To the Graduate Council:

I am submitting herewith a thesis written by Jolie Carin Fainberg entitled "A Comparison of Auditory Intensity Discrimination between Normally Hearing Infants and Adults." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Audiology.

Allan O Diefendorf

Allan O. Diefendorf, Major Professor

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A COMPARISON OF AUDITORY INTENSITY DISCRIMINATION BETWEEN NORMALLY HEARING INFANTS AND ADULTS

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Jolie Carin Fainberg

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ABSTRACT

The past decade of infant auditory research has generated new empirical and methodological insight. Studies have compared the sensory capabilities of infants and adults on various auditory measures; however, at present there are no studies on intensity discrimination. The purpose of this study was to compare the just noticeable difference (jnd) for intensity in normally hearing infants and adults.

Eight infants were tested using an adaptation of the Visual Reinforcement Audiometry (VRA) paradigm. Subjects were trained to head-turn for the correct detection of an intensity increment between 1 dB and 10 dB. A correct head-turn response was reinforced by activating an animated mechanical toy in a plexiglas box. The jnd was determined for each subject at 20 dB and 70 dB HTL carrier tones of 1000 Hz. A bracketing procedure was utilized and the criterion measure was three correct increment discriminations at the same level. Eight adult subjects were tested by raising their hand when they detected an increment. The same stimulus parameters and response criterion were used.

The results of this study indicate that intensity discrimination can be assessed reliably in both populations. While infants required a greater intensity change before detecting increments than adults, the jnd was smaller at 70 dB HTL than at 20 dB HTL for both groups. Statistical analysis revealed significant differences between jnds at

20 dB HTL and 70 dB HTL for both infants and adults. In addition, significant differences were found between infant and adult jnds at each presentation level.

The difference in the jnd between the adults and infants may reflect maturation of the auditory system; however, other factors such as attention, motivation, cognition and infant state may contribute to the observed differences. While there was a quantitative difference between groups, infants and adults were qualitatively similar in the processing of intensity information.

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CHAPTER I

INTRODUCTION AND STATEMENT OF PURPOSE

The past decade of infant auditory research has generated new information about the capabilities of the developing child. With these empirical and methodological advances, the infant is now viewed as an active receptor of auditory information. Studies completed on measures of absolute threshold (Wilson and Moore, 1978), masked threshold (Nozza, 1981), discrimination of different speech sounds (Eilers, Wilson and Moore, 1977), and simple binaural processes (Diefendorf, 1981) have compared the capabilities of infants and adults and found that the two populations reveal only slight differences in these auditory abilities. Other studies have investigated frequency and intensity discrimination for various stimuli. These studies have added valuable information about infant auditory capabilities, however, our knowledge of the maturational or developmental changes in basic auditory processes remains primitive.

Infants and young children have demonstrated the ability to discriminate frequency, although not at the levels obtained with adults. Olsho, Schoon, Sakai, Turpin and Sperduto (1982) reported on the frequency difference limen (DLF) in infants four to eight months of age. They employed the head-turn response with a visual reinforcement procedure. The subjects were conditioned to respond to decreasing changes in frequency for 1,000, 2,000, and 3,000 Hz tones presented at 77, 78, and 77 dB SPL, respectively. The infants in this study had mean DLF's higher than the adults at all frequencies.

The measurement of intensity discrimination has been mainly limited to adults (Reisz, 1928; Harris, 1963; Swisher, Stephens and Doehring, 1966; Sanders and Harless, 1976; Jesteadt, Wier and Green, 1976). These studies indicate that adults discriminate small changes in intensity more easily at higher sensation levels. Several studies have indicated that infants are able to discriminate gross differences in intensity. Steinscheider, Lipton and Richmond (1966) used white noise stimuli at 55, 70, 85, and 100 dB SPL to measure the cardiac rate and motor responses to changes in intensity in nine neonates. When the stimulus intensity was increased, the magnitude of the infant's heart rate increased and the latency decreased. The same was true for the motor responses. By increasing the intensity of pulsed pure tones from 15 to 25 dB, Moffitt (1973) examined cardiac rate using a habituation-disinhibition paradigm. Twenty-eight subjects between the ages of 20 to 24 weeks of age were stimulated with a 500 Hz pulsed tone for six trials. At the seventh trial, the intensity was changed and the infants showed a deceleration in heart rate. Only one study (Fior, 1972) has measured the difference limen for intensity in children. Utilizing the Luscher difference limen test, thresholds were established at 80 dB SL for the frequencies 1,024, 2,048, and 4,096 Hz in children three to 13 years of age. For children under five years, a 0.75 dB difference limen could be detected by most subjects. In the group under age eight, the difference limen value increased to 1 dB while values for older subjects decreased again to 0.75 dB.

