# OPERANT AUDIOMETRY WITH THE HARD OF HEARING CHILD

by

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CHAPTER I

# INTRODUCTION

Early identification and management of the auditorily handicapped child has been recognized to be of major significance for the development of a child's speech and language skills, as well as for his general development (Linden, Kankkunnen, 1969; Rupp, Wolski, 1969; Morre, Valois, 1968). The optimum age for special training and management of the hard-of-hearing child is believed to be by the age of two years (Davis, 1965; Hardy, et al., 1959). However, many would like to begin the use of amplification as early as two months of age, if a reliable threshold estimate could be obtained (Davis, 1965). The acquisition of a reliable threshold estimate has been the chief limiting factor in providing an effective means of amplification for the hard-of-hearing child (McCandless, 1967).

Although the identification of infants with hearing deficits has progressed in recent years, the procedures employed in neonatal screening do not provide sufficient information to be used in determining needed therapeutic assistance (Linden & Kankkunen, 1969).

In children six years and older, auditory sensitivity can usually be measured directly and reliably by the conventional auditory testing procedure in which the subject is instructed to respond in a defined manner to stimuli which he can detect. On repeated testings, the audiograms of individuals with no known hearing deficits will generally fluctuate no more than ± 5 dB (Rapin & Costa, 1969; Barr, 1954). Information concerning the reliability of successive audiograms in preschool children is scanty since accurate measurement of their auditory sensitivity is often difficult and time consuming (DiCarlo, Dendall & Goldstein, 1962; Miller & Polisar, 1964; Davis, 1965; Rapin & Costa, 1969; Fisch, 1964). Preschool children with hearing losses provide even further difficulties since verbal directions are virtually useless as a means of instruction (Pollack, 1970; Griffiths, 1967).

Since early identification and management of the hearing impaired child has been recognized to be of major importance, it would seem practical to review the existing audiometric procedures in relation to their application to hard of hearing children.

# REVIEW OF LITERATURE

The audiometric procedures used with children generally measure one of two different classes of responses; either physiological or behavioral (Fox, 1965). Electrodermal audiometry and electroencephalic audiometry both measure physiologic responses while operant audiometric procedures measure behavioral responses.

In electrodermal audiometry, the physiologic response measured is an activation of the sweat glands through the autonomic nervous system. This audiometric procedure has its basis with classical conditioning. The electrodermal response occurs normally in response to any painful stimulus. The response is detected by measuring the resulting change in electrical resistance (the Fere effect) or electrical potential (the Tarchanoff effect). A mild electrical shock is the unconditioned stimulus with which the test tones are paired (Davis & Silverman, 1970). The shock is gradually increased until the auditory stimulus becomes associated with the unconditioned stimulus. A response similar to that which is evoked by the shock alone is elicited by the auditory stimulus (Shepard, 1971). Electrodermal audiometry, however, has demonstrated several disadvantages. The unconditioned stimulus is an unpleasant experience for the child and often makes management of the child difficult (Davis, 1965). Neither is this use of aversive stimuli conducive to gaining parental support. An experienced and skillful team of personnel is also needed since the pattern of skin resistance varies from individual to individual (Millar & Polisar, 1964). It is quite difficult to stabilize a young child's behavior and many extraneous responses result, making an objective evaluation difficult (Pollack, 1970). Goodhill and associates (1954) feel that electrodermal audiometry is not in any way an objective technique because of the many subjective factors involved in the examiner's interpretation of the electrodermal responses. Reliability and validity studies, with a criterion of $\pm$ 5 dB on test-retest data, were conducted on electrodermal audiometry by Bordley (1949). The results indicated that only 56% of the 86 ears tested met the criterion. Another disadvantage is the fact that some children have such inadequate electrodermal resistance changes, that to obtain a good measurement is almost impossible (Bordley, 1969). Many times the children who respond well to the electrodermal audiometry, can also be successfully tested by easier methods such as play audiometry. Conversely, children who are difficult to assess by the use of behavioral observations or play audiometric procedures have often proven to be impossible to condition by the electrodermal audiometric procedures (Goodhill, et al., 1954). It would seem that electrodermal audiometry is too complex to allow for objective interpretations, too unpleasant of an experience for the child and too unreliable to be used as a practical means for assessing the hearing of young children.

Another method of hearing assessment which measures physiologic responses is electroencephalic audiometry. This method records the changes in brain activity as a result of acoustic stimulation. This test, as with the electrodermal tests can be given only by those who are well trained in interpreting the EEG. Also, due to the prohibitive cost of instrumentation (Pollack, 1970), electroencephalic audiometry is seldom available unless a clinic is associated with a medical center.

Another factor which further complicates electroencephalic audiometry interpretation is that the electrical patterns from the brain are continually active, are extremely sensitive and are affected by the state of the subject. Factors such as whether the subject is tense or relaxed, asleep or awake, eyes are opened or closed and other such things will elicit changes in the EEG pattern. In audiometry, the EEG has proved to be of the greatest benefit when the patient is asleep (Fisch, 1961; Davis, 1970). Perhaps the greatest difficulty with this method of testing is that even when you succeed in eliciting a response, one can only conclude that the system tested works. This does not mean, necessarily, that the responses elicited are evidence of "hearing" unless a particular type of functional definition is agreed upon (Davis, 1970). Derbyshire (1970) points out that a normal electroencephalic reading does not rule out disturbances in areas not recorded or detectable by present means. Due to the relative difficulty of an objective interpretation of the responses, the high expense of the equipment and the uncertainty of exactly what the listener is "hearing," electroencephalic audiometry does not seem to be a practical method for assessing the hearing of young children.

Play audiometry, an early form of operant audiometry, was introduced with the hope of making the testing situation "pleasurable" for the child, increasing his attention to the stimulus and thus produce more accurate responding to the stimulus. Dix & Hallpike (1947) made the initial attempt in this area when they introduced the peepshow technique. The stimulus was presented in a sound-field situation. Basically, the procedure included the rewarding of the child with a visual reward (a picture) when he pressed a button in the presence of the stimulus. No retest data was reported, however, and the use of sound field yields information only about the state of the better-hearing ear. Furthermore, the sound field situation would not enable the determination as to which was the better ear.

Since the introduction of the play audiometric procedure by Dix and Hallpike, several refinements have evolved. Many of the more recent methods present the stimulus via earphones; thus information can be gathered concerning both ears. Lesak (1970), Statten and Wishart, (1956), Sullivan, Millar and Polisar (1962) and Guilford and Haug (1960) are among those who have reported modified versions of the "peep show" under earphones. Yet another variation was reported (Linden & Kankkunnen, 1969) as a free field peep show technique in which the non-test ear was blocked by an insert ear plug and an external ear muff. None of these studies reported more than 50 percent success with three-year-olds and younger, and this data was gathered on children without any known auditory handicaps.

Barr (1955), and Mykelburst (1954), reported a type of play audiometry that presented the stimulus through earphones, but changed the required response from pushing a button to moving a block, dropping marbles in a box, or stacking rings. Retest reliability (criterion of $\pm$ 5 dB variance) was established with less than 40 percent of the cases tested. Also, these procedures used with children under 2 1/2 years of age were only successful approximately 20 percent of the time. No data was reported concerning the use of the procedures with hard of hearing children.

