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PSYCHOACOUSTIC PERFORMANCE IN CHILDREN:

A DEVELOPMENTAL STUDY

by

ANTONIA B. MAXON

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1977

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

PSYCHOACOUSTIC PERFORMANCE IN CHILDREN:

A DEVELOPMENTAL STUDY

by

ANTONIA B. MAXON

Adviser: Professor Irving Hochberg

This study investigated the development of psychoacoustic behavior in normal children between 4 and 12 years of age. Three psychoacoustic tasks were employed: Difference limen for intensity, difference limen for frequency and temporal integration, as well as pure tone sensitivity.

The psychoacoustic procedures were appropriately modified to accommodate the youngest subjects, but were controlled to be enough like normal adult procedures to accurately assess the sensitivity and discrimination characteristics of the subjects (4, 6, 8, 10 and 12 years).

Results showed: 1) a significant increase in pure tone sensitivity with increased age, 2) a significant decrease in size of the difference limen for intensity (DLI) with increased age, 3) a significant decrease in size of the difference limen for frequency (DLF) with increased age, and 4) a significant improvement in temporal integration thresholds with increased age. The configuration of the threshold-duration functions for temporal integration were similar to adult norms with a 15.1 dB threshold shift between 25 and 200 msec durational changes, and were the same for all age groups.

In general, the configurations of the functions obtained for all age groups on all tasks were similar to those which had been found with normal adults. The older the subject, the closer to adult values were the thresholds obtained, indicating an overall improvement in psychoacoustic performance with increased age.

The data were also analyzed with a predictive model to assess the validity of the tasks employed. In general, it was found that the main effects could be predicters for all tasks and that the observed results were not significantly different from the reconstructed estimates.

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Chapter I

Introduction

The concept of perceptual development or the refining of sensory perception with increasing age has been studied by developmental psychologists. In discussing perception, Dember (1965) indicated what might be the underlying reasons for maturational differences in perception.

> An individual may fail to make a discrimination for at least two reasons. (a) His receptor system is incapable of responding to the stimulus...or responding differentially to two stimuli...which are physically different. (b) The stimulus(i) elicit(s) neural (or differential neural) activity at the input level, but this potential input is not utilized at some higher level (p 256).

Perceptual maturity appears to be a function of the older child's improved specificity of discrimination of stimulus input, and refinement of the ability to differentiate between incoming stimuli. The younger child is confused by the "amorphous" quality of stimuli. With maturation comes a structure which forms a basis for judging incoming stimuli differentially. In order for this structure to develop, the child must first be able to categorize items into finite sets, and having acquired that ability, he must be able to distinguish among the members of the set by using their salient features. Therefore, development of perception is dependent on one making use of the similarities and differences (distinctive features) among the stimuli to make accurate judgments (Gibson and Levin, 1975).

The changes observed in general perceptual development have also been demonstrated for audition. Through the observation of maturational changes in infants, Eisenberg (1970, 1971) hypothesized that audition was made up of a hierarchy of functions that demonstrated the mechanisms for processing sound; the more advanced the processing mechanism, the more refined the

perceptual function. Since predisposition of the developing auditory system to discriminate frequency, duration and intensity was demonstrated in infants, a perceptual model of increasing neural ability for processing stimuli through improved use of salient, distinctive features of those stimuli can be extended to later stages of child development.

Evidence in support of the developmental perceptual model has been collected, particularly in the visual modality. Generally, the results of early research indicated an increase in visual acuity (thresholds) and an increase in differential sensitivity (discrimination) with increasing age. Similar results for pitch perception, weight judgment and saturation, and recognition of hue were also reported (Wohlwill, 1960).

Referring to the documentation of those trends found in other modalities, Lasky (1973) urged the documentation of similar trends in audition, to better understand the auditory percpetual mechanism. Development would be considered to have occurred when one could demonstrate either an improvement in a particular ability with increased age or improved ability to progress from simple to complex tasks.

Assessment of the auditory processing mechanism could be accomplished therefore by a variety of tasks, including measurement of acuity, through simple threshold finding procedures, and measurement of differential sensitivity, a more difficult discrimination task. A hierarchy of tasks, through which there can be a comparison of the functioning of the younger and older child to each other could be structured. Such a hierarchy would meet the criteria of a) assessment of the differences in perceptual responses for various age groups and b) assessment carried out through tasks differing in difficulty.

Designing the proper hierarchy of tasks so that there would truly be a measure of developmental change was not an easy one. Aside from methodological problems which arose from the necessarily wide age range, one also encountered the possibility that intelligence rather than age would influence the results. It had to be demonstrated that the between age group differences that arose were a result of chronological age differences not mental age differences.

Some authors have argued that merely being able to demonstrate age differences with respect to response was proof enough that the change in response was a function of chronological age. The expanded experience of the older child was likely to be reflected in his improved response patterns. Certainly the older child has had a greater experience in manipulating stimuli and making refined discriminations through the school experience, yet stronger evidence against the influence of intelligence was sought (Reese and Lipsitt, 1970).

If intelligence rather than age were truly the factor influencing developmental perception, one would expect improved response with increased mental age, regardless of chronological age. Using perceptual constancy as the model for this hypothesis, Jenkins and Fealock (1960) postulated that one would find a higher degree of constancy with increased intelligence; accurate judgments of constancy being dependent upon integrating a number of different cues. Instead, the opposite was found, i.e., constancy improved with increased chronological age but not with increased mental age. Therefore, variation in response on perceptual tasks by various age groups can be assumed to stem from the chronological age differences and the experiential differences that accompany them.

To fully understand the behaviors, such as learning, thinking and motivation, all of which depend on perceptual skills, one must further study perceptual development. The demonstration of developmental differences in audition would lead one to consider the interaction between auditory development and that of speech perception and production. Increased specificity of audition is primary to hearing and for producing phonemic, syntactic and semantic variations (Gibson and Levin, 1975). "The question of how these mechanisms become organized during development may be central to our understanding of language learning..." (Eisenberg, 1970).

Improvement of sensory acuity and discrimination with increased age leads one to the assumption that a maturation of auditory perceptual judgments could be demonstrated through appropriately modified psychoacoustic procedures. The purpose of the present study was to describe psychoacoustic behavior developmentally, in an attempt to provide normative data among children aged four through twelve years. Such a description would yield information about the most appropriate assessment of the developing auditory system, and implications about auditory perceptual development.

Chapter II

Review of the Literature

Perceptual Development

In order to make satisfactory progress during early school years, the child must acquire skills which are dependent on the ability to make accurate discriminations, to recognize the transformations of stimuli, and to integrate these stimuli temporally or separate them spatially. The acquiring of such skills is developmental and appears to increase with age (Reese and Lipsitt, 1970).

Elkind (1964) demonstrated the development of perceptual organization through the use of ambiguous pictures. His subjects, normal children aged six through eleven years, had to tell what they saw when presented with an ambiguous stimulus. Each picture was designed so that one could attend either to the parts or the whole stimulus and see recognizable objects. Results indicated that there was a regular increase in ability to recognize "hidden" figures with increased age, except from ten to eleven years. Eleven-year olds were the oldest subjects used which made it difficult to know if the leveling off of the trend occurred because the ten-year old subjects had reached a ceiling of performance on those stimuli. Had subjects older than eleven years been used, one could have observed if that plateau was indicative of maximum performance on the task.

Elkind did not attempt to explain what mechanisms were at work or had been refined in the older child which allowed him to perform more like an adult on that task. It did seem likely that the older child was more specific in his visual scanning, therefore making better use of the discriminative features. Nodine and Lang (1971) photographed the eye

movements of children, kindergarten through third grade, while they made judgments about strings of letters. Through the use of a matching task and by measuring reaction time, Nodine and Lang were able to demonstrate that the older subjects were more attentive to informative details, i.e., distinctively different features than the younger subjects. The younger children also tended to focus on non-relevant material more and for a longer time than did the older children. That study indicated that the younger child had neither acquired the ability nor learned how to make discriminations about significance of stimuli. Attending to distinctive features of stimuli, particularly in the visual and auditory modes of language, should improve with age, if only for the exposure one gets from learning to read.

Attention to discriminative differences in auditory stimuli has been evaluated through the use of pitch discrimination tasks. Early studies of pitch discrimination in children (Gilbert, 1893; Hittwick, 1935; Peters, 1927; Ivanshiva, 1930) generally indicated that between the ages of five and ten years, there was an improvement in discrimination (Kidd and Kidd, 1966). They reported the work of Russian experimenters (Endovitskaya, 1959, Repina, 1961a, 1961b) whose results indicated that a subject younger than 4.6 years could not be conditioned to make pitch discriminations. Older children could learn and that learning was facilitated with increased age.

Maccoby (1967) demonstrated that the ability to make discriminations among the salient features of auditory stimuli improved with age. Kindergarten, second and fourth grade children listened to dichotically presented stimuli spoken by a male and female. The subjects had to repeat the word spoken by either a "man's voice" or a "woman's voice" when requested to do so by the examiner. Results were analyzed for the number

of intrusion errors, i.e., reporting the word spoken by the incorrect voice. The older subjects made fewer intrusion errors, indicating they were better able to ignore the non-relevant information and to attend to the salient material than were the younger subjects.

The increased ability to attend to and make use of the distinctive features of auditory stimuli indicates a developmental trend in auditory perception. Abromovitz (1971) attempted to assess the development of auditory perception through the use of four tasks, graded in complexity. The tasks were designed to fit into a developmental hierarchy of pure recognition to discrimination. The tasks, in ascending order of complexity, were recognition of environmental sounds, discrimination of phonemic or intonational parameters of speech sounds, identification of two or more simultaneously occurring environmental sounds, and discrimination of pitch, loudness, duration and interval of tone pairs. In the fourth task the subjects had to report if the two tones were "same" or "different."

The results showed a trend of correct responses increasing with age. There was a significant difference in percent of correct responses between the youngest group, five years, and the oldest group, ten years. The older subjects were more often correct on the most complex task than were the younger subjects, but a significant difference between adjacent chronological age groups could not be demonstrated. Although the hierarchy developed by Abromovitz did not show those significant differences, he did demonstrate that some type of developmental change in auditory perception was taking place.

Through the use of a battery of seven commonly used psychoacoustic procedures, Fior (1972) also attempted to assess the development of auditory perception. The procedures employed assessed pure tone acuity, difference

limen for intensity (DLI), individual masking functions, and speech intelligibility in noise for subjects between three and thirteen years of age.

The data for the younger subjects (below 5 years) were incomplete because of the difficulty they had attending to and performing some of the tasks. These procedures were not modified for them, the data were just not collected. The tests on which significant results were obtained indicated an increase in pure tone acuity with increasing age up to seven years, at which age acuity was at its maximum. Results also demonstrated an improvement in speech intelligibility in noise between the ages of five and eight years, after which a plateau was demonstrated. The results of the DLI, measured by a Lüscher procedure (1948), gave a U function, i.e., a decrease in size of the DL from age five to eight years and an increase in DL size for the "older" subjects. Fior stated that the overall trend of all data indicated a gradual maturation of auditory perceptual abilities up to thirteen years at which age it was maximum. He did note that some of his subjects reached maximum maturity at ten years.

It seems that both Fior and Abromovitz demonstrated that developmental trends existed for auditory perception. In the earlier study, the tasks were not sensitive enough to yield significant between group differences. The later study did seem to have more refined tasks, but they were not always suited to all the subjects and so complete information was not obtained. In both studies, the developmental trends were observable but the adjacent age group differences were not statistically significant.

Fior made a point of suggesting that maximum maturation of auditory perception ocurred, for the more complex tasks, between ten and thirteen years. That finding was not demonstrated by Abromovitz's data because the

oldest subjects used were ten-year olds. One can find evidence for Fior's suggestion in data collected by Eguchi (1976) and Gengel (1969). Though his task, DL for fundamental frequency, was different than any used by Fior, Eguchi's subjects formed a range (seven through fifteen years) which contained the hypothetical maximum maturation age. Using synthetic Japanese vowels, DL for fundamental frequency was obtained. The largest DLs were found for the youngest subjects and the DL size decreased with increasing age until eleven years. There was no significant decrease in DL between eleven and fifteen years, i.e., after which "maximum maturity" had been reached. Gengel's experimental subjects were hearing impaired children, but he also used a control group of normal hearing subjects aged ten through seventeen years. Difference limen for frequency (DLF) was measured at 250 and 500 Hz at 30 dB SL (sensation level). The mean DLF was 3 Hz at 250 Hz and 4 Hz at 500 Hz with no significant age differences demonstrated.

Fior's hypothesis of "maximum maturity" occurring between 10 and 13 years appears reasonable from his and other experimental data. At least there was good evidence in the few available studies that the auditory perceptual mechanism changed with age. The ability to use salient information to make more accurate, finer discriminations increased with age.

There was also evidence that aside from the perceptual mechanism changing there was an increase in the sensitivity of the organism with maturation. Pick and Pick (1970) demonstrated such a change for tactile sensitivity. Subjects, aged three through fifteen years, had to report how many (one or two) and what point(s) on the body had received tactile stimulation. Correct detection of two points of stimulation increased

and the number of errors (reporting only one point or misperception of a point) decreased significantly with increased age.

That auditory sensitivity improved with age had been demonstrated (Eagles, 1967; Leninhan, et al., 1971; Roberts, 1972a, 1972b). The general results obtained for the standard clinical audiometric frequencies (250, 500, 1000, 2000, 4000, 8000 Hz) indicated that the youngest subjects' (five or six years) sensitivity was poorest, and was significantly poorer than the oldest subjects (thirteen or fourteen years). The increase in sensitivity was demonstrated between five and ten years after which there was a plateau at which the children's sensitivity was similar to, if not better than, the adult normative thresholds.

Pure Tone Sensitivity

Hughson and Westlake (1944) recommended an ascending threshold finding procedure. In such a procedure the subject must respond to stimuli that progress from an inaudible to an audible signal. The stimulus should be presented for a short period of time (1-2 seconds) and so should reduce the amount of variability and increase the reliability of the response.

Hirsh (1952) reported an unpublished study by Rosenblith and Miller in which they compared ascending and descending procedures with an interrupted and continuous tone of 4000 Hz. (In a descending procedure the subject must respond to stimuli that progress from audibility to inaudibility). Results of the study showed that the descending procedure improved threshold by approximately 4 dB when the interrupted tone was used. When the continuous tone was used, the ascending procedure improved threshold by approximately 3 dB. Approximately equal thresholds were obtained when both procedures were started near threshold.

Carhart and Jerger (1959) also compared both procedures and added a third, ascending-descending. They found approximately equal thresholds with all three procedures, the descending technique yielding slightly better thresholds than either of the other two. In that study, Carhart and Jerger's main purpose was to determine which of the three procedures was clinically most appropriate. They recommended the Hughson-Westlake method because of the control over the variability and reliability that one can get with that method as opposed to the other two. That procedure has also been recommended by the American Academy of Ophthamology and Otolaryngology and was reported by Green (1972) to be the preferred standard procedure among clinical audiologists.

Temporal Integration

The basic premise in temporal integration is that the auditory mechanism does not respond solely to the intensity of the signal, but to the complex relationship that exists between intensity and duration. Temporal integration can be indirectly measured through a subject's response to variations in duration and intensity of a signal.

The early work of Garner (1947a, 1947b) and Garner and Miller (1947), which dealt with the auditory system's ability to integrate energy, demonstrated that total energy in the system can be changed. Changing the duration of the signal changed total energy which was observed in measured threshold shifts. The shorter the signal duration, the poorer the measured threshold.

An integration of energy in the system will occur when a complex sound enters the cochlea. In such a condition, the basal end of the cochlea will always be stimulated. As the signal travels along scala media,

the higher frequencies will filter out and only the fundamental frequency will remain, i.e., as the signal travels toward the apex, the spectrum will decrease and there will be a loss of energy. That will be particularly true for short duration signals for which most of the energy would be concentrated at the cochlea base. To compensate for the loss of energy, there must be an increase in the intensity of the incoming stimulus or there will be an observable increase in the subject's threshold (Zwislocki, 1960).

Wright (1960) was concerned with the practical application of temporal integration,i.e., would a pathological cochlea yield an abnormal temporal integration pattern? In order to make use of observable threshold-duration functions clinically,it became necessary to perfect the procedure which would yield reliable functions. In that early study, using a Bekesy tracking procedure, he determined that for durations shorter than 200 milliseconds (msec) there was a 10 dB change in threshold for every tenfold change in duration (Zwislocki reported a 12.7 dB shift for a 10 to 500 msec change); that was not true for durations greater than 200 msec.

One of the greatest problems encountered in designing the procedure to obtain reliable functions was to control rise-decay time of the shorter duration signals. The rise-decay time had to be relatively short to allow even the shortest signals to reach their maximum values, but not so short to produce transients. The transients would cause measurable threshold shifts. Varying rise-decay times (0 through 10 msec) of 10 msec tones, Wright found a 5 msec rise-decay time acceptable, but suggested using a 10 msec time in the laboratory and the clinic. Low frequencies and high frequencies were most sensitive to rise-decay times.

That particular finding was not unusual when one considers that the difference between short and long tones was not so much one of length, but rather one of spectrum spread. With short durations, the energy was distributed across a broader audible frequency range producing audible transients. Transients were less likely to be a problem in the mid-frequency range because the "sidetones" produced, for example, by 1000 Hz, were more likely to remain inaudible because of the sensitivity of the ear at 1000 Hz. Transients were more likely to be audible for higher and lower frequency sounds because these sounds were on the higher part of the normal human hearing function and their "sidetones" could more easily reach suprathreshold levels (Miskolczy-Fodor, 1960). Therefore, the greater measured threshold differences for 1000 Hz than for higher and lower frequencies found by Wright were probably the result of the audible transients produced by the short duration low and high frequency tones.

Recognizing and controlling for these methodological problems, Wright (1968a, 1968b) designed an experimental procedure which was feasible with the average clinical population. He used a psychophysical tracking method (on a Bekesy audiometer) in which frequency was constantly changing and duration was experimentally manipulated. To control for audible transients with low frequency short duration stimuli, the lowest frequency used was 500 Hz. A rise-decay time of 10 msec and a 500 msec inter-stimulus interval were employed. Threshold was taken as the midpoint of the excursion of the tracing and threshold-duration functions were plotted with 20 msec as the referent.

The data obtained on normal adult subjects indicated that for durations shorter than 200 msec a tenfold decrease in duration produced

That particular finding was not unusual when one considers that the difference between short (20 msec) and long (500 msec) tones was not so much one of length, but rather one of spectrum spread. With short durations (less than 50 msec), the energy was distributed across a broader audible frequency range producing audible transients. Transients were less likely to be a problem in the mid-frequency range because of the "sidetones" produced, for example, by 1000 Hz, were more likely to remain inaudible because of the sensitivity of the ear at 1000 Hz. Transients were more likely to be audible for higher and lower frequency sounds because these sounds were on the higher part of the normal human hearing function and their "sidetones" could more easily reach suprathreshold levels (miskolczy-Fodor, 1960). Therefore, the greater measured threshold differences for 1000 Hz than for higher and lower frequencies found by Wright were probably the result of the audible transients produced by the short duration low and high frequency tones.

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The data obtained on normal adult subjects indicated that for durations shorter than 200 msec a tenfold decrease in duration produced

approximately a 10 dB increase in threshold. The function varied with frequency, being steepest at the lowest frequencies examined and flattest at the highest. Generally, an integration slope of 8-10 dB for each decade change was found. Two hundred milliseconds appeared to be the critical duration above which little threshold shift was observed (Zwislocki, 1960; Wright, 1968a, 1968b).

Difference Limen for Intensity (DLI)

Knudsen (1923) was the first experimenter to attempt to make accurate measurements of difference limen for intensity (DLI). His use of abruptly changing amplitude (50 fluctuations per minute) produced audible clicks. Those transients made it relatively easy for a subject to determine when an amplitude change had taken place, and so a true measure of DLI was not obtained.