The continuing investigation of the infant's auditory system may result in new and more advanced clinical practices relating to amplification and other methods of habilitation. In addition, information concerning the relationship of infants' auditory capabilities to those of adults will add to our understanding of the development of the auditory system. The auditory system of the infant appears to follow a developmental process for frequency discrimination. Presently, the evaluation of another auditory function, intensity discrimination, is needed. Thus, the purpose of this study is to determine the just noticeable difference (jnd) for intensity in normally hearing infants and to compare this with the ability of adults. Specifically, the questions presented in this study are:

1. Are there significant differences between the jnds for intensity at 70 dB HTL and 20 dB HTL carrier tones in normally hearing infants and normally hearing adults?
2. Are there significant differences between the jnds for intensity of normally hearing infants and normally hearing adults?

CHAPTER II

REVIEW OF LITERATURE

Intensity Discrimination

The investigation of intensity discrimination has concentrated on the determination of the difference limen for intensity (DLI). The DLI has been defined as the smallest change in intensity that can just be detected (Martin, 1978). Normally hearing persons are capable of detecting small increments at levels above threshold but have difficulty close to threshold. Some studies have attempted to explain this phenomenon from a physiological basis (Swisher, 1966; Eggermont and Odenthal, 1974). The compound cochlear action potential is caused by two populations of auditory neural units. One population has a shorter latency and higher threshold than the other. Since amplitude modulated stimuli produce compound action potentials, the amplitude of the potential depends in part on the amount of the increment, but primarily on the level of the carrier tone. If it lies below the threshold of the shorter latency neurons, the increment will not be detected. The rate of impulses traveling up the auditory nerve tends to be greater for the higher threshold neurons at increased sound pressure level (SPL) than for the lower threshold neurons. As the SPL of the carrier tone increases, the impulse rate increases and the increments are more easily detected. Therefore, the intensity of the carrier signal appears to determine the area of the cochlea that is stimulated.

The size of the difference limen in normal ears varies among subjects and depends on the method used in the measurement (Table 1). Reisz (1928) found a DL of 1 dB at 4,000 Hz for tones at 20 dB SL. Using 12 normally hearing adults, he asked his subjects to detect beats between tones close in frequency. Utilizing Reisz's techniques, Harris (1963) obtained a mean DLI of 1.64 dB for a 1,000 Hz tone at 20 dB SL. Additionally, he found a difference limen between 0.5 to 1 dB for pure tones at 1,000 to 6,000 Hz at a sensation level of 20 dB using a method of loudness memory.

Swisher, Stephens, and Doehring (1966) measured DLI's for 25 normally hearing adults. They used an ascending-descending method of limits to vary the intensity of the increments to a standard tone. The increments varied from 0 to 4.5 dB in discrete steps. The difference limens were determined at 2,000 Hz for tones of 40, 50, 60, 70, 80, 90, and 100 dB HL. There tended to be a decrease in the DL with increased hearing level, but there was considerable variability at each intensity. At 40 dB there was a range of 2.5 to 0.75 dB and at 80 dB the DLIs ranged from 1.0 to 0.5 dB.

Sanders and Harless (1976) varied the intensity of an increment superimposed on a 4,000 Hz carrier tone to determine their measure of DLI. They tested 24 normally hearing subjects in two test sessions. A mean DL of 1.65 dB was measured in session one while a 1.55 dB intensity difference limen was obtained in the second session. The range of DLIs across subjects was from 3 dB to 1 dB.

Utilizing an adaptive, two-interval forced choice procedure, Jesteadt, Wier, and Green (1976) measured DLIs at 5, 10, 20, 40,

