the frequencies to be tested were 250 through 6000 Hz, and by not tracing the entire 100-10,000 Hz range considerable time was saved. This was important because of the generally short attention span of preschool age children. The test stimulus was initiated at 125 Hz, at -15 dB, so that the intensity could reach the maximum output of the audiometer before 250 Hz was approached. This means that the subject should definitely have responded at least once before the actual threshold testing began. By allowing the tracing to continue until 6500 Hz was reached, it was insured that a measure was made at 6000 Hz. The entire frequency range was mapped in approximately six minutes. The total attenuation range for the Békésy audiometer is 120 dB, or from -15 dB to 105 dB, re: 1964 ISO reference threshold.

The transducer for the Békésy audiometer was a calibrated air-conduction earphone, model TDH 39, mounted in a MX41/AR cushion. This was attached to a headband along with another earphone, which was not calibrated for pure tones and was not used for testing; however, was employed to help keep the headset in place on the subject's head.

Because the portable audiometer was not capable of measuring a pure tone signal below 0 dB (re: hearing level, 1964 ISO standard), and the pure tone stimulus produced by the Békésy audiometer could be attenuated to -15 dB, a 20 dB air-conduction pad was built for the portable unit. A schematic diagram of the -20 dB air-conduction pad is presented in Figure 3.

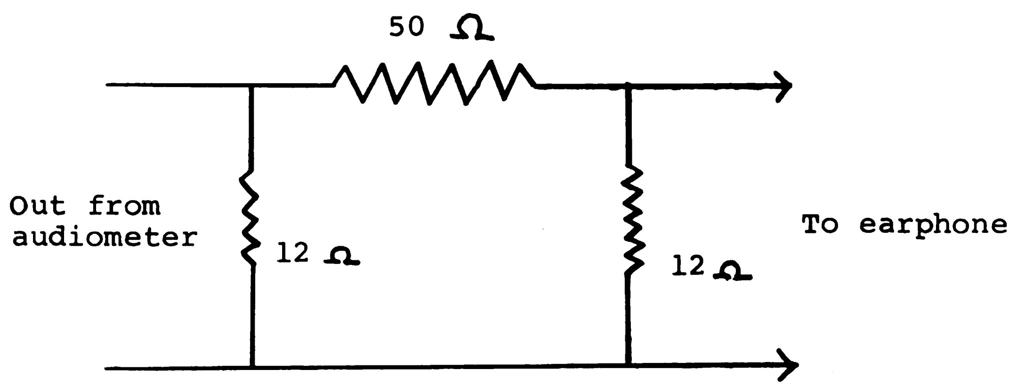

Figure 3.--Schematic diagram of -20 dB air-conduction pad.

With the employment of this 20 dB pad the signal produced by the portable pure tone audiometer could be attenuated to -20 dB. The Békésy audiometer also has a 20 dB pad; however, its pad is built in during factory construction. The Békésy pad can be employed to increase, or attenuate, the stimulus signal by 20 dB at any time. The pad is controlled by moving a toggle-switch in one direction to increase the stimulus by 20 dB, and in the other direction to attenuate the stimulus by 20 dB.

Frequency and intensity calibration of the input stimulus was conducted before each Békésy audiometric test, and was carried out as directed in the Békésy manual.[56] A calibration of the output stimulus was conducted at least every other day that testing took place. This was done by connecting the calibrated earphone to the artificial ear, which in turn was connected to the sound level meter. The Békésy audiometer was then set to produce a 60 dB signal, and the output was measured at octave intervals between 125 and 8000 Hz. The portable audiometer was calibrated the same day, and essentially the same procedure was employed. Both pieces of equipment stayed in calibration during the entire testing procedure, and the variations in output were never greater than 0.9 dB for the Békésy audiometer at any frequency, and 1.4 dB for the portable audiometer. These measured differences are within the specification as directed by the American Standards Association.[57]

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[56] Instruction Manual for the Békésy Audiometer E-800, (West Concord, Massachusetts: Grason-Stadler).

[57] "American Standard Specification for Audiometers for General Diagnostic Purposes," American Standard Association, Incorporated (1960), p. 9.

Peabody Picture Vocabulary Test

The Peabody Picture Vocabulary Test is an intelligence test designed to provide an estimate of a subject's verbal intelligence.[58] The stimulus 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.

The author of the PPVT presents the results of various validity studies 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. The correlations as presented in the manual are, respectively, 0.88, 0.82, 0.86, and 0.82.

PROCEDURE

A subject was seated in a small chair in a sound-treated audiometric test room. The investigator then administered Form A of the Peabody Picture Vocabulary Test, and gave the directions as dictated in the test

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

manual.[59] Only 10 to 15 minutes are required to give the PPVT, which is an untimed test. The scale is administered only over a critical range of items for a particular subject, and the starting point, basal and ceiling scores vary from testee to testee. The starting points are listed in the manual, and do vary as a function of age and assumed ability. From the indicated starting point one works forward until the subject makes his first error, and in the event that eight correct responses have not been made to this point, goes back immediately to the starting point and works backward consecutively until a total of eight consecutive correct responses have been obtained. This then is the basal score. To obtain the ceiling score, the examiner continues testing forward until the subject makes six errors in any eight consecutive presentations; considers the last item presented as the subject's ceiling. The test is discontinued when a basal and ceiling score have been established. In order to determine the intelligence quotient, the number of incorrect responses are counted and then subtracted from the ceiling score. This, then, is the raw score which is employed to obtain the IQ score from the tables in the manual. These tables are constructed so that if the raw score and subject's age are known, the IQ score can be read directly. The tables have IQ Scores

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[59] _Ibid._, pp. 7-8.

for every combination of age and raw score.

After the Peabody test had been given, a conventional pure tone hearing evaluation was administered. An auditory threshold was obtained for only one ear, and the ear chosen was that ear on the cerebrally dominant side. In order to determine this, the parent accompanying the child was asked whether the child was right- or left-handed. Play audiometry-type techniques were employed during the conventional pure tone testing. First the subject was given a "ring and peg" game and instructed that he could place a ring on the peg every time a sound was heard. The examiner then attempted to determine thresholds for the frequencies 250, 500, 1000, 2000, 4000, and 6000 Hz, employing the Hughson-Westlake[60] technique. When the subject had finished putting the rings on the peg for the second time, the game was changed and a simple child's puzzle was used. Here, as in the peg game, the subject could place a piece of puzzle whenever he heard a sound. The process of determining thresholds was continued. If the puzzle was completed before the required thresholds were obtained, the examiner again changed the behavioral task. The child was given a toy house that had various shaped holes in the sides, and

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[60]Raymond 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.

which also had various shaped wood blocks that fit into these holes. When the child heard a sound, he could put one of the wooden pieces into the house. The activities were changed frequently in order to prevent the child from becoming bored and subsequently not attending to the task. This procedure was found to be very successful. Occasionally, with the four and five year old children, the last game was not employed, but rather, they were asked to raise their hand when they heard a sound. This was done only when it was believed that the subject was mature enough to handle this approach. This, too, was successful and definitely saved time during the pure tone testing. As indicated earlier, each subject was screened with bone conduction testing at 500, 1000 and 2000 Hz. The same techniques that were used to obtain air conduction thresholds were also employed to obtain the audiometric thresholds with bone conduction testing.

Once the subject's auditory threshold was determined with conventional audiometry, a Békésy audiometric hearing test was administered. The subject was shown the electronic switch and told how to operate it. The instructions were as follows:

> Now we're going to play another listening game. See this little black box? Well, it has a button you can push (examiner demonstrates).--You try it!--Now, every time we hear a sound we're going to chase it away, and we do that by pushing this button. Then, when the sound is all gone, we take our finger off the button (examiner makes a "beee"

> sound and pushes button, and then slowly lets sound die and lets up on button), and when the sound is gone we let up on the button. Let's practice once.

The Békésy audiometer was then turned on, and the auditory signal was presented in the sound-treated room through a speaker. This method of presentation was employed only during the practice session. During the actual threshold testing, the sound stimulus was presented through an earphone. The examiner sat with the subject, and they practiced chasing the sound away and taking their finger off the button when the sound was gone. This was continued until the subject understood the task he was supposed to perform.

Following the practice session the examiner put earphones on the subject, went into the adjoining test room, and from there administered the Békésy audiometric test. A continuous tone was employed and was presented at the Békésy slow speed, of one octave per minute, because it affords Békésy audiometric results that are in best agreement with conventionally determined thresholds.[61,62] The frequencies 250 through 6000 Hz were tested; however, the Békésy tracing was begun at 125 Hz to give the subject an opportunity for practice before the actual threshold tracing

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[61] Hardick, <u>op. cit.</u>, p. 27.

[62] Stream and McConnell, <u>loc. cit.</u>

at 250 Hz was initiated. In other words, the test was begun at 125 Hz, and if the subject did not respond in a manner which indicated that he understood how to perform the Békésy audiometric test, the stimulus was interrupted and the subject was coached as to the proper procedure. Again a threshold was obtained for only one ear, and as before, the ear of choice was the one on the cerebrally dominant side.

Once the stimulus reached 250 Hz, the test was not stopped unless the subject traced down to the -15 dB level and kept the stylus there for a distance of 500 Hz on the audiogram blank. If this happened, a -20 dB pad was introduced and continued until the subject released the button. This was done to determine if the child did in fact hear the stimulus at the -15 dB traced level, or if he was merely not attending to the task and simply pushing the electronic switch without awareness. However, the -20 dB change in calibration was never continued for more than a distance of 500 Hz on the audiogram blank. If it ran that long, the examiner stopped the test and re-administered the directions. Once the directions were re-administered, the test was begun again from the point of interruption. This only needed to be done with three of the sixty subjects. For most subjects the test was not interrupted once the stimulus reached 250 Hz. The subjects were all viewed through the window connecting the two rooms and were frequently given a smile or nod of approval.

A retest session was conducted one week after the initial testing period. The Békésy audiometric test was administered during this retest, and was given exactly as during the first session. The conventional pure tone test and the Peabody Picture Vocabulary Test were not administered during this retest period.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the major results obtained by the procedures described in Chapter III. It will include a discussion of validity and reliability, including the statistical procedures employed, and a discussion of the mean number of tracing excursions revealed on the Békésy audiograms. This chapter will also present the null hypotheses to be tested and a discussion of the resulting findings in terms of the original questions posed in this investigation.

Procedure for Determining Auditory Thresholds from the Békésy Audiometric Technique

To determine an auditory threshold from the Békésy audiogram, the "midpoint" technique, as suggested by Burns and Hinchcliffe,[63] was employed. An example of that technique as employed in this investigation is illustrated in Figure 4. As illustrated, line A was drawn across the upper peaks of the excursions, and line B was drawn across the bottom peaks of the excursions. All tracing excursions

[63]Burns and Hinchcliffe, loc. cit.

which exceeded a 3 dB increase in intensity were included. Lines A and B, then, actually formed an envelope enclosing the Békésy tracings; and to determine the specific auditory threshold, a mid-line (line C) was drawn through the approximate center of this envelope. Line C, therefore, represented a carefully measured mid-point tracing between lines A and B. The intensity level at which this mid-line crossed any given frequency was considered to be threshold.