Riesz (1928) controlled for the problem of audible transients by using "beats" (3 cps). His subjects judged the presence or absence of amplitude modulation. His results, like those of Knudsen, showed DLI to be a function of frequency and sensation level. Both sets of data indicated that above 60 dB SL, DLI was virtually constant for all frequencies, but decreasing the intensity below 60 dB increased the size of the DL. The best differential sensitivity was found when the stimulating tone was in the mid-frequency range, the poorest differential sensitivity was in the low frequencies with a medium range of differential sensitivity being found in the high frequencies. That pattern of sensitivity was consistent with the pure-tone sensitivity of the normal ear. The frequency differences were most noticeable near threshold indicating that sensation level had a stronger influence on DL size than did frequency.

A replication of both methods for measuring DLI was performed by Churcher, King and Davies (1934). They measured DLI at 8000 Hz with both an abruptly changing tone and a gradually changing (beating) tone and found data in close correspondence to those of Knudsen and Riesz.

The two methods, though producing the same results, could not have been measuring the same phenomenon. The presence of audible transients decreased the likelihood that an abruptly changing stimulus allowed for a valid measure of DLI. The use of "beats" raised the question of whether amplitude modulation was really a measure of discrimination at all. Dimmick and Olsen (1941) did not think that the ability to perceive audible beating was tapping a discriminative ability. They doubted Riesz's results were the result of a true estimate of the differential sensitivity of the ear.

In their study, they presented two consecutive stimuli (tone pulse pairs) with an interstimulus interval of 0.5 seconds. The subjects had to judge if the comparison stimulus was greater than, equal to, or less than, the standard stimulus. Although Dimmick and Olsen found trends similar to those of Riesz (Knudsen,Churcher et al.), i.e., DL decreased with increased sensation level, the size of the DLs was larger than that found by any of the previous experimenters. The smallest DLs found were: Dimmick and Olsen - 2.3 dB at 60 dB SL; Curcher et al. - 1.2 dB at 50 db SL (abrupt), 0.8 dB at 50 dB SL (amplitude modulation); Riesz - 0.6 dB at 50 dB SL.

Dimmick and Olsen demonstrated that different methodology yielded different DL size. The exact effect of the procedural differences on differential sensitivity was carefully explored by Harris (1963).

Through a series of precisely designed experiments, Harris was able to compare differences which arose as a result of various procedures and subject response patterns. The technique of loudness modulation, including "beats" was strongly affected by sensation level because of the difficulty of the task at low sensation levels. At higher sensation levels, where modulation was easier to hear, DLI size decreased.

Designing an "optimal DL" experiment could be done, according to Harris, by using a two-comparison tone technique and having subjects judge the comparison tone as "louder" or "softer" with no judgment of equality allowed. He believed that allowing a subject to make the response "equal" decreased his having to make finer decisions and so yielded larger DLs which were more easily affected by frequency and sensation level.

In designing an appropriate measure of DLI, one must also take into account the difficulty of the procedure and/or the subject's ability to perform such a procedure. A method not suited to the subjects would be as bad as one which was not measuring differential sensitivity directly or one in which there were audible transients. The possibility that the data could be the result of measuring something other than what it was thought was being measured because the task was not subject-appropriate was demonstrated by Mencher et al. (1970).

Although the Mencher study used temporal lobe damaged subjects, the question of subject-appropriate methodology has a general application. The authors found their subjects did not demonstrate hypersensitivity for DLI post-operatively. That was in direct contrast to Swisher (1967) who had originally demonstrated that hypersensitivity was usual with such subjects. The difference between the studies was that Swisher used a

sustained tone with periodic increments and Mencher et al. used amplitude modulation to measure DLI. The subjects in the later study had a great deal of difficulty performing the actual task and so the larger DLs obtained were most likely a result of the task not being subject-appropriate rather than a real difference in sensitivity.

In general, the literature which, for the most part, described normal adult discrimination ability, demonstrated that DLI was affected by the stimulating frequency, the method of presentation and particularly the presentation level. Differential sensitivity increased with increasing sensation level through at least 40 dB SL (Dallos and Carhart, 1963). The literature also indicated that in designing a DLI experiment, one must consider the procedure being used, the subjects' ability to perform the task relevant to the procedure, and the response the subjects must give. All of these variables will influence the acuity of the discrimination being made.

Difference Limen for Frequency (DLF)

In examining the literature on difference limen for frequency (DLF), one must again refer to data obtained on normal adults. These data, like those for DLI, were subject to change with changing methodology. The judgment required in DLF was reported to be more difficult and to require a great amount of pretraining to obtain reliable values, particularly with naive listeners.

Shower and Biddulph (1931) wanted to improve on the technique used by Knudsen (1923) because the earlier work was subject to question due to audible transients and difficulties controlling intensity. Using a frequency modulated tone at 40 dB SL, they obtained data over a wide

frequency range which indicated that DLF decreased with increased frequency and with increased intensity.

Harris (1948) avoided the problem of audible transients but encountered the problem of response "anchoring" when he used a method of constant stimuli. He demonstrated that the occurrence of the latter problem could also be reduced by a random presentation of the standard tone. Though Harris could reduce the intra-serial effects,i.e., interactions occurring among stimuli in a given series, pitch judgments were shown to be affected, to a degree, by the preceding levels of stimuli in the same experimental series (Dougherty, 1949). Although the main probe of the study was the effect of methodology on constant error, Dougherty did demonstrate that different standard stimuli used in one experimental series would yield lower judgments of stimuli used with a low standard when they were preceded by stimuli with a higher standard. One could control the degree of the inter-seriel effect by randomization of the standard. The problem of asymmetry, i.e., more stimuli higher or lower than the standard used could be ruled out be keeping a relatively narrow range of comparison tones.

The precise experiment that could be designed for obtaining an accurate measure of DLF, method of constant stimuli or frequency modulation, was explored by Harris (1952). He felt that the technical problems, for example, audible transients, associated with frequency modulation did not allow for a true measurement of pitch discrimination. He chose a pitch memory procedure (two comparison tones, method of constant stimuli) to obtain a measure of differential sensitivity. Koester (1945) had previously obtained DLF measurements with a two-comparison tone procedure. Harris' experiment drew from and expanded on the work of Koester so that his stimuli encompassed a wide frequency range and

various presentation levels. Harris confined his subjects' judgments of the comparison tone to "higher" or "lower" than the randomly presented standard tone. Based on the results, which closely agreed with Koester's data, Harris suggested measuring DLF at a sensation level near 30 dB, where he found frequency to have the least effect. Regardless of loudness, DLF decreased with frequency. His recommendation for a true measure of frequency discrimination was based on using a method of constant stimuli.

Methodological Considerations

Psychophysical Procedure: It was obvious from the literature cited above that a major problem in designing a psychoacoustic experiment was finding a subject and phenomenon-appropriate procedure. The experimenter had to be sure that the data were not confounded by a subject's inability to perform the task, or by the task not measuring the phenomenon it was supposed to measure. When dealing with the normal adult population, those intervening variables were more easily controlled than would be by using children of varying ages as subjects. With subject younger than seven years, the major concerns in experimental design were finding a procedure which would accurately measure what one was interested in measuring and one to which all the subjects could respond appropriately.

The use of play audiometry for obtaining pure-tone thresholds had long been accepted as a clinical procedure to accommodate younger clients (Martin, 1975).

Several studies had dealt with the comparison of Bekesy and standard audiometric techniques for pure-tone thresholds of children. The interest was in the reliability of the Bekesy procedure with children and/or the youngest age at which a child could perform the task. Price and Falck

(1963) trained normal children (six through eleven years) on a Bekesy procedure. A subject was considered trained when he could complete the audiogram without the experimenter either re-instructing him or reminding him to attend to the task. The youngest subjects that could complete either a sweep or fixed frequency tracing were those with a chronological or mental age of seven years. Subjects younger than seven years old could not attend to the task for longer than three minutes, some being unable to operate the audiometer for even shorter periods of time.

In an effort to determine which procedure, Bekesy or standard audiometric, better suited children, Hartley and Siegenthaler (1964) found thresholds for 250,500 and 1000 Hz on normal children aged four, five, eight and ten years old. For the standard procedure a method of limits was used; the older children raised their hands and the younger children performed a motor task (play audiometry) as a response. With the Bekesy procedure, there were detailed instructions and pretrial runs. The younger children, even after practice, needed at least ten minutes to perform the task with assistance.

The mean thresholds showed greater sensitivity for the standard procedure than for the Bekesy, and there was an increase in sensitivity with age regardless of procedure. For all subjects, the intrasubject variability was greater on the Bekesy procedure and was most pronounced for the younger children. The difficulty the four and five-year olds had performing this task was reflected in the results. For these subjects, the excursion widths were greater and often the pen would run to the limits of the audiometer and then come back, after the child had been reminded of the task.

Stark (1968) found similar results with normal and hard of hearing

children (five through ten years). For children seven years and older, there was a high correlation between the two methods, but for the younger children (five and six years) there were differences as large as 11.1 dB with the Bekesy procedure yielding the poorer thresholds.

Most of the experimental studies of temporal integration were carried out using a Bekesy tracking method. As the studies cited above indicated, such a procedure would be inappropriate for subjects younger than seven years old. The question then arises as to the validity of obtaining measures of temporal integration through a different procedure, i.e., would one be sacrificing a true measure of temporal integration in order to find an age-appropriate procedure.

Richards and Dunn (1974) examined the effect of methodology on threshhold-duration functions. They compared the functions of twenty-three normal adults obtained with Bekesy tracking and the method of adjustment. They used a 1000 Hz tone at 20, 50, 100, 200 and 500 msec and found no demonstrable differences in test-retest reliability for either procedure; mean threshold data for all durations was relatively unchanged. Due to the seeming lack of interaction between methodology and threshold-duration function, the authors suggested that other psychophysical methods, e.g., constant stimuli, could be employed. The limiting factor with other methods would be the necessity of repeated measures to obtain threshold, causing an increase in the length of the experimental session. Still, an experimenter could select the method best suited to the subjects because methodology did not have a significant effect on threshold-duration function.

Barry and Larson (1973) found it necessary to abandon both the Bekesy tracking procedure and the method of adjustment because they were

using a population that consisted of a group of deaf and normal children, some of whom could not learn those procedures. By a modified method of limits, they were able to obtain temporal integration data on deaf and normal children aged six through fourteen years. They restricted durations to two (20 vs 500 msec) and frequencies to four (500,1000,2000,4000 Hz). The normal children approached theoretical values, but did not demonstrate the small threshold differences usually found in adults.

The difficulty in accepting the use of the method of limits in their study was that Barry and Larson did not demonstrate the applicability of such a procedure for obtaining true threshold-duration functions. In a pilot study performed prior to the present research, Bekesy tracking and a method of limits were compared as procedures for obtaining temporal integration measures with children because the research mentioned earlier comparing Bekesy and standard audiometric techniques indicated that a method other than Bekesy tracking would have to be substituted for children younger than 7 years old.

In the pilot study, thresholds were obtained on normal children aged three, five, seven, nine, and eleven years, using a 1000 Hz tone of 25 and 500 msec durations. Results clearly indicated that the three-year old subjects could not perform either task reliably and that the five-year olds could not be readily trained on a Bekesy procedure. The older subjects (older than seven years) could perform both tasks, although the Bekesy tracking did require more pretraining. There was no significant difference between the threshold-duration functions (and actual intensity of the thresholds) obtained with the two procedures when the subjects could perform both tasks. These findings indicated that a method of limits could be used for a temporal inte-

gration study without confounding the data and accomodating the youngest children. The youngest subjects that could participate in such a study would have to be older than three years since the three-year old pilot subjects could not perform the tasks.

Response Modes: Other modifications in procedures which had to be considered for the present study were the responses (judgments) of the subjects. Carter, Ricker and Corsini (1972) reported that when children were presented with two suprathreshold sounds, it was easier for them to correctly identify the louder than the softer sound. That presumably would also be true for pitch discriminations. It had been demonstrated that pitch discriminations were more difficult, in general, for children (six years) to make than loudness discriminations, especially when they had to judge tha comparison stimulus as "higher" or "lower" (McKee and Riley, 1962).

Carter et al. felt that the immaturity of the developing auditory perceptual mechanism was the cause.A child younger than six-years old (Piaget's preoperational stage) would have to make relational discriminations without having the concept of comparative relation. Therefore, the judgment "louder' or "softer" and/or "higher' or "lower" for the same set of stimuli would be made independently of each other. Using three, four, and five-year old normal subjects, they demonstrated that the younger the child, the more difficult was a relational discrimination. For children younger than six years, a more accurate estimate of their discrimination could be made having them use less specific judgment and respond "same" or "different."

The literature and the pilot data revealed that a method of constant stimuli could be substituted for a Bekesy tracking procedure in measuring temporal integration. It was also demonstrated that a "same"

"different" response would yield a more accurate measure of frequency and intensity discriminations for younger subjects. In order to control for any significant differences which could have arisen from varying methodology, the present study employed the same procedures for all subjects. Although they were modifications of those employed with normal adults, it had been demonstrated that those procedures assessed the auditory functions being studied. Therefore, any significant differences obtained should have been the result of differences in auditory perception of the subjects rather than procedural influences.

Chapter III
Method

Subjects: The subjects were twenty-five normal hearing children selected according to five age groups. Five subjects were in each age group of 4 (Mn=4.5), 6 (Mn=6.3), 8 (Mn=8.5), 10 (Mn=10.2), and 12 (Mn=12.4) years of age.

All subjects were one of at least two siblings and came from a family in which the average income was $30,000 per annum. The parents of the subjects were interviewed to determine that none of the subjects came from a family in which there was a history of congenital hearing impairment. They were also questioned to rule out any pre- or post-natal developmental problems (maternal illness during pregnancy, birth difficulty, delayed motor or language development). None of the subjects had any history of otologic disease or hearing loss.

The population from which the subjects were selected was obtained through personal contact between the experimenter and the parents of the potential subjects. This population was comprised of personal friends, family and coworkers of the experimenter.

The selection of the youngest subjects was most difficult because some of the 4-year old children interviewed would not perform readily on the pure-tone threshold procedure, i.e., these children would not perform the procedure without a great deal of coaxing. They were, therefore, ruled out as subjects on the judgment that it would be difficult to have them return and cooperate for the four long experimental sessions.

Procedure: During each experimental session, only one task was completed. All subjects were tested in the following order: Pure-tone thresholds, temporal integration, difference limen for intensity (DLI),

difference limen for frequency (DLF). This order was chosen so that the tasks would become progressively more difficult with each session. According to Dember (1965) absolute threshold detection tasks (pure-tone thresholds and temporal integration) are easier to perform and require less ability to manipulate perceptual information than do difference detection threshold tasks (DLI and DLF).

During the experimental sessions, the subjects received tokens at fifteen-minute intervals and were allowed to "buy" toys at the end of each session. Since only one measure was employed at each experimental session, the subjects had to return on four different occasions to complete the entire test battery. The duration of the experimental sessions varied according to the needs of the subject. The younger children usually required more rest periods. These periods were either given on request, but not less than seven minutes apart, or every fifteen minutes, at which time the subjects were reinforced. The length of the rest period was always one minute; therefore, the more rest periods given, the longer the test session. No test session lasted longer than two hours.

Pure-tone thresholds: Thresholds were obtained on a Grason-Stadler two-channel audiometer (model 1701) calibrated to ANSI-1969 reference thresholds. The signal was delivered through TDH-39 headphones mounted in MX-41AR cushions. Thresholds were obtained for both ears employing an ascending procedure (Hughson and Westlake, 1944). Threshold was taken as the lowest intensity level at which a minimum of four stimulus presentations was given and correctly identified at least fifty percent of the time. The threshold for a particular frequency was the average of the four threshold crossings (two trials per ear). Air conduction thresholds were obtained in the following order: 1000, 2000, 4000, 8000, 250 and 500 Hz

with a random selection of the right or left ear being tested first. Bone conduction thresholds were measured to rule out any air-bone gap.

The older subjects (8, 10, 12 years) raised their hands whenever they perceived the presentation of a stimulus; play audiometry was used with the younger subjects (4, 6 years). The older subjects were given the following instructions:

> You are going to hear some tones ("beeps"). Some are going to be loud and some are going to be soft. Some are going to be high like this (gave example of 4000 Hz) and some are going to be low like this (gave example of 500 Hz). Whenever you hear a tone ("beep") I want you to raise your hand. Even if the sound is very soft, raise your hand. If you don't hear anything, keep your hand down. Any questions?

The younger subjects were given the following instructions:

> You are going to hear some sounds ("beeps"). Some are going to be loud and easy to hear. Some are going to be soft and hard to hear. Whenever you hear a sound, put a block in the box. Some sounds will be high like this (gave example of 4000 Hz) and some are going to be low like this (gave example of 500 Hz). Whenever you hear a sound ("beep") put a block in the box. Let's try it together. (Continue training until the child appropriately performs the task). Do you know what to do?

Temporal integration: Temporal integration was measured using a method of limits. Figure 1 displays the block diagram of the equipment used for the temporal integration procedure.

A pure-tone was produced by the oscillator of a Grason-Stadler two-channel audiometer (model 1701) and amplified by a Krohn-Hite amplifier (model 101-AR). The amplifier was needed in order to produce the appropriate intensities for the short duration signals (25 milliseconds). The signal was then fed to "A in" of channel two of a Grason-Stadler electronic switch (model 829E) and a Grason-Stadler interval timer (model 471-1) where it was electronically controlled to have a rise-decay

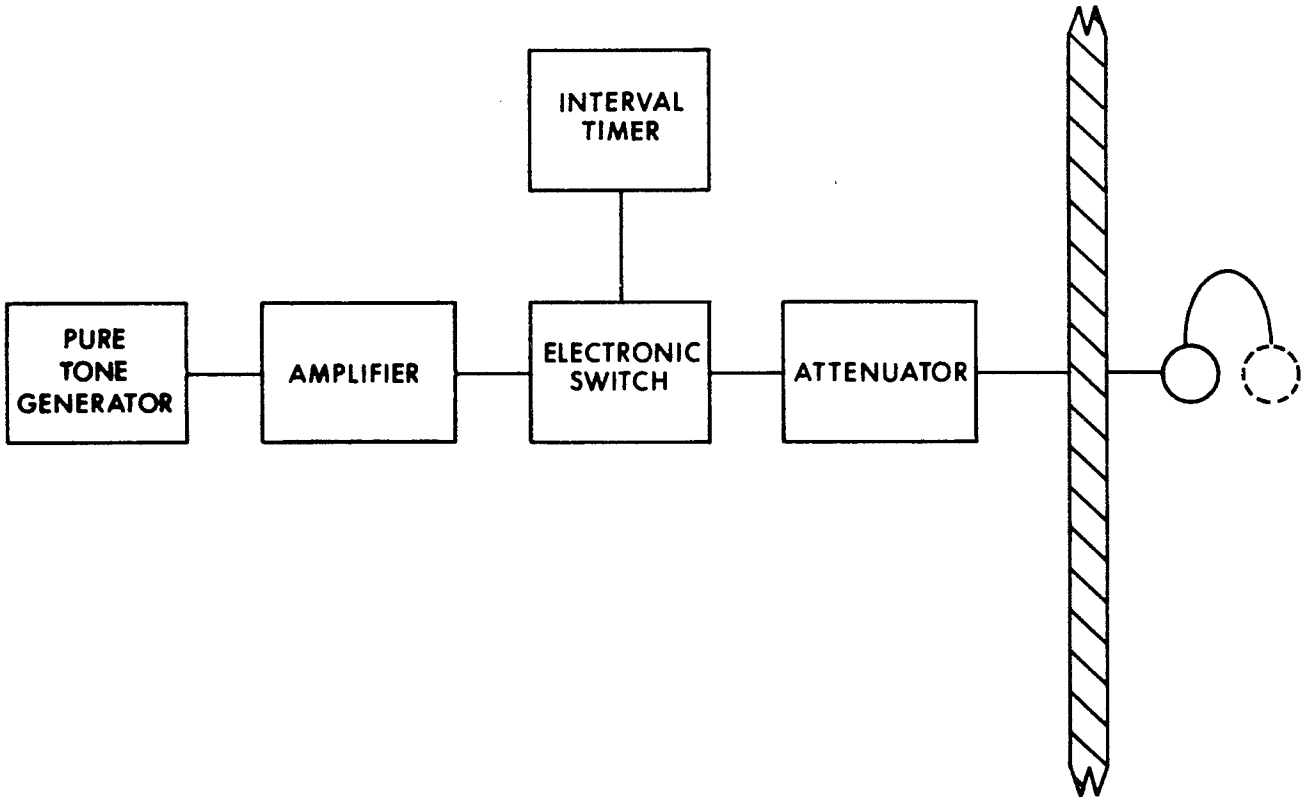

Figure 1. Block diagram of temporal integration equipment.

time of 10 milliseconds (msec) and varying durations (25, 50, 100, 200, 400 and 800 msec). Each stimulus block lasted 1 second and each stimulus was presented at a rate of one/second (Wright, 1968a). The signal was routed back to the attenuator of the audiometer where the intensity could be easily manipulated in one dB steps and then fed to a pair of matched TDH-39 headphones housed in MX-41AR cushions.