Linden and Kankkunen (1969) reported the use of a visual reinforcement procedure specifically used for evaluating the threshold level of young deaf children. The pure tone presentation was immediately followed by the presentation of a picture. The purpose of the picture in this study was to make pure tones more interesting to the child. No definite response to stimuli was required and the examiner simply watched for behavioral changes. Due to the absence of a well defined response, the threshold estimate is left to the subjectivity of the examiner, and this subjectivity is what pediatric audiometry is trying to eliminate (Davis, 1965).

In 1969, Rapin and Costa conducted a study of the reliability of serial pure tone audiograms in a deaf school population. Forty-nine percent of the 414 audiogram pairs were found to differ by 20 dB or more. Any procedure which differs on test retest data by greater than $\pm$ 5 dB (Barr, 1955), is not considered to be a reliable testing means. The data gathered by Rapin and Costa disclosed relatively low reliability of the serial audiometry conducted on hard-of-hearing population.

The conventional audiometric procedure of instructing the individual to respond in some defined manner to stimuli he can detect is satisfactory for many subjects, but has yielded unsatisfactory results with many very young or difficult-to-test children. It is the general opinion that with "normal" children five years of age is about the youngest level at which conventional audiometric procedures are reliable (O'Neill, 1969; Davis, 1967; Eagles & Wishik, 1961). Nevertheless, it is essential that there be some reliable means to assess the hearing sensitivity of the preschool and difficult-to-test child, in order that appropriate habilitation procedures may be instituted if needed. With the hard-of-hearing child, one encounters an individual who is linguistically handicapped, in need of evaluation as early as possible, often exhibits deviant behavior, motivation is difficult to assess and to whom sound of any kind may carry very little meaning (Davis, 1965; Eagles & Wishik, 1963; Bricker & Bricker, 1969). These factors have much in common with the problems which are encountered in testing the hearing of the retarded child (Mykelburst, 1956; Goldstein, 1963; Fulton & Lloyd, 1969). Because of the similarities, it would seem reasonable to look to studies employing operant methods for hearing assessment as have been done among the mentally retarded population.

Assessment of hearing by operant procedures was first employed by Myerson and Michael (1961). They proposed that the procedure would need to be: (1) simple enough for use with a two-year-old child and other "hard-to-test" subjects; (2) verbal behavior would not be required on the part of the audiologist or subject; (3) a positively reinforcing environment to which the subject could be exposed for a long period of time would need to be created; and (4) once the subject was placed at the automated audiometer, he would plot his own audiograms without further intervention by the audiologist. In the Myerson and Michael study, the discriminative stimulus ($S^D$) was the presentation of a tone and a light simultaneously. The unconditioned reinforcers used were a variety of trinkets and candies. The child was trained to give two responses: (1) to depress one button upon presentation of the stimulus, and (2) to depress another button upon cessation of the stimulus. Both responses received positive reinforcement (candies or trinkets). A bonus reward was also included for a quick response. Delivery of reinforcement was by means of an automat.

Lloyd (1965) reported the use of another operant audiometric procedure in which the reinforcements used were slides rather than candy and trinkets.

In this procedure, the child had no direct control over what would serve as reinforcement. Only one response was desired of the child; he was to press a button upon presentation of a tone. The button press was then reinforced with the presentation of a slide picture. If a response was made when no tone was present, no reinforcement was delivered, and a delay in tone presentation was introduced.

A further investigation in operant audiometry was conducted by Lloyd, Spradlin and Reid, in 1968. This procedure has several similarities to the procedure described by Myerson and Michael. The reinforcers employed were candies, trinkets, liquids such as pop and, in some cases, social reinforcement delivered under controlled conditions. The determination of reinforcement to be used was conducted by showing the child the various choices and watching for a sign of preference on the part of the child. The determination of a reinforcer was conducted once, at the onset of the conditioning procedures. As in the Myerson and Michael study, a visual cue (a light) was presented simultaneously with the introduction of a tone as a facilitator for the acquisition of stimulus control. Instead of a 2-button response however, Lloyd, Spradlin and Reid employed a 1-button response; a lever press at tonal presentation was the desired response. A response when no tone was present resulted in no reinforcement and a delay in tone presentation. The exact criterion for demonstrating stimulus control in conditioning was not reported.

Another variation of the operant audiometric procedures was reported by Fulton and Spradlin (1968). Once again the reinforcers used were edibles, small trinkets, and controlled social reward. The examiner selected a reinforcer prior to the beginning of training, and showed it to the child in order to evaluate the motivation of the child. The child was conditioned to depress a button upon stimulus presentation. Responses during the tone-off period ($S^{\Delta}$) led to a delay in presentation of the $S^D$. The criterion for response control was defined as responding to all $S^D$ periods for five consecutive stimuli presentations with no responses during $S^{\Delta}$. The test-retest data was reported to have a reliability of $\pm$ 5 dB in five out of six sessions with 5 out of 6 subjects.

Fulton and Lloyd (1969) conducted a study in which the main concern was the question of reliability and validity in the operant audiometric procedure when positive reinforcement was employed. Reinforcements used in this procedure were edibles and controlled social reward. The reaction of the child to the edibles was used to determine which reinforcer would be used; if presentation of a reinforcer increased responding by the child (smiling or reaching for the object), it was used. The data did not report how frequently the child was given the opportunity to determine the reinforcement. The child was conditioned to press a button upon presentation of a tone. Upon an appropriate response, the reinforcer was delivered into a tray. The tray was illuminated simultaneously with the delivery of the reinforcer. The purpose of the light (a conditioned reinforcer) was to strengthen the "button-press" response. To meet criterion for beginning threshold testing, the child had to respond 90 percent of the time when the $S^D$ was present, and could not respond more than 10 percent of the time during $S^{\Delta}$. On 5 out of 6 subjects, criterion of $\pm$ 5 dB on test retest reliability was met. The data seemed to indicate that operant audiometry is an efficient means of evaluating the hearing of severely retarded children.

Fulton and Spradlin (1971) conducted yet another study with operant audiometric procedures, which was designed to compare ascending and descending methods for obtaining threshold estimates. The results suggested that ascending-descending techniques are not a critical variable. The method of determination of reinforcement was not described. The criterion of stimulus control was 90 percent response rate to the stimuli, and no more than 10 percent response rate to S in the conditioning phase of the test. The results indicated a test-retest reliability of $\pm$ 5 dB with 5 out of 6 individuals.

Knowles (1971) reported the use of an operant procedure similar to those previously described. The population for the study, however, was not retarded and had a mean age of 26.3 months. The reinforcements were made up of edibles and small trinkets. Before each testing session, the child was able to sample and choose the reinforcer for which he wished to work. The sampling and choosing before each testing session was introduced in an attempt to maintain a high level of motivation. The criterion for stimulus control was a response rate of 90 percent during $S^D$ and less than 10 percent response rate during $S^\Delta$. This control check, however, was not limited to the conditioning phase; before each testing session, the child was required to meet the previous criterion. If he did not meet the criterion, a conditioning, rather than a testing session was imposed. The response rate during $S^\Delta$ was also monitered during testing sessions; if the response rate was greater than 10 percent, the data was not used. It was reported that the test-retest criterion of $\pm$ 5 dB was met with 10 out of 10 children.