Table 1. Summary of intensity discrimination studies for adults

Author, Date	Frequencies (Hz)	Presentation Level (dB)	DLI	Method (re: Harris 1963)
Reisz, 1928	4,000	20 dB SL	1 dB	loudness modulation
Harris, 1963	1,000	20 dB SL	1.64 dB	loudness modulation
Harris, 1963	1,000-6,000	20 dB SL	1.0-0.5 dB	loudness memory
Swisher et al., 1966	2,000	40, 50, 60, 70, 80, 90, 100 dB HL	2.5-0.5 dB	loudness masking
Sanders et al., 1976	4,000	20 dB SL	3.0-1.0 dB	loudness masking
Jesteadt et al., 1976	400, 600, 800, 1,000, 2,000, 4,000 and 8,000	5, 10, 20, 40, 80, dB SL	1.51-0.43 dB	loudness modulation
Fainberg, 1984	1,000	20 dB, 70 dB HL	3.0-1.0 dB	loudness masking

and 80 dB SL for frequencies of 400, 600, 800, 1,000, 2,000, 4,000, and 8,000 Hz. The stimuli were two pulsed pure tones differing in intensity. The subjects were asked to identify the more intense of the two. There was not a significant effect of frequency on the intensity discrimination levels measured. The DLI ranged from 1.51 dB at 5 dB SL to 0.43 dB at 80 dB SL showing a decrease of the DL as intensity increased.

Antonelli, Sambatoro, and Gaini (1976) monitored intensity discrimination using evoked response audiometry (ERA) for 19 normally hearing adults. Intensity discrimination was tested at 500 and 1,000 Hz for carrier tones of 20, 40, and 60 dB SL. Intensity increments of 10 dB to 1 dB (in 1 dB steps) were superimposed on the carrier tone. Change in the intensity of the increment resulted in a change in the amplitude of the waveform. As the SL of the carrier tone increased, the response amplitude became larger and the latency of the waveform became shorter.

Frequency Discrimination

An infant's ability to discriminate frequency has been demonstrated in several studies. Subjects between the ages of 16 to 60 days were able to discriminate between the 200 Hz and a 500 Hz tone (Wormith, Pankhurst, and Moffitt, 1975). The frequency of non-nutritive sucking increased over baseline when reinforced with the presentation of a tone of either 500 or 200 Hz. Following habituation to the stimuli, a shift in frequency produced an increase in the frequency of the sucking response.

Andrews and Maderia (1977) paired auditory stimuli with visual and tactile cues to assess pitch discrimination in children. Thirty-six subjects from six to eight and a half years of age were conditioned to discriminate between tones of 262 and 523 Hz. Eguchi (1975) investigated the development of the difference limen for frequency in children. Ninety normal hearing children aged seven to fifteen years were tested at 500 and 1,500 Hz. As with adults, the children's DLFs were larger at the high frequencies and smaller at the lows. In addition, there appeared to be a developmental variable for the discrimination of frequency. The younger children had larger DLFs reaching comparable adult values by twelve years of age.

Intensity discrimination in adults has been investigated utilizing several different methods which have yielded various values for DLI. The common aspect of these studies is that as sensation level increases, DLI decreases. At present there are no studies for intensity discrimination in infants.

CHAPTER III

METHODS

Procedure and Experimental Design

An adaptation of the Visual Reinforcement Audiometry (VRA) paradigm (Moore et al., 1977) was used to test the infants. The auditory stimuli were presented to the infant's left eat through earphones. Each infant was trained to turn his/her head to the left of midline when he/she detected an increase in intensity from a continuous carrier tone. A left head-turn was chosen to overcome the suggestion that infants are more prone to turn right than left (Murphy, 1961). A correct head-turn was reinforced by the activation of a three-dimensional mechanical toy in a plexiglas box located to the left of the infant at eye level. Throughout the entire procedure, the infant was seated in his/her parent's lap at a 45° angle relative to the reinforcer (see Figure 1).

Both an experimenter and an assistant were used in this study. So as not to bias the results, the two people who served in these roles changed places throughout the project since one had more experience with VRA testing. The experimenter was located in the control room operating the audiometer and visual reinforcer. The assistant was seated in the test room at the infant's midline manipulating noiseless toys. With the earphones in place, the parent was unable to hear the signal. Music was presented to the assistant so the test tone could not be heard. This eliminated the possibility