Thresholds were obtained by an ascending technique at four frequencies (500, 1000, 2000 and 4000 Hz) and the six durations. An ascending procedure was used because of its recommendation in conventional pure-tone audiometry. For the younger subjects (4 and 6 years) play audiometry was used. The older subjects (8, 10 and 12 years) raised their hands in response to a perceived signal. The older subjects received the following instructions:

> You are going to hear some tones ("beeps"). Some are going to be loud and some are going to be soft. Some are going to be high and some are going to be low. Some of the tones ("beeps") are going to be short like this (gave example of 50 msec 1000 Hz 50 dB HTL tone). Some are going to be long like this (gave example of 400 msec 1000 Hz 50 dB HTL tone). Whenever you hear a tone ("beep"), I want you to raise your hand. Even if the tone is very short or very low, raise your hand. When you don't hear the tone ("beep"), keep your hand down. Any questions?

The younger subjects were given the following instructions:

> You are going to hear some sounds ("beeps"). Some are going to be loud and easy to hear. Some are going to be soft and hard to hear. Whenever you hear a sound ("beep") put a block in the box. Some are going to be high and some are going to be low. Some sounds ("beeps") are going to be long like this (gave example of 400 msec 1000 Hz 50 dB HTL tone) and some are going to be very short like this (gave example of 50 msec 1000 Hz 50 dB HTL tone). Whenever you hear one, put a block in the box. Do you know what to do? Let's do it together. (Continue training until the subject appropriately performed the task).

A trial period preceded the experimental session until a subject was able to give ninety percent correct responses over ten trials of a 1000 Hz, 50 msec tone of 30 dB sensation level (SL). Reinforcement (FR3) was used during the training.

During the experimental session, each duration was presented randomly six times at each frequency, yielding a total of 144 thresholds per subject. Thresholds were obtained monaurally, the same ear being used throughout the session, the selection of that ear being made randomly. Threshold was defined as the lowest intensity level at which the subject was able to respond correctly fifty percent of the time. Threshold of temporal integration was taken as the mean of the thresholds at each frequency and each duration.

Difference limen for intensity (DLI): Difference limen for intensity was measured with a two-tone comparison procedure, employing a method of constant stimuli. Figure 2 shows a block diagram of the equipment used.

A pure-tone was produced by a Hewlett-Packard audio oscillator (model 200AB) and fed to two Hewlett-Packard attenuator sets (model 350D). One attenuator (A) controlled the comparison tone, which was routed through a .5dB step attenuator (C). The signal was then fed to "A in" of channel two of a Grason-Stadler electronic switch (model 829E) and a Grason-Stadler interval timer (model 471-1). The other attenuator (B) controlled the standard tone which was fed directly to "B in" of channel two of the electronic switch and interval timer. Prior to each experimental session, attenuators A and B were calibrated so that the signals were matched for intensity at that point in the system. Any intensity differences at the headphones were produced by attenuator C which controlled the size of the intensity increments. Both signals A and B were controlled by

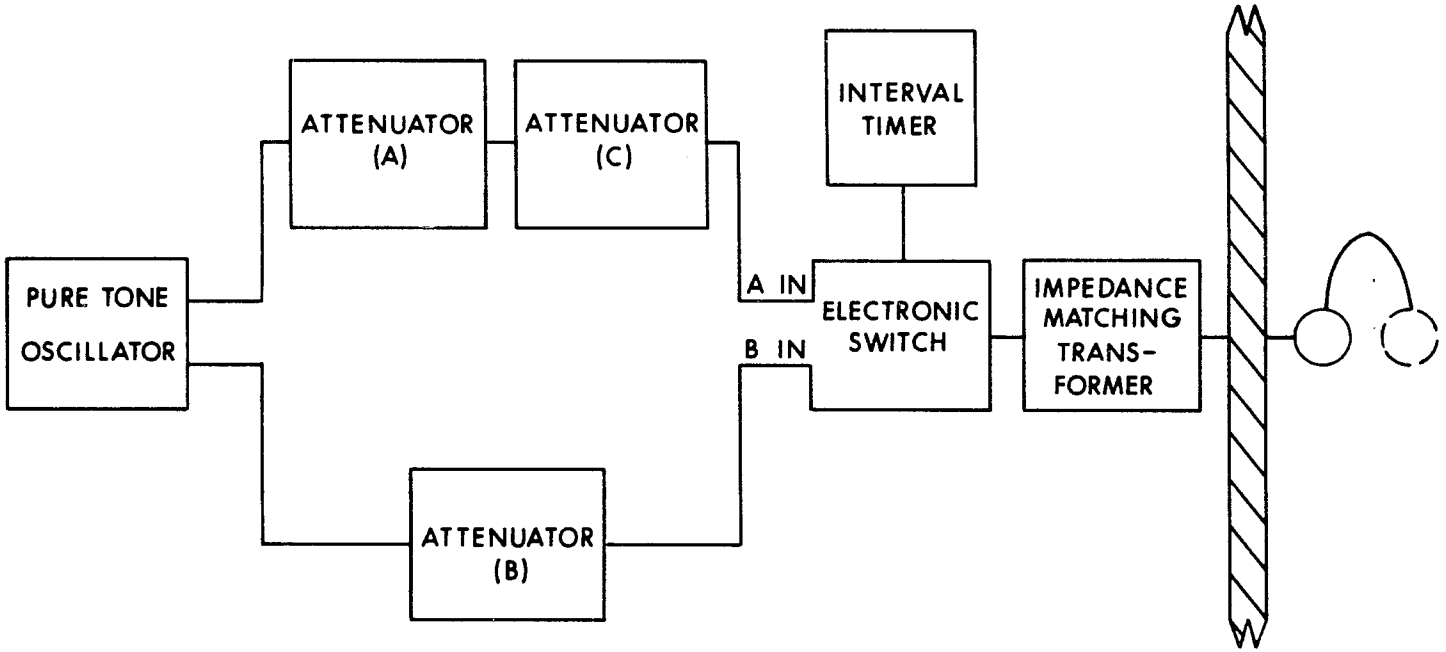

Figure 2. Block diagram of difference limen for intensity (DLI) equipment.

the timer and switch so that each had a rise-decay time of 25 msec. The period of the entire stimulus block was set at 1000 msec. The signals, A and B, had an "on time" of 400 msec and an"off time" of 600 msec (40% duty cycle), i.e., each signal was presented for 400 msec with a 200 msec interstimulus interval. The experimenter was able to choose which signal, A or B, was being presented by manually manipulating the switch. Both signals were then fed through a Grason-Stadler impedance matching transformer (model E10589A) and then to a pair of matched TDH-39 headphones housed in MX-41AR cushions.

DLI was measured monaurally at four frequencies (500, 1000, 2000 and 4000 Hz) and four sensation levels (10, 20, 40 and 60 dB) for the standard tone. The experimenter referred back to the pure-tone thresholds obtained in order to determine the intensity needed for each sensation level at each frequency. The intensity was measured in dB SPL (re: .0002 dynes/cm^2) by a Bruel and Kjaer sound level meter (model 2203). The subjects listened to the standard and comparison tones and reported if they were the same or different. All of the subjects were given the following instructions:

> You are going to hear two tones ("beeps"). Sometimes they tones ("beeps") are going to sound the same like this (gave 1000 Hz tone at 40 dB SL twice). Sometimes the are going to sound different like this (gave 1000 Hz tone at 20 dB SL and at 40 dB SL). I want you to tell me if the two tones ("beeps") sound the same or different. Sometimes the tones will be loud and easy to hear and sometimes they will be soft and hard to hear. Just tell me if they are the same or different. If you think the two tones ("beeps") sound the same tell me. If you think they sound different tell me. Do you know what to do? Let's try it together.

A training period preceded the experimental session in which the subjects had to make intensity difference judgments at 1000 Hz. A reinforcement schedule (FR3) was used and a subject was considered trained

when he could achieve ninety percent correct responses over ten trials with a 10 dB difference between the comparison and standard tones. The training stimuli were presented at 40 dB SL.

During the experimental session, each trial consisted of two tones, the standard and the comparison. The order of presentation, standard first or comparison first, was made randomly. The comparison tone was varied in .5 dB steps, either above or below the standard in intensity. Threshold was considered to be the lowest (smallest) intensity difference at which the subject responded "different" fifty percent of the time. The mean of the thresholds obtained above and below the standard was the measured DLI. Five measures of DLI were obtained at each frequency and at each sensation level so that a total of eighty DLIs were obtained per subject.

Difference limen for frequency (DLF): Difference limen for frequency was measured with a two-tone comparison procedure, employing a method of constant stimuli. Figure 3 shows a block diagram of the equipment used.

A standard tone (A) was produced by a Hewlett-Packard audio oscillator (model 200 AB) and then fed to "A in" of channel two of a Grason-Stadler electronic switch (model 829E) and a Grason-Stadler interval timer (model 471-1). The comparison tone (B) was produced by a Bruel and Kjær sine random generator (type 1024) and fed to "B in" of channel two of the electronic switch. Both signals were controlled by the timer and switch so that each had a rise-decay time of 25 msec. The period of the entire stimulus block was set at 1000 msec so that signals A and B had an "on time" of 400 msec and an "off time" of 600 msec (40% duty cycle), i.e., each signal was presented for 400 msec with a 200 msec interstimulus

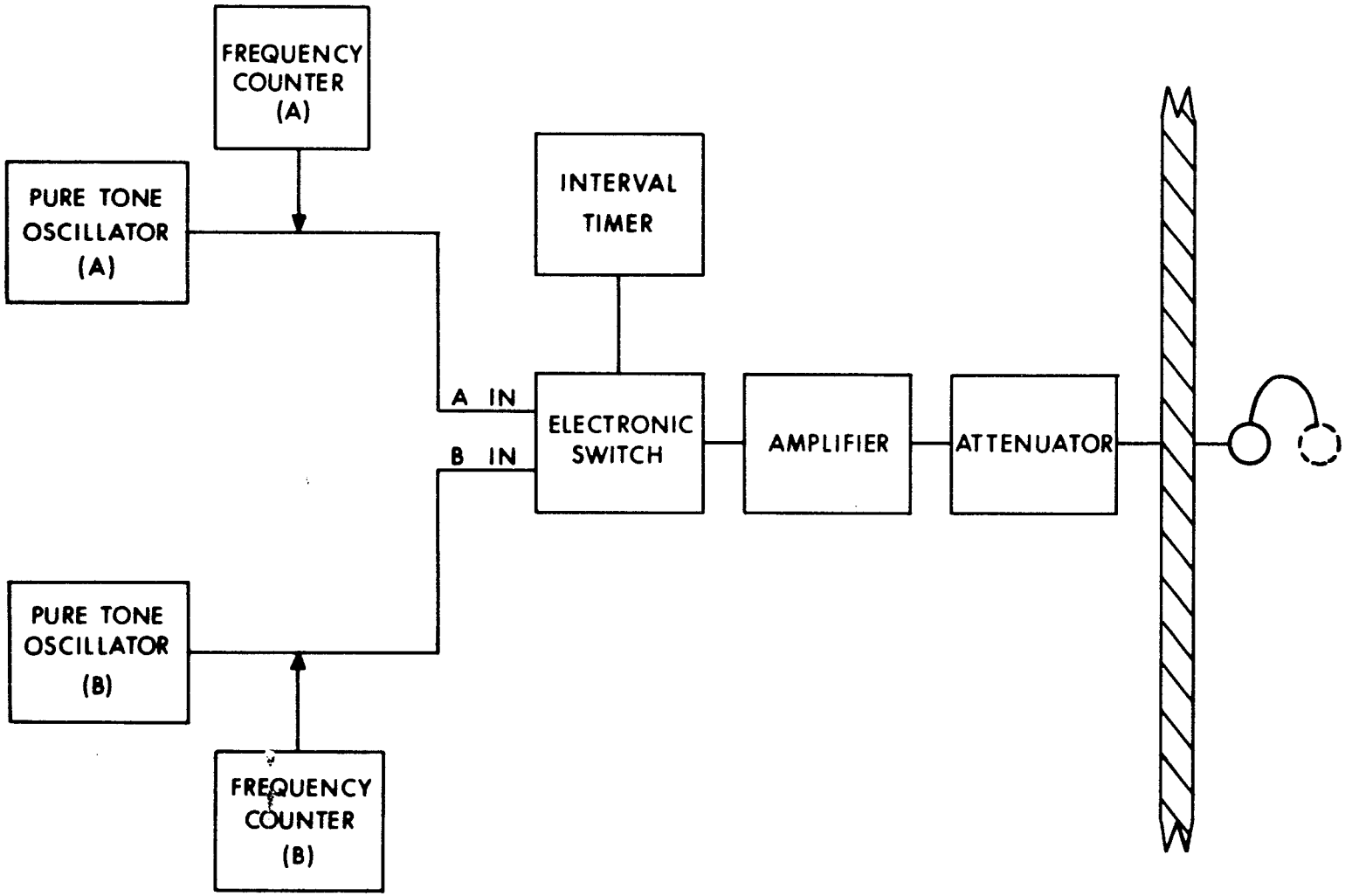

Figure 3. Block diagram of difference limen for frequency (DLF) equipment.

interval. The experimenter was able to choose which signal, A or B, was being presented by manually manipulating the switch. Both signals were then amplified by a Krohn-Hite amplifier (model UF 101AR) and then attenuated by a Hewlett-Packard attenuator set (model 350D). The signal was reproduced through matched TDH-39 headphones housed in MX-41AR cushions and presented monaurally.

The subject listened to the two tones, standard and comparison, and reported if they were the "same" or "different." All the subjects received the following instructions:

> You are going to hear two tones ("beeps"). Sometimes the tones ("beeps") are going to sound the same like this (gave two 1000 Hz tones). Sometimes they are going to sound different like this (gave a 1000 Hz tone and a 1500 Hz tone). Listen to the two tones ("beeps") and tell me if they are the same or different. If you think the two tones ("beeps") are the same, tell me. If you think the two tones ("beeps") are different, tell me. Do you know what to do? Let's do it together.

A training period preceded the experimental session in which the subjects practiced making pitch difference judgments. The 1000 Hz training stimulus was presented at 40 dB SL. Harris (1952) reported that this sensation level would lead to the easiest task for the subject. During this period a reinforcement schedule (FR3) was used and a subject was considered trained when he could give ninety percent correct responses on ten trials with a 25 Hz minimum difference between the standard and comparison tones.

In the experimental sessions, there were two conditions, Condition A in which the comparison tone was greater than or equal to the standard, and Condition B in which the comparison tone was less than or equal to the standard in frequency. The test signals were presented

at 30 dB SL. The experimenter referred back to the pure-tone thresholds obtained in order to calculate the intensity of the sensation level. The intensity was measured by a Bruel and Kjær sound level meter (model 2203). DLF was obtained at each of four frequencies (500, 1000, 2000 and 4000 Hz). The stability of the frequencies was constantly monitored by a Hewlett-Packard frequency counter (model 5221A).

Five estimates of DLF were obtained at each frequency in each condition, A and B, yielding forty thresholds per subject. Threshold was considered the smallest frequency difference at which a subject responded "different" fifty percent of the time.

Chapter IV

Results

The results of this study were analyzed through several methods. They are discussed in three separate sections, one which explains the descriptive analysis, one which explains the statistical analysis, and one which explains the analysis of internal validity. In each section, the individual tasks are discussed separately.

Descriptive Analysis

Pure tone sensitivity: Mean pure tone thresholds were computed in dB SPL by averaging thresholds obtained for both ears for all subjects, within each age group. These data, as well as adult ANSI 1969 norms, can be seen in Table 1 and represented graphically in Figure 4.

Generally, threshold improved with age at all frequencies. The four-year olds demonstrated the poorest thresholds and the twelve-year olds the best. The thresholds for the 12-year olds were closer to adult thresholds than were any of the other age groups. The functions for each group were similar to each other and to adult norms in configuration. The configuration showed that threshold varied with frequency. The poorest thresholds were found at 250 Hz with an improvement until the mid-frequency range (1000-2000 Hz), where hearing was most sensitive, after which threshold decreased again. In other words, hearing was most sensitive in the mid-frequency range with less sensitivity at the highest frequency (8000 Hz) and least sensitivity at the lowest frequency (250 Hz). The only exception to that pattern was the function found for the 10-year olds, where the mean threshold found at 8000

Table 1

Mean pure tone thresholds in dB re: .0002 dynes/cm^2. Thresholds for both ears were averaged for pooled subjects in each age group.

Age Group (Yr)	Frequency (Hz)					
	250	500	1000	2000	4000	8000
4	34.5	18.1	15.4	14.7	15.6	16.1
6	32.6	17.8	11.1	13.3	14.8	15.8
8	31.2	17.5	11.5	13.6	14.4	13.8
10	28.3	16.5	12.9	11.8	11.2	9.6
12	28.1	13.6	5.2	11.1	11.0	12.5
ANSI,1969	25.5	11.5	7.0	9.0	9.5	13.0

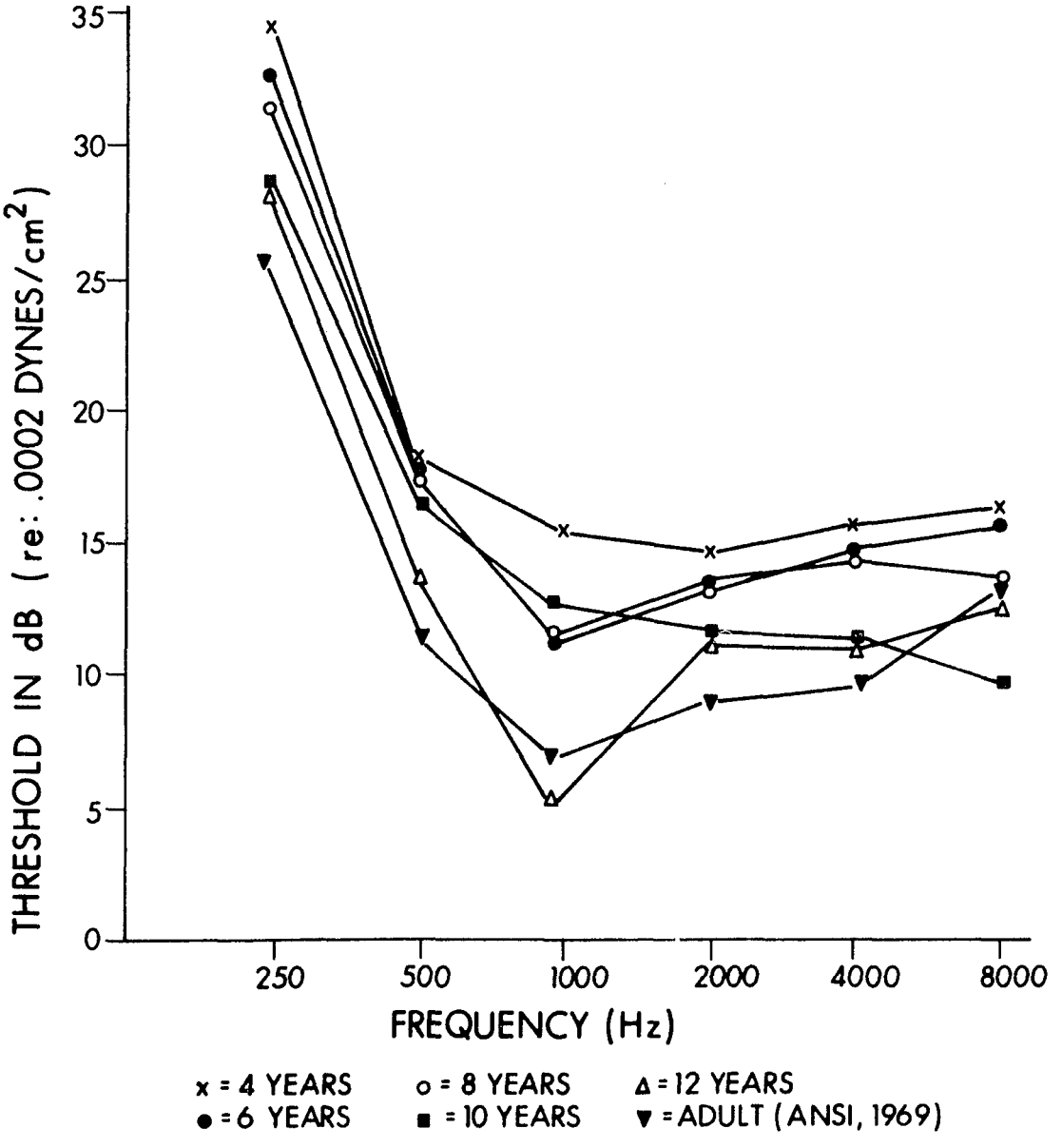

Figure 4. Mean pure tone thresholds in dB SPL for each age group and normal adult data (ANSI, 1969).