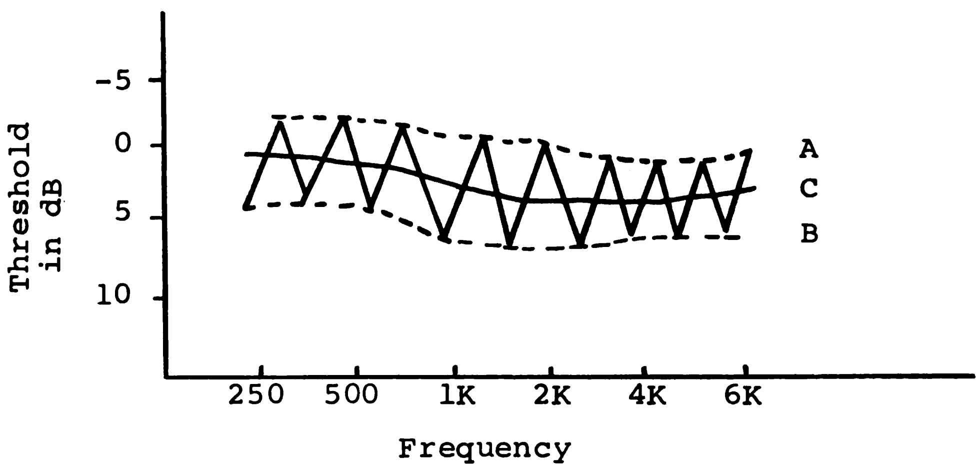

Figure 4.--Illustration of method employed to determine auditory threshold from Békésy audiograms.

Occasionally there would be an excursion which was extreme in length when compared with the other excursion tracings. If, when viewing the general pattern of the tracing, an excursion was approximately three times the length of the average excursion in the pattern, it was not employed as a peak for determining the basic envelope. An example of this is seen in Figure 5. It can be seen that peak A does not fit the general pattern of the tracing and, therefore, it was not used when drawing the envelope. If peak A would have been used, the resulting envelope would have been distorted. It is quite obvious that if such a peak were employed, an unrealistic threshold would have resulted at that point or frequency. It should be pointed out that these peaks seemed to be caused by a subject's inattentiveness. Frequently, when one of these peaks was traced, the subject could be seen looking around the room or examining the control switch.

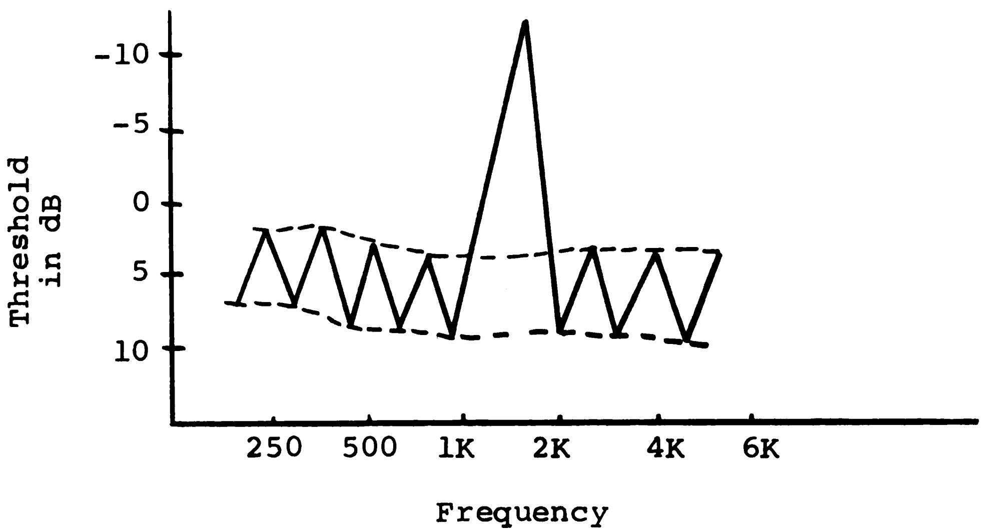

Figure 5.--Illustration of procedure used to disregard a peak when tracing the envelope to determine auditory thresholds.

Validity

In an attempt to determine the validity of the Békésy audiometric procedures with preschool-age children, a Pearson Product Moment Correlation was computed, using the conventionally obtained thresholds as the criterion measure. The correlations were actually computed between the audiometric threshold scores obtained on the first Békésy audiometric test and on the conventional pure tone test. The same procedure was conducted for the second Békésy audiometric test. Each Békésy audiometric test threshold score at 250, 500, 1000, 2000, 4000, and 6000 Hz, was correlated with the corresponding conventional test threshold score, for each subject at all three age levels. The correlations were calculated on a Control Data Corporation 3600 Digital Computer, employing the program "Calculation of Basic Statistics on the BASTAT Routine."[64] The results of these procedures are revealed in Table 2.

The information in Table 2 reveals that for the five year old subjects the auditory thresholds obtained on the second Békésy audiometric test seem to afford results most highly correlated with the criterion measure. While a few of the correlations for the five-year old subjects are not

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

TABLE 2.--Correlations computed between the conventional pure tone test and each of the two Békésy audiometric tests.

Age	Frequency (in Hz)	Correlation Coefficients Between the Conventional Test and the: 1st Békésy Test	2nd Békésy Test
Five	500	0.49	0.63
	1000	0.53	0.83
	2000	0.57	0.79
Four	500	0.11	0.11
	1000	0.42	0.28
	2000	0.04	-0.09
Three	500	0.37	0.52
	1000	0.36	0.26
	2000	0.20	0.44

too high, it must be remembered that a few extreme deviations in scores will result in a low, rather unrealistic correlation. An example of extreme score effects can be seen at 1000 Hz for the first Békésy audiometric test. When all threshold scores were employed, the correlation was only 0.53; however, when the two most extreme scores were disregarded for the correlation computation, the correlation increased to 0.78. Because there were a few extreme threshold scores observed for every age group, the face value of the obtained threshold correlations is not completely realistic. Another method of observing the relationship of the Békésy audiometric tests and the criterion measure is in the presentation of composite audiograms. The composite audiograms in Figures 6, 7, and 8 include the mean threshold scores obtained for each of the three auditory tests.

The composite audiograms below show that, for the five-year old subjects, the second Békésy audiometric test produced a threshold very similar to that of the conventional pure tone test results. It would appear, then, that in the clinical situation the audiologist should administer the Békésy audiometric test twice for the five-year old subjects in order to determine the most accurate threshold. This does not hold true for the four-year old child, however. In that instance it appears that the first Békésy audiometric test is the better estimate of the children's actual threshold, as measured by the conventional pure tone test technique. During the testing procedures it appeared that the four year old children did not respond as well during the second Békésy audiometric test as they did for the first Békésy audiometric test. Subjectively, it appeared that they considered that they had already completed that task and subsequently were not interested in doing it again. In the clinical situation, then, the best estimate of auditory threshold for the four-year old child, who willingly participates in the Békésy audiometric task, is the result

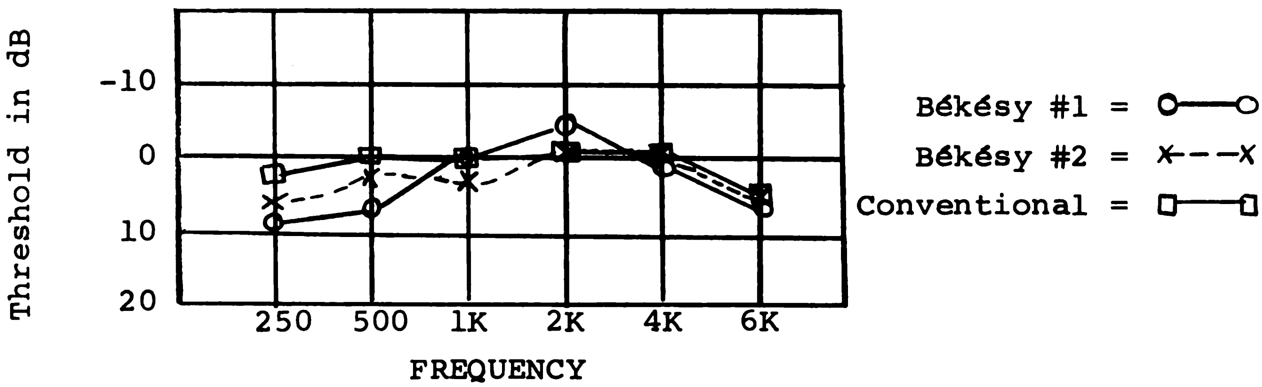

Figure 6.--Mean threshold scores for the five-year old subjects on the three auditory tests.

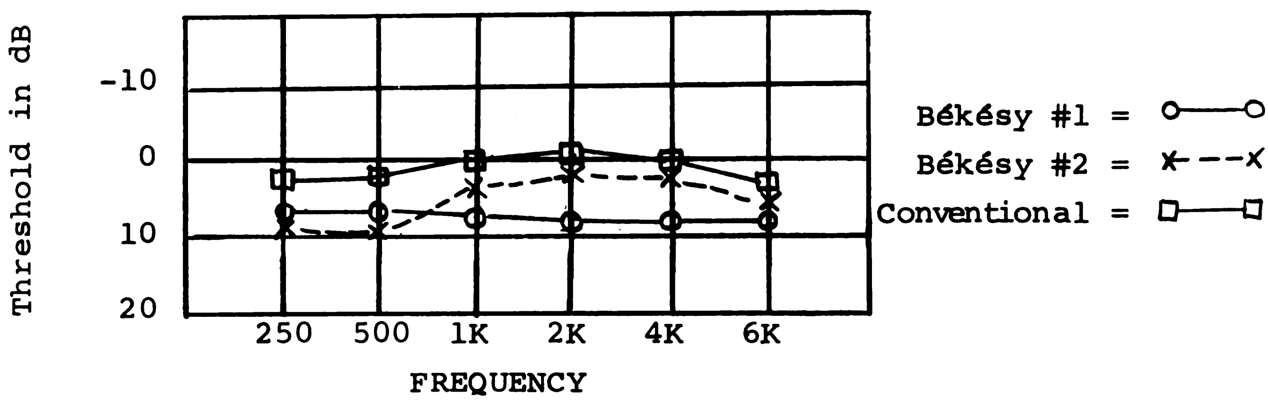

Figure 7.--Mean threshold scores for the four-year old subjects on the three auditory tests.

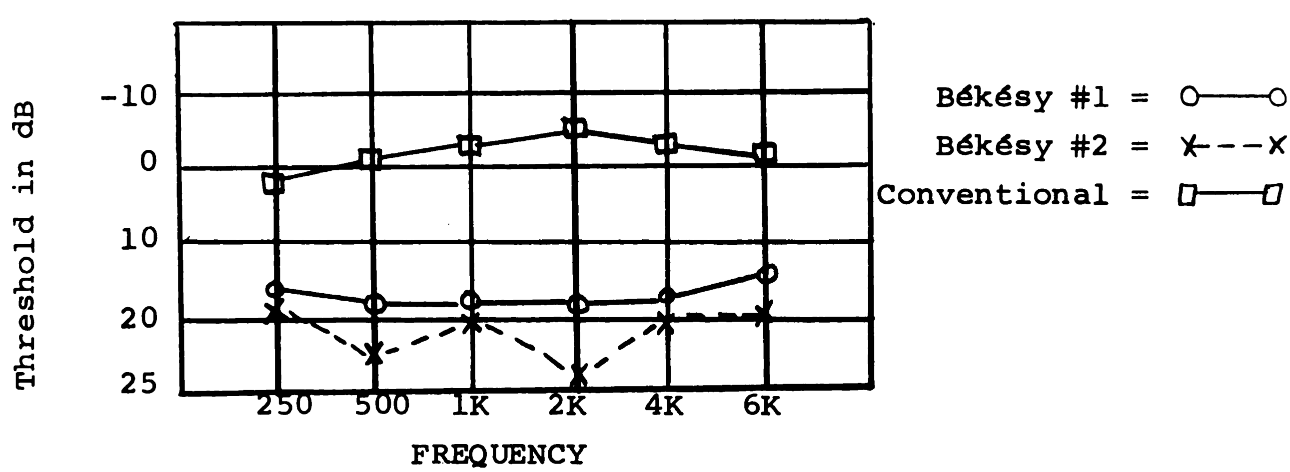

Figure 8.--Mean threshold scores for the three-year old subjects on the three auditory tests.

obtained from the first Békésy audiometric test.