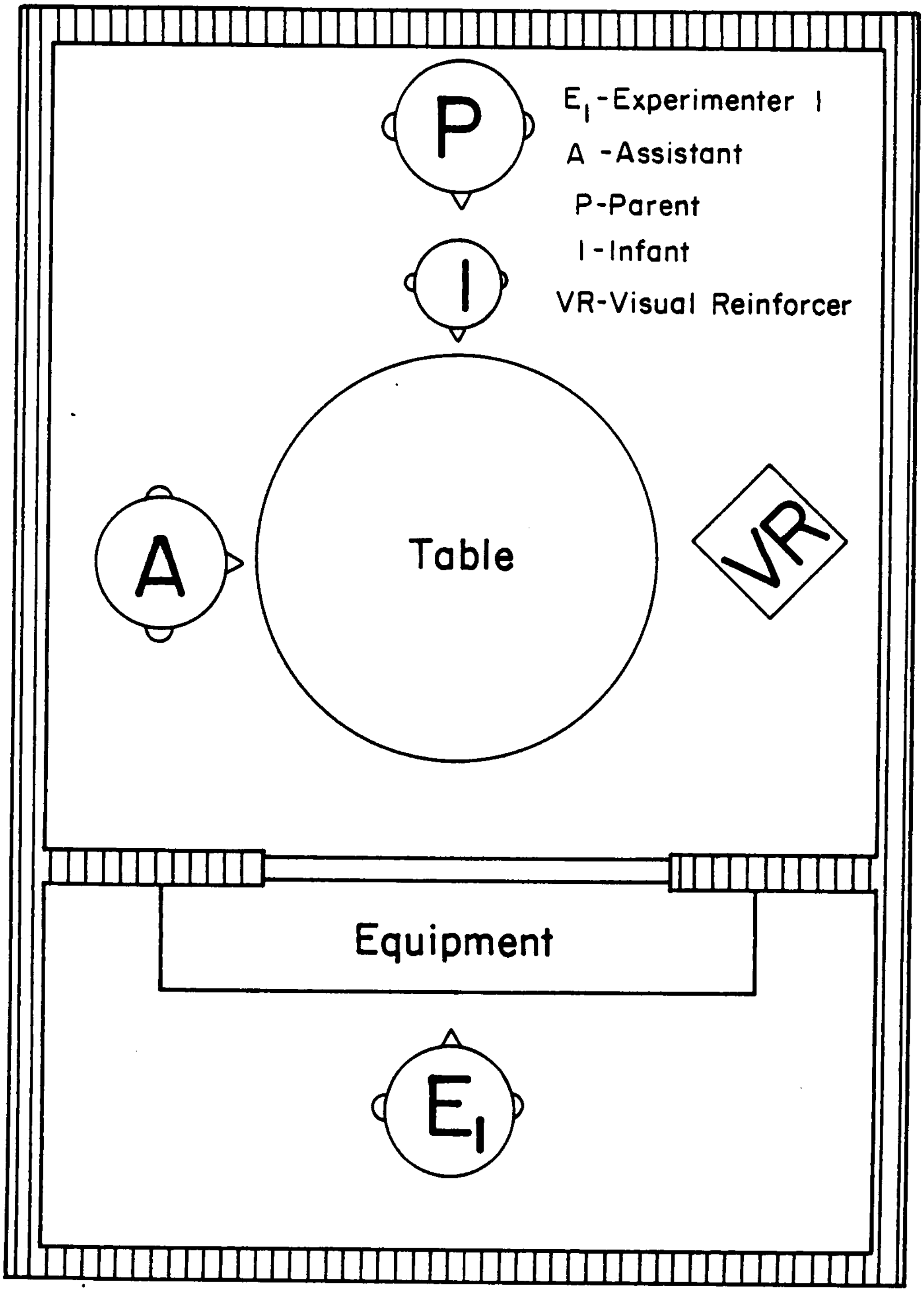

Figure 1. Test room arrangement for visual reinforcement paradigm.

of the parent or assistant providing cues to the infant to prompt a response.

The testing began when the infant was in a "ready state," that is, when he/she was quiet and maintaining midline eye contact with the assistant's noiseless toys. A four-second observation interval was employed wherein a head-turn response had to take place in order for reinforcement to occur. If the experimenter observed a head-turn upon presentation of the intensity increment, the visual reinforcer was activated for four seconds. If a response did not occur during the observation interval, the infant would not be reinforced. The experimenter controlled the reinforcer using the override button on a logic device. Since past studies (Moore et al., 1975; Moore et al., 1977; Morgan, 1978) have demonstrated high reliability ($\geq$ 93%) of voter agreement between multiple assistants, this study used only one voter (the experimenter) to record responses.

Either a change trial or a control trial occurred at the beginning of an observation interval. A change trial consisted of the presentation of an intensity increment, a control trial consisted of only the carrier signal. Control trials were interspersed between change trials at irregular intervals (Figure 2). During control trials reinforcement did not occur even if the infant responded. If the experimenter did not observe a response during a control trial, the trial was considered a correct rejection. If a head-turn was observed, the trial was considered a false response. In order for the testing to be considered valid, the false response rate could be no greater than 20% (Wilson, 1978).