In all the operant conditioning procedures, two major learning principles are present: (1) use of reinforcers to develop and maintain relevant responses, and (2) bringing the desired response under control of tonal stimuli by the systematic sequencing of environmental events (Bricker & Bricker, 1969). The majority of data gathered concerning test-retest reliability of operant audiometric procedures has shown to be relatively high. There are also additional benefits provided by operant audiometry: (1) an objective assessment is possible; (2) sustained motivation is possible; (3) verbal interaction between examiners and subject is eliminated; (4) no fluctuation in reinforcement is present as occurs with uncontrolled social reinforcement; (5) immediate reinforcement is possible; and (6) standardization of procedures between audiologists and clinics can be obtained (Smith & Hodgson, 1970; Roberts, 1972).

Due to the apparent "success" of operant audiometric procedures when employed among the retarded and preschool children, it would seem reasonable to employ these procedures with hard-of-hearing children. The purpose of this study is to assess the feasibility of employing a particular operant audiometric procedure (Knowles, 1971) in the determination of threshold estimates of hard-of-hearing children. Since the children employed were all hearing aid users, a further use of the procedure was explored in connection with obtaining an estimate of the amount of amplification provided by the aid on any given day.

# CHAPTER II

## METHOD

Subjects:

The subjects for this research were six hearing impaired children whose ages ranged from 3 years 4 months to 7 years 10 months, with a mean of 5 years 8 months. Five subjects were male and one subject was female. The subjects were obtained through the class-for-the-hearing-impaired in the public schools.

Apparatus:

The pure tone stimuli (250, 500, 1000, 2000, 4000, 6000, and 8000 Hz) were generated and controlled by a Maico Model MA-8A audiometer. The stimuli were presented through TDH-39 earphones. Stimulus levels were calibrated using a Bruel and Kjaer artificial ear, type 4152, a Bruel and Kjaer, type 4144 condenser microphone and Bruel and Kjaer, type 2615 pre-amplifier with a Bruel and Kjaer model 2603 microphone amplifier.

When an estimate of aplification was obtained, the narrow band noise signals, with center frequencies of 500, 1000, 2000, and 4000 Hz and a nominal width of 36 Hz, were generated by modulating a sinusoidal carrier with a low pass noise. The output of a Hewlett-Packard model 200 CDR oscillator was led to the carrier input on a Grason-Stadler model E 3382C modulating switch. The signal, led to the modulator input of the switch, was obtained by low-pass filtering the output of a Grason-Stadler, model E 10588A noise generator by an Allison model 2BR filter. The output of the modulating switch was monitered on the VU meter of the Maico audiometer.

All tests were administered in an Industrial Acoustics Company model 1203 auditory test suite. The response-reinforcement delivery box in the test suite contained a Davis universal feeder, model 310, which was activated by the programming equipment in the control room. Upon delivery of reinforcement, the reinforcement tray was illuminated for approximately one second. The response button, a perforated metal plate activated by the subject's touch, was to the right of the reinforcement tray. A schematic diagram of the apparatus of provided in Fig. 1.

Two experimenters were utilized; Experimenter I remained with the subject in the test suite, while Experimenter II controlled the frequency and intensity of the test stimulus at the audiometer. Stimulus duration, reinforcement delivery and stimulus-response records were controlled and recorded by a relay rack consisting of timers, relays and counters. The schedule controlled by the relay equipment is shown in a Mechner diagram form in Figure 2.

In the threshold determination phase of this study, a pure tone was presented to the subject's earphones at the onset of the $S^D$ condition. A response (R), within the time interval (2 seconds) led to reinforcement ($SR^+$). If no response (R) occurred within the time interval (2 seconds), this produced the recycling of the tone off ($S^\Delta$) condition. Lapse of a variable time period (VT) of tone off led to a subsequent presentation of the pure tone ($S^D$). If a response occurred during the tone off condition, the VI tone off condition was recycled.

When an estimate of the amplification provided by the subject's hearing aid was obtained, the signal ($S^D$) employed was a narrow band of noise delivered via sound field. All conditions, except the stimulus and method of delivery, were the same as those described in the previous paragraph.

Procedure:

The procedure consisted of five phases: 1) determining an effective reinforcer; 2) stimulus control training conducted through earphones with conditioning frequency determined from the child's previous history (intensity used was 40 dB above previously estimated threshold level or 100 dB, whichever provided to be the lower intensity); 3) obtaining threshold estimates under earphones for 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz by a descending method of limits (stimulus lowered in 10 dB steps until no response; then the tone was increased 10 dB and lowered in 5 dB steps until there was no response; repeat until a 50% or three out of six level is obtained as the threshold estimate); 4) obtaining threshold estimates for narrow band noise in a sound field with hearing aid and; 5) obtaining threshold estimates for narrow band noise in a sound field without a hearing aid.

Prior to each session, the child was allowed to sample, to handle, and to select his reinforcer before entering the sound treated room. The items for which the child indicated a preference were then loaded into the reinforcement delivery mechanism.

Once the reinforcer was selected and loaded into the delivery box, the child was seated in front of the reinforcement delivery mechanism and the earphones were placed on his head. A pulsing tone was presented as the discriminative stimulus. Both frequency and intensity of the conditioning tone were individually determined for each child because of the varied hearing losses among the children. Experimenter I attracted the child's attention and demonstrated the response reinforcement relationship by touching the response button. The subject observed the reinforcer being delivered as a result of Experimenter I touching the response button. Several subjects responded appropriately and independently following the demonstration. However, if the subject did not respond appropriately, Experimenter I demonstrated the response again. After the subject emitted five consecutive responses, the conditions were changed. The new contingencies were as follows: A response in the presence of the tone provided a reinforcement and terminated the tone-on condition for the variable interval. If no response occurred during the variable interval of the tone-off condition, the tone-on condition was then reinstated. Each response during the tone-off condition delayed the reinstatement of the tone-on condition for five seconds. Additionally, during the tone-off condition, no reinforcers were delivered.

The duration of the tone-off condition was gradually lengthened from the initial two second duration to a variable duration of five to twenty-five seconds with a mean length of ten seconds. Responses which occurred during the tone-off condition further delayed the reinstatement of the tone-on condition. Concomitantly, the tone-on condition was gradually shortened from a pulsing thirty second tone to a pulsing two second tone. Thus the subject has two seconds in which to respond to the tone. Failure to respond caused reinstatement of the tone-off condition. This training schedule was held in effect until the training criteria were met. These criteria were: a response rate of at least ninety percent to $S^D$ and a response rate of less than ten percent during the tone-off condition.

After the criteria were met, threshold testing was initiated. At the onset of each testing session, the child had to demonstrate stimulus control at the frequency and intensity at which conditioning was conducted. If the criterion was not met, a training rather than testing session was conducted. Intensity generalization (Knowles, 1971) was not conducted due to the extreme hearing losses of the subjects; in order to assess stimulus control, it is essential that the experimenter knows that the child is perceiving the $S^D$. Response rate during $S^{\Delta}$ was also monitered during each testing session. If the rate exceeded ten percent, data from that session was discarded. During threshold testing, the $S^D$ duration was two seconds, with a VI ten second $S^{\Delta}$ condition.