The relationship of the Bekesy audiometric tests and the conventional pure tone test of the three-year old subjects does not appear to be highly correlated. The composite audiogram reveals a rather obvious difference between the Békésy audiometric tests and the conventional pure tone test results. The smallest difference is a magnitude of at least 15 dB, and there are discrepancies as great as 30 dB. This would indicate, then, that neither of the Békésy audiometric tests is a very realistic indication of actual auditory threshold for a three-year old child.

An idea of the relationship between thresholds obtained with Békésy audiometry and those obtained with conventional audiometric techniques is seen when considering the percentage of children, at each age level, who have Békésy audiometric thresholds within plus or minus 5 dB of the criterion measure, which in this case are the thresholds obtained with the conventional audiometric test. Table 3 shows the percentage of agreement between those measures.

The percentages shown in Table 3 reveal a substantial difference in threshold agreement for the various age groups. It can be seen that for the five-year old subjects the percentage of agreement is quite high, for the four-year old subjects the agreement is moderate, and for the three-year

TABLE 3.--Percentage of subjects scoring within $\pm$ 5 dB of the criterion during the first Békésy audiometric test (Average of 500, 1000, and 2000 Hz).

	Percentage of Agreement		
	3 years	4 years	5 years
1st Békésy Threshold	25%	60%	75%
2nd Békésy Threshold	20%	65%	95%

old subjects the percentage of agreement is low. It is also interesting to note that, for the five-year old subjects, the second Békésy audiometric test results are much more in agreement with the criterion measure than are the results from the first Békésy audiometric test. This obvious improvement is not seen for the three- and four-year old subjects. These percentages of agreement give some evidence of validity. They indicate that, for the children who participated in the Békésy audiometric task, the results for the five-year old subjects were more valid than Békésy results of the four-year old subjects, and obviously, the Békésy results for the three-year old subjects revealed very little validity.

The validity of the Békésy audiometric tests can be seen to vary as a function of age. In reviewing the correlations, the composite audiograms, and the percentage of agreement, for the five-year old subjects who participated with the Békésy audiometric task, it can be seen that the Békésy audiometric test results are an adequate measure of the individual's actual threshold. For that age group, the second Békésy audiometric test is a better indicator than the first Békésy audiometric test. For the four-year old subjects who will take the Békésy audiometric test, the results are only a fair estimate of their actual auditory threshold, and for the three year old subjects the results do not seem to afford any valid measure.

Reliability

In this context the word reliability is employed in the general sense of repeatability of test scores. When measuring reliability, both absolute and relative consistency should be considered.[65] Absolute consistency refers to the absolute variability in performance from test to retest, whereas relative consistency refers to the extent to which individuals preserve their rank order in the group from test to retest. In a discussion of pure tone audiom-

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[65] R. L. Thorndike and Elizabeth Hagen, Measurement and Evaluation in Psychology and Education (New York: John Wiley and Sons, Inc., 1961), p. 184.

etry, Jerger[66] stated that the audiologist is generally more concerned with the precision of the estimate of the subject's auditory threshold than with the estimation of the subject's relative standing in a group of all subjects with a hearing loss. In other words, he is more interested in a measure of absolute consistency, and this is defined by the standard error of measurement (SE_m). Descriptively one can define the standard error of measurement as an estimate of the standard deviation that would be obtained for a series of measurements of the same individual. Therefore, in an attempt to present the most meaningful indication of reliability, both a coefficient of reliability and the standard error of measurement will be presented. It is believed, however, that for this investigation the SE_m provides the most meaningful information. Table 4 summarizes the relevant data for the Békésy audiometry conducted for this study.

In reviewing Table 4, for the three-year old subjects, it can be seen that the correlations are relatively low and the standard errors of measurement are quite high. This means, then, that the repeatability or reliability of Békésy audiometric tests for this age group is not very good. With an average SE_m of 10 dB, we expect that repeated

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[66] James Jerger, "Evaluation of Some Auditory Measures," Journal of Speech and Hearing Research, 5 (1962), p. 6.

TABLE 4.--Mean test and retest hearing level (Békésy audiometric test #1 and Békésy audiometric test #2) in dB, standard error of measurement (SE_m) in dB, and coefficient of reliability (r) for the two Békésy audiometric tests at 500, 1000, and 2000 Hz.

Age	Frequency	Mean Thresholds (in dB) Békésy Tests #1	#2	SE_m	r
3 years	500	18.0	21.0	9.7	0.47
	1000	16.0	19.0	10.13	0.53
	2000	19.5	14.0	10.15	0.35
4 years	500	5.3	9.5	5.8	0.48
	1000	5.8	4.0	3.6	0.10
	2000	5.3	2.5	6.4	0.48
5 years	500	5.8	3.3	4.2	0.70
	1000	0.0	0.3	5.2	0.60
	2000	-4.8	-2.8	3.9	0.78

measures would reveal scores of plus or minus 10 dB, or in terms of an interval, a range of 20 dB. This means that there might be a difference between tests as great as 20 dB, which in the clinical situation is not an acceptable degree of variability. This poor reliability, coupled with poor validity for three-year old children functioning with Békésy audiometry, tends to indicate that Békésy audiometry is probably not a good technique to employ with this age group.

The average standard error of measurement for the four-year old group is 5 dB. This would indicate, then, that in a series of repeated Békésy measurements, a threshold score of plus or minus 5 dB would be obtained approximately 68% of the time. According to reports in the literature on clinical reliability, this is an acceptable amount of error for auditory testing.[67, 68] Therefore, it appears that the reliability for the four-year old child functioning with Békésy audiometry is within clinically acceptable limits. It is noted that the coefficients of correlation are not very impressive; however, the concern here is with the precision of measurement irrespective of rank order preservation, and not with the consistency of the extent to which an individual preserves his rank order from test to retest. Remembering that the composite audiogram for the four-year old child revealed only fair agreement between the first Békésy audiometric test and the conventional pure tone threshold, but seeing that the measure of repeatability is within clinically acceptable limits, it might be stated that even if a four-year old child willingly accepts taking the Békésy audiometric test, it should be approached cautiously and with these limits in mind.

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[67] Ibid.

[68] Raymond Carhart, and C. Hayes, "Clinical Reliability of Bone Conduction Audiometry," Laryngoscope, 59 (1949), pp. 1084-1101.

The coefficient of reliability and the standard error of measurement both reveal fairly impressive results for the five-year old subjects. The average SE_m is about 4 dB, which means that repeated Békésy audiometric measures would result in scores no greater than plus or minus 4 dB of the obtained threshold 68% of the time. Coupling this good reliability with the reasonably good validity of a second Békésy audiometric test, it would appear that Békésy audiometry can be employed rather meaningfully with the five-year old child. One would expect that a second Békésy audiometric test would afford results as clinically acceptable as those obtained by the conventional audiometric technique.

Significant Differences Among Mean Thresholds

In order to test the differences among mean thresholds as obtained in this investigation, six null hypotheses were postulated and are enumerated below.

1. There is no significant difference in the mean thresholds obtained with Békésy audiometry between three, four- and five-year old children.

2. There is no significant difference in the mean thresholds obtained with Békésy audiometry between male and female subjects at each of the three age levels evaluated.

3. There is no significant difference in the mean thresholds obtained with Békésy audiometry between subjects who have an average intelligence quotient and those who have a high intelligence quotient for each of the three age groups evaluated.

4. There is no significant difference between the mean thresholds obtained on the first Békésy audiometric test and the subsequent Békésy retest for each of the three age groups evaluated.

5. There is no significant difference in the number of tracing excursions among three, four, and five year old subjects.

6. There is no significant difference in the number of tracing excursions between the first and second Békésy audiometric test for the three, four, and five year old subjects.

The null hypotheses which have been postulated were tested statistically. A presentation of the statistical technique and the resulting findings will be offered, and a discussion of whether or not the null hypotheses could be rejected will follow.

To determine the significance of differences among the variables in the principle comparisons (Ho_1, Ho_2, Ho_3

and Ho_4) a "Three-Dimensional Design" analysis of variance was employed. The data from the experiment were entered in a three-dimensional table, which geometrically may be represented as a parallelpiped. In this instance it consisted of three 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 actual analysis of variance was conducted on a Control Data Corporation 3600 Digital Computer.[69] The F-ratio was used in testing the significance of the variations. Specifically, a three-way analysis of variance was computed for the first Békésy audiometric test, the second Békésy audiometric test, and the conventional pure tone test at three different frequencies. The frequencies employed as criterion values were 500, 1000, and 2000 Hz. Therefore, nine different three-way analyses were computed; one at each of the three frequencies for each of the three audiometric tests. The source of variation for each of these analyses were age, sex, and IQ. A summary of those nine analyses, as well as the means employed in testing the variables, will be presented in tables 5 to 20.

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

The means used in comparing differences of age, sex, and IQ for the first Békésy audiometric test at 500 Hz are presented in Table 5, and a summary of the analysis is offered in Table 6.

TABLE 5.--Mean thresholds employed in comparing differences of age, sex, and IQ for the first Békésy audiometric test at 500 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	18.0
	4 years	5.3
	5 years	5.8
SEX	male	10.6
	female	8.6
IQ	average	13.0
	high	6.3

The main factors involved in the analysis summarized in Table 6 were age, sex, and IQ. As can be noted, the only factor showing statistical significance for the first Békésy audiometric test at 500 Hz was the age factor. Levels within sex, levels within IQ, and interactions were nonsignificant. In order to visualize the difference effect operating across the age groups, a composite audio-

TABLE 6.--Summary of analysis of variance comparing differences of age, sex, and IQ on the first Békésy audiometric test at 500 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	1042.91	5.95*
Sex	1	60.00	0.34
IQ	1	666.66	3.80
Age x Sex	2	226.25	1.29
Age x IQ	2	280.41	1.60
Sex x IQ	1	166.66	0.95
Age x Sex x IQ	2	395.41	2.25

*Significant beyond the 0.01 level.

gram of the auditory thresholds on the first Békésy audiometric test will be presented in Figure 9.

It can be seen that the greatest difference is between the three-year old group and the other two groups. Throughout the entire frequency range the three-year old subjects revealed thresholds elevated above those of the other two groups. This points out that audiometric thresholds of three-year old subjects, obtained on a Békésy audiometric test, are much different than audiometric thresholds, obtained with the Békésy audiometric test, of four and five year old subjects.