Hz (9.6 dB) was better than any found at any of the other frequencies.

Temporal Integration: Mean thresholds in dB were calculated for the temporal integration data. Means were obtained by pooling the thresholds from all durations and frequencies within each age group. The data can be found in Table 2 and represented graphically in Figure 5. Threshold improved with increased age. There was a gradual improvement between 4 and 10 years and then a sharp change from 10 to 12 years. The difference in threshold from 4 to 10 years was 3.55 dB while the difference in threshold from 10 to 12 years was 5.58 dB.

The same data were re-averaged so that mean threshold as a function of duration could be observed. The means were obtained by pooling thresholds from all age groups and all frequencies for each duration. These data are displayed in tabular form in Table 3 and graphic form in Figure 6. Threshold improved as duration increased from 25 to 800 msec. As duration increased from 25 to 800 msec, threshold changed by 20.79 dB. The threshold shift from 25 to 200 msec was 15.31 dB, similar to the adult normative threshold shift found by Wright (10dB) and Zwislocki (12.5 dB) for a tenfold duration change. As duration increased after 200 msec, the thresholds continued to improve, but the change in threshold from one duration increase to the next was smaller than it was for the shorter durations. For example, the shift from 25 to 50 msec was 6.45 dB, while the threshold shift from 400 to 800 msec was 2.84 dB.

Threshold-duration functions, shown in Figure 7, were drawn from the mean threshold shifts displayed in Table 4. Mean thresholds were calculated by pooling the thresholds found for all frequencies at each

Table 2

Mean thresholds in dB for temporal integration data. Thresholds for all durations and frequencies were pooled and averaged within each age group.

	Age (Yr)				
	4	6	8	10	12
Mean Threshold (dB)	10.49	8.14	7.26	6.94	1.36

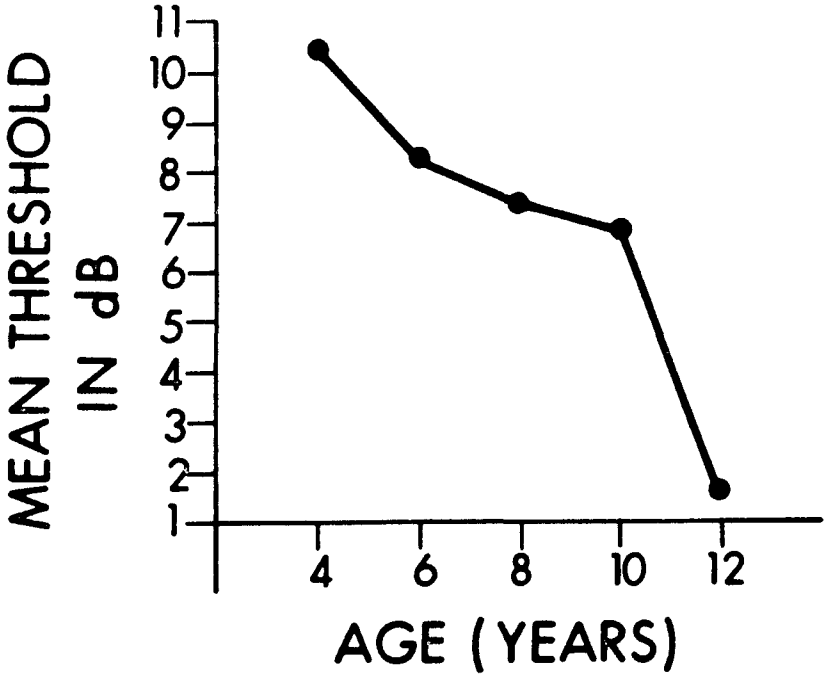

Figure 5. Mean thresholds for temporal integration data, pooled and averaged over durations and frequencies for each age group.

Table 3

Mean thresholds in dB for temporal integration data. Thresholds for all age groups and all frequencies were pooled and averaged at each duration.

	Duration (msec)					
	25	50	100	200	400	800
Mean Threshold (dB)	18.83	12.38	7.35	3.52	0.88	-1.96

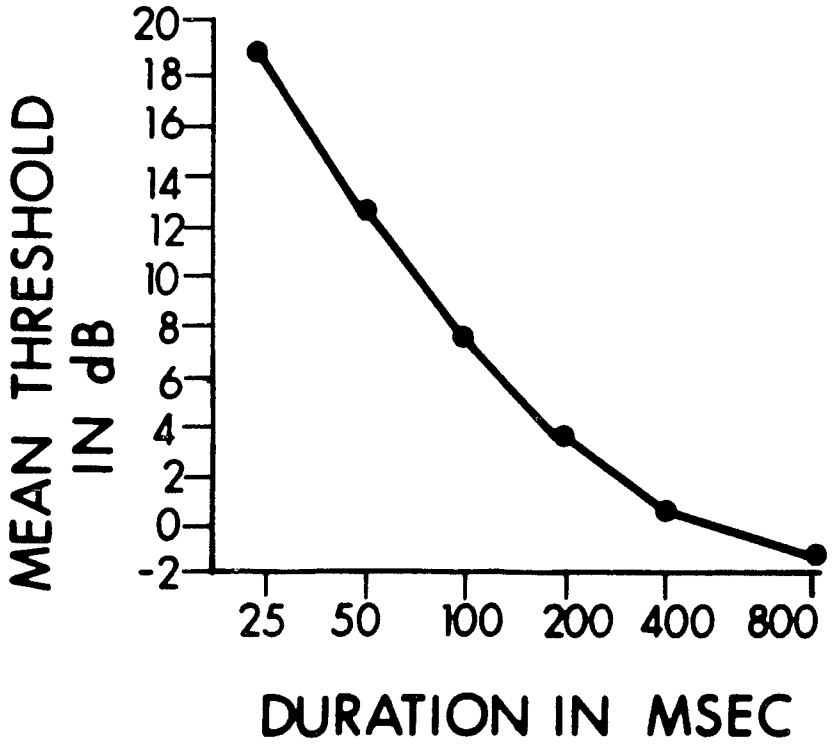

Figure 6. Mean thresholds for temporal integration data, pooled and averaged over ages and frequencies for each duration.

Table 4

Mean thresholds and threshold shifts in dB as a function of the interaction between age and duration for temporal integration data. Shifts were calculated with reference to 25 msec thresholds.

Age Group (Yr)	Duration (msec)					
	25	50	100	200	400	800
4	22.6	15.4 (7.2)	10.8 (11.8)	7.2 (15.4)	4.7 (17.9)	2.4 (20.2)
6	20.9	12.9 (8.0)	8.2 (12.7)	4.7 (16.2)	2.7 (18.2)	-0.6 (21.5)
8	18.8	12.6 (6.2)	8.9 (9.9)	4.7 (14.1)	0.7 (18.1)	-2.2 (21.0)
10	18.9	13.4 (5.5)	7.5 (11.4)	3.6 (15.3)	1.5 (17.4)	-3.1 (22.0)
12	13.0	7.7 (5.3)	1.3 (11.7)	-2.5 (15.5)	-5.1 (18.1)	-6.3 (19.3)

*Numbers in parenthesis are the threshold shifts.

duration. Means were obtained for each age group. Threshold shift was considered in reference to the thresholds obtained at 25 msec, that is the change in threshold from 25 msec to any particular duration. Also displayed in Figure 7 was the normal adult threshold-duration function of Zwislocki. His threshold shifts were calculated with 10 msec as the reference, and it should be noted that he used several durations not used in the present study. Like Zwislocki's data, the results of this study showed that threshold shift increased with increased duration. Threshold shifts for all age groups were approximately the same. The shift from 25 to 200 msec ranged from 14.1 dB (8 years) to 16.2 dB (6 years); the shift from 25 to 800 msec ranged from 19.3 dB (12 years) to 22 dB (10 years).

The configurations of the function for each age group were similar to each other and all fell within 3 dB of each other, that is there was no change in the size of the threshold shift with change in age. As was seen from the mean threshold data, the intensity level at which threshold was found differed with age, the 4-year olds had the poorest and the 12-year olds had the best thresholds.

Intensity difference limen (DLI): Mean thresholds in dB for intensity difference limen data were obtained by pooling thresholds for all sensation levels and frequencies within each age group. These average threholds are displayed in Table 5 and represented graphically in Figure 8. The data demonstrated an increase in differential sensitivity with increased age. The smallest mean DLI was 1.82 dB obtained from the 12-year olds, and was similar to the mean DLI of Riesz's adult norms (1.5 dB). The function showed that the decrease in DL size from 4 to 6 years was the sharpest, while the change between the

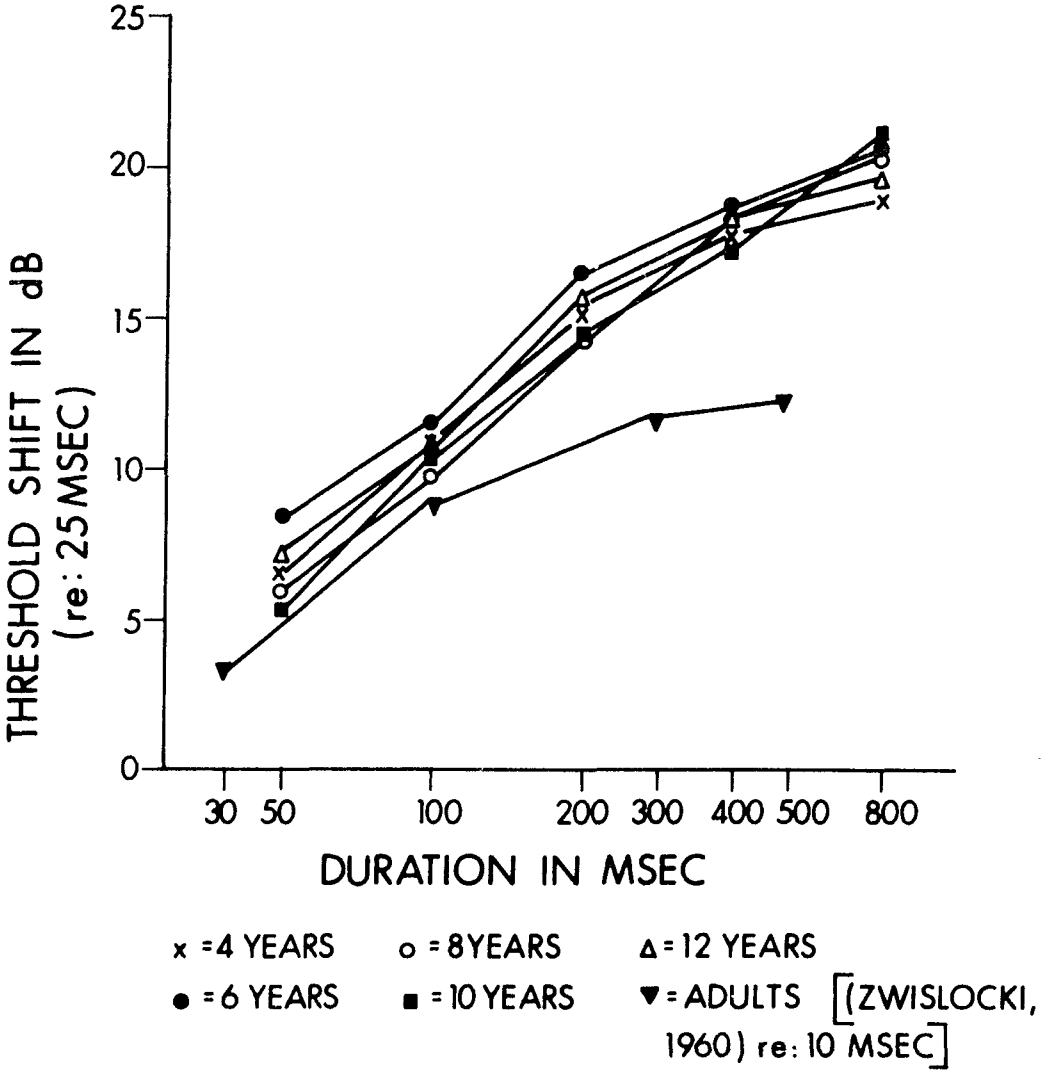

Figure 7. Threshold-duration functions obtained with temporal integration thresholds with reference to 25 msec thresholds. The theoretical normal adult function of Zwislocki (1960) which used a 10 msec reference is also shown.

Table 5

Mean thresholds in dB for intensity difference limen data. Mean DLs were averaged over pooled sensation levels and frequencies within each age group.

	Age (Yr)				
	4	6	8	10	12
Mean DLI (dB)	3.89	2.44	2.07	12.15	1.82

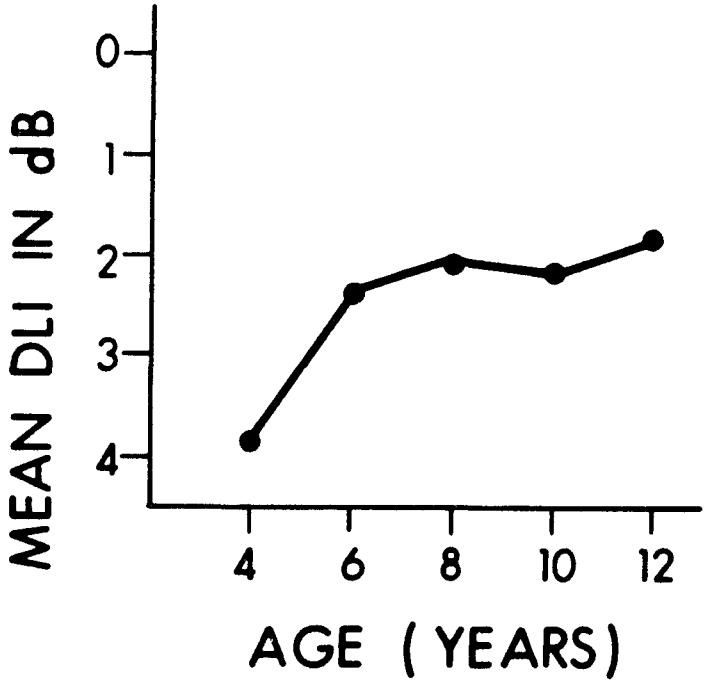

Figure 8. Mean DLs for intensity pooled and averaged over sensation levels and frequencies for each age group.

rest of the adjacent age groups was more gradual. The decrease in DL size from 4 to 6 years was 1.45 dB while the decrease in DL from 6 to 12 years was 0.62 dB.

The data were recalculated to obtain mean DLIs for each age group by pooling the thresholds of all frequencies at each sensation level. These DLIs and the normal adult data of Riesz (1928) and Harris (1963) are displayed graphically in Figure 9. Like the normative data of Riesz, the DLs obtained in the present study decreased with increased sensation level. The configurations of the functions for all age groups were similar. The function of the 4-year old subjects showed a greater change in DL size with sensation level than did the other subjects, but in general the configuration was the same. All the functions obtained were dissimilar to that obtained by Harris in his "optimal DL" experiment. His results showed no change in DL size with change in sensation level.

The decrease in DL size with increased age can again be observed with the data plotted in this manner. It was also clear that the 12-year olds came closer to adult norms than did any of the younger subjects.

The effect of frequency on DLI size can be seen in Figures 10 and 11. The mean DLs plotted in Figure 10 were obtained by pooling all thresholds for all age groups and sensation levels at each frequency. The configuration of the function indicated that DLI was largest at 500 Hz, the lowest frequency used, and smallest at 2000 Hz. The trend was a decrease in DL size with increased frequency until 2000 Hz after which DL increased with frequency, 4000 Hz being the highest frequency used. The frequency effect became less noticeable graphically, when the data were replotted for each age group at each sensation level, as in Figure

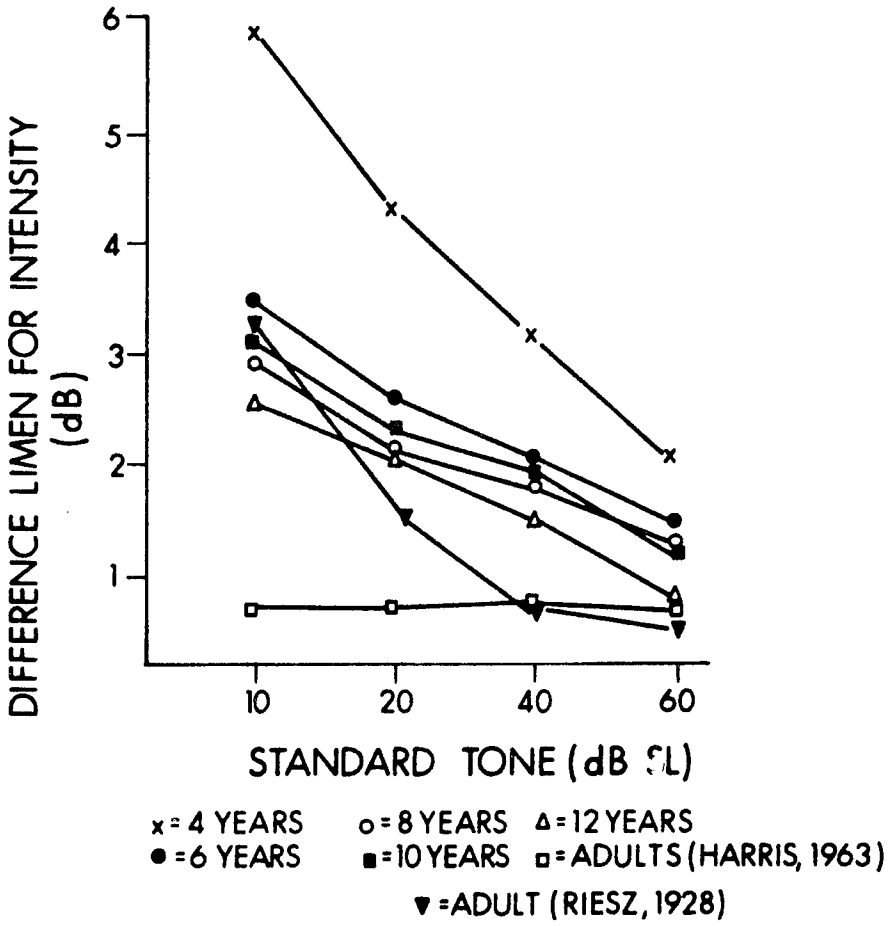

Figure 9. Difference limen for intensity for each age group at each sensation level. The normal adult data of Harris (1963) and Riesz (1928) are also shown.