Retesting followed the same procedures as discussed for initial testing. Testing and retesting, however, were not done in the same session.

The procedures for obtaining an estimate of the amplification provided by the subject's hearing aid (unaided threshold minus aided threshold) were the same as for obtaining threshold estimates under earphones. A time lapse between threshold estimates under earphones and threshold estimates in the sound field was introduced to observe what affect it might have on the stimulus control. During this phase of testing, two variables were not rigorously controlled; (1) no attempt was made to control the gain setting of each child's aid; (2) no attempt was made to control the condition of the batteries in each child's aid. Thus, the data gathered provided only an estimate of the amount of amplification provided by the child's hearing aid on a given day.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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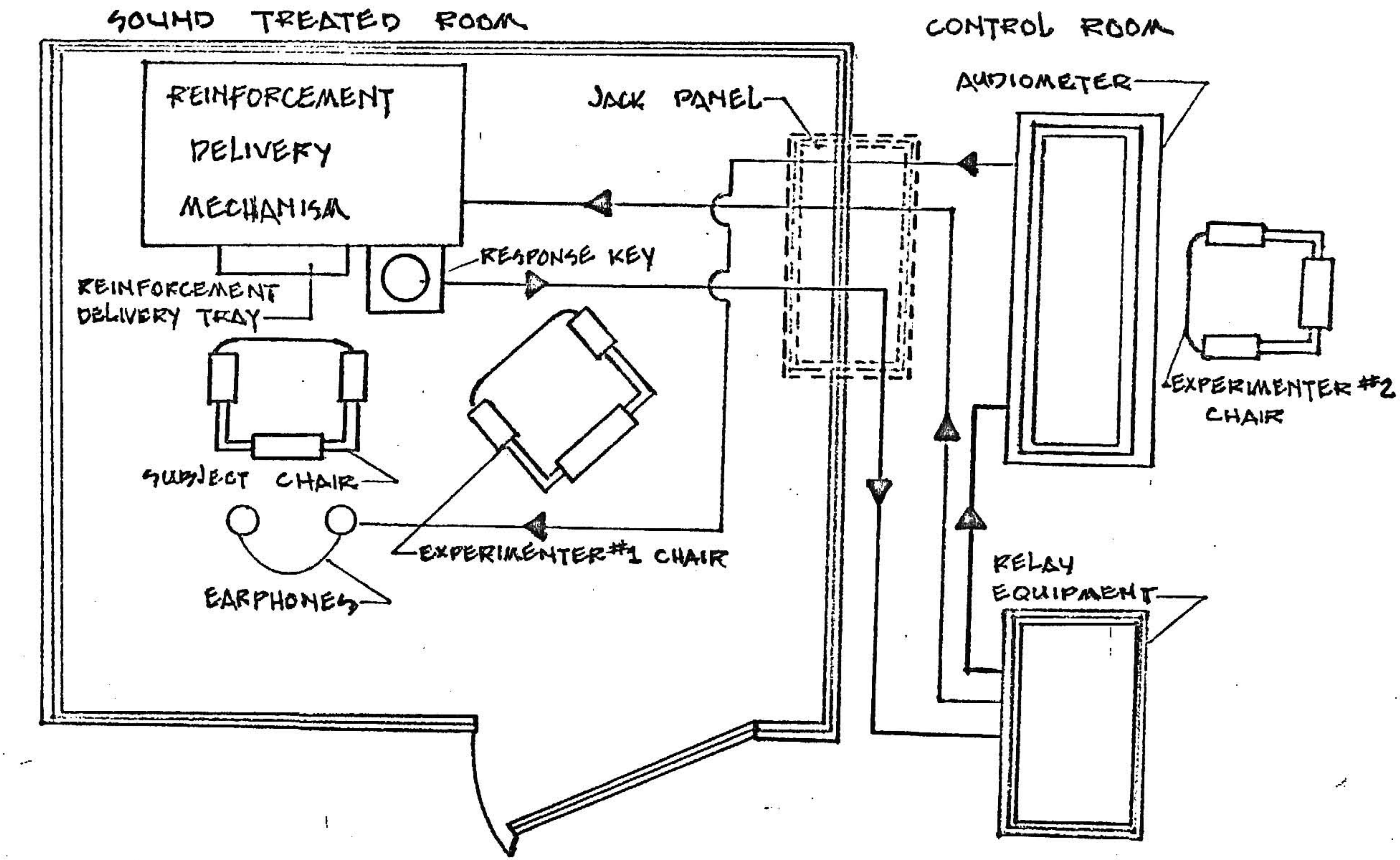
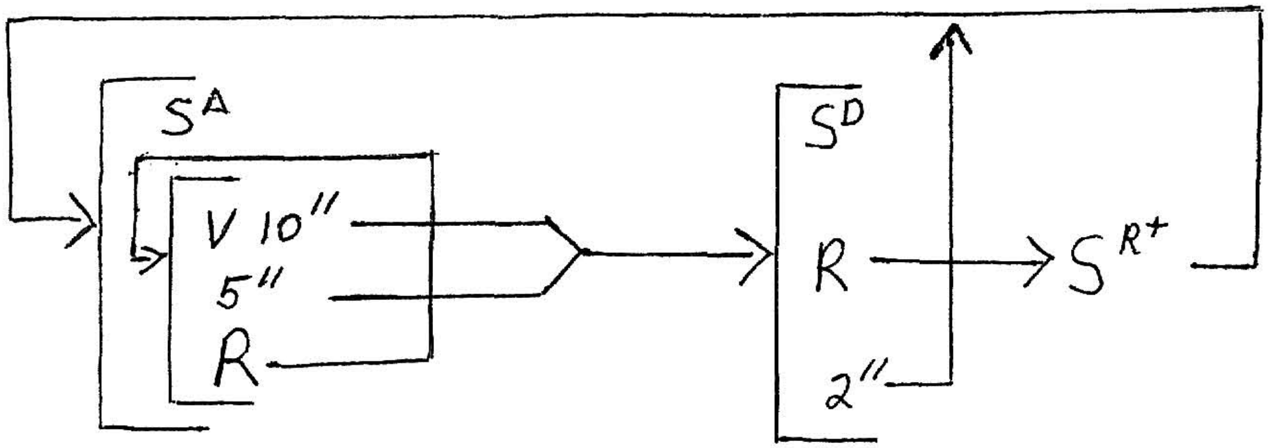



Fig.1 Schematic drawing of testing suite.




R = touch response key

$S^D$ = tone on

$S^{\Delta}$ = tone off

→ = produces

↑ = prevents

$S^{R+}$ = reinforcing stimulus

V = variable time

→ = produces

conditions listed against the bracket go into effect simultaneously

Figure 2. Mechner diagram of the terminal training schedule for operant audiometry with hearing impaired children.

# CHAPTER III

# RESULTS

The results of this research are presented in reference to stimulus control training, reliability of threshold estimates, stimulus control following a time lapse and amplification provided on a given day by the S's hearing aid.