TRIAL	INTENSITY	RESPONSES
1		
2		
3		
4	control	
5		
6		
7	control	
8		
9		
10	control	
11		
12	control	
13		
14	control	
15		
16		
17		
18	control	
19		
20		
21		
22		
23	control	
24		
25		
26		
27	control	
28		
29		
30		
31		
32		
33	control	
34		
35		
36	control	
37		
38		
39		
40		

Figure 2. Distribution of control trials and change trials for presentation of intensity increments.

Training. Each infant was first tested for normal hearing (threshold of 20 dB HTL or less; ANSI, 1969) at 1,000 Hz in the left ear using VRA. During the training phase, the infant was conditioned to a 10 dB increase in intensity above a 70 dB HTL carrier tone. Since the carrier tone was continuously on, the subject was required to discriminate the change in the intensity of the increment. Initially, the presentation of the increment was paired with the visual reinforcer. After two or three paired trials, the infant would anticipate the reinforcer and turn his/her head when the increment was detected. The training session ended when the subject spontaneously responded to three consecutive trials.

Experimental design. Once the subject was under stimulus control, the test session began. Jnds were determined with a 70 dB HTL carrier tone and then with a 20 dB HTL carrier tone. Two consecutive correct responses led to a 2 dB decrease in the intensity of the increment. The signal increment size was decreased in 2 dB steps until the subject failed to respond to two consecutive increments out of three trials. At this point, change trials were presented until there was a 75% or greater correct response rate (six trials maximum).

When the 75% correct criterion was met, the intensity of the increment was decreased 2 dB, while failure to meet this criterion resulted in an increase of 1 dB. This bracketing continued until the lowest level at which 75% or greater correct responses was reached.

The determination of the jnd required between 19 and 34 trials per subject at each carrier tone level. Sessions lasted approximately 15 minutes and testing could be completed for both levels within one session. Only three subjects required two sessions to complete the task.

Adult subjects were tested in a different manner. They were asked to raise their hand when they heard an increment. The same stimulus parameters and response criteria were used.

Adult subjects were tested in a similar manner. They were asked to raise their hand when they heard an increment. The same testing procedure and response criteria were used.

<u>Subjects</u>

Eight infants (four males and four females) were selected from the community of Knoxville, Tennessee. The infants' chronological ages ranged from six months to ten months with a mean age of eight months. Each subject was required to meet the following criteria:

1. Normal development (as reported by the parent);
2. No unusual medical history;
3. Type A tympanograms (± 100 mm H_2O) at the left ear;
4. Normal hearing for the left ear at 1,000 Hz tested by Visual Reinforcement Audiometry.

Eight adult subjects (four male and four female) 24 to 30 years of age, were selected from graduate students at The University of Tennessee, Knoxville, to serve as a comparison group. Each subject was required to meet the following criteria:

1. No history of otologic disease;

2. Normal hearing for the left ear at 1,000 Hz.

Instrumentation and Stimuli

Intensity jnds were measured for each subject at 20 dB HTL and 70 dB HTL. These pure tone carrier signals were generated by a Grason-Stadler 1704 audiometer at the frequency of 1,000 Hz. An increase in intensity was superimposed on the carrier tone using a Grason-Stadler 829E electronic switch. The intensity of the increment could be adjusted from 1 dB to 10 dB (in 1 dB steps) by a Hewlett Packard 350D attenuator set and were presented by pressing a button connected to a University of Tennessee assembled timing switch. Each increment had a rise-fall time of 35 msec and a duration of 500 msec. The inter-increment interval was variable from between 15 seconds to 1 minute which allowed the experimenter to present an increment only when the child was quiet and attentive. Auditory stimuli were delivered to a Telephonics TDH-50 earphone mounted on a MX-41/AR cushion. The visual reinforcer was activated by a University of Tennessee assembled logic device. All testing took place in an IAC two-room audiometric suite (see Figure 3).