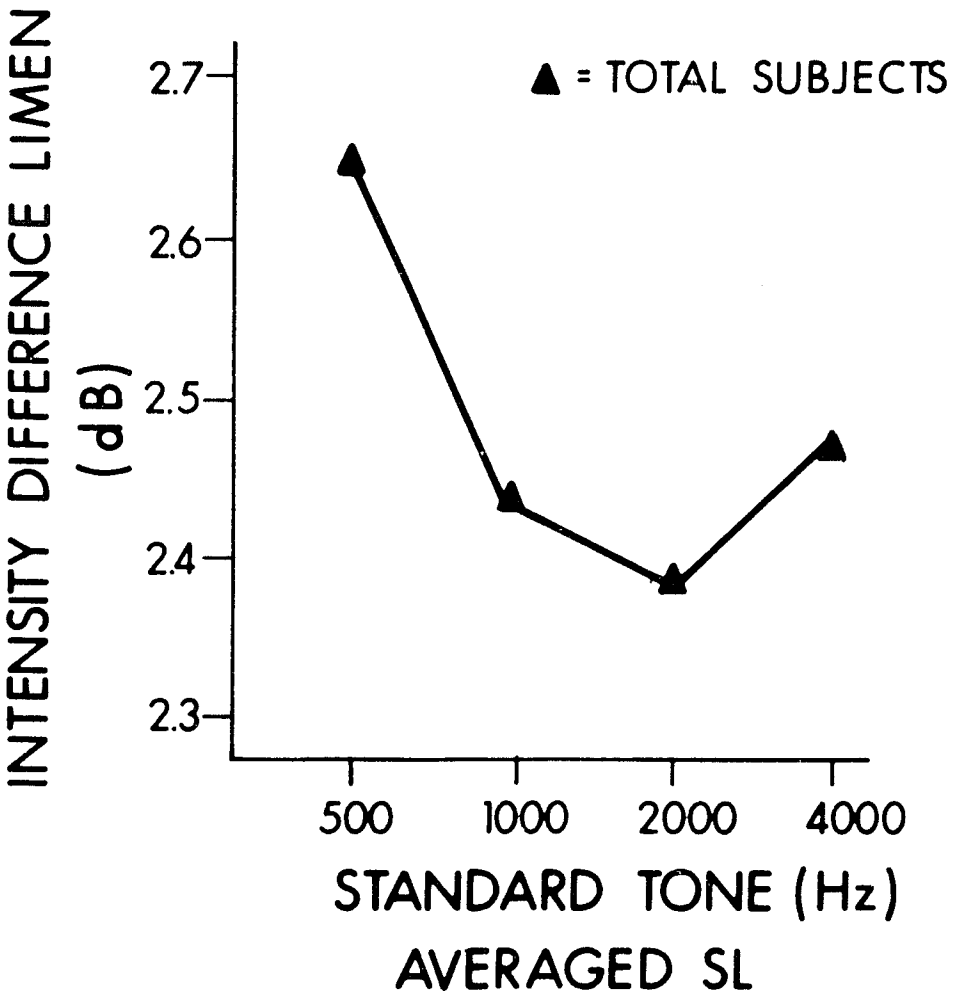

Figure 10. Mean DLs for intensity obtained by pooling age groups and sensation levels at each frequency.

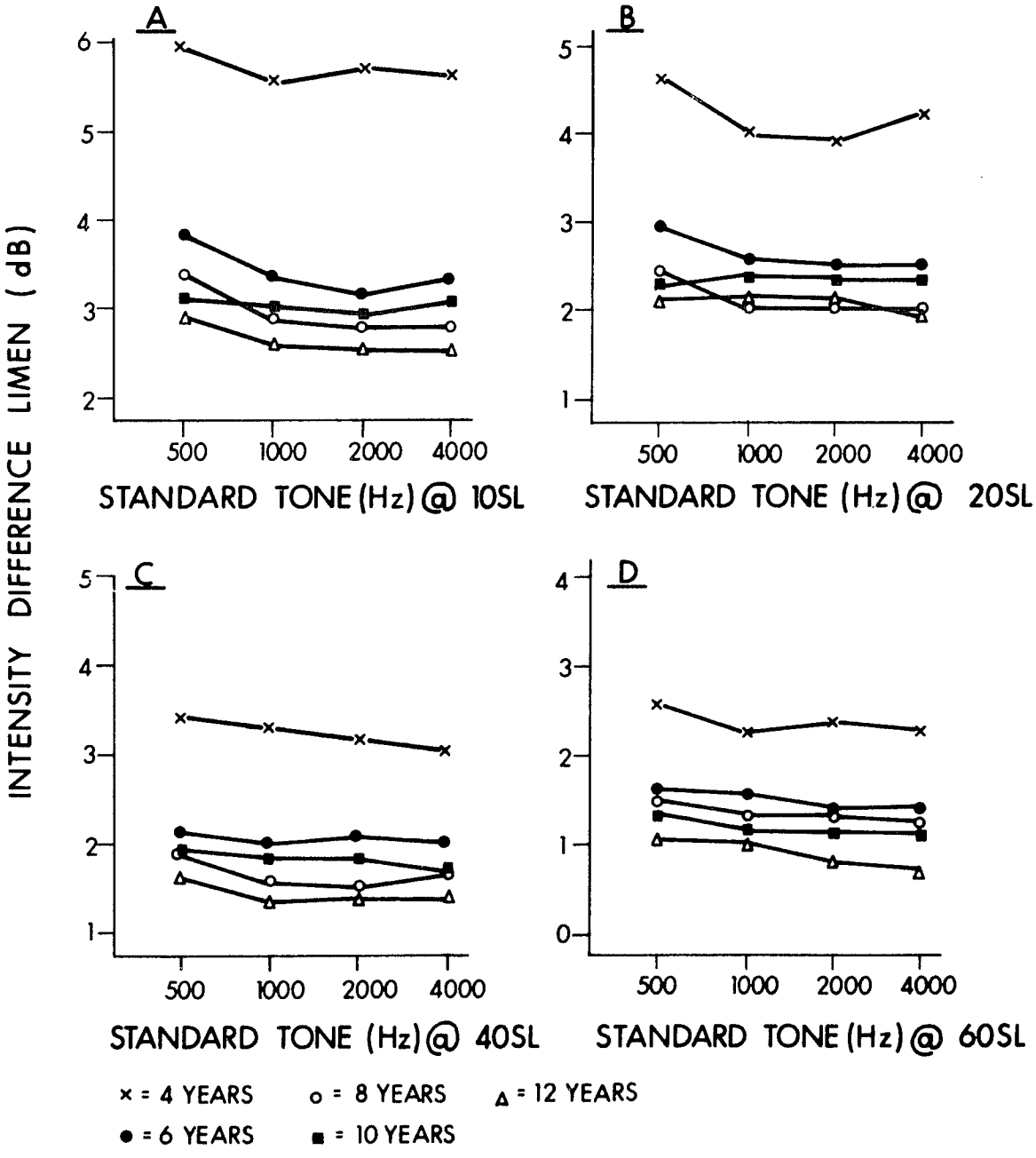

Figure 11. Mean DLs for intensity as a function of frequency, at each sensation level.

11. The lower sensation levels, 10 dB and 20 dB, tended to show more of a frequency effect than did the flatter configurations of the higher sensation levels, 40 dB and 60 dB. In general, the DLIs at 500 Hz were poorest and the best DLIs were found in the mid-frequencies (1000-2000 Hz) regardless of age or sensation level.

The general trend of increased differential sensitivity with increased age can be seen at all sensation levels and all frequencies. The only exception was at 20 dB SL, where there was some overlapping among the DLs obtained for the 8, 10 and 12-year olds from 1000 to 4000 Hz.

Frequency difference limen (DLF): Mean thresholds for frequency difference limen data were calculated by pooling thresholds obtained over all trials and frequencies within each age group. These mean thresholds are displayed in Table 6 and graphically represented in Figure 12. DLF decreased with increased age. The smallest DLF obtained by the 12-year olds was 4.77 Hz which was similar to the mean DLF obtained by Harris' normal adults (4.6 Hz). The change in DLF size between adjacent age groups decreased with the older subjects, for example, the difference in DL size between 4 and 6 years was 3.97 Hz and gradually became smaller until the difference in DL size between 10 and 12 years was 1.40 Hz. That tendency toward gradual slowing of age differences can be more readily seen from the graphic display.

The data were recalculated so that the effect of frequency on DLF could be observed. The mean frequency DLs, obtained by pooling the thresholds of all trials at each frequency for each age group, are displayed graphically in Figure 13. The normative adult data of Harris (1952) are also shown in the figure. In general, differential

Table 6

Mean thresholds in Hz for frequency difference limen data. Mean DLs were averaged over pooled trials and frequencies within each age group.

	Age (Yr)				
	4	6	8	10	12
Mean DLF (Hz)	15.87	11.90	8.50	6.17	4.77

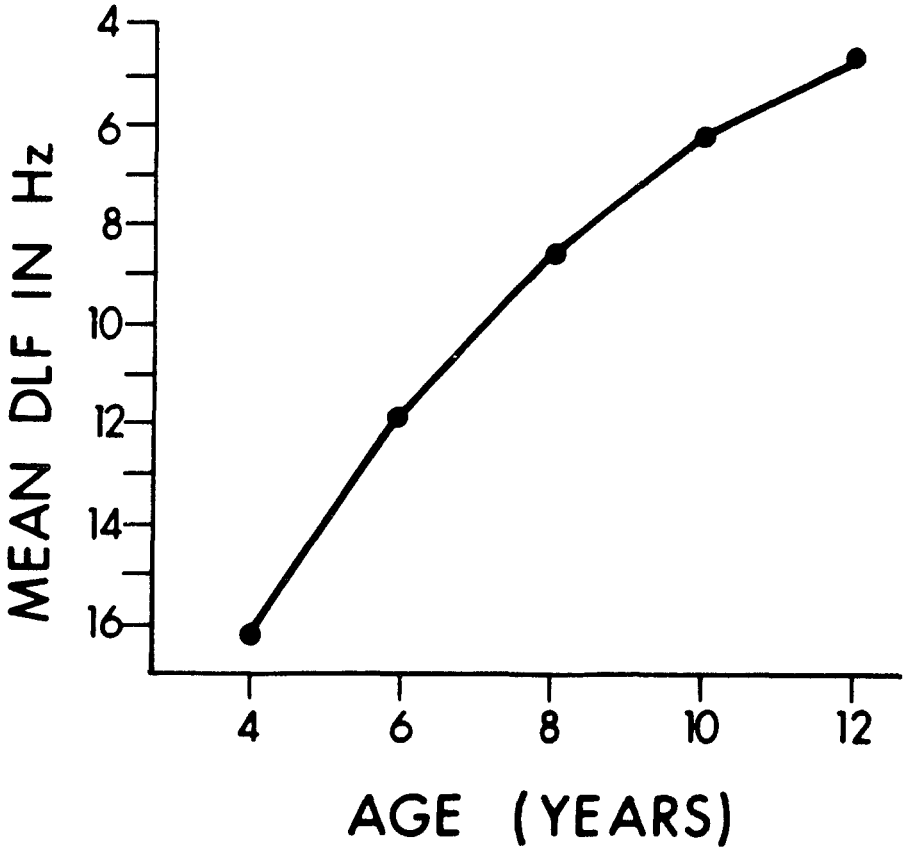

Figure 12. Mean DLs for frequency pooled and averaged over trials and frequencies within each age group.

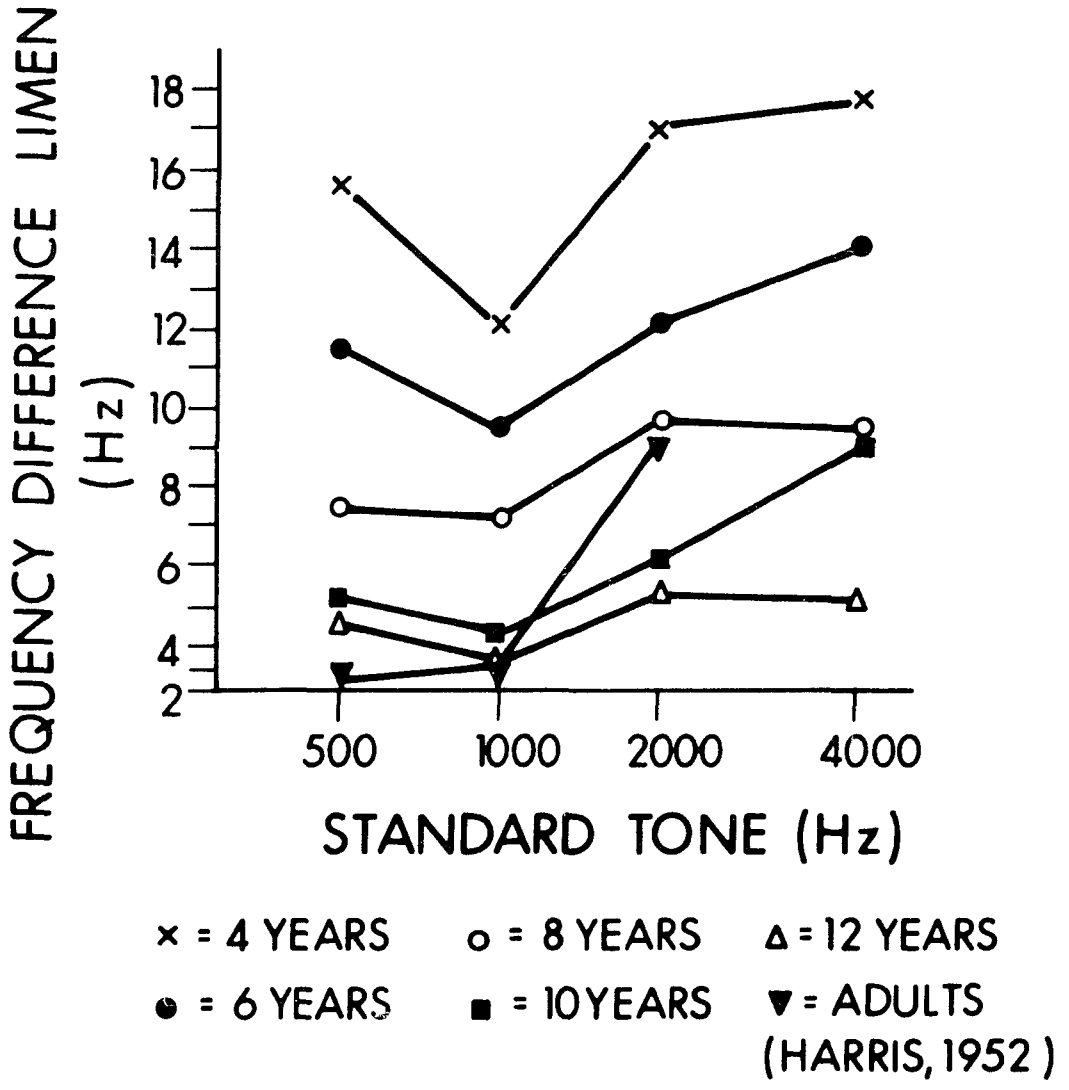

Figure 13. Mean DLs for frequency obtained by pooling and averaging subjects, and trials at each frequency within each age group, and normal adult data of Harris (1952).

sensitivity was best at 500 and 1000 Hz and became poorer with increased frequency, like the adult norms. The younger subjects (4 and 6 year olds) demonstrated DLFs that were poorer at 500 Hz than 1000 Hz.

Analysis of Variance (ANOVA)

A two-way analysis of variance (ANOVA) was performed on the data obtained for each task. One task analysis was performed for each age group. In that analysis, the data were collapsed over subjects in each age group in order to determine if the subjects could be treated as replications, that is, was intersubject variability small enough to allow age to be analyzed as a main effect. If subjects could be treated as replications, then what appeared to be significant age differences found in a three-way ANOVA could be accepted as true age variation.

Pure tone sensitivity: Table 7 displays the results of the analyses of pure tone sensitivity. Those particular analyses had only one main effect, frequency, when the data were collapsed over subjects and age was not treated as a main effect. Frequency was a significant effect at the .001 level for all age groups.

Temporal integration: The two-way analyses for temporal integration data are displayed in Table 8. Duration was a significant effect at the .001 level for all age groups. Frequency was a significant main effect at the .001 level except for the 8-year olds, where significance was reached at the .006 level.

Intensity difference limen (DLI): Table 9 displays the two-way analyses of each age group for intensity difference limen data.

Table 7

One-way Analyses of Variance for pure tone sensitivity data collapsed over subjects. One analysis was performed for each age group.

Age	Effect	Degrees of Freedom	Mean Squares	F	Significance
4	Frequency	5	292.45313	6.649	.001*
	Residual	24	43.98331		
6	Frequency	5	296.85327	45.35	.001*
	Residual	24	6.54583		
8	Frequency	5	260.69995	14.968	.001*
	Residual	24	17.41666		
10	Frequency	5	237.37500	15.746	.001*
	Residual	24	15.07499		
12	Frequency	5	295.02832	20.323	.001*
	Residual	24			

* Statistically significant

Table 8

Two-way Analyses of Variance for temporal integration data collapsed over subjects. One analysis was performed for each age group.

Age	Effect	Degrees of Freedom	Mean Squares	F	Significance
4	Duration (D)	5	1410.67969	71.901	.001*
	Frequency (F)	4	108.70483	5.541	.001*
	DF	20	5.90875	0.301	.998
	Residual	120	19.61961		
6	Duration	5	1514.06006	134.194	.001*
	Frequency	4	127.36896	11.289	.001*
	DF	20	6.24595	0.544	.936
	Residual	120	11.28264		
8	Duration	5	1507.97656	329.747	.001*
	Frequency	4	17.46925	3.820	.006
	DF	20	2.25841	0.494	.965
	Residual	120	4.57313		
10	Duration	5	1636.52490	136.149	.001*
	Frequency	4	174.24591	14.496	.001*
	DF	20	4.05022	0.337	.996
	Residual	120	12.02006		
12	Duration	5	1461.77100	113.928	.001*
	Frequency	4	117.48505	9.157	.001*
	DF	20	11.96873	0.933	.547
	Residual	120	12.83062		

*Statistically significant

Table 9

Two-way Analyses of Variance for intensity difference limen data, collapsed over subjects. One analysis was performed for each age group.

Age	Effect	Degrees of Freedom	Mean Squares	F	Significance
4	Frequency (F)	4	0.50571	6.978	.001*
	Level (L)	3	56.80583	783.837	.001*
	FL	12	0.05479	0.756	.694
	Residual	80	0.07247		
6	Frequency	4	0.26377	3.319	.014
	Level	3	16.85403	212.097	.001*
	FL	12	0.04908	0.618	.822
	Residual	80	0.07946		
8	Frequency	4	0.33125	3.186	.017
	Level	3	12.17801	117.111	.001*
	FL	12	0.03018	0.290	.989
	Residual	80	0.10399		
10	Frequency	4	0.04012	0.551	.702
	Level	3	15.63942	214.934	.001*
	FL	12	0.03018	0.415	.954
	Residual	80	0.07276		
12	Frequency	4	0.21164	2.786	.031
	Level	3	15.24760	200.727	.001*
	FL	12	0.03404	0.448	.938
	Residual	80	0.7596		

* Statistically significant

Sensation level was a significant main effect at the .001 level for all age groups. The only group which showed a significant frequency effect at the .001 level was the 4-year olds.

Frequency difference limen (DLF): The two-way analyses for frequency difference limen data performed for each age group are shown in Table 10. The significant frequency effect at the .001 level was found for all age groups.

Since it had been demonstrated that the main effects were significant within each age group when the data were collapsed over subjects, a three-way ANOVA with age as a main effect was then performed. Any significant age differences would have to have resulted from true age variation as opposed to subject variation.