## Stimulus Control

The criterion of stimulus control was met if the S responded to 90 percent of pure tone presentations with a less than 10 percent probability of response during variable tone-off intervals. The restuls of stimulus control for training are shown in Table I. Five of six S's met the criterion for $S^D$, with a mean of 100 percent. In the $S^{\Delta}$ condition, the mean response probability for these S's was 0.2 percent. These S's were conditioned in twenty-five minutes or less, with a mean training time of seventeen minutes.

S-6 did meet the criterion for $S^D$, but demonstrated a 93 percent response rate rather than the 100 percent rate demonstrated by the other S's. Also, S-6 frequently exhibited a response probability greater than 10 percent during $S^{\Delta}$ . Consequently, data from these sessions were discarded. Another variance between S-6 and the remaining S's was that S-6 demonstrated stimulus control after 200 minutes, while the remaining S's demonstrated stimulus control after a mean of seventeen minutes.

## Reliability

Table II shows the test-retest data. Reliable threshold estimates (difference of 5 dB or less between test-retest data) were obtained with the first five S's on both left and right ears. During the threshold search, the mean response probability of five of the six S's during $S^{\Delta}$ was 0.8 percent. During retesting, their mean probability of response during S was 0.7 percent. These percentages were well within the established criterion. Approximately two hours per S was the mean time taken to obtain threshold estimates and retest data with five out of six S's.

With S-6, after eight hours and thirty minutes of threshold searching, reliable threshold estimates were obtained for the left ear only. Frequently, S-6 demonstrated greater than a 10 percent probability of response during $S^{\Delta}$. When this occurred, the session was ended, and the data from that session were discarded.

Stimulus Control Following Time Lapse

The mean time lapse between test and retest sessions for pure tone testing was two days, while there was a time lapse of at least one week between pure tone testing, and the sound field testing which utilized noise bands. A measurement of $S^D$ control was obtained when estimating the amplification provided by the child's aid since this provided a time lapse of at least one week. Table III depicts aided and unaided threshold estimates, $S^D$ control, probability of response during $S^{\Delta}$, and the testing time. Five of the six S's met the previous criterion. All of the five S's responded to 100 percent of the $S^D$'s. The mean response rate during $S^{\Delta}$ of these subjects was 1.0 percent, which was also well within the established criterion. The mean time taken to obtain the aided and unaided threshold estimates was approximately twenty-five minutes. Pure tone testing and testing in the sound field were each accomplished at approximately the same rate;

about five minutes per frequence.

S-6 demonstrated a 93 percent response rate to the $S^D$, which was within the criterion, but below that of the remaining five S's. The response rate of S-6 during $S^\Delta$ was 4.1 percent, which was greater than that of the other S's, but within the criterion. One hundred twenty minutes were taken in order to obtain aided and unaided threshold estimates for S-6. This S was the only one whose response rate during $S^\Delta$ necessitated the discarding of data.

Amplification

Figure 3 displays the amplification provided by the Ss' aids to narrow bands of noise with center frequencies of 500, 1000, 2000, and 4000 Hz. All six Ss' hearing aids were providing some amplification. In the following discussion, the means referred to are the means of 500, 1000, and 2000 Hz, since these are the frequencies included in the HAIC method. S-1's hearing aid provided a mean amplification of 50 dB, with a fairly even distribution. S-3's aid provided a mean amplification of 55 dB with a fairly sharp drop in the amplification provided at 4000 Hz. S-4's aid provided a mean amplification of 35 dB, with a fairly sharp peak at 1000 Hz. S-5's aid provided a mean amplification of 35 dB, with a fairly even distribution of amplification. S-6 wore her hearing aid in the right ear, the ear with which no reliable threshold estimates were obtained. The data gathered with S-6's aid in the sound field, revealed that some amplification was being provided. The amplification levels revealed, however, may not be reliable since no retest information was obtained.

Figure 4 displays the Ss' pure tone threshold estimate in accordance with the level which the amplification would approximately provide. The pure tone threshold points were shifted by the amount of amplification displayed in the aided and unaided testing.

TABLE I. Observed stimulus control prior to threshold search ($S^D$ = discriminative stimulus, $S^\Delta$= no tone intervals).

| Subjects | Stimulus $S^D$ | Control $S^\Delta$ | Training Time (min.) |
|---|---|---|---|
| S-1 | 100% | 0% | 15 |
| S-2 | 100% | 1% | 20 |
| S-3 | 100% | 0% | 25 |
| S-4 | 100% | 0% | 10 |
| S-5 | 100% | 0% | 15 |
| S-6 | 93% | 6% | 200 |

TABLE II. Age, test and retest threshold estimates. The mean percent of probability of response to S$\Delta$ during test and retest sessions. Time required for test and retest of left and right ears.

| | Age | | .25K Hz | .5K Hz | 1K Hz | 2K Hz | 4K Hz | 6K Hz | 8K Hz | T | Stimulus Control Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S-1 | 7 yr. | R Test | 75 dB | 75 dB | 75 dB | 105 dB | 100 dB | NR | NR | | Test .5% |
| | 1 mo. | R Retest | 70 dB | 70 dB | 75 dB | 100 dB | 95 dB | NR | NR | | |
| | | | | | | | | | | | Retest .6% |
| | | L Test | 40 dB | 50 dB | 70 dB | 100 dB | 90 dB | NR | 85 dB | 2 hr. | |
| | | L Retest | 40 dB | 55 dB | 70 dB | 105 dB | 90 dB | NR | 85 dB | | |
| S-2 | 3 yr. | R Test | 55 dB | 70 dB | 90 dB | 100 dB | 90 dB | NR | NR | 2 hr. | Test .9% |
| | 6 mo. | R Retest | 50 dB | 75 dB | 90 dB | 100 dB | 90 dB | NR | NR | 50 min. | |
| | | | | | | | | | | | Retest 1.5% |
| | | L Test | 60 dB | 65 dB | 90 dB | 100 dB | 95 dB | NR | NR | | |
| | | L Retest | 55 dB | 65 dB | 95 dB | 100 dB | 100 dB | NR | NR | | |
| S-3 | 6 yr. | R Test | 80 dB | 85 dB | 95 dB | 100 dB | NR | NR | NR | | Test 1.2% |
| | | R Retest | 85 dB | 90 dB | 95 dB | 100 dB | NR | NR | NR | 2 hr. | |
| | | | | | | | | | | | Retest 1.3% |
| | | L Test | 75 dB | 90 dB | 90 dB | 100 dB | 100 dB | NR | NR | | |
| | | L Retest | 75 dB | 85 dB | 90 dB | 95 dB | 95 dB | NR | NR | | |
| S-4 | 7 yr. | R Test | 75 dB | 90 dB | 80 dB | 70 dB | 70 dB | 80 dB | 80 dB | | Test .6% |
| | 7 mo. | R Retest | 75 dB | 90 dB | 85 dB | 75 dB | 75 dB | 80 dB | 80 dB | 1 hr. | |
| | | | | | | | | | | 45 min. | Retest .5% |
| | | L Test | 80 dB | 85 dB | 85 dB | 80 dB | 70 dB | 70 dB | 70 dB | | |
| | | L Retest | 75 dB | 85 dB | 85 dB | 80 dB | 70 dB | 75 dB | 70 dB | | |