Calibration

Calibration of the output intensity of the audiometer was performed on a daily basis using a Bruel and Kjaer 2203 sound level meter and a Bruel and Kjaer 2 cm^3 artificial ear. The intensity of the increment was monitored during testing using the volume unit (VU) meter

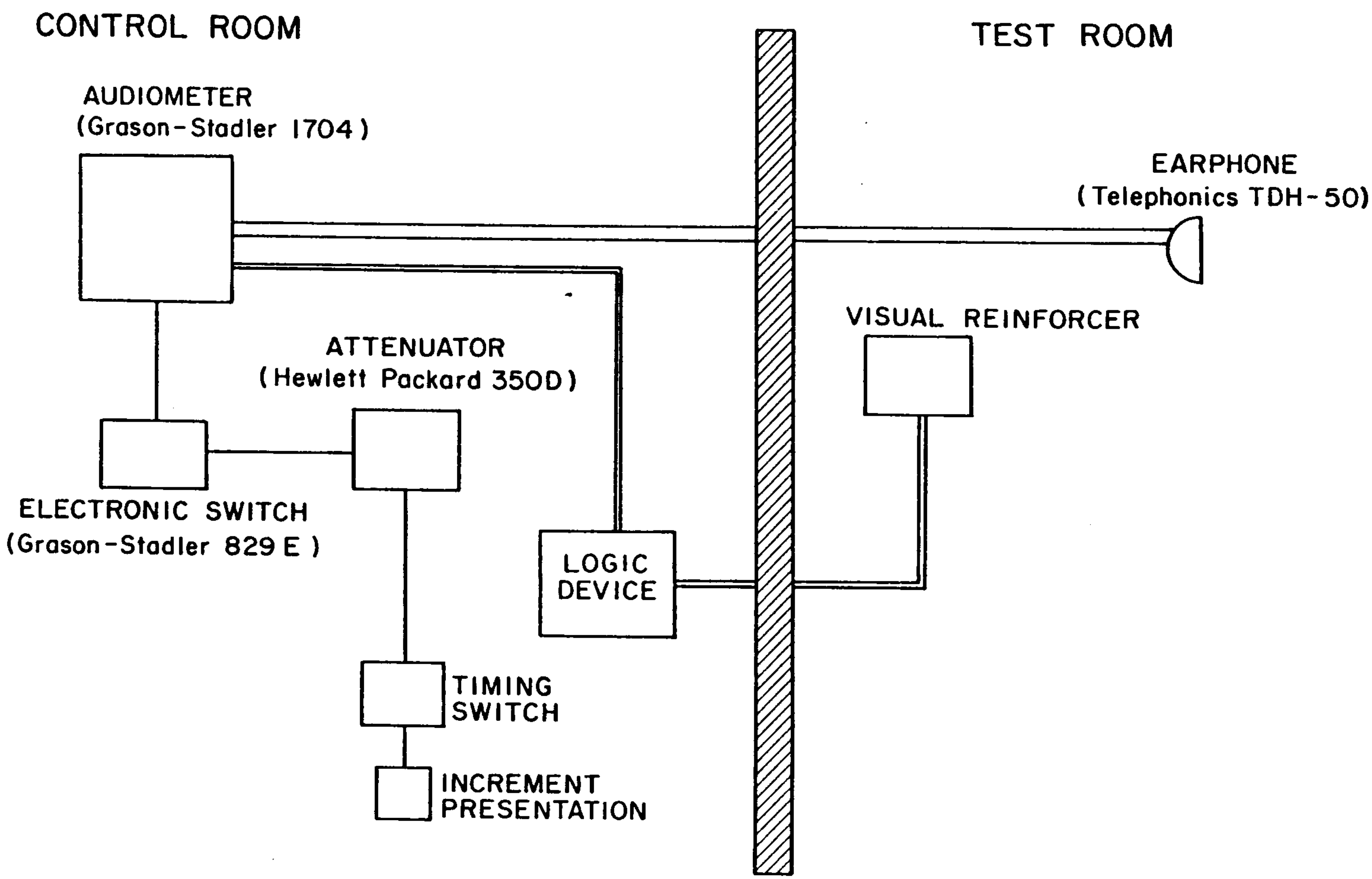

Figure 3. Block diagram of instrumentation.

on the audiometer. The calibration of the VU meter was completed before each test session. Frequency was calibrated at the beginning of this study using a Bruel and Kjaer 159 calibrator.

CHAPTER IV

RESULTS

The jnd for intensity was measured by all eight infants and adults using a 70 dB HTL carrier tone and a 20 dB HTL carrier tone (Table 2). Although the infants exhibited higher jnd's than the adults at each level, the jnd increased with decrease in carrier tone intensity for both groups. The mean jnd for the infants was 1.87 dB at 70 dB HTL and 4 dB at 20 dB HTL. The adult means were 1 dB at 70 dB HTL and 1.87 dB at 20 dB HTL (see Figure 4). The range of scores across infants was small; jnds ranged from 1 dB to 3 dB at 70 dB HTL and 3 dB to 6 dB at 20 dB HTL. The adults also exhibited a small range in jnds (all subjects scored 1 dB at 70 dB HTL and 1dB to 3 dB at 20 dB HTL. The calculation of presentation level ratios indicated a 47% difference between 20 dB HTL and 70 dB HTL for infants while the adults demonstrated a 53% difference.