Pure tone sensitivity: A two-way ANOVA with subjects treated as replications was performed for pure tone sensitivity, those results are shown in Table 11. Age was a significant effect at the .001 level, indicating that pure tone thresholds varied significantly with age. There was also a significant frequency effect at the .001 level. Thresholds were poorest at 250 Hz and improved significantly with frequency until the mid-frequencies (1000-2000 Hz) after which they became significantly poorer again with increased frequency.

Temporal integration: Table 12 displays the three-way ANOVA for temporal integration data when subjects were treated as replications. The improvement in thresholds with increased age was statistically significant since age was a significant effect at the .001 level. The thresholds obtained at the various frequencies were also significantly

Table 10

Two-way Analyses of Variance for frequency difference limen data, collapsed over subjects. One analysis was performed for each age group.

Age	Effect	Degrees of Freedom	Mean Squares	F	Significance
4	Trial (T)	2	1.47216	0.691	.511
	Frequency (F)	3	77.67346	36.435	.001*
	TF	6	1.97615	0.927	.515
	Residual	48	2.13183		
6	Trial	2	0.04050	0.081	.922
	Frequency	3	54.00146	107.734	.001*
	TF	6	0.18050	0.360	.900
	Residual	48	0.50125		
8	Trial	2	0.07200	0.034	.967
	Frequency	3	33.06395	15.474	.001*
	TF	6	0.01333	0.006	1.000
	Residual	48	2.13674		
10	Trial	2	0.01867	0.032	.969
	Frequency	3	60.77454	103.212	.001*
	TF	6	0.78670	0.134	.990
	Residual	48	0.58883		
12	Trial	2	0.00800	0.029	.972
	Frequency	3	8.96198	32.738	.001*
	TF	6	0.03067	0.112	.993
	Residual	48	0.27375		

* Statistically significant

Table 11

Two-way Analysis of Variance for pure tone sensitivity data collapsed over subjects.

Effect	Degrees of Freedom	Mean Squares	F	Significance
Frequency (F)	5	1338.16235	68.597	.001*
Age (A)	4	139.30579	7.141	.001*
FA(Interaction)	20	11.06183	0.567	.928
Residual	120	19.50748		

*Statistically significant

Table 12

Three-way Analysis of Variance for temporal integration data, collapsed over subjects.

Effect	Degrees of Freedom	Mean Squares	F	Significance
Duration (D)	5	7474.76953	619.542	.001*
Frequency (F)	4	395.68530	32.796	.001*
DF	20	7.63167	0.633	.890
Age (A)	4	1698.57422	140.785	.001*
DA	20	14.05980	1.165	.278
FA	16	37.39716	3.100	.001*
DFA	80	5.70002	0.472	1.000
Residual	600	12.06500		

* Statistically significant

different from each other because frequency was a significant main effect at the .001 level. Like the results of the pure tone sensitivity anlysis, these thresholds were poorest at the lowest frequency (500 Hz) , improved significantly until the mid-frequencies (1000-2000 Hz) and became significantly poorer at the highest frequency (4000 Hz). The interaction of frequency and age was significant at the .001 level, that is, the thresholds obtained at the various frequencies were significantly different for the different age groups. The threshold differences found among durations were significantly different at the .001 level. Threshold improved significantly with increased duration.

Intensity difference limen (DLI): The three-way ANOVA for intensity difference limen is displayed in Table 13. DLI decreased significantly in size with increased age indicated by age being a significant main effect at the .001 level. The frequency effect was also significant at the .001 level, indicating the difference in DL size at the various frequencies was significant. DLI was largest at 500 Hz and decreased significantly in size with increased frequency until 2000 Hz, after which it increased significantly in size with increased frequency. The sensation level at which DLI was measured had a significant effect on DL size, sensation level being significant at the .001 level. DL size decreased with increased sensation level. The interaction of sensation level and age was also significant at the .001 level, indicating that the difference in DL size obtained at the various sensation levels was different for each age group.

Frequency differnece limen (DLF): Table 14 displays the three-way ANOVA for the frequency difference limen data. Age was a signif-

icant main effect at the .001 level, indicating that DL size decreased significantly with increased age. The frequency effect was also significant at the .001 level. DLF decreased significantly from 500 to 1000 Hz and then increased significantly with increased frequency. The interaction of frequency and age was also significant at the .001 level, indictaing that the difference in DL size at the various frequencies was different for each age group.

Reconstructed Data

The data were also analyzed in terms of the main-effects-only model. Assuming that the main effects are the most important parts of the analyses, an estimate of each term is made and a residual score plotted. In the model the assumption is made that interactions do not exist so that a prediction of the score that each subject gave can be made from the main effects only. The formula for prediction of the pure tone data for this study was:

$$X_{ijk} = k + A_i + B_j + C_k + e_{ijk} \quad (1)$$

where X_{ijk} is the measured threshold
A_i is the age effect
B_j is the frequency effect
C_k is the subject effect
e_{ijk} is the experimental error

The formula for the temporal integration data obtained in the present study was:

$$X_{ijkl} = k + A_i + B_j + C_k + D_l + e_{ijkl} \quad (2)$$

where X_{ijkl} is the measured threshold
A_i is the age effect
B_j is the frequency effect
C_k is the subjects effect
D_l is the duration effect
e_{ijkl} is the experimental error

The formula for the intensity difference limen data obtained in the present study was:

$$X_{ijkm} = k + A_i + B_j + C_k + E_m + e_{ijkm} \quad (3)$$

where X_{ijkm} is the measured threshold
A_i is the age effect
B_j is the frequency effect
C_k is the subject effect
E_m is the intensity effect
e_{ijkm} is the experimental error

The formula for the frequency difference limen data obtained in the present study was:

$$X_{ijkn} = k + A_i + B_j + C_k + F_n + e_{ijkn} \quad (4)$$

where X_{ijkn} is the measured threshold
A_i is the age effect
B_j is the frequency effect
C_k is the subject effect
F_n is the learning effect (trials)
e_{ijkn} is the experimental error

Pure tone sensitivity: Figure 14 displays the residuals of the observed data in refernce to the reconstructed estimates for the pure tone data. It can be seen that most of the points fell within two standard deviations (8.072) of the 0 residual, the place where the reconstructed estimate equals the measured data. It can also be seen that most of the thresholds were less than 22 dB.

There were eight scores which fell outside of two standard deviations. Four of them were from the same 4-year old whose thresholds were significantly poorer than estimated at 250, 500, 1000 and 8000 Hz. One deviant score was obtained from a 10-year ol whose threshold at 250 Hz was significantly better than estimated. One 12-year old's threshold was significantly better at 1000 Hz and one 12-year old's thresholds at 4000 Hz and 8000 Hz were significantly poorer than estimated by the main-effects-only model.

Table 13

Three-way Analysis of Variance for intensity difference limen data collapsed over subjects.

Effect	Degrees of Freedom	Mean Squares	F	Significance
Frequency (F)	4	1.14532	14.152	.001*
Level (L)	3	105.20320	1299.957	.001*
FL	12	0.03501	0.377	.971
Age (A)	4	67.33972	832.092	.001*
FA	16	0.05180	0.640	.851
LA	12	2.88038	35.592	.001*
FLA	48	0.04194	0.518	.997
Residual	400	0.08093		

* Statistically significant

Table 14

Three-way Analysis of Variance for frequency difference limen data collapsed over subjects.

Effect	Degrees of Freedom	Mean Squares	F	Significance
Trial (T)	2	0.58973	0.524	.599
Frequency (F)	3	189.01025	167.790	.001*
FT	6	0.63871	0.567	.758
Age (A)	4	1211.44336	1075.434	.001*
TA	8	0.25540	0.227	.985
FA	12	11.36621	10.090	.001*
TFA	24	0.41015	0.364	.997
Residual	240	1.12647		

*Statistically significant

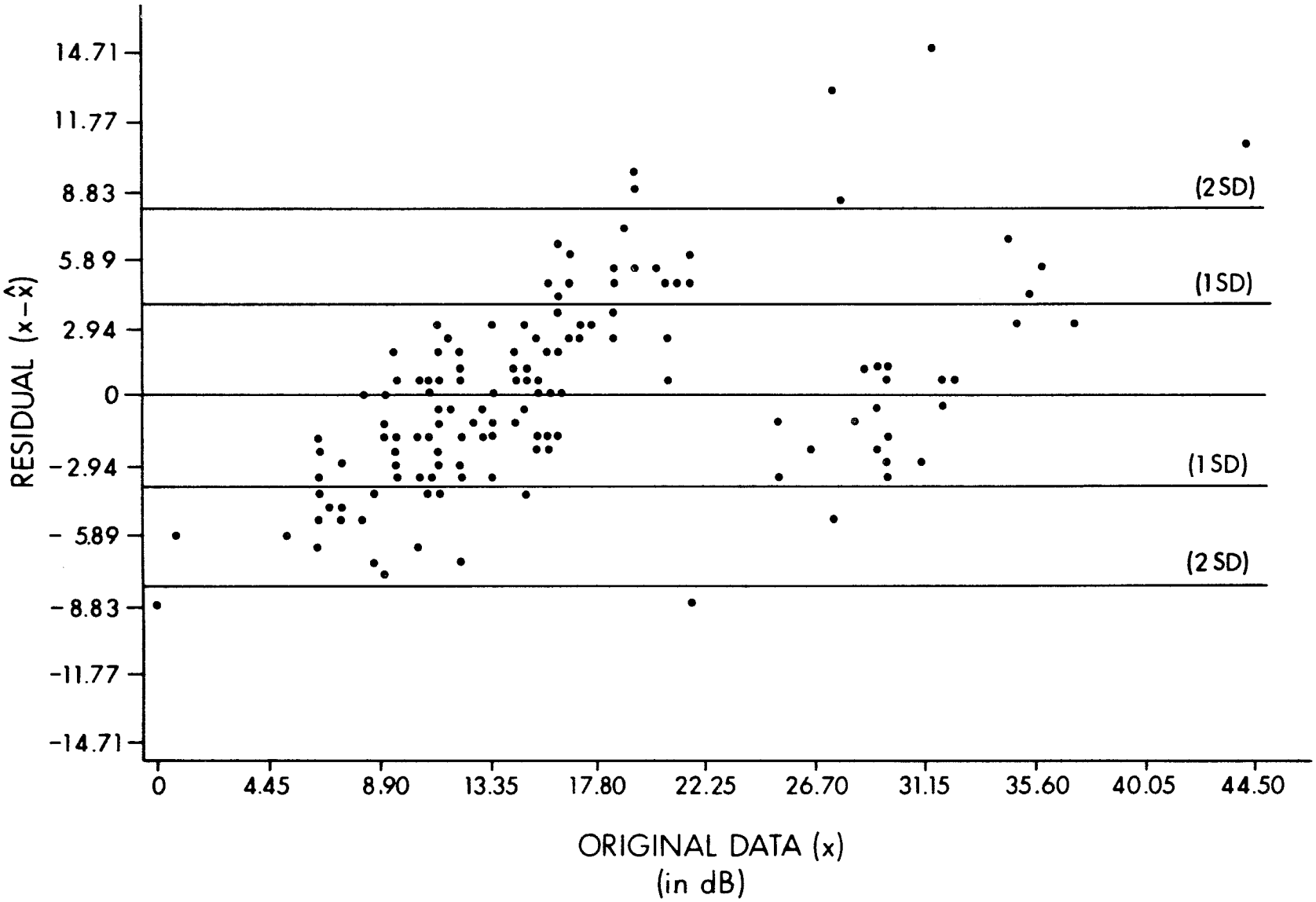

Figure 14. Residuals ($x-\hat{x}$) of pure tone sensitivity data plotted as a function of the measured thresholds (in dB).

Mean observed thresholds, mean reconstructed estimates and their residuals were obtained at each frequency by pooling subjects within each age group. These data are displayed in Table 15 and represented graphically in Figure 15. Most of the points clustered in the area representing 10 through 20 dB. The five points that lie off to the right of the figure, the poorer thresholds, were those found at 250 Hz. The other two extreme points, those which deviated the furthest from the 0 residual in a positive and negative direction, were the thresholds of the 10-year olds (12.9 dB) and the 12-year olds (5.2 dB) at 1000 Hz. Those points showed that these age groups performed poorer (10 years) and better (12 years) than would be predicted from the main effects. The standard deviation for these data was 4.036. As can be seen from the table and the figure, all of the mean residual points fell within one standard deviation of the 0 residual line; therefore, when considering age scores, rather than individual subject scores, the significance of the main effects of age and frequency could be predicted from the data.

Temporal integration: The residual sum of squares $(x-\hat{x})$ of the observed temporal integration data in reference to the reconstructed estimates $(\hat{x})$ are displayed in Figure 16. The points tended to spread out rather evenly, indciating a wide range of threshold intensities. All but 27 of the points fell within two standard deviations of the 0 residual line. The points were represented by the following conditions: two were the result of one 4-year old at 4000 Hz for 25 and 100 msec, better than estimated; three were the result of one 6-year old at 500 Hz for 400 and 800 msec and at 2000 Hz for 800 msec, poorer than estimated; one 6-year old yielded deviant thresholds at 4000 Hz for

Table 15

Mean reconstructed estimates of pure-tone thresholds, mean observed scores and their residuals (observed-reconstructed), obtained from a prediction model. Mean thresholds, at each frequency, were obtained by pooling subjects within each age group. The standard deviation was 4.036.

Age	Frequency (Hz)	Observed Data (x)	Reconstructed Estimates ($\hat{x}$)	Residuals ($x-\hat{x}$)
4	250	34.5	33.553	0.947
	500	18.1	19.313	-1.213
	1000	15.4	13.833	1.567
	2000	14.7	15.513	-0.813
	4000	15.6	16.013	-0.413
	8000	16.1	16.173	-0.073
6	250	32.6	32.053	0.547
	500	17.8	17.813	-0.013
	1000	11.1	12.333	-1.230
	2000	13.3	14.013	-0.713
	4000	14.8	14.513	0.287
	8000	15.8	14.673	1.127
8	250	31.2	31.486	-0.286
	500	17.5	17.247	0.253
	1000	11.5	11.767	0.267
	2000	13.6	12.447	0.153
	4000	14.4	13.947	0.453
	8000	13.8	14.107	-0.307

Table 15 (continued)

10	250	28.3	29.537	-1.237
	500	16.5	15.297	1.203
	1000	12.9	9.817	3.083
	2000	11.8	11.497	0.303
	4000	11.2	11.997	-0.797
	8000	9.6	12.157	-2.557
12	250	28.1	28.07	0.030
	500	13.6	13.83	-0.230
	1000	5.2	8.35	-3.150
	2000	11.1	10.03	1.070
	4000	11.0	10.53	0.470
	8000	12.5	10.69	1.810

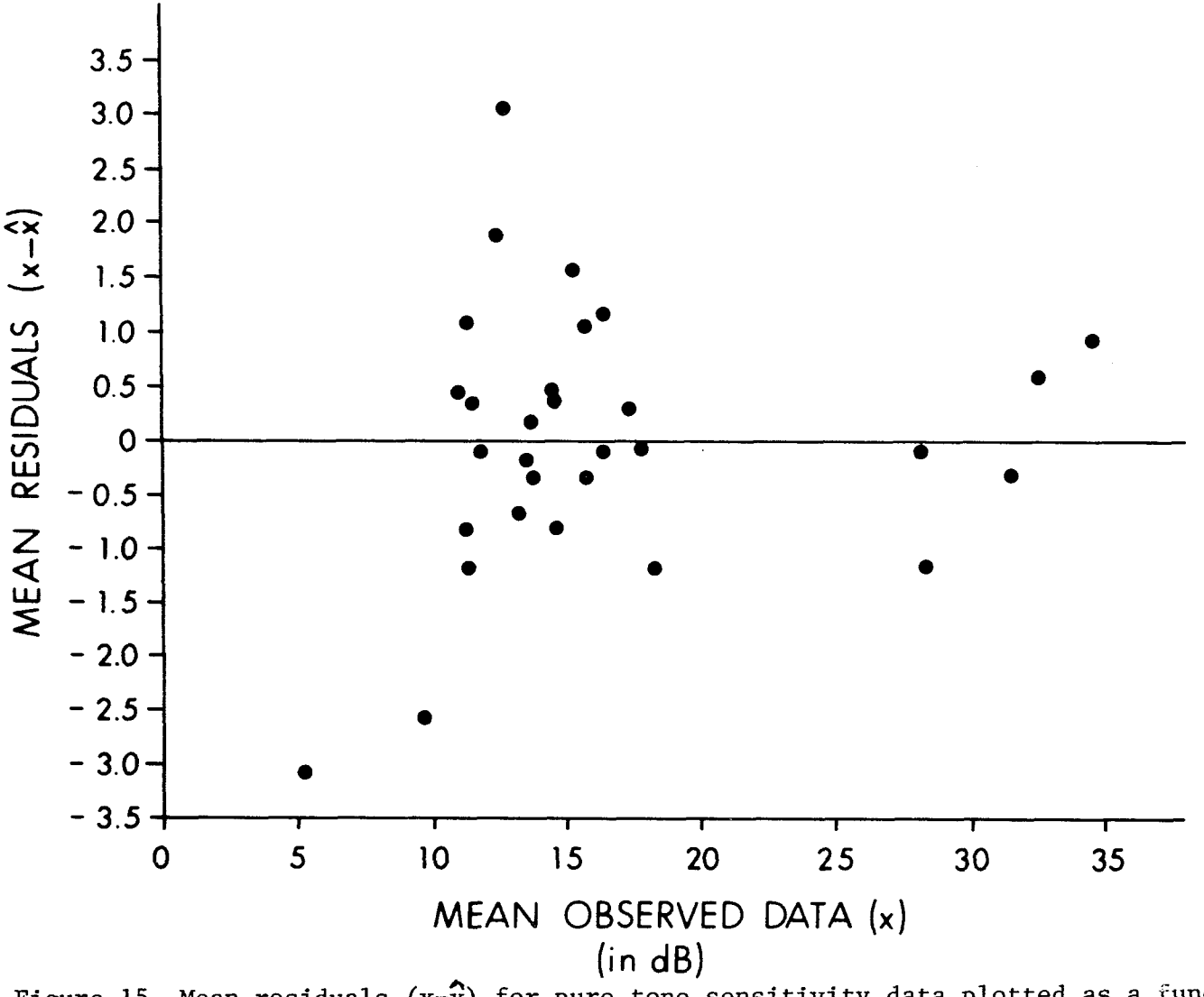

Figure 15. Mean residuals ($x-\hat{x}$) for pure tone sensitivity data plotted as a function of the mean measured thresholds (in dB).