TABLE II. (Continued)

| | Age | | .25K Hz | .5K Hz | 1K Hz | 2K Hz | 4K Hz | 6K Hz | 8K Hz | T | Stimulus Control | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-5 | 5 yr. | R Test | 80 dB | 90 dB | 100 dB | 105 dB | NR | NR | NR | | Test | .5% |
| | 7 mo. | R Retest | 80 dB | 90 dB | 95 dB | 105 dB | NR | NR | NR | 1 hr. | | |
| | | | | | | | | | | 45 min. | Retest | .4% |
| | | L Test | 80 dB | 100 dB | 100 dB | NR | NR | NR | NR | | | |
| | | L Retest | 80 dB | 100 dB | 100 dB | NR | NR | NR | NR | | | |
| S-6 | 5 yr. | R Test | No reliable thresholds were obtained for the right ear | | | | | | | | Test | 5.4% |
| | 5 mo. | R Retest | | | | | | | | 8 hr. | | |
| | | | | | | | | | | 30 min. | Retest | 6.7% |
| | | L Test | 65 dB | 60 dB | 50 dB | 60 dB | 30 dB | 90 dB | 100 dB | | | |
| | | L Retest | 65 dB | 60 dB | 50 dB | 60 dB | 35 dB | 90 dB | 95 dB | | | |

TABLE III. Aided and unaided threshold estimates. Stimulus control at onset of session. Mean response probability during $S^{\Delta}$ condition. Time required for aided and unaided testing.

| | | 500 | 1000 | 2000 | 4000 | $S^D$ Control at Onset | $S^{\Delta}$ Response Probability | Time |
|---|---|---|---|---|---|---|---|---|
| S-1 | Aided | 30 dB | 30 dB | 55 dB | 80 dB | 100% | .6% | 30 min. |
| | Unaided | 60 dB | 70 dB | NR | 85 dB | | | |
| S-2 | Aided | 30 dB | 30 dB | 50 dB | 60 dB | 100% | 1.5% | 35 min. |
| | Unaided | 80 dB | 80 dB | NR | NR | | | |
| S-3 | Aided | 40 dB | 30 dB | 35 dB | 65 dB | 100% | 1.7% | 30 min. |
| | Unaided | 90 dB | 90 dB | NR | NR | | | |
| S-4 | Aided | 60 dB | 30 dB | 50 dB | 60 dB | 100% | .4% | 20 min. |
| | Unaided | 85 dB | 80 dB | 80 dB | 65 dB | | | |
| S-5 | Aided | 55 dB | 55 dB | 65 dB | 70 dB | 100% | .6% | 25 min. |
| | Unaided | 95 dB | 95 dB | NR | NR | | | |
| S-6 | Aided | 0 dB | 0 dB | 10 dB | 0 dB | 93% | 4.1% | 120 min. |
| | Unaided | 40 dB | 40 dB | 40 dB | 35 dB | | | |

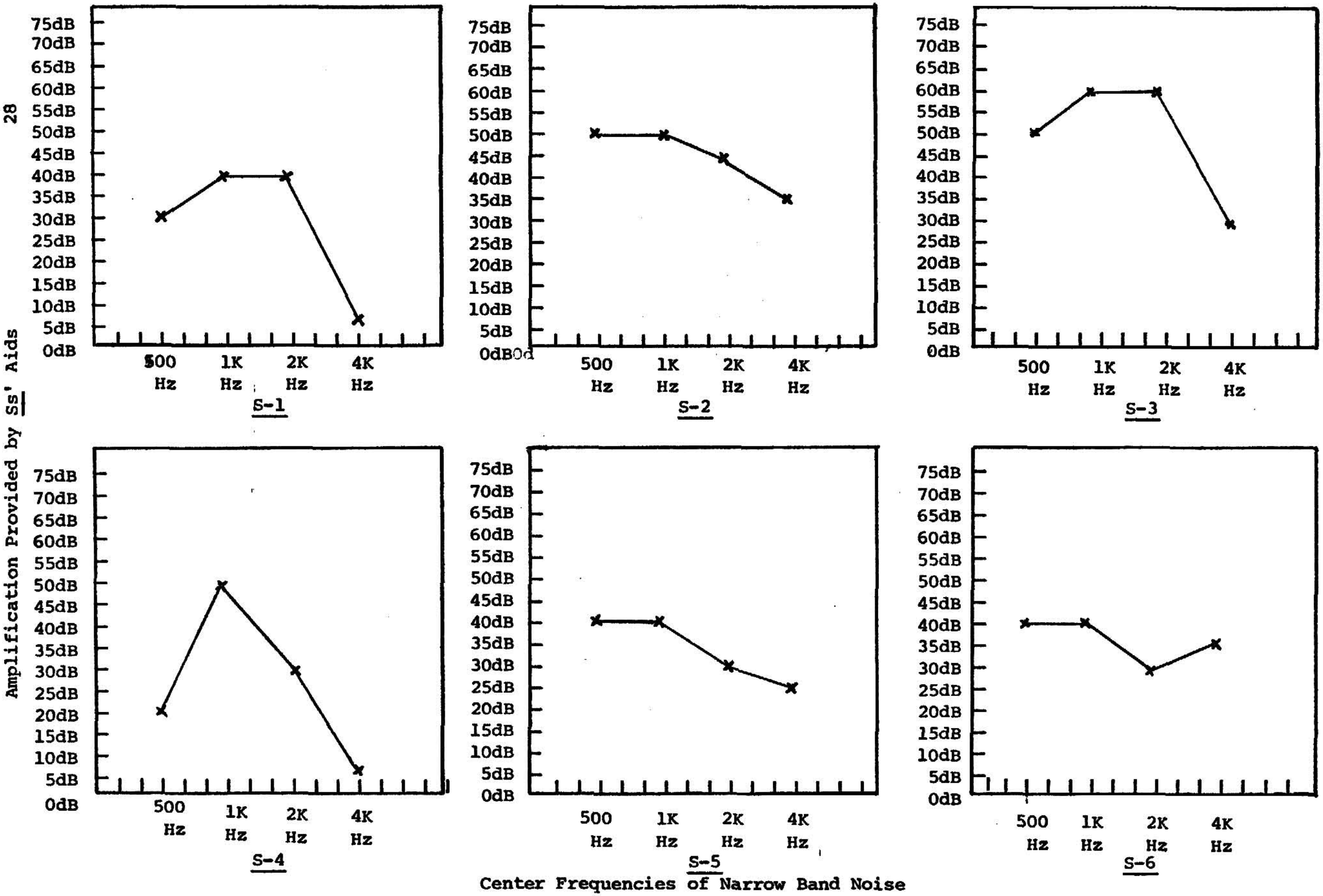



**Fig. 3** Ampliffcation provided by the Ss' aids to narrow band noise with center frequencies of 500, 1000, 2000 and 4000 Hz on a given day.