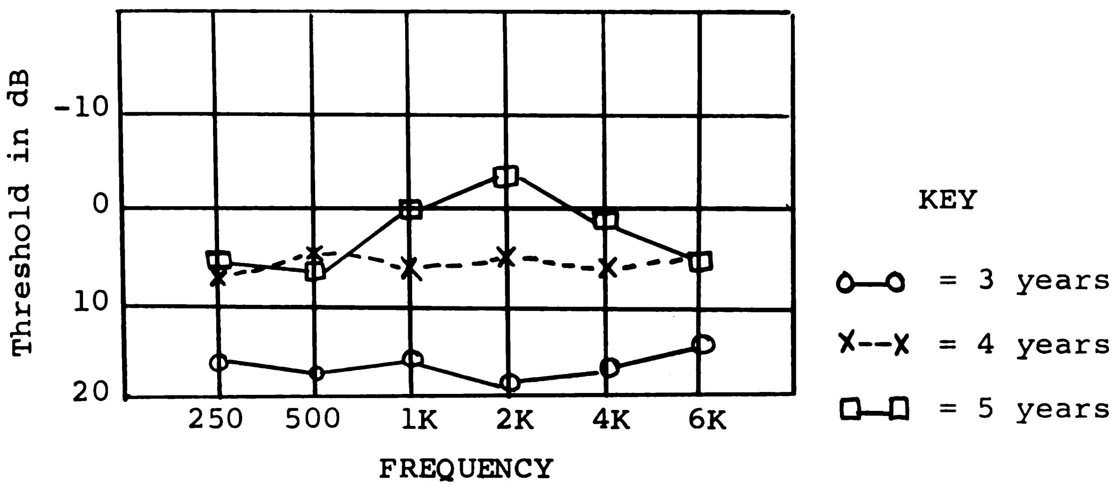

Figure 9.--Composite audiogram for all age groups for the first Békésy audiometric test.

The significant F-ratio shown in Table 6 was investigated by employing the Newman-Keuls[70] statistic for determining the difference between treatment means. The actual means employed are seen in Table 5. The results of the Newman-Keuls statistic, which are displayed as q-scores in Table 7, revealed that the threshold obtained for the three year old subjects at 500 Hz on the first Békésy test, was significantly different at the 0.01 level, from the thresholds obtained by the four- and five-year old subjects. However, the thresholds for the four- and five-year old subjects were not significantly different.

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[70]B. J. Winer, Statistical Principles in Experimental Design. (New York: McGraw-Hill Book Company, Inc., 1962), p. 80.

TABLE 7.--Newman-Keuls q-scores for difference between treatment means of the first Békésy audiometric test at 500 Hz, for the age-variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	12.75 *
3 and 5 years	12.25 *
4 and 5 years	0.50

*Significant beyond the 0.01 level.

Returning to the earlier discussion concerning the specific results at the various frequencies of the first Békésy audiometric test, Table 8 presents the means employed in comparing the differences of the first Békésy audiometric test at 1000 Hz, and a summary of the complete analysis is offered in Table 9.

The information in Table 9 shows that the factor revealing statistical significance, at the 0.01 level of confidence, was age. Levels within sex, levels within IQ, and the interactions were nonsignificant. However, if the 0.05 level of confidence would have been employed, the factor of IQ would have been significant. The effect of IQ is shown in a graph displayed in Figure 10, and it is interesting to note the effect operating for the three-year old subjects. While not statistically significant at the 0.01

TABLE 8.--Mean thresholds employed in comparing differences of age, sex, and IQ for the first Békésy audiometric test at 1000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	16.0
	4 years	5.8
	5 years	0.0
SEX	male	9.5
	female	5.0
IQ	average	11.5
	high	3.0

TABLE 9.--Summary of analysis of variance comparing differences of age, sex, and IQ in the first Békésy audiometric test at 1000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	1313.75	7.84*
Sex	1	303.75	1.72
IQ	1	1083.75	6.17
Age x Sex	2	386.25	2.19
Age x IQ	2	286.25	1.62
Sex x IQ	1	453.75	2.58
Age x Sex x IQ	2	263.75	1.50

*Significant beyond the 0.01 level.

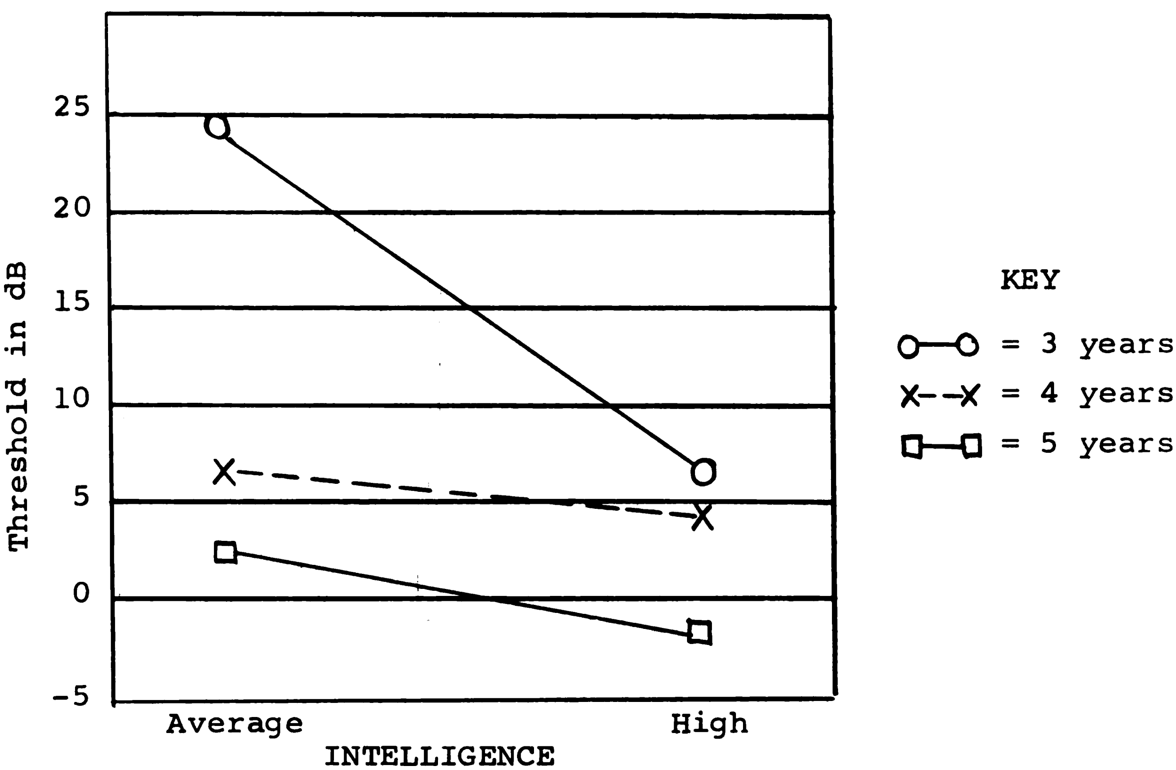

Figure 10.--Mean thresholds for the average and high IQ groups at each of the three different age levels, for the first Békésy audiometric test at 1000 Hz.

level, it can be seen that the factor of intelligence appears to have some effect, and seems to be most important for the three-year old children. The mean thresholds for the four- and five-year old age groups are essentially parallel, but for the three-year old group a discrepancy is revealed. The mean threshold obtained for the above average intelligence three-year old child seems to be much more in agreement with the mean thresholds of the four-and five-year old children than does the mean threshold of the three-year old child with an average intelligence quotient.

The Newman-Keuls statistic was computed, and the resulting q-scores are displayed in Table 10. It shows that at the 0.01 level of confidence, the mean threshold obtained for all three-year old subjects was significantly different from the mean thresholds obtained for the four- and five-year old subjects. The threshold difference for the four- and five-year old subjects was not statistically significant. These results, then, show that the auditory thresholds obtained for three-year old subjects with Békésy audiometry are much different than the thresholds obtained for the four- and five-year old subjects.

TABLE 10.--Newman-Keuls q-scores for difference between treatment means of the first Békésy audiometric test at 1000 Hz, for the age variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	10.25*
3 and 5 years	16.00*
4 and 5 years	5.75

*Significant beyond the 0.01 level.

The means employed in testing the variables for the first Békésy audiometric test at 2000 Hz are presented in Table 11, and a summary of the complete analysis is shown in Table 12. In Table 12 it can be seen that, at the 0.01 level of confidence, the significant factors are age and intelligence. The Newman-Keuls statistic for difference between treatment means for the age variable was computed, and the results are shown in Table 13. It is revealed that the thresholds obtained for the three- and four-year old subjects were not significantly different, but that their thresholds were significantly different from those of the five-year old subjects. This is a change from the pattern of significance as revealed at 500 and 1000 Hz, in that, for those frequencies the thresholds of the three-year old subjects were different from the thresholds of both the four- and five-year old subjects, and in this instance it is the five-year old group that is different from the other two groups.

TABLE 11.--Means employed in comparing differences of age, sex, and IQ for the first Békésy audiometric test at 2000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	19.5
	4 years	5.3
	5 years	-4.8
SEX	male	11.0
	female	3.0
IQ	average	12.5
	high	1.8

TABLE 12.--Summary of analysis of variance comparing differences of age, sex and IQ on the first Békésy audiometric test at 2000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	2642.91	12.69*
Sex	1	881.66	4.23
IQ	1	1706.66	8.20*
Age x Sex	2	697.91	3.35
Age x IQ	2	212.91	1.02
Sex x IQ	1	326.66	1.56
Age x Sex x IQ	2	177.91	0.85

*Significant beyond the 0.01 level.

TABLE 13.--Newman-Keuls q-scores for difference between treatment means of the first Békésy audiometric test at 2000 Hz, for the age variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	4.25
3 and 5 years	12.75*
4 and 5 years	8.50*

*Significant beyond the 0.01 level.

The factor of intelligence at 2000 Hz also proved significant, and the effect can be noted in Figure 11.

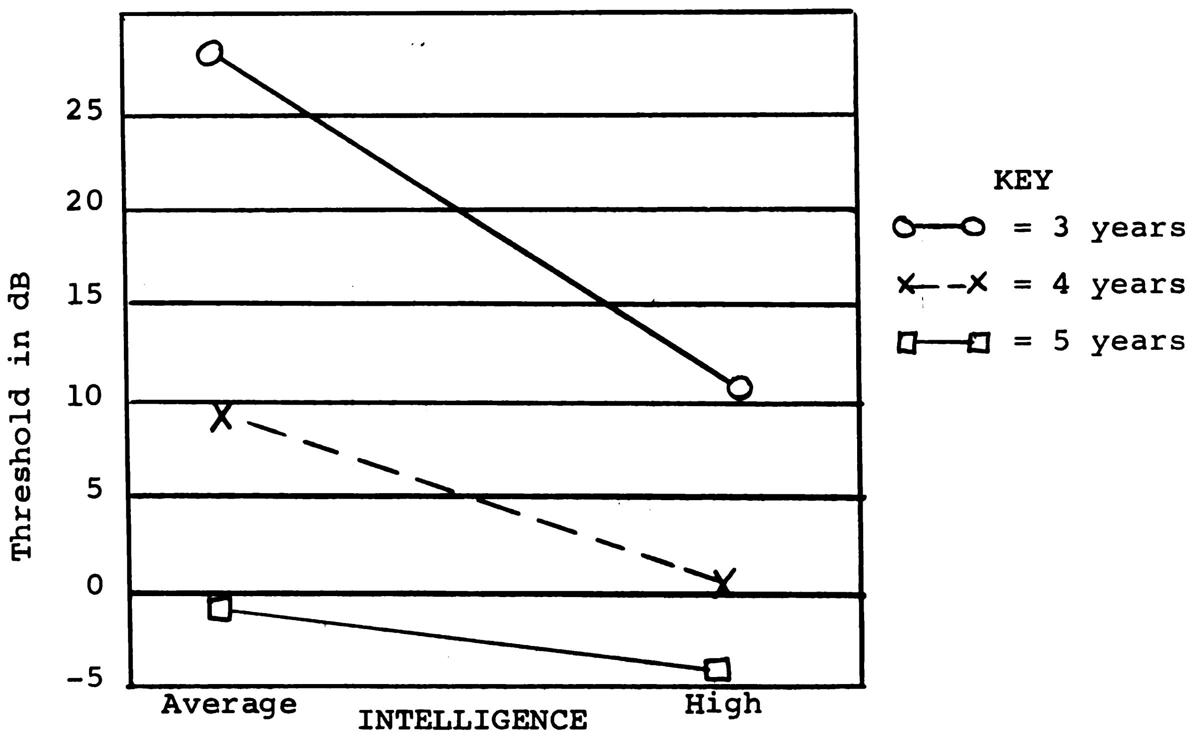

Figure 11.--Mean thresholds for the average and high IQ groups at each of the three different age levels, for the first Békésy audiometric test at 2000 Hz.