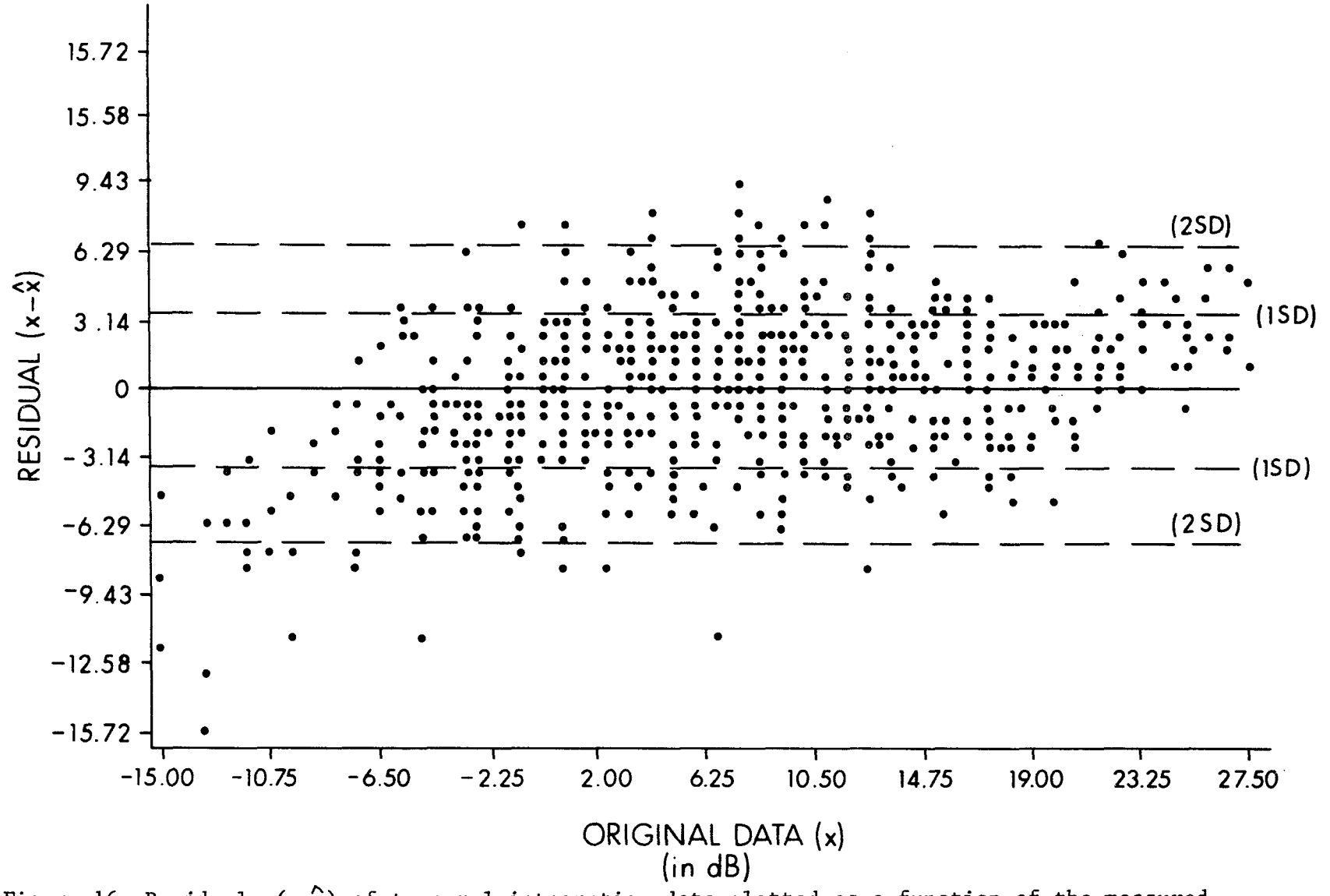

Figure 16. Residuals ($x-\hat{x}$) of temporal integration data plotted as a function of the measured thresholds (in dB).

200 msec, poorer than estimated and 800 msec, better than estimated; one deviant threshold was obtained from an 8-year old at 4000 Hz for 800 msec, better than estimated; five were the result of one 10-year old at 500 Hz for 100 msec and for 4000 Hz at 25,200,400 and 800 msec, poorer than estimated; two deviant thresholds were obtained from one 12-year old at 1000 Hz for 50 msec, better than estimated and 2000 Hz for 800 msec, poorer than estimated. The other five deviant scores were obtained from one 12-year old at 2000 Hz for 100 and 200 msec, better than estimated and 4000 Hz for 50,100 and 200 msec, poorer than estimated.

Mean observed temporal integration thresholds, mean reconstructed estimates of temporal integration and their residuals were obtained for each duration by pooling subjects and frequencies within each age group. These data were displayed in Table 16 and graphically represented in Figure 17. Most of the mean residual points fell within an intensity range of -3 through +16 dB. The four points which fell into a higher intensity range represented the 25 msec thresholds of all age groups but the 12-year olds, indicating that the poorest thresholds were found at 25 msec by all but the oldest subjects. The four points which fell into a lower intensity range than most were the 8, 10 and 12-year olds' thresholds for 800 msec tones and the 12-year olds' threshold at 400 msec.

All of the residual points fell within one standard deviation (3.326) of the 0 residual line, indicating that when mean age values, rather than individual subject values were used, the significance of the main effects could be predicted.

Table 16

Mean reconstructed estimates of temporal integration thresholds, mean observed thresholds and their residuals (observed-reconstructed) obtained through a prediction model. Mean thresholds at each duration were obtained by pooling subjects and frequencies within each age group. The standard deviation was 3.326.

Age	Duration	Observed Data (x)	Reconstructed Data ($\hat{x}$)	Residuals ($x-\hat{x}$)
4	25	22.604	23.550	-0.946
	50	15.416	16.044	-0.628
	100	10.756	11.008	-0.252
	200	7.152	7.188	-0.031
	400	4.664	4.533	0.131
	800	2.368	1.692	0.676
6	25	20.904	20.141	0.763
	50	12.876	13.690	-0.814
	100	8.236	8.654	-0.418
	200	4.708	4.829	-0.121
	400	2.696	2.184	0.512
	800	-0.580	-0.661	0.081
8	25	18.759	19.258	-0.499
	50	12.564	12.807	-0.243
	100	8.944	7.771	1.173
	200	4 736	3.946	0.790
	400	0.728	1.301	-0.573
	800	-2.192	-1.545	-0.677

Table 16 (continued)

10	25	18.904	18.945	-0.041
	50	13.368	12.494	0.874
	100	7.480	7.468	0.022
	200	3.576	3.634	-0.058
	400	1.452	0.988	0.464
	800	-3.116	-1.857	-1.259
12	25	13.024	13.357	-0.333
	50	7.720	6.907	0.813
	100	1.348	1.918	-0.570
	200	-2.532	-1.954	-0.573
	400	-5.128	-4.599	-0.529
	800	-.6296	-7.445	1.149

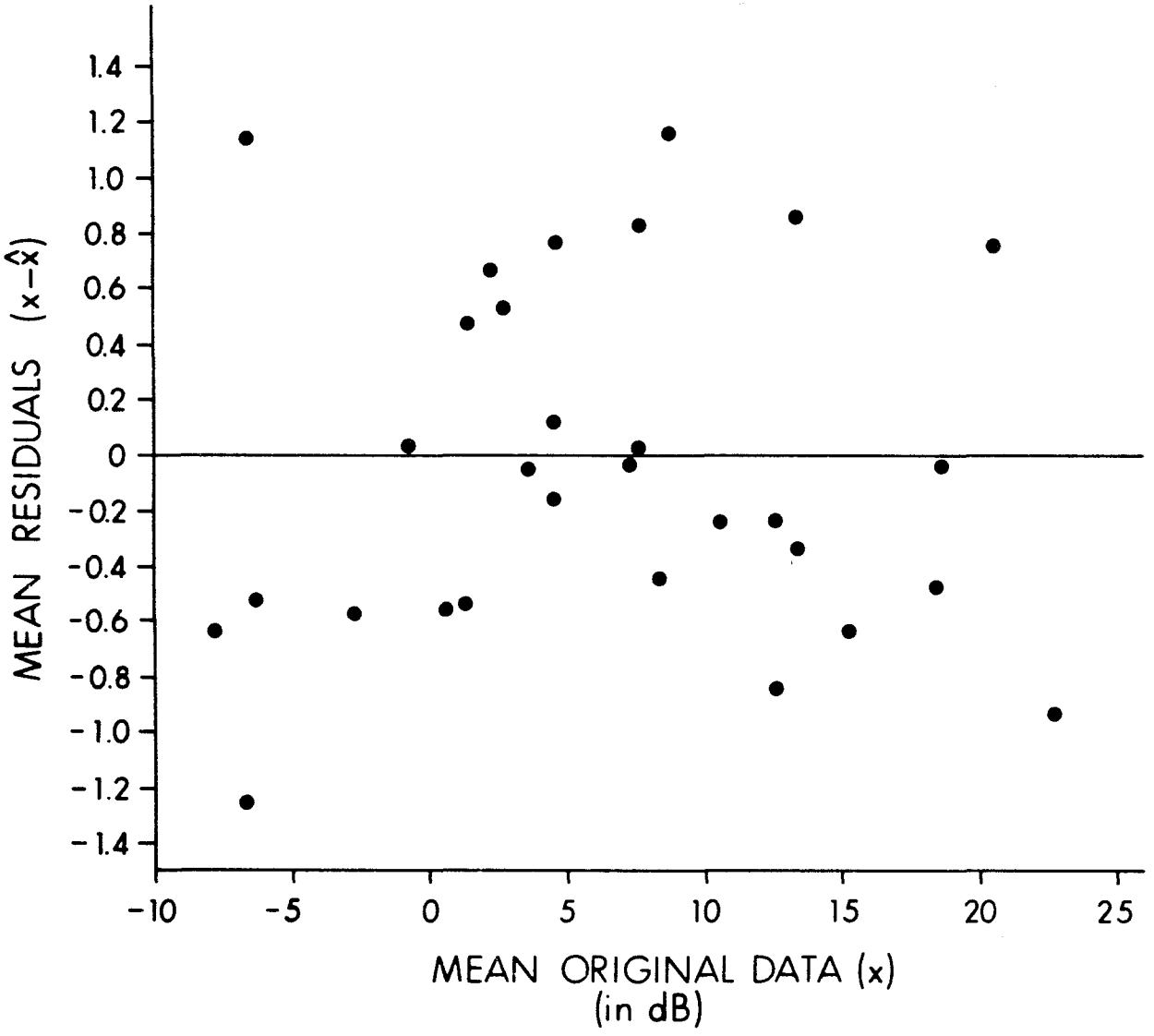

Figure 17. Mean residuals ($x-\hat{x}$) of temporal integration data plotted as a function of mean measured thresholds (in dB).

Difference limen for intensity (DLI): The residual sum of squares for the intensity difference limen data plotted as a function of the observed scores are shown in Figure 18. Most of the residual points clustered toward the left side of the figure, showing that most of the observed DLIs were smaller than approximately 4 dB. The points which fell further to the right, indicating larger DLs, were obtained from the younger subjects (4 and 6 years).

Most of the points fell close to the reconstructed estimates, at least within two standard deviations (0.732) of the 0 residual. There were 27 residual points which were significantly deviant. Those points were the result of the following conditions: eight were obtained from the same 4-year old at 500, 200, 4000 Hz and total frequency at 60 dB SL, better than estimated; seven deviant scores were from the same 4-year old at 500, 2000 and 4000 Hz and total frequency at 10 dB SL, poorer than estimated and at 500, 1000, 2000 Hz at 60 dB SL, better than estimated; a 4-year old subject obtained six deviant scores at 500, 1000, 2000, 4000 Hz and total frequency at 10 dB SL, poorer than estimated, and at 4000 Hz at 60 dB SL, better than estimated; a 4-year old yielded five deviant scores at 500, 1000, 2000, 4000 Hz and total frequency at 10 dB SL, poorer than estimated; one 12-year old performed better than estimated at 1000 Hz 10 dB SL and one 12-year old performed poorer than estimated at 1000 Hz at 20 dB SL.

Table 17 displays the mean reconstructed estimates of DLI, the mean observed scores and their residuals obtained at each sensation level within each age group by pooling subjects and frequencies. These data are also represented graphically in Figure 19. As can be seen, all but two residual points fell between 1.0 and 3.6 dB, indicating that mean DLI fell within that range for all age groups. All but two

Table 17

Mean reconstructed estimates of intensity difference limen thresholds, mean observed thresholds and their residuals (observed-reconstructed) obtained through a prediction model. Thresholds were obtained by pooling subjects and frequencies for each sensation level within each age group.

Age	Sensation Level	Observed Data (x)	Reconstructed Data ($\hat{x}$)	Residuals ($x-\hat{x}$)
4	60	2.2344	2.871	-0.6366
	40	3.2644	3.494	-0.2296
	20	4.2792	4.177	0.1022
	10	5.7696	5.006	0.7636*
6	60	1.5396	1.423	0.1166
	40	2.0792	2.046	0.0332
	20	2.6896	2.729	-0.0394
	10	3.4496	3.559	-0.1094
8	60	1.3696	1.054	0.3156
	40	1.7108	1.677	0.0338
	20	2.2244	2.359	-0.1346
	10	2.9744	3.189	-0.2146
10	60	1.2244	1.129	0.0954
	40	1.8544	2.088	-0.2336
	20	2.4296	2.435	-0.0054
	10	3.0744	3.265	-0.1906

Table 17 (continued)

12	60	0.9148	0.807	0.1078
	40	1.4896	1.429	0.0606
	20	2.1896	2.112	0.0776
	10	2.6944	2.942	-0.2476

* more than two standard deviations away from the 0 residual ($x=\hat{x}$)

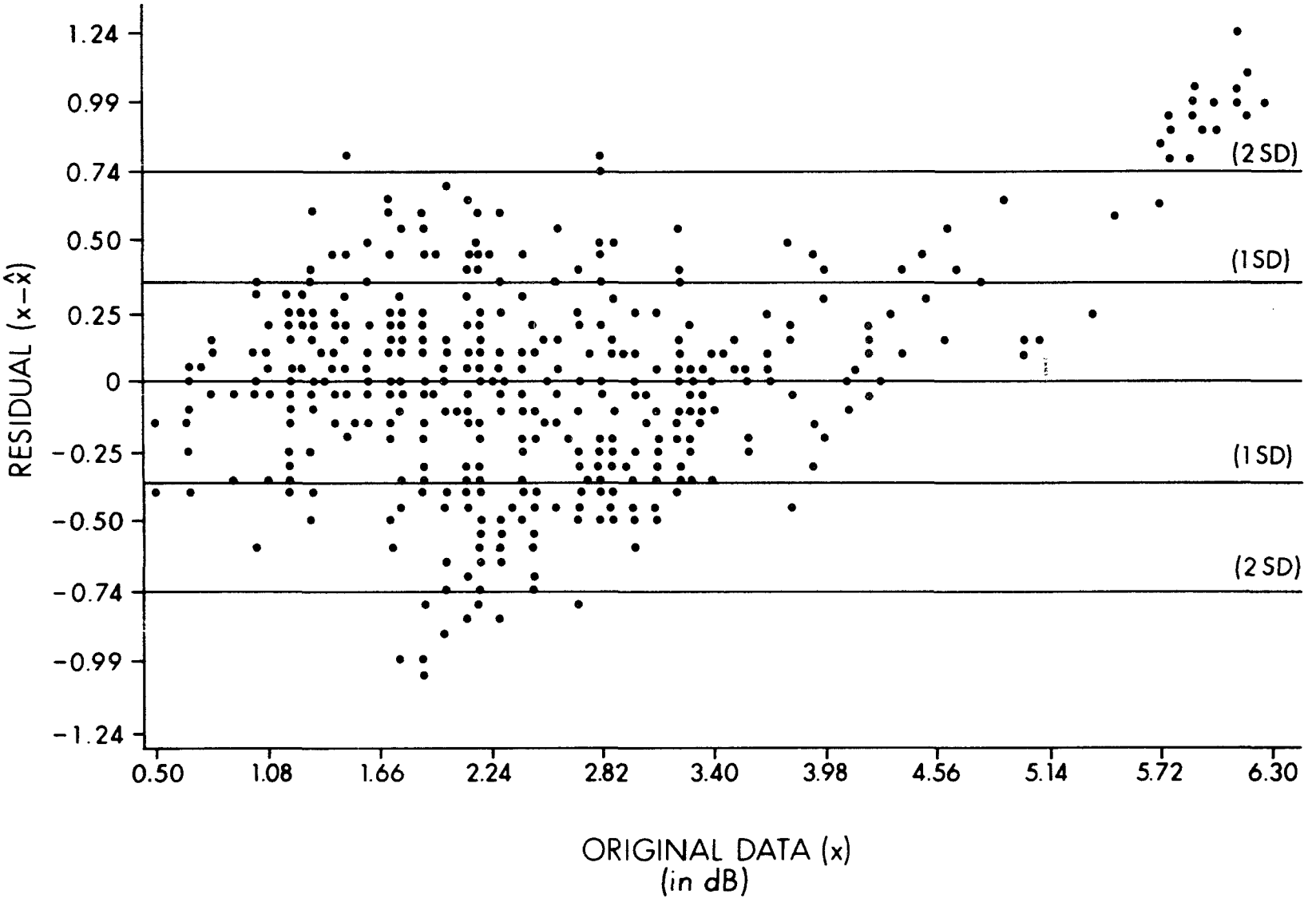

Figure 18. Residuals ($x-\hat{x}$) of intensity difference limen data plotted as a function of the measured thresholds (in dB).

points fell within one standard deviation (.366) one of which was statistically deviant, falling outside of two standard deviations. Those extreme points were obtained from the 4-year olds. Since most of the points were within one standard deviation, the significance of the main effects of sensation level and age could be predicted from the data when mean age scores rather than individual subject scores were used.

Difference limen for frequency (DLF): Figure 20 shows the plotted residual points, as a function of the observed data for the frequency difference limen. Generally, the points spread evenly across the figure, indicating that DLF ranged from 3.4 to 18.9 Hz for most age groups. All but seventeen of the residual points fell within two standard deviations (2.362) of the 0 residual. Those points which were significantly deviant could be accounted for by the following conditions: one 4-year old performed better than estimated at 1000 Hz; one 4-year old performed poorer than estimated at 1000 Hz; four scores were yielded from one 8-year old at 2000 Hz, poorer than estimated, and three times at 4000 Hz, better than estimated; an 8-year old yielded five deviant scores at 1000, 2000 Hz, poorer than estimated, and three times at 4000 Hz, poorer than estimated; three deviant scores, better than estimated, were yielded by the same 12-year old three times at 4000 Hz.

The mean observed frequency difference limen thresholds, the mean reconstructed estimates and their residuals were obtained by pooling subjects and trials for each frequency within each age group. The data are displayed in Table 18 and graphically represented in

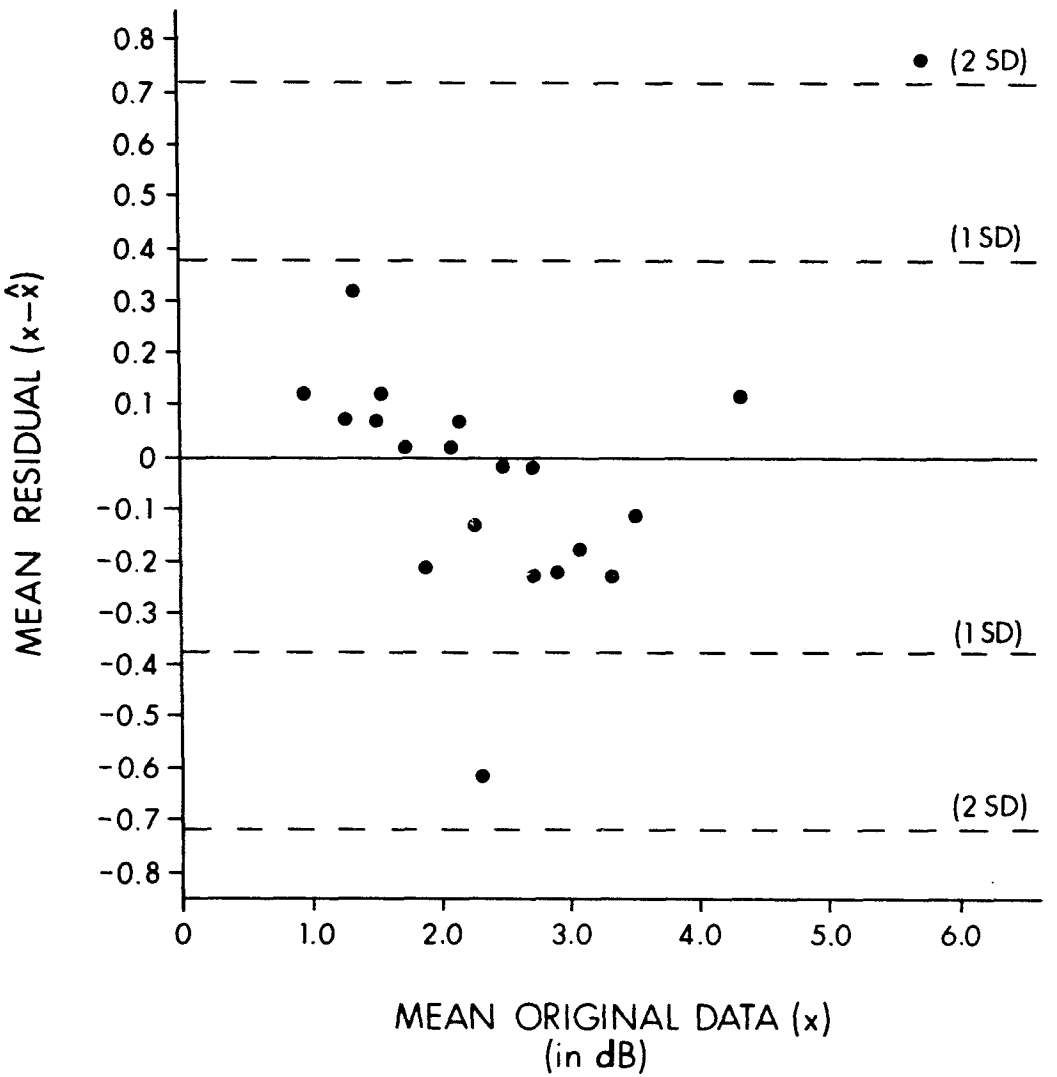

Figure 19. Mean residuals of intensity difference limen data plotted as a function of the mean meansured thresholds (in dB).