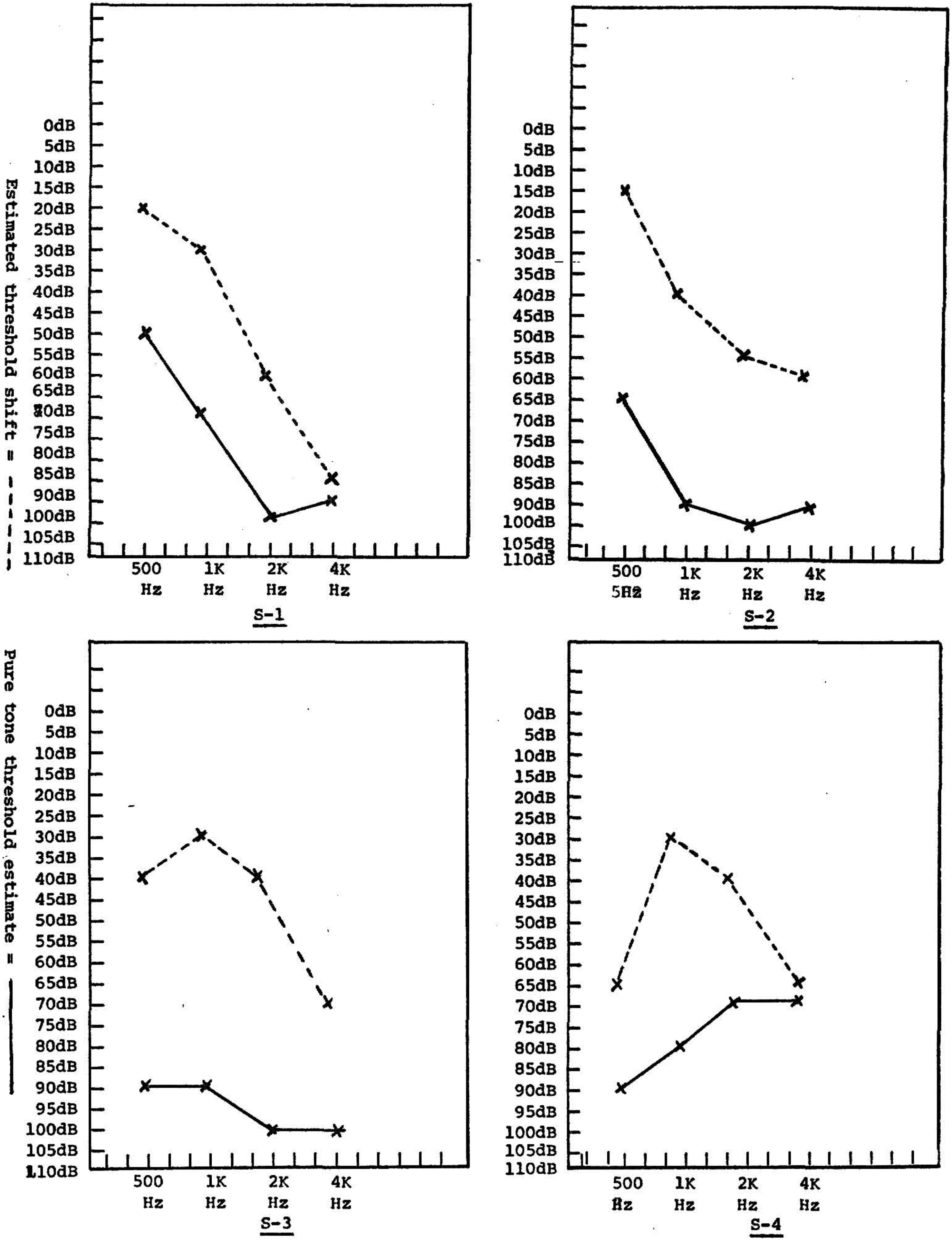



Fig. 4 Pure tone threshold shift in relation to amplification provided by Ss' aids.

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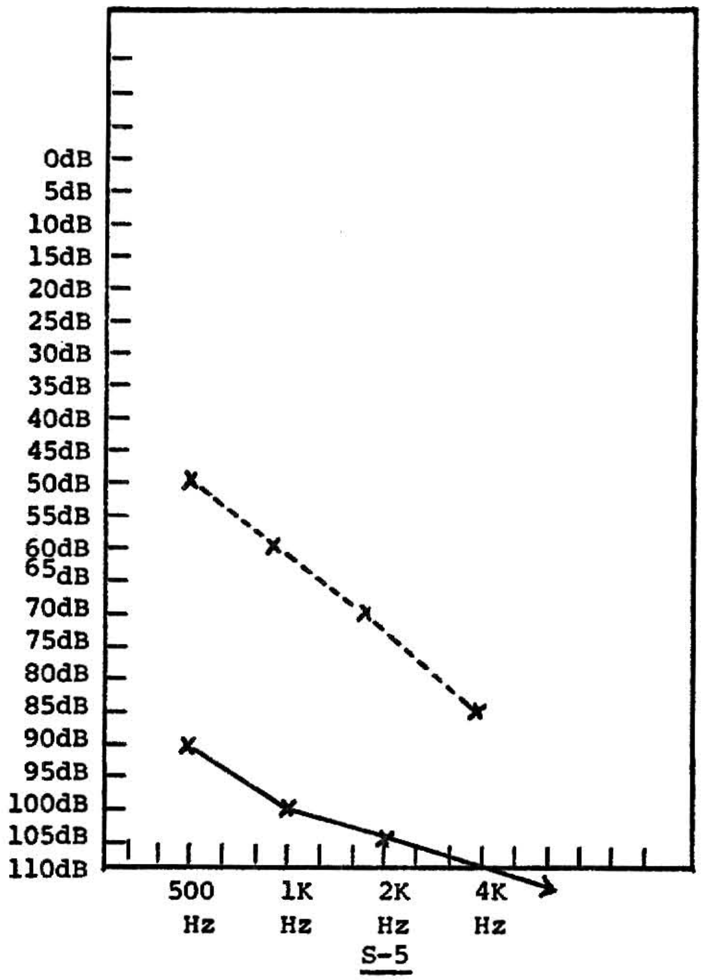


Fig. 4 Continued.

# CHAPTER IV

## DISCUSSION

The results of this research have provided several implications concerning the use of operant audiometry with the hearing impaired child. With five of the six subjects (approximately 83 percent) reliable threshold estimates (test-retest differing by ± 5 dB) were obtained for both the left and right ears, at 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. It was not known whether previous testing on these subjects was subject to any reliability criterion. The present research compared favorably with research conducted by Fulton and Spradlin (1968). They reported that five of six subjects (approximately 83 percent) demonstrated test-retest reliability to be within ± 5 dB. Bricker and Bricker (1969) reported similar results with a slightly differing definition of reliability. In their study, reliability was defined as a difference of ± 10 dB rather than ± 5 dB. With the ± 10 dB criterion, Bricker and Bricker reported approximately 83 percent reliability. Another operant audiometry study (Knowles, 1971) reported a slightly higher percentage of reliability (criterion of ± 5 dB) of 100 percent with ten of ten subjects. Reviewing the findings concerning the reliability of operant audiometric procedures, it would seem that the data have all been relatively similar. The fact that two of the studies used low-functioning children (Fulton and Spradlin, 1968; Bricker and Bricker, 1969), one used "normal" two-year-olds (Knowles, 1971) and the present study used hard of hearing children, did not seem to have any significant effect on the reliability of test-retest data.