Also, the Newman-Keuls statistic was computed for the IQ variable, and the results which are displayed in Table 14 indicate that the influence of intelligence is not significant for the four- and five-year old subjects; however, it is for the three-year old subjects. The three-year old subjects who are above average in intelligence obtain audiometric threshold scores that are much more like the audiometric threshold scores obtained by the four- and five-year old subjects with average intelligence. In other words, three-year old subjects with above average intelligence have mean thresholds that are more realistic, in terms of hearing threshold, than do three-year old subjects of average intelligence.

TABLE 14.--Newman-Keuls q-scores for differences between treatment means of the first Békésy audiometric test at 2000 Hz, for the sex variable.

Age level at which q-statistic was computed	q-score
3 years	18.50*
4 years	8.50
5 years	5.50

*Significant beyond the 0.01 level.

A three-way analysis of variance was also computed for the second Békésy audiometric test. Again, the three-dimensional design was computed for the separate frequencies (500, 1000, and 2000 Hz). The means employed in comparing the differences and a summary of the analysis will be presented in Tables 15 through 20. A Newman-Keuls statistic for difference between treatment means was computed for every significant F-ratio, and the resulting q-scores are presented in Tables 21 through 23. All the tables will be presented simultaneously, and then a discussion of their implications will be offered.

TABLE 15.--Means employed in comparing differences of age, sex, and IQ for the second Békésy audiometric test at 500 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	21.0
	4 years	9.5
	5 years	3.3
SEX	male	10.3
	female	12.2
IQ	average	14.2
	high	8.3

TABLE 16.--Summary of analysis of variance comparing differences of age, sex, and IQ on the second Békésy audiometric test at 500 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	1621.25	8.09*
Sex	1	50.41	0.25
IQ	1	510.41	2.54
Age x Sex	2	302.91	1.51
Age x IQ	2	117.91	0.58
Sex x IQ	1	50.41	0.25
Age x Sex x IQ	2	662.91	3.31

*Significant beyond the 0.01 level.

TABLE 17.--Means employed in comparing differences of age, sex, and IQ for the second Békésy audiometric test at 1000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	19.0
	4 years	4.0
	5 years	0.3
SEX	male	8.0
	female	7.5
IQ	average	10.0
	high	5.5

TABLE 18.--Summary of analysis of variance comparing differences of age, sex, and IQ on the second Békésy audiometric test at 1000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	1968.75	8.48*
Sex	1	3.75	0.01
IQ	1	303.75	1.30
Age x Sex	2	138.75	0.59
Age x IQ	2	16.25	0.07
Sex x IQ	1	20.41	0.08
Age x Sex x IQ	2	402.91	1.73

*Significant beyond the 0.01 level.

TABLE 19.--Means employed in comparing differences of age, sex, and IQ for the second Békésy audiometric test at 2000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	14.0
	4 years	2.5
	5 years	-1.3
SEX	male	6.6
	female	3.5
IQ	average	7.8
	high	2.3

TABLE 20.--Summary of analysis of variance comparing differences of age, sex, and IQ on the second Békésy audiometric test at 2000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	1262.91	6.11*
Sex	1	150.41	0.72
IQ	1	453.75	2.19
Age x Sex	2	72.91	0.35
Age x IQ	2	48.75	0.23
Sex x IQ	1	10.41	0.05
Age x Sex x IQ	2	615.41	2.98

*Significant beyond the 0.01 level.

TABLE 21.--Newman-Keul q-scores for differences between treatment means of the second Békésy audiometric test at 500 Hz, for the age variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	11.50*
3 and 5 years	17.75*
4 and 5 years	6.25

*Significant beyond the 0.01 level.

TABLE 22.--Newman-Keul q-scores for differences between treatment means of the second Békésy audiometric test at 1000 Hz, for the age variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	15.00*
3 and 5 years	18.75*
4 and 5 years	3.75

*Significant beyond the 0.01 level.

TABLE 23.--Newman-Keul q-scores for differences between treatment means of the second Békésy audiometric test at 2000 Hz, for the age variable.

Age-group combinations employed for q-statistic	q-score
3 and 4 years	11.50*
3 and 5 years	15.25*
4 and 5 years	3.75

*Significant beyond the 0.01 level.

The results revealed in analysis of variance summary Tables 16, 18, and 20 show that for the second Békésy audiometric test the only factor which revealed a significance was age. To visually represent this, a composite audiogram for all age groups is presented in Figure 12. When viewing this composite audiogram, it is quite obvious that the Békésy audiometric thresholds obtained by the three-year old subjects are quite different than the threshold of the four- and five-year old subjects. It appears that the four- and five-year old subjects trace thresholds around zero decibels, which is within normal audiometric limits, but the three-year old subjects traced thresholds at approximately 20 dB. This is probably not a normal auditory threshold for that age group.

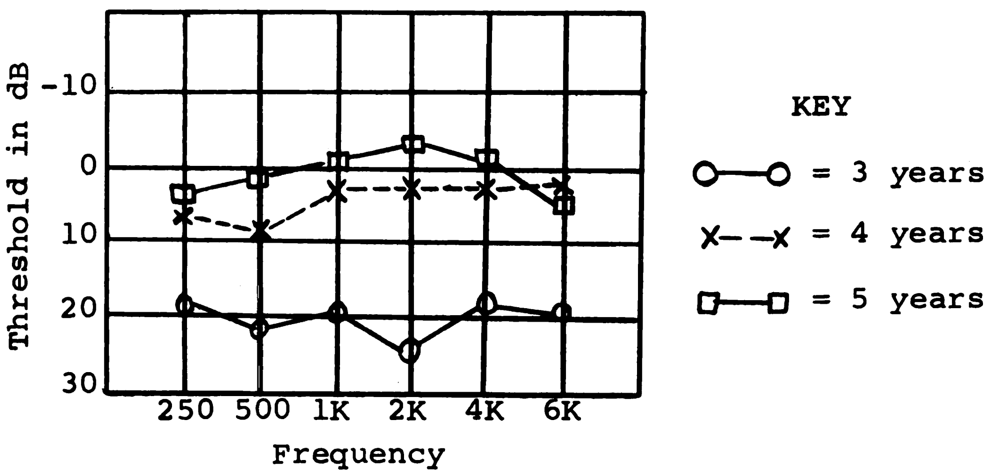

Figure 12.--Composite audiogram for all age groups for the second Békésy audiometric test.

The Newman-Keuls statistic was computed for the means of the age variable, (Tables 21, 22, and 23) and again it was revealed that the mean threshold of the three-year old subjects was significantly different from the mean thresholds obtained for the four- and five-year old subjects. At this point, then, it can be seen that the three-year old subjects perform differently on the Békésy audiometric task, even after having had the opportunity for learning during the pretest practice and during the first actual Békésy audiometric test.

A three-dimensional analysis of variance was also computed for the conventional pure tone test at 500, 1000, and 2000 Hz. The means employed in comparing the differences, and a summary of the analysis, will be presented in tables 24 through 29. The tables will be presented simultaneously, and then a discussion of their implications will be offered.

The results shown in the tables reveal that for the frequencies of 500 and 1000 Hz the thresholds for the various age groups were not significantly different; however, for the frequency of 2000 Hz the five-year old subjects obtained a threshold significantly different than the three- and four-year old subjects. It is interesting to note that if acceptance had been set at the 0.05 level of confidence, all thresholds would have been significantly different from one another. A composite audiogram for the thresholds

TABLE 24.--Means employed in comparing differences of age, sex, and IQ for the conventional pure tone test at 500 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	-1.0
	4 years	0.8
	5 years	1.0
SEX	male	0.5
	female	0.0
IQ	average	0.3
	high	0.2

TABLE 25.--Summary of analysis of variance comparing differences of age, sex, and IQ on the conventional pure tone test at 500 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	23.75	0.95
Sex	1	3.75	0.15
IQ	1	0.41	0.01
Age x Sex	2	33.75	1.35
Age x IQ	2	2.91	0.11
Sex x IQ	1	20.41	0.81
Age x Sex x IQ	2	12.91	0.51

Note: None of the F-ratios was significant at the 0.01 level.

TABLE 26.--Means employed in comparing differences of age, sex, and IQ for the conventional pure tone test at 1000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	-4.0
	4 years	-0.7
	5 years	0.0
SEX	male	-1.2
	female	-2.0
IQ	average	-0.8
	high	-2.3

TABLE 27.--Summary of analysis of variance comparing differences of age, sex, and IQ on the conventional pure tone test at 1000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	90.41	2.91
Sex	1	10.41	0.33
IQ	1	33.75	1.08
Age x Sex	2	25.41	0.81
Age x IQ	2	8.75	0.28
Sex x IQ	1	150.41	4.84
Age x Sex x IQ	2	45.41	1.46

Note: None of the F-ratios was significant at the 0.01 level.

TABLE 28.--Means employed in comparing differences of age, sex, and IQ for the conventional pure tone test at 2000 Hz.

Variable		Mean Threshold Score (in dB)
AGE	3 years	-6.0
	4 years	-3.5
	5 years	-0.5
SEX	male	-2.4
	female	-4.4
IQ	average	-2.7
	high	-4.0

TABLE 29.--Summary of analysis of variance comparing differences of age, sex, and IQ on the conventional pure tone test at 2000 Hz.

Source of Variance	df	Mean Square	F-Statistic
Age	2	151.66	5.00*
Sex	1	60.00	2.01
IQ	1	26.66	0.89
Age x Sex	2	5.00	0.16
Age x IQ	2	11.66	0.39
Sex x IQ	1	60.00	2.01
Age x Sex x IQ	2	35.00	1.17

*Significant beyond the 0.01 level.

obtained with the conventional pure tone test are presented in Figure 13. It can be seen that while all thresholds do tend to cluster around the 0-dB level, the mean threshold for the three-year old subjects was slightly lower (better) than the threshold of the four-year old subjects, and subsequently both those thresholds were lower than that obtained by the five-year old subjects.