A repeated measures analysis of variance was performed between the jnds at 70 dB HTL and 20 dB HTL carrier tones for each group. This analysis indicated statistically significant differences between scores at each level (for the infants, $F(1,7) = 5.59$, $p < .05$; adults, $F(1,7) = 14.91$, $p < .05$). A t-test (Bruning and Kintz, 1977) was used to determine the difference in the jnds between groups at both carrier tone intensities. There was a statistically significant difference between the infants and adults at both 70 dB HTL and 20 dB HTL, $t = 5.34$, $p < .05$ and $t = 2.96$, $p < .05$, respectively.

Table 2. Testing variables and intensity jnds of infants and adult subjects at two carrier tone intensities

Subjects	Age (Month-Day; Adult)	Sex	jnd 70 dB HTL	jnd 20 dB HTL
1	10-9	F	2 dB	4 dB
2	9-3	F	1 dB	6 dB
3	6-0	F	2 dB	3 dB
4	6-22	F	3 dB	4 dB
5	7-7	M	1 dB	4 dB
6	7-18	M	2 dB	4 dB
7	9-20	M	3 dB	4 dB
8	9-25	M	1 dB	3 dB
			$\overline{X}$ = 1.87 dB	$\overline{X}$ = 4 dB
1a	Adult	M	1 dB	1 dB
2a	Adult	F	1 dB	2 dB
3a	Adult	F	1 dB	2 dB
4a	Adult	F	1 dB	2 dB
5a	Adult	F	1 dB	2 dB
6a	Adult	M	1 dB	1 dB
7a	Adult	M	1 dB	2 dB
8a	Adult	M	1 dB	3 dB
			X = 1 dB	$\overline{X}$ = 1.87 dB

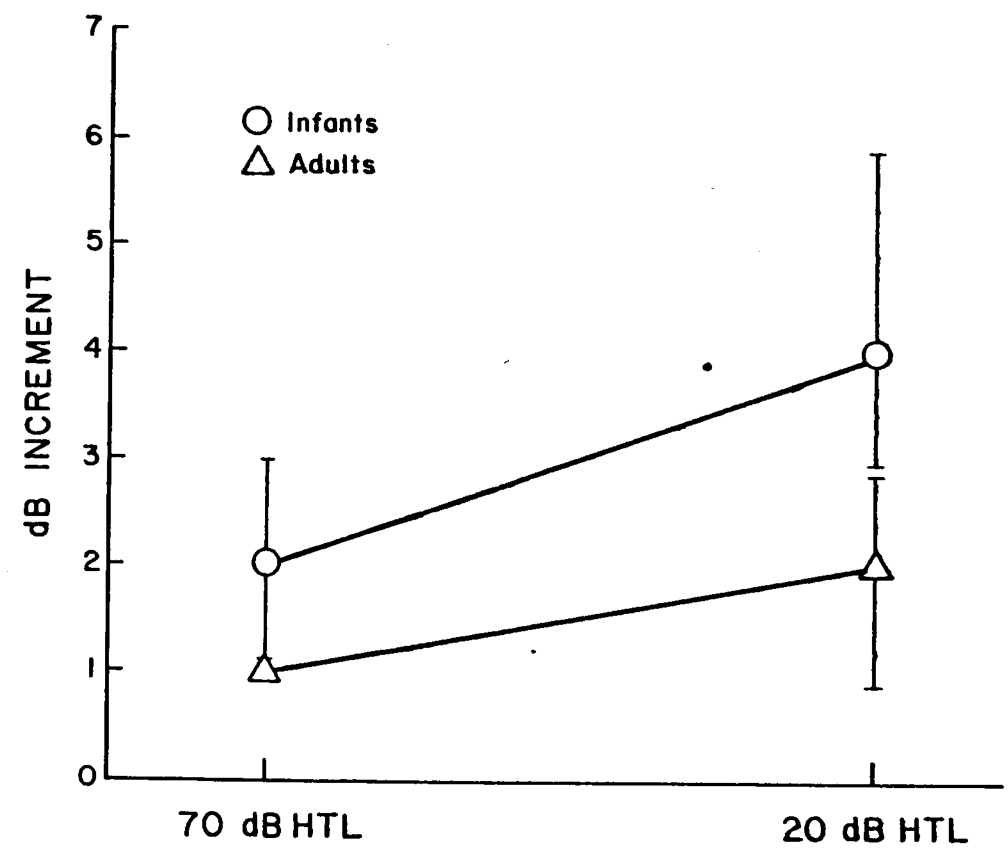

Figure 4. Means and ranges of intensity jnds for infants and adults at two carrier tone intensities.