When considering the training time, however, the findings of this study were not consistent with previously reported data. In the present study, the mean training time per subject, with five of the six subjects, was seventeen minutes. This was a considerably shorter training time than had been previously reported with similar procedures. Bricker and Bricker (1969) researched four variances of operant procedures with low-functioning children. The shortest mean training time per subject reported was approximately 212 minutes. Lloyd, Spradlin and Reid (1968) reported that training was ceased after approximately 200 minutes if the stimulus criterion had not been met. Eight of the fifty subjects tested fell into that category. In Knowles' (1971) study with "normal" two-year-olds, approximately 110 minutes per subject were necessary to achieve stimulus control. There are several factors which could attribute to this variance in training time between the present study and previous studies. The population for the present study was not known to be mentally retarded and was generally older than the population used by Knowles (1971). Another factor which must be considered, is that five of the six subjects in the present study had undergone some form of previous testing. It is possible that these children adjusted to the setting more quickly than would children with no prior experience. However, the subject who had not previously been tested did not demonstrate a training time (twenty-five minutes) significantly different from the remaining subjects. This child was also the youngest child included in this study (three years, six months).

Another temporal relationship which was studied in this research, dealt with the effect of a time lapse upon the stimulus control. This time lapse between threshold testing and sound field testing did not seem to have any significant effect on the stimulus control. The stimulus control remained approximately the same even following the time lapse. Neither did the lapse of time seem to affect the speed in which the threshold estimates were obtained. The pure tone threshold testing and the aided and unaided testing were each accomplished at approximately the same rate. Since there was no apparent change in the stimulus control or time rate between the two testing settings, it could also be assumed that the change of $S^D$ from a pure tone to a narrow band noise did not have any significant effect upon the testing. It would be interesting to determine how large a time lapse would be necessary to elicit a substantial change in $S^D$ control. If it was found that a year's time lapse elicited no substantial change, this operant procedure should be able to save some time taken in the child's annual exams. If there was good carry-over annually, this would eliminate the training time initially involved.

A further use of the present study was to aid in the acquisition of an estimate of the amplification provided by the child's aid. An estimate of the amplification was readily obtained with five of the six subjects. There was, however, no attempt made to monitor the battery condition of each aid, or to control the gain setting. If a more precise measure of amplification was desired, those variables would have to be controlled.

During this study, S-6 was the only subject with whom any difficulties were encountered. This subject was the only one to have an acquired loss which was obtained at the age of four when the child suffered from spinal meningitis. During this study, a great deal more time was necessary to train and test this subject than was necessary with the remaining subjects. In addition, S-6 never demonstrated the high degree of stimulus control that was exhibited by the other subjects. With the remaining five subjects, reliable threshold estimates were obtained for both the left and right ears, whereas with S-6, reliable threshold estimates were only obtained on the left ear. Testing was ceased due to time limitations. It is possible that this subject might have learning difficulties other than those directly associated with a hearing handicap. This factor has not been substantiated, however.

Throughout each phase of this study, every attempt was made to sustain the motivation of the child by enabling him to determine his reinforcer prior to each session. With the younger children, edible items frequently seemed to be the most rewarding; the older children, however, often chose small toys. The selected toy was displayed to the subject during the session and following completion of the session (if the subject had obtained the predetermined number of tokens) the child received the toy. If this procedure was conducted with older children, it might prove to be useful to introduce a more complete token system (Ayllon and Azrin, 1968).

The following conclusions appear warranted on the basis of the data collected: with hearing impaired children, this procedure seems to be (1) a reliable means of hearing assessment; (2) a relatively efficient means of obtaining threshold estimates with respect to testing time; and (3) a relatively rapid method for obtaining useful data concerning the amplification being provided the child by his hearing aid.

For further substantiation of this procedure, several variables should be more rigorously controlled. In the future, research should be conducted with hearing impaired subjects of younger age levels who have no history of previous testing. If a precise estimate of the gain of the hearing aid is desired, the state of the battery should be checked and the gain setting of the aid should be controlled.

Presently, it would seem that operant audiometric methods do hold promise for use with the hearing impaired child. The data from this study along with the previous data, indicate operant audiometric procedures to be very reliable and not excessively time consuming.

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OPERANT AUDIOMETRY WITH
THE HARD OF HEARING CHILD

by

BEVERLY GAYLE VOLKLAND

B.S., Kansas State University, 1971

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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This research attempted to assess the effectiveness of operant audiometry with hard-of-hearing children. A specific operant procedure (Knowles, 1971) was utilized to obtain pure tone threshold estimates and an estimate of amplification provided by the child's hearing aid on a given day.

The effectiveness of the operant audiometric procedure was contingent upon several measures: (1) percent of subjects brought under stimulus control. Stimulus control was defined as discriminative control of the response to a stimulus, or responding to ninety percent of $S^D$ presentations with a less than ten percent probability of response during S ; (2) testability factor; defined as the number of subjects who produced sufficient data to obtain pure tone threshold estimates; (3) reliability criterion; defined by test-retest procedures of threshold estimates of $\pm$ 5 dB; (4) stimulus control following a time lapse of at least one week; and (5) number of subjects who produced sufficient data to obtain an estimate of amplification provided by their hearing aids.

The mean age of the six subjects was five years and ten months, ranging from three years, six months to seven years, seven months. Automatic programming equipment controlled and recorded the stimulus duration, variable time intervals between stimulus presentation, response detection, reinforcement delivery and stimulus response records. Stimulus intensity and frequency were controlled by the experimenter at the audiometer. Narrow bands of noise were utilized to obtain estimates of amplification provided by the aids.

The procedural sequence for each subject was as follows:

1. Stimulus control training with pure tone stimulus presented through earphones.
2. Obtaining threshold estimates with descending method of limits for 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz, for right and left ears.
3. Retest of step two.
4. Obtaining aided threshold estimates via sound field for narrow band noise with center frequencies of 500, 1000, 2000, and 4000 Hz.
5. Obtaining unaided threshold estimates via sound field for narrow band noise with center frequencies of 500, 1000, 2000, and 4000 Hz.

Reinforcement exposure and selection procedures preceded each session.

The data on stimulus control training indicated that five of the six subjects did meet the previously stated criterion. With five of the six subjects, the stimulus training was affected relatively quickly. Stimulus training with the sixth subject, however, took a considerably longer amount of time. Reliable threshold estimates were obtained for right and left ears with five of six subjects. With subject six, reliable threshold estimates were only obtained on the left ear. Estimates of amplification provided by the hearing aids were obtained for all six subjects. Again, however, subject six required a great deal more time to obtain the necessary data than did the remaining five subjects. The time lapse between pure tone testing and the sound field testing had no apparent effect on stimulus control.

With respect to achievement of stimulus control, testability and reliability, the findings of this research indicate operant audiometry to be a useful technique with the hearing impaired child. Further research should be attempted with even younger hearing impaired children who have undergone no previous type of testing.