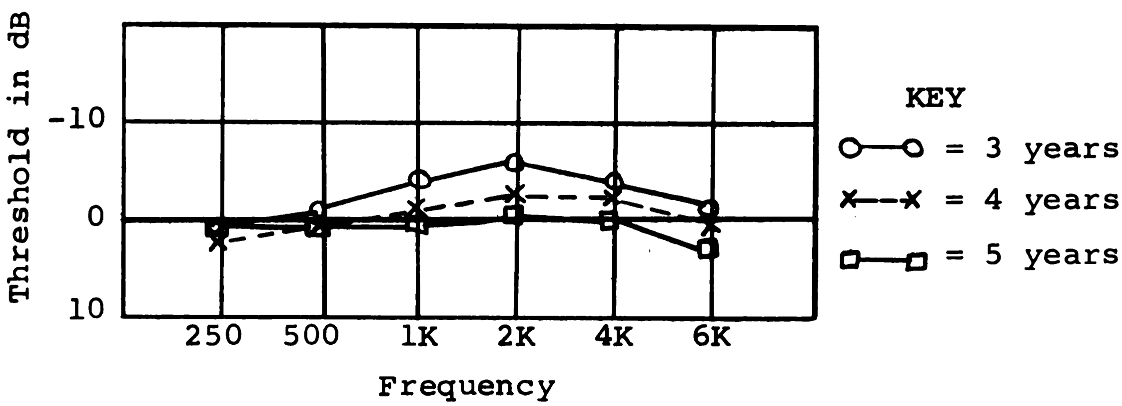

Figure 13.--A composite audiogram for all age groups on the conventional pure tone audiometric test.

In reviewing the analyses of variance it can be seen that for the Békésy audiometric tests, the factors of significance were age and IQ. This means, then, that one might expect to obtain different thresholds for the various subjects depending upon their age and their IQ. When one inspects the obtained means, it is obvious that the major difference is from the three-year old subjects. Their composite Békésy audiometric thresholds seem to differ much more from their conventional pure tone thresholds than is true for the four- and five-year old subjects. In observing all of the data presented thus far, it is noted that the five-year old subjects obtain Békésy audiometric thresholds that are more in agreement with their conventional pure tone test results than do the four-year old subjects; and in turn, the four-year old subjects reveal better Békésy-conventional agreement than do the three-year old subjects. And, interestingly enough, the first Békésy audiometric thresholds for the three- and four-year old subjects agreed with the conventional audiometric thresholds as well as did their results from the second Békésy audiometric test. However, for the five-year old subjects, the agreement between the second Békésy audiometric threshold and the conventional audiometric threshold was significantly better than the first Békésy-conventional audiometric threshold agreement.

Number of Stylus Excursions

During the administration of the two Békésy audiometric tests it was quite obvious that various subjects performed differently with the task. Some audiograms revealed a large number of tracing excursions while other audiograms showed a small number of excursions. The mean number of tracing excursions obtained on each of the two

Békésy audiometric tests for the three age groups are presented in Table 30. If an audiogram consists of a large number of excursions, it means that the tracing width is quite small and the subject is probably tracing along a rather well-defined threshold. However, if the audiogram consists of a small number of tracings, it means that many of the excursions are rather wide and the threshold is probably not very specifically defined. In order to determine if there was any difference in the number of tracing excursions among the three age groups, and between the first and second Békésy audiometric test, *t*-tests for difference between means were computed. A *t*-test for difference between independent means was computed to determine significant differences in the number of excursions among the three age groups, and a *t*-test for difference between dependent means was computed to determine significant differences in the number of excursions between the first and second

TABLE 30.--Mean number of excursions obtained on each of the two Békésy audiometric tests for the three age groups.

Age Group	Mean number of Excursions	
	1st Békésy Test	2nd Békésy Test
3 years	21.9	21.8
4 years	30.8	31.6
5 years	39.5	44.9

Békésy audiometric test for each of the three age groups. The number of traced excursions per audiogram was determined by counting every ascending and descending trace, over 3 dB in length, between the 250 and 6000 Hz positions on the Békésy audiogram. The results of the *t*-tests are presented in Tables 31 and 32. The results of the analysis indicated that there was a significant difference between the number of traced excursions for the three- and five-year old subjects; however, the number of excursions traced by the four-year old subjects was not significantly different from either the five- or the three-year old subjects. The three-year old subjects traced an audiogram having the least mean number of excursions and the five-year old subjects traced an audiogram with the greatest mean number of excursions. Because the mean number of traced excursions of the four-year old subjects was not significantly

TABLE 31.--The *t*-scores for the difference between the mean number of tracing excursions on the first and second Békésy audiometric test for the three age groups.

Age	*t*-score
3 years	0.219
4 years	0.659
5 years	3.690*

*Significant beyond the 0.01 level.

TABLE 32.--The *t*-scores for the difference between the mean number of tracing excursions among the three age groups.

Combination of Age-Groups Employed for *t*-test	*t*-score
3 and 4 years	1.19
3 and 5 years	2.64*
4 and 5 years	1.32

*Significant beyond the 0.01 level.

different from that of the other two groups, but the two other groups were significantly different from each other, the mean number of traced excursions for the four-year old subjects must have been somewhere between those obtained by the three- and five-year old subjects. Generally speaking, this indicated that the three-year old subjects trace wide excursions and do not define a very specific threshold, whereas the five-year old subjects reveal an audiogram having a much more narrow tracing envelope and a more defined threshold. Apparently, the width of traced excursions and definition of threshold for the four-year old subjects must depict a compromise of the three- and five-year old subject's audiograms. The analysis also concerned the difference in number of excursions between the first and second Békésy audiometric tests within each age group. Results show that for the three- and four-year old subjects there was no significant difference in the number of excursions between tests; however, there was a significant difference for the five-year old subjects. This would tend to indicate that the younger subjects did not benefit from practice, but that the five-year old subjects did. This fact was pointed out earlier during the discussion of validity when it was shown that, for the five-year old subjects only, the second Békésy audiometric tracing most closely agreed with the threshold obtained by conventional pure tone test techniques.

Summary

In reviewing the statistical information presented in this chapter, it can be seen that some of the null hypotheses cited earlier can be rejected, whereas some of them cannot be rejected. Specifically, Ho_1, which was concerned with the mean Békésy audiometric thresholds among three-, four- and five-year old children, was rejected. There was a difference, and upon statistical inspection we find that the three-year old subjects obtained audiometric thresholds significantly different than those obtained by four- and five-year old subjects. However, when viewing all the information available, including the composite audiograms, it can be seen that all the age groups do differ somewhat in mean performance. The percentage of five-year old subjects who revealed Békésy audiometric thresholds that were within plus or minus 5 dB of their conventional audiometric threshold was 95%. For the four-year old subjects this threshold agreement was 65%, and for the three-year old subjects it was 25%.

Ho_2 was concerned with the difference between the sexes, within the various age groups, and ability to perform Békésy audiometry. The results indicate that the null hypothesis could not be rejected, and subsequently, it might be said that there is no apparent difference in the obtained Békésy audiometric thresholds between male and female preschool age children. One can assume, then, that when testing children who are three, four or five years of age with Békésy audiometry, there is no reason to expect that the sex of the child will influence the results.

Ho_3 was concerned with the difference in mean Békésy audiometric thresholds as obtained by bright and average three, four, and five year old children. This null hypothesis was rejected and therefore, a difference between means statistic was computed. The results showed that the factor of intelligence does not have influence for subjects who are four and five years of age; however, it does have influence for the three-year old subjects. Bright three-year old children produce a mean Békésy audiometric threshold score that is much more in agreement with their mean conventional audiometric threshold score than do the average three-year old children. Therefore, when testing three-year old children, the audiologist would expect to obtain a more realistic picture of audiometric threshold from the bright child than for the average child if he were to employ Békésy audiometry.

Ho_4 was concerned with the difference between audiometric thresholds obtained on the first Békésy test and on the subsequent Békésy retest for the various age groups. The results revealed that this null hypothesis is to be rejected. Generally, the three- and four-year old children traced an audiometric threshold that most closely agreed with the conventional results the first time they took the Békésy test; however, for the five-year old children their second Békésy test afforded the most valid threshold.

Ho_5 stated that there is no significant difference in the number of tracing excursions among the three-, four- and five-year old subjects, and results of the statistical evaluation indicate that this is to be rejected. Category means show that the three-year old subjects trace the fewest number of excursions and the five-year old subjects trace the greatest number of excursions. This means that the Békésy envelope traced by the five-year old subjects is more narrow, and the resulting audiometric threshold more rigidly defined, than is the envelope traced by the three-year old subjects. The mean number of traced excursions of the four-year old subjects was not significantly different from the three-year old group, or from the five-year old group.

The final null hypothesis to be tested, Ho_6, was concerned with the difference in the number of tracing excursions between the first and second Békésy audiometric test for the various age groups. The results indicate that this hypothesis is rejected. It was found that, for the five-year old subjects, there was a significant increase in number of excursions between the first and second Békésy audiometric tests. However, this was not the case for the other two age groups. Neither of the other age groups revealed any significant increase in number of tracing excursions between the first and second Békésy audiometric test.

In terms of clinical importance, it would seem that the information provided by this investigation reveals that some preschool age children yield valid and reliable audiometric thresholds when evaluated with a Békésy audiometer. The audiologist could expect to obtain valid and reliable audiometric thresholds from five-year old children of average intelligence and above, especially from a second Békésy audiometric test. While four-year old children do yield Békésy audiometric results that are reasonably reliable, a look at a composite audiogram would indicate that their mean Békésy audiometric threshold is not as close in agreement with conventional pure tone test results as is true for the five-year old child. It is also important to note that, with the present conditioning techniques employed, three-year old children cannot be adequately evaluated with Békésy audiometry. However, at the same time it is interesting to note that the Békésy audiometric thresholds for the above-average intelligence three-year old children are much more in agreement with conventional pure tone test results than is true for the average three-year old children.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The basic purpose of this research was to evaluate the ability of preschool age children to function with Békésy audiometry. Questions were posed concerning the effect of age, intelligence, and sex on the possibility of obtaining clinically useful auditory thresholds from the preschool age child. Concern was also given to whether or not practice affected the resulting auditory threshold as obtained with Békésy audiometry.

Summary

Sixty preschool subjects, ages three through five years, were selected for this study. The subjects were divided so that twenty children were in each of the three age groups, and so that there was an equal number of male and female subjects in each group. Further, half of the subjects in each group had average intelligence and half had above-average intelligence quotients.

The hearing of each subject was individually evaluated with a portable pure tone audiometer, by the use of play audiometric techniques, and also with Békésy audiometry.

The first Békésy audiometric test was given immediately following the conventional pure tone test, and the second Békésy audiometric test was administered one week later. Statistical analysis was conducted to determine the validity and reliability of the auditory thresholds obtained by Békésy audiometry. Concern was also given to the mean number of tracing excursions evidenced on the audiograms of the three different age groups. Implications of the difference in number of excursions were discussed.

Results indicated that there is a significant difference in the ability to perform with Békésy audiometry as a function of age. It was revealed that five-year old subjects produce a valid and reliable Békésy audiogram, four-year old subjects present fair results, and three-year old subjects could not perform the task adequately. It was also learned that intelligence does affect the ability to take the Békésy audiometric test; however, the most significant difference appeared at the three-year old level. For the three-year old group, the bright subjects obtained a different threshold (better) than did the subjects with average intelligence. The two older groups showed no difference that was statistically significant. There was also a significant difference in the mean number of excursions for the three age groups. The three-year old subjects had the least number of excursions, and the five-year old subjects showed the greatest number of excursions per audiogram. It was interesting to note that while the three- and four-year old subjects did not show an increase in the number of excursions between the two Békésy audiometric tests, the five-year old subjects did reveal a significant difference.

Conclusions

1. Five-year old children with average or above intelligence, when properly conditioned, can be tested with Békésy audiometry and produce valid, reliable auditory threshold tracings.

2. Three- and four-year old children do not seem to benefit from practice with the Békésy audiometer; however, five-year old children do improve their ability to take the Békésy audiometric test when they have an opportunity for practice.