The results of this study indicate statistically significant differences between the jnds for intensity at 70 dB HTL and 20 dB HTL carrier tones in normally hearing infants and adults. Additionally, there are significant differences between the jnds for infants and the jnds for adults at both carrier tone intensities.

CHAPTER V

DISCUSSION

The results of this study indicate that infants can discriminate small changes in intensity. Although as a group the infants had higher jnds, several were close to adults jnds.

The difference in jnds between the infants and adults may reflect maturation of the auditory system; however, other factors may be involved. A problem in most behavioral research comprising infants and adults involves differences in attention, memory, motivation and cognition (Nozza and Wilson, 1984). Some of these differences cannot be eliminated and the extent to which they affect results is not known. In this study, the time limitations imposed by the infants' state may have contributed to the observed age differences. The jnds could usually be measured in 6 to 10 minutes; however, no session lasted longer than 20 minutes because the infants became restless. Five subjects completed the task in that time; the other three infants became restless after 70 dB HTL jnd determination and had to return for a second session. Further study using multiple sessions may determine the effect of some of these factors on intensity discrimination.

The VRA procedure used in this study appears to be an adequate method for assessment of jnd for intensity in infants. Previous studies using cardiac rate and motor responses could determine only a gross discrimination of intensity (Steinscheider et al., 1966; Moffitt, 1973). The VRA paradigm appears to have advantages not found with these other discrimination procedures. It is applicable to a large number of infants, is efficient (children can be tested in a few minutes), enables testing of a single child's discrimination, is applicable across a wide age range (5-24 months), enables evaluation of multiple contrasts for each infant and employs a reinforcer that is independent of the stimuli to be discriminated.

Equally as important as the absolute size of the infant increment jnd; however, is the fact that the jnd decreased when the carrier tone intensity was increased for both infants and adults. Several studies of intensity discrimination in adults (Luscher and Zsislocki, 1949; Denes and Naunton, 1950; Swisher, Stephens and Doehring, 1966; Swisher, 1966; Jesteadt, Weir and Green, 1976) as well as physiological explanations for intensity discrimination (Swisher, 1966; Eggermont and Odenthal, 1974) support this finding. The frequency discrimination study with infants (Olsho et al., 1981) demonstrated a similar trend. Although infants exhibited higher frequency DLs than adults, jnds increased with increase in standard frequency for both infants and adults. Thus, it appears that the cochlea responds to intensity and frequency changes in the same way from early infancy through maturity.

CHAPTER VI

SUMMARY AND CONCLUSION

The purpose of this study was to determine if there was a difference in the jnds for intensity between infants and adults for a 1,000 Hz signal presented at 70 dB and 20 dB HTL. The results indicated that adults have smaller jnds than infants at both presentation levels. Both the infants and the adults exhibited a similar decrease in jnds with increase in carrier tone intensity.

Although factors contributing to the observed age difference could not be determined in this study, it can be concluded that infants are capable of relatively fine intensity discrimination. Equally significant is the similar pattern followed by both infants and adults in regard to the effect of carrier tone intensity on the increment jnds. Thus, while there was a quantitative difference between groups, infants and adults are qualitatively similar in the processing of intensity information.

Further research is needed to provide a greater understanding of intensity discrimination in early life. The expansion of our knowledge in this area may lead to new clinical practices for identification and habilitation of hearing loss in infants. Some areas for investigation include:

1. Discrimination of intensity increments at other frequencies (e.g., 500 and 4,000 Hz);

2. Assessing intensity discrimination for infants with pathological hearing (both conducive and cochlear losses);
3. Determining the jnd for intensity using continuously variable intensity increments.

Two limitations of this study were:

1. The increments used for discrimination were in discrete steps. The use of continuously variable intensity increments would give a more exact measure of intensity discrimination.
2. Calibration of the increments was not checked acoustically.

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VITA

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