3. Four-year old children do not perform very consistently with Békésy audiometry. Some children this age will trace a Békésy audiometric threshold that is valid, whereas other children will trace thresholds that are not a true representation of their actual auditory threshold.

4. Typically, three-year old children, as presently conditioned, are not candidates for Békésy audiometry. However, if Békésy audiometry is employed with this age group, the children with above average intelligence will probably produce a more valid threshold tracing than the

children of average intelligence.

5. The sex of a child does not apparently affect his ability to take the Békésy audiometric test.

6. Intelligence does not apparently have any effect on the ability of four- and five-year old children to take the Békésy audiometric test; however, it does affect the three-year old children's ability.

7. Five-year old children will trace an audiogram that has relatively narrow excursions and a well defined threshold, whereas the three-year old child will trace wide excursions and produce a poorly defined threshold. The four-year old children will trace an audiogram which might be described as a compromise of these two.

8. In the hands of a skilled audiologist the Békésy audiometer is a valuable tool for obtaining auditory thresholds from five-year old children. However, if employed to test children four years of age, it must be used cautiously, and further, it is not an adequate technique for testing three-year old children.

Recommendations for Further Research

An investigation should be made to determine whether or not a Békésy control-switch different from the one constructed by the Grason-Stadler company would make it easier for young children to perform the Békésy audiometric task. During the present study several children seemed to have some difficulty holding the small box and simultaneously pressing the switch. Also, the spring on the switch seemed to be rather strong and occasionally appeared to interfere with the child's ability to respond.

The attenuation rate employed when administering the Békésy audiometric test to children is another aspect that should be investigated. It may well be that children can respond better to the Békésy audiometric test if the tone disappears and reappears quickly, rather than if the tone has a slow attenuation rate.

Various kinds of conditioning techniques should also be researched. Perhaps if a light would go on when the control-switch was pressed, it would help the young child remember that he was "pushing the button" and also help him realize if his finger "accidentally" came off the switch.

Research should be conducted to determine if children with cochlear and retrocochlear lesions trace the same Békésy patterns as do adults who suffer these lesions. Certainly the evidence of these lesions is not common to a population of children; however, exploitation of every possible use of Békésy audiometry must be made. Any new tool to aid in differential diagnosis with children is certainly desirable.

Further investigation should be conducted with above-average intelligence three-year old children. They performed significantly different from three-year old children of average intelligence, and therefore, further study may prove that the bright three-year old child can be conditioned to perform adequately with Békésy audiometry.

Research should also be conducted to determine if more valid audiometric thresholds would be obtained if a pulsed tone, rather than a continuous tone, were employed when testing preschool age children. Perhaps they would find the pulsed tone a more interesting signal to listen to than the continuous tone.

BIBLIOGRAPHY

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Books

Rudmose, W. "Automatic Audiometry," Modern Developments in Audiology. J. Jerger, editor. New York: Academic Press, Inc., 1963.

Walker, H. M., and Lev, Joseph. Statistical Inference. New York: Holt, Rinehart and Winston, Inc., 1953.

Reports

Avery, C. B., *et al.* "Report of Subcommittee on Hearing Problems in Children," JSHD Monograph Supplement, 5 (1959).

Barr, Bengt. "Pure Tone Audiometry for Pre-School Children," Acta Oto-Laryngologica: Supplementum, 121 (1955), 5-82.

Bender, Ruth E. "A Child's Hearing," Maico Audiological Library Series, 3 (Report 2).

Committee on Child Health, Services for Children with Hearing Impairment, New York: The American Public Health Association, Inc., 1956.

Darley, F. L. "Identification Audiometry," JSHD Monograph Supplement, 9 (1961), 23.

Eagles, "Hearing Levels in Children and Implications for Identification Audiometry," Appendix B of "Identification Audiometry," JSHD Monograph Supplement, 9 (1961), 52-56.

Haug, and Guilford. "Hearing Testing on the Very Young Child: Follow-Up Report on Testing the Hearing of 968 Preschool Patients with the Pediacoumeter," Transactions of the AAOO, 64 (1960), 269-271.

Kodman, Frank, Jr. "Identification of Hearing Loss by Parents and Teachers vs Audiometry," Maico Audiological Library Series, 2 (Report 9).

Periodicals

Belkin, et al. "A Demonstration Program for Conducting Hearing Tests in Day Care Centers," Journal of Speech and Hearing Disorders, 29 (1964), 335-338.

Bilger, Robert C. "Some Parameters of Fixed-Frequency Békésy Audiometry," Journal of Speech and Hearing Research, 8 (1965), 85-89.

Bloomer, Harlan. "Simple Method of Testing Hearing of Small Children," Journal of Speech and Hearing Disorders, 7 (1942), 311-312.

Burns, W., and Hinchcliffe, R. "Comparison of the Auditory Threshold as Measured by Individual Pure Tone and by Békésy Audiometry," Journal of the Acoustical Society of America, 29 (1957), 1274-1277.

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

Corso, John F. "Effect of Testing Methods on Hearing Thresholds," AMA Archives of Otolaryngology, 63 (1956), 78-91.

________. "Evaluation of Operating Conditions on a Békésy-Type Audiometer," AMA Archives of Otolaryngology, 61 (1955), 649-653.

Curry, E. T. "The Efficiency of Teacher Referrals in a School Hearing Testing Program," Journal of Speech and Hearing Disorders, 15 (1950), 211-214.

Dallos, P. J., and Tillman, T. W. "The Effects of Parameter Variations in Békésy Audiometry in a Patient with Acoustic Neurinoma," Journal of Speech and Hearing Research, 9 (1966), 557-572.

Dix, M. R., and Hallpike, C. S. "The Peep Show," British Medical Journal, (Nov., 1947), 719-723.

Downs, M. P., Doster, M. E., and Weaver, Marlin. "Dilemmas in Identification Audiometry," Journal of Speech and Hearing Disorders, 30 (1965), 360-364.

Empery, Margaret. "Pure Tone Audiometry with Young Children," Volta Review, 55 (1953), 439-442.

Froeschels, Emil. "Testing the Hearing of Young Children," AMA Archives of Otolaryngology, 43 (1946), 93-98.

Geyer, Margaret L., and Yankauer, Alfred. "Teacher Judgment of Hearing Loss in Children," Journal of Speech and Hearing Disorders, 21 (1956), 482-486.

Green, Davis S. "The Pup Show: A Simple Inexpensive Modification of the Peep-Show," Journal of Speech and Hearing Disorders, 23 (1958), 118-120.

Hanley, Clair N., and Gaddie, Barbara G. "The Use of Single Frequency Audiometry in the Screening of School Children," Journal of Speech and Hearing Disorders, 27 (1962), 258-264.

Hardy, Wm. G., and Bordley, John E. "Special Techniques in Testing and Hearing of Children," Journal of Speech and Hearing Disorders, 16 (1951), 123-131.

Hardy, J. B., Dougherty, A., and Hardy, W. G. "Hearing Responses and Audiologic Screening In Infants," Journal of Pediatrics, 55 (1959), 382-390.

Harrington, Donald A. "Fifty Years of Work with Children," Hearing News, 30 (1962), 7-8.

Hartley, H. V. Jr., and Seigenthaler, B. M. "Relationship Between Békésy Fixed-Frequency and Conventional Audiometry with Children," Journal of Auditory Research, 4 (1964), 15-22.

Ishisawa, H. "A Study on Play Audiometry," dsh Abstracts, 2 (1962), 201.

Jerger, James. "Békésy Audiometry in Analysis of Auditory Disorders," Journal of Speech and Hearing Research, 3 (1960), 275-287.

Jerger, James, and Herer, G. "Unexpected Dividend in Békésy Audiometry," Journal of Speech and Hearing Disorders, 26 (1961), 390-391.

Johnson, Steen. "Clinical Aspects of High Tone Perceptive Deafness in Children," Acta Oto-Laryngologica, 44 (1954), 24-43.

Keaster, Jacqueline. "A Quantitative Method of Testing the Hearing of Young Children," Journal of Speech and Hearing Disorders, 12 (1947), 159-160.

Kendall, D. C. "The Audiological Examination of Young Children," Volta Review, 66 (1964), 734-740.

Kinney, Charles E. "Hearing Impairments in Children," Laryngoscope, 63 (1953), 220-226.

Lerman, Ross, and McLauchlin, "A Picture Identification Test for Hearing-Impaired Children," Journal of Auditory Research, 5 (1965), 273-279.

Leshin, G. J. "Childhood Nonorganic Hearing Loss," Journal of Speech and Hearing Disorders, 25 (1960), 290-292.

________. "Preschool Hearing Conservation on a Statewide Basis," Journal of Speech and Hearing Disorders, 25 (1960), 346-348.

Lloyd, L. L. "Behavioral Audiometry Viewed as an Operant Procedure," Journal of Speech and Hearing Disorders, 31 (1966), 128-136.

________. "Comment on Dilemmas in Identification Audiometry," Journal of Speech and Hearing Disorders, 31 (1966), 161-165.

Lowell, E. L., et al., "Evaluation of Pure Tone Audiometry with Preschool Age Children," Journal of Speech and Hearing Disorders, 21 (1956), 292-302.

Marcus, R. E. "Hearing and Speech Problems in Children: Observation and Uses of Electroencephalography," Archives of Otolaryngology, 53 (1951), 134-146.

Melnick, W., Eagles, E. L., and Levine, H.S. "Evaluation of a Recommended Program of Identification Audiometry with School-Age Children," Journal of Speech and Hearing Disorders, 29 (1964), 3013.

Miller, Alfred L. "The Use of Reward Techniques in Testing Young Children's Hearing," Hearing News, 30 (1962), 5-7.

Miller, M. H., and Bella, J. L. "Limitation of Selected Frequency Audiometry in the Public Schools," Journal of Speech and Hearing Disorders, 24 (1959), 402-407.

Morley, D. E. "Rationalism in Testing the Hearing of Children," Volta Review, 50 (1948), 468-476.

Myklebust, Helmer R. "Differential Diagnosis of Deafness in Young Children," Journal of Exceptional Children, 17 (1951), 97-101.

Norton, M. C., and Lux, E. "Double Frequency Auditory Screening in Public Schools," Journal of Speech and Hearing Disorders, 25 (1960), 293-298.

O'Neill, J. J., Oyer, H. J., and Hillis, J. W. "Audiometric Procedures Used with Children," Journal of Speech and Hearing Disorders, 26 (1961), 61-66.

Pauls, M. D., and Hardy, W. G. "Hearing Impairment in Preschool-Age Children," Laryngoscope, 63 (1953), 534-544.

Peterson, John L. "Nonorganic Hearing Loss in Children and Békésy Audiometry," Journal of Speech and Hearing Disorders, 28 (1963), 153-158.

Price, L. L. "Threshold Testing with Békésy Audiometry," Journal of Speech and Hearing Research, 6 (1963), 64-69.

Price, L. L. and Falck, V. T. "Békésy Audiometry with Children," Journal of Speech and Hearing Research, 6 (1963), 129-133.

Price, L. L., and Goldstein, R. "Average Evoked Responses for Measuring Auditory Sensitivity in Children," Journal of Speech and Hearing Disorders, 31 (1966), 248-256.

Reger, Scott N. "Clinical and Research Version of the Békésy Audiometer," The Laryngoscope, 62 (1952), 1334.

Rintelmann, Wm., and Harford, Earl. "The Detection and Assessment of Pseudohypoacusis Among School-Age Children," Journal of Speech and Hearing Disorders, 28 (1963), 141-152.

Robertson, D. G. "Use of Békésy Findings in Auditory Diagnosis," Journal of Speech and Hearing Disorders, 30 (1965), 367-369.

Rosenberg, Philip E. "Misdiagnosis of Children with Auditory Problems," Journal of Speech and Hearing Disorders, 31 (1966), 279-282.

Shepard, D. C., and Goldstein, Robert. "Relation of Békésy Tracings to Personality and Electrophysiologic Measures," Journal of Speech and Hearing Research, 9 (1966), 385-411.

Shimizu, Hirosh, and Nakamura, Fumio. "Pure-Tone Audiometry in Children: Lantern-Slide Test," Annals of Otology, Rhinology and Laryngology, 66 (1957), 392-398.

Siegenthaler, B. M., and Sommers, R. K. "Abbrevaited Sweep-Check Procedures for School Hearing Testing," Journal of Speech and Hearing Disorders, 24 (1959), 249-257.

Stark, E. W. "Békésy Audiometry with Normal Hearing and Hearing Impaired Children," Journal of Auditory Research, 4 (1964), 73-83.

Stein, Laszlo. "Some Observations on Type V Békésy Tracings," Journal of Speech and Hearing Research, 6 (1963), 339-348.

Stream, R. W., and McConnell, Freeman. "A Comparison of Two Methods of Administration in Békésy-Type Audiometry," Journal of Auditory Research, 1 (1961), 263-271.

Thorne, Bert. "Conditioning Children for Pure Tone Testing," Journal of Speech and Hearing Disorders, 27 (1962), 84-85.

Watson, J. W., and Voots, R. J. "A Report on the Use of the Békésy Audiometer in the Performance of the Stenger Test," Journal of Speech and Hearing Disorders, 29 (1964), 36-46.

Whitehurst, Mary Wood. "Testing the Hearing of Preschool Children," Volta Review, 63 (1961), 430-432.

Wishik, S. M., and Dramm, E. R. "Audiometric Testing of Hearing of School Children," Journal of Speech and Hearing Disorders, 18 (1953), 360-365.

Zwislocki, J., et al., "On the Effect of Practice and Motivation on the Threshold of Audibility," Journal of Acoustical Society of America, 30 (1958), 254-262.

Unpublished Material

Hardick, Edward J. "A Comparison of the Audiometric Thresholds of Children Obtained with the Békésy Audiometer and a Conventional Pure Tone Audiometer," Unpublished Master's Thesis, The Ohio State University, 1955.

Other Sources

________. "American Standard Specification for Audiometers for General Diagnostic Purposes," American Standards Association, Incorporated (1960), 9.

Dunn, Lloyd M. Expanded Manual for the Peabody Picture Vocabulary Test, Minneapolis: American Guidance Service, Inc., 1965, 7-8.

________. Instruction Manual for the Békésy Audiometer, E-800. West Concord, Massachusetts, Grason-Stadler.

APPENDIX A

THRESHOLD SCORES FOR THE FIRST BÉKÉSY AUDIOMETRIC TEST

Subject	Threshold scores (in dB) for each frequency tested (Hz).					
	250	500	1000	2000	4000	6000
1	40	25	20	25	25	10
2	30	35	40	40	30	45
3	35	35	35	60	45	40
4	20	25	15	35	30	20
5	15	25	25	10	30	25
6	25	45	40	25	25	15
7	25	10	0	5	20	5
8	20	25	15	5	-5	-5
9	20	30	40	40	20	5
10	15	0	15	20	5	-5
11	-5	-5	-5	10	15	15
12	0	-5	-5	-5	-5	10
13	40	50	50	70	70	55
14	5	15	35	40	10	40
15	5	-5	5	-5	5	5
16	5	-5	-5	-10	-10	-5
17	15	20	-10	-10	0	-5
18	15	10	10	10	10	15
19	10	10	0	0	5	0
20	15	15	0	5	5	15
21	0	-10	-10	0	15	20
22	5	0	0	-5	5	0
23	0	-5	-5	0	-5	0
24	10	0	0	10	0	10
25	0	-5	5	10	-10	5
26	10	0	5	15	0	0
27	10	35	30	45	40	35
28	20	20	25	25	50	65
29	10	5	5	-5	0	0
30	30	15	15	0	5	-5

Subject	Threshold scores (in dB) for each frequency (Hz) tested.					
	250	500	1000	2000	4000	6000
31	5	10	0	0	-5	-5
32	-5	10	20	15	20	10
33	15	30	20	5	0	0
34	15	-5	-5	10	10	5
35	5	0	5	0	15	5
36	10	5	10	-5	5	0
37	5	0	5	-5	0	0
38	0	10	0	0	-5	-5
39	-5	-5	-10	-5	-5	-5
40	5	-5	0	-5	0	5
41	20	15	5	5	15	20
42	40	45	50	20	40	45
43	10	5	-5	-10	-10	-10
44	-5	-5	-5	0	-10	5
45	15	0	-5	-10	-5	-5
46	5	-5	-5	-5	-5	0
47	0	-5	0	-5	-5	-5
48	5	10	10	15	20	25
49	0	20	-10	-5	-5	-5
50	5	0	-5	-10	5	5
51	25	15	5	-5	20	25
52	5	5	5	0	5	0
53	5	0	-5	-10	-5	5
54	5	5	0	-10	-5	0
55	5	10	-5	5	5	10
56	0	5	-5	-10	-10	5
57	0	0	-10	-10	0	0
58	0	-5	-5	-10	-5	-10
59	0	-5	-5	-10	-5	0
60	5	5	-5	0	-10	0

APPENDIX B

THRESHOLD SCORES FOR THE SECOND
BEKESY AUDIOMETRIC TEST

Subjects	Threshold scores (in dB) for each frequency (Hz) tested.					
	250	500	1000	2000	4000	6000
1	40	40	45	50	40	30
2	15	40	15	15	25	30
3	15	20	30	25	25	30
4	15	35	25	30	35	10
5	20	10	20	10	10	10
6	60	70	55	50	40	70
7	10	-5	-5	-5	10	0
8	10	5	-5	-5	-5	-5
9	50	35	40	10	30	25
10	10	-5	0	5	0	5
11	10	15	0	20	35	15
12	-5	-5	-10	-10	0	10
13	15	25	25	15	25	30
14	0	15	35	5	0	5
15	10	0	0	0	5	5
16	40	60	60	50	60	50
17	15	10	0	-10	0	-5
18	15	35	35	20	30	50
19	20	10	-5	10	5	15
20	10	0	10	-5	0	-5
21	20	5	0	0	0	5
22	10	5	-5	-5	-5	0
23	0	5	0	-5	-5	0
24	10	5	5	0	5	0
25	0	-5	0	0	-5	5
26	10	20	30	30	25	30
27	10	35	-5	25	25	10
28	15	25	5	-10	-5	-5
29	15	30	30	15	15	15
30	10	20	5	-10	-15	-15

Subjects	Threshold scores (in dB) for each frequency (Hz) tested. 250	500	1000	2000	4000	6000
31	10	0	0	0	-5	0
32	10	10	5	0	-5	-10
33	10	0	5	5	5	10
34	10	15	5	30	10	15
35	5	5	0	-5	-5	0
36	10	5	5	5	5	5
37	10	5	0	-5	-5	-5
38	5	5	5	0	0	5
39	-5	-5	-10	-10	-10	0
40	10	5	0	-10	-5	5
41	10	5	0	5	15	15
42	20	20	20	20	10	10
43	-5	-5	0	-5	-5	0
44	5	5	-5	0	5	5
45	5	0	-5	-5	-5	-5
46	0	-5	0	-5	-5	0
47	5	0	0	0	0	0
48	15	15	15	15	15	30
49	0	5	-5	-10	-5	0
50	5	-5	-5	-5	-5	5
51	10	5	0	0	-5	10
52	0	0	-5	-10	-5	0
53	-5	5	-5	-5	-5	0
54	15	10	5	-5	0	-5
55	15	15	25	25	20	30
56	0	5	-5	-5	-5	-5
57	-5	-5	-10	-10	-5	0
58	0	-5	-5	-10	-5	-10
59	0	0	-5	-5	0	5
60	0	0	-5	-10	-5	0

APPENDIX C

THRESHOLD SCORES FOR CONVENTIONAL TEST

Subjects	Threshold scores (in dB) for each frequency (Hz) tested.					
	250	500	1000	2000	4000	6000
1	5	5	0	0	0	10
2	0	0	0	-5	0	0
3	-5	-5	-10	-10	-5	-10
4	0	0	0	-5	-5	-5
5	5	0	0	-5	0	0
6	0	0	0	-5	-5	0
7	0	-5	-10	-10	-5	-5
8	10	5	10	0	-5	5
9	0	0	-5	-5	-5	0
10	-5	-10	-10	-10	-5	-5
11	0	0	-5	-5	0	5
12	-5	-5	-10	-10	-5	10
13	5	5	0	-5	-5	-5
14	0	0	-5	-5	-5	-5
15	0	0	-5	-5	-5	-5
16	5	0	-5	-5	-5	0
17	5	-5	-5	-10	-10	-5
18	5	5	0	0	0	5
19	0	-5	-10	-10	-5	0
20	0	-5	-10	-10	-5	0
21	0	-5	-10	-5	0	5
22	0	0	0	-5	0	0
23	0	-5	-5	-5	-5	0
24	5	5	0	0	-5	0
25	0	0	0	0	-5	0
26	0	-5	-5	-5	0	5
27	0	0	5	0	0	0
28	5	5	5	-5	-5	0
29	5	5	5	-10	-10	5
30	10	10	10	5	5	0

Subjects	Threshold scores (in dB) for each frequency (Hz) tested. 250	500	1000	2000	4000	6000
31	0	0	0	-5	-5	0
32	-5	-5	-5	-5	-5	5
33	0	0	5	5	5	5
34	0	0	0	-5	-5	-5
35	5	5	0	0	0	0
36	5	5	0	0	0	0
37	0	0	0	-5	-5	0
38	5	5	0	0	-5	0
39	0	-5	-10	-10	-10	-5
40	5	5	0	-10	-5	0
41	0	0	0	5	5	20
42	10	10	10	0	5	5
43	0	0	-5	-5	-5	0
44	-5	-5	-5	5	5	5
45	5	0	-5	-5	-5	-5
46	0	0	0	0	0	5
47	0	0	0	0	0	5
48	15	15	15	15	15	20
49	-5	-5	0	0	0	5
50	5	0	-5	-5	-5	0
51	5	5	5	0	0	15
52	5	5	5	-10	-5	0
53	0	0	0	5	0	0
54	-5	-5	-5	-5	-5	-5
55	10	10	15	20	10	15
56	0	0	-5	-5	-5	-5
57	-5	-5	-5	-5	0	0
58	0	-5	-5	-10	-10	-10
59	0	0	-5	-5	0	0
60	0	0	-5	-5	-5	0

APPENDIX D

INTELLIGENCE QUOTIENT SCORES

INTELLIGENCE QUOTIENT SCORES

Subject	IQ	Subject	IQ
1	102	31	143
2	101	32	123
3	102	33	120
4	99	34	127
5	104	35	120
6	90	36	120
7	103	37	120
8	110	38	120
9	101	39	120
10	105	40	120
11	125	41	102
12	127	42	103
13	122	43	95
14	133	44	101
15	120	45	102
16	131	46	109
17	129	47	103
18	120	48	109
19	120	49	106
20	124	50	102
21	109	51	121
22	104	52	120
23	108	53	125
24	106	54	121
25	109	55	122
26	110	56	120
27	110	57	122
28	109	58	120
29	104	59	124
30	109	60	123