Table 18

Mean reconstructed estimates of frequency difference limen thresholds, mean observed thresholds and their residuals (observed-estimates) obtained through a prediction model. Mean thresholds were obtained by pooling subjects and trials for each frequency within each age group. The standard deviation is 1.181.

Age	Frequency	Observed Data (x)	Reconstructed Data ($\hat{x}$)	Residuals ($x-\hat{x}$)
4	500	15.86	15.352	0.502
	1000	12.02	13.932	-1.912
	2000	17.02	16.376	0.644
	4000	17.90	17.613	0.287
6	500	11.60	11.389	0.211
	1000	9.58	9.968	-0.388
	2000	12.26	12.612	-0.352
	4000	14.18	13.649	0.531
8	500	7.36	7.985	-0.625
	1000	7.08	6.983	0.097
	2000	9.88	9.207	0.673
	4000	9.68	10.245	-0.565
10	500	5.12	5.658	-0.538
	1000	4.46	4.236	0.223
	2000	6.09	6.881	-0.791
	4000	9.02	7.918	1.102

Table 18 (continued)

12	500	4.70	4.255	0.445
	1000	3.72	2.833	0.887
	2000	5.50	5.477	0.023
	4000	5.16	6.515	-1.355

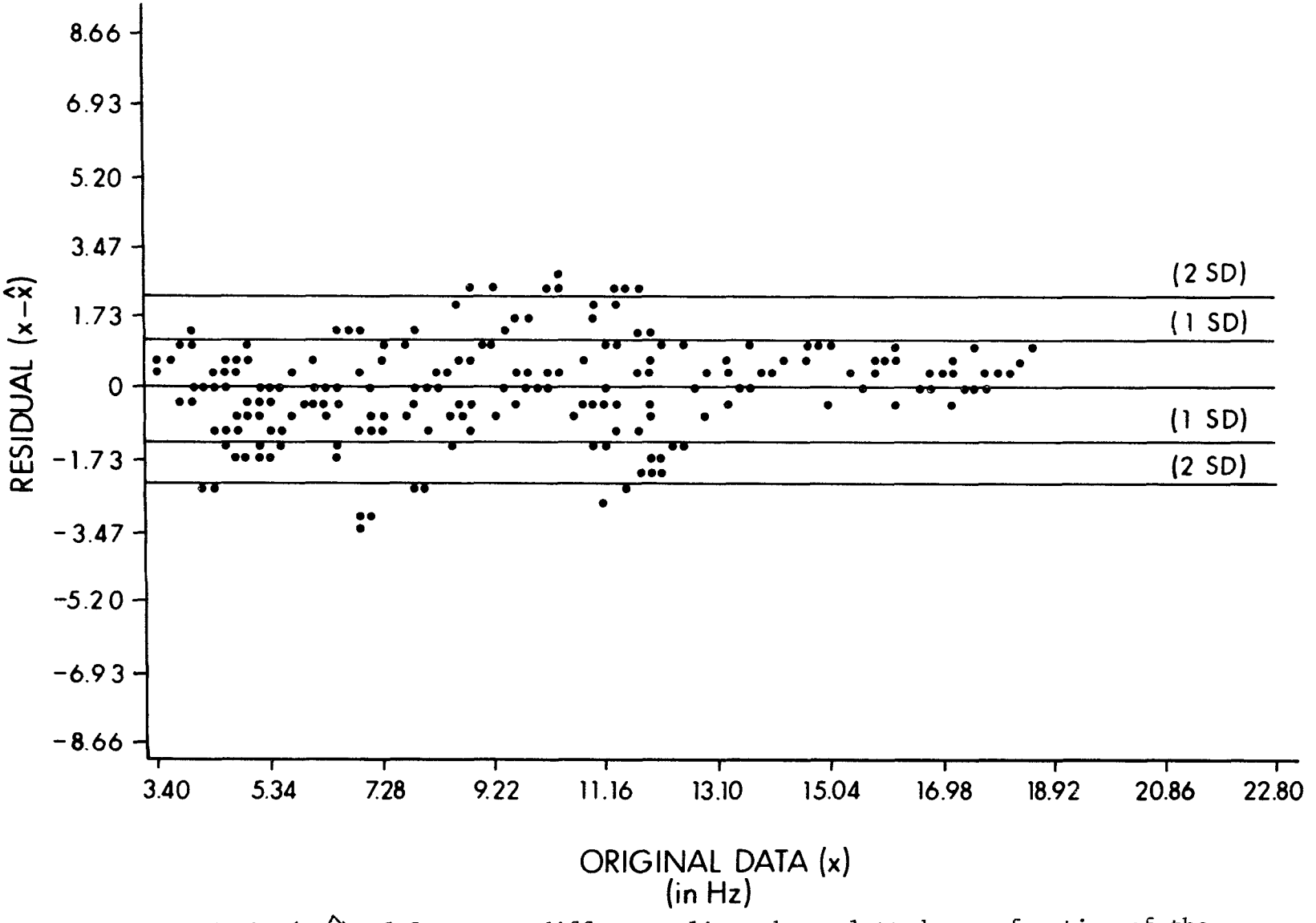

Figure 20. Residuals ($x-\hat{x}$) of frequency difference limen data plotted as a function of the measured thresholds (in Hz).

Figure 21. All mean residual points fell within a range of 3.5 to 14.5 Hz with the younger subjects falling toward the higher end of the range. The four points which fell outside of that range were the DLFs of the 4-year olds at all frequencies but 1000 Hz.

All points fell within two standard deviations (2.362) of the 0 residual line and all but two points fell within one standard deviation (1.181). Therefore, the significance of the main effects of age and frequency could be predicted from the mean data.

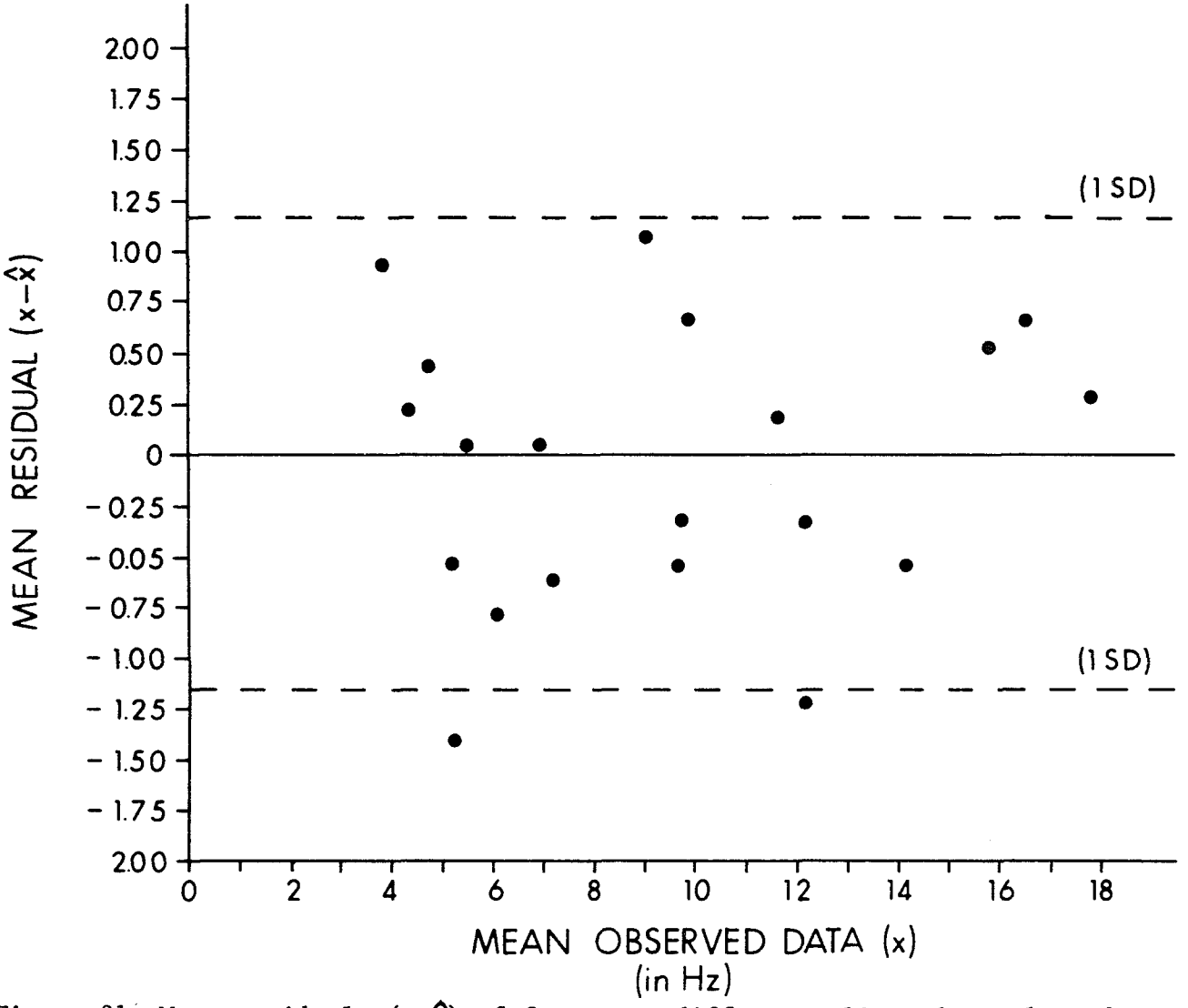

Figure 21. Mean residuals ($x-\hat{x}$) of frequency difference limen data plotted as a function of mean measured thresholds (in Hz).

Chapter V

Discussion

This chapter has been divided into two major sections: a) A discussion of the results of the analysis of variance and b) a discussion of the results of the predictive model. In both sections each task was discussed separately within a subsection. The developmental implications of the analysis of variance may also be found within the first major section.

Pure tone sensitivity: That pure tone sensitivity improved with age was not a new finding. Eagles (1967) found, through a longitudinal study, that pure tone acuity increased between 5 and 12 years. Leninhan et al. (1971) demonstrated an improvement in pure tone threholds between 5 and 14 years. Roberts (1972a, 1972b) showed increasing sensitivity with age from 6 through 11 years, and suggested that the consistent change with age was dependent on variables other than short attention span or poor reliability.

In the present study, age differences were found to be greater for the lower frequencies (250-1000 Hz) and the highest frequency (8000 Hz) than for the other frequencies. Similar findings were reported by both Eagles and Roberts.

That pure tone sensitivity varied as a function of frequency was not unusual considering the findings of the studies mentioned above and all of the results of adult research (ASA, 1959; ISO, 1964; ANSI, 1969). Although the ear's sensitivity to intensity changes with age, the same pattern of frequency sensitivity was present from 4 through 12 years. The one exception to that finding was the mean threshold of

the 10-year olds at 8000 Hz (9.6 dB). That particular finding was unusual because it was better than any of the mean thresholds for the 10-year olds at any of the other frequencies tested. Reference to the raw data indicated that two subjects (MM and SE) showed unusually acute thresholds at 8000 Hz in comparison to the rest of the subjects. Their thresholds at the other measured frequencies were not unusual when compared to the other subjects. Had the mean of the other three subjects been computed it would have been 11.0 dB SPL which would have been more like the adult frequency effect on pure tone sensitivity. The variability of sensitivity for individual subjects was also found by Leninhan et al. That is, they had subjects whose acuity was significantly better than the rest of the subjects in a particular age group.

The fact that Goldstein et al. (1955) also found improved threshold sensitivity with increased age lends support to the data obtained in the present study. They used normal children between 7.6 years and 12.8 years and found threshold using conditioning and electrodermal responses. That type of procedure is more objective than conventional behavioral techniques and may add strength to the idea that the changes seen in sensitivity with age were not due solely to changes in attention and motivation.

Temporal integration: The improvement in temporal integration thresholds with increased age was not unusual in light of the studies mentioned above. The thresholds for pure tone sensitivity improved with increased age. Temporal integration thresholds were another measure of the ear's sensitivity which was found for signals of varying durations. Therefore, since auditory sensitivity improved when measured through conventional audiometric techniques it was not

unusual to find the same improvement when sensitivity was measured through temporal integration techniques.

Although mean temporal integration thresholds varied as a function of age, the threshold-duration functions did not. Threshold shifts are an indirect measure of the integrating characteristics of the cochlea, and cochlear impairment affects the temporal integration patterns obtained (Miskolczy-Fodor, 1958; Brahe Pedersen, and Elberling, 1973; Wright, 1968a, 1968b; Elliot, 1974).

Barry and Larson (1973) found that normal hearing subjects between the ages of 6 and 14 years, used as a control group, yielded threshold-duration functions that were similar to each other, but significantly different from the flatter functions of the experimental deaf subjects. That lends evidence to the assumption that the integrating characteristics of the cochlea were influenced more by pathology than by a variable such as age.

The variable which had a great effect on threshold was, as expected, duration. Like the results obtained with normal adults (Wright, 1967, 1968a, 1968b; Olsen et al. 1974), threshold improved with increased duration of the signal. Zwislocki's (1960) theoretical adult norms indicated that a threshold shift of 12.7 dB would occur for a change in duration from 10 to 500 msec. Wright found a 10 dB threshold shift for a ten-fold durational change below 200 msec. The 15.31dB threshold shift found between 25 and 200 msec in the present study was similar to that found with adults. That is, the relationship of threshold to durational change followed that same pattern but was larger than would be predicted. In the present study, mean threshold continued to decrease with increased duration after 200 msec, specifically, a 5.5 dB shift was found

between 200 and 800 msec. In the adult findings, the change in threshold with increased duration above 200 msec was significantly smaller than, and could not be described with, the same slope as that found below 200 msec. Wright (1968a) pointed out that there was a great deal of variability in the size of the shift in normal adults after 200 msec.

The fact that more intensity was needed by the children than by the adults for integration below 200 msec could have been the result of individual subject variability. Gengel and Watson (1971) demonstrated a great deal of intrasubject variability with normal adults when only one or two measurements were made. In the present study, six measurements were made at each frequency and each duration and may account for the apparent differences between these and the adult norms. Gengel and Watson also reported that a difference in slope occurred with normal adults when two different types of procedures (method of adjustment vs. Bekesy tracking) were used. That difference was particularly noticeable at 4000 Hz. In the present study, threshold-duration functions were plotted with frequency averaged and perhaps the interaction of frequency and methodology were affecting the results as suggested by Gengel and Watson.

There is another possibility in that the reduced integration function of adults as compared to children may be the result of the adults having been exposed more often to over-stimulation of the cochlea and were more likely to have cochlear impairment than were the children. Wright (1967) pointed out that temporal integration can be affected even when pure tone sensitivity is normal. Therefore, damage which may not be affecting sensitivity can be demonstrated by depressed integration

slopes. Barry and Larson (1973) lent credence to that argument by demonstrating small difference scores among their normal subjects (aged 6-14 years) as compared to normal adults. They suggested that the unusually small differences may have occurred because children were less likely to be exposed to over-stimulation of the auditory system and so less likely to have undetected cochlear damage. Therefore, the difference in degree of threshold shift between that found in the present study and the adult norms, as well as the fact that threshold-duration functions did not change with age, may have been due to the difference in condition of the cochlea between children and adults. The difference was not found among young children of various ages.

The effect of frequency on temporal integration thresholds was that thresholds were poorer at 500 Hz than any of the other frequencies tested. That finding was expected from the thresholds obtained in the pure tone sensitivity measurements of this and previously reported studies. That is, the ear was less sensitive for lower frequencies than mid and high frequencies. That particular trend was true for all age groups except the 10-year olds for whom the threshold found at 4000 Hz was significantly better than that found at any of the other frequencies. Reference to the raw data indicated that one particular subject (AR) had exceptionally low (good) thresholds at 4000 Hz for both temporal integration and pure tone thresholds. Since temporal integration thresholds are measures of sensitivity, as was pointed out earlier, it was not unusual to find a subject with particularly sensitive hearing compared to other subjects. This particular subject had unusually sensitive hearing at 4000 Hz which was demonstrated consistently on all threshold measurements.

Difference limen for intensity (DLI): Difference limen for intensity showed a decrease in size with increased age, regardless of sensation level or frequency of the stimulating tone. Fior (1972) reported a change in DLI with age using a Luscher test on normal hearing children. Below 5 years, subjects detected 0.75 dB differences, below 8 years subjects detected 1.0 dB differences and "older" subjects detected 0.25-0.75 dB differences. The validity of using a Luscher type of procedure as a measurement of the ear's differential sensitivity has been questioned by several authors (Harris, 1963; Dimmick and Olsen, 1941). It is likely that the difference between Fior's results and those of the present study which can be seen in Table 19 were due to differences in methodology. In the present study a great deal of effort was spent to assure that procedures would be appropriate for all subjects and be a valid measure of intensity discrimination.

DLI is a measure of discrimination. Abromovitz (1971) assessed intensity discrimination by varying the intensities of tone pairs and having subjects judge them for sameness. There was an increase in correct response as age increased from 5 to 10 years for normal hearing subjects. Although Abromovitz was not attempting to measure DLI, changes in perception of intensity differences was evaluated and like the present study were found to improve with increased age.

In the present study, the frequency of the stimulating tone was found to have a significant effect upon DLI size, particularly at low sensation levels. A similar phenomenon was found by Dimmick and Olsen (1941) who also used a two-comparison tone procedure. DL was found to be smallest at the mid-frequency range, largest at the low frequency and in a mid-range at the high frequencies, the trend being most notice-

Table 19. Mean difference limen for intensity thresholds (in dB) displayed for a comparison between data of the present study and that of Fior (1972).

Study	Age Range	Below 5 years	5-8 years	9-13 years
Fior (1972)		0.75 dB	1.0 dB	0.5 dB
Present study		3.8 dB	2.3 dB	1.9 dB

able near threshold. The frequency effect reported here and in the adult study was not found by Harris (1963) in his "optimal DL" procedure. The difference may have been due to the fact that Harris so precisely controlled his procedures, particularly the subject response mode. To this writer's knowledge, no other researchers have been able to replicate the results or report DLIs whose size was not affected by the stimulating tone's frequency.

Another finding in the present study and those with adults (Dimmick and Olsen, 1941) that differed with Harris' data was that DLI size decreased with increased sensation level, at least until 60 dB SL. Dimmick and Olsen's smallest mean DLI was found to be 2.3 dB at 60 dB SL. The smallest mean DLI found in this study was 1.46 dB at 60 dB SL with the 12-year old subjects. Harris' optimal DLI was 0.75 dB which was not only uneffected by frequency change, but also by change sensation level.

As was previously mentioned, Harris strongly controlled the response mode of his subjects limiting it to "louder" and "softer," and not allowing for a judgment of "equal." He stated that not allowing a judgment of equality forced the subjects to make finer discriminations than if they were allowed to judge two stimuli as being the same. Therefore, the exceptionally small DLs he obtained which showed no frequency or sensation level effects were the result of his forcing his subjects to make finer discriminations than they were used to making. The younger subjects in the present study were not able to make that type of judgment, so subjects responded "same" or "different" which, admittedly, may have yielded grosser discriminations than those found by Harris. The decision to use that type of subject response was based on the

work of Carter, Ricker and Corsini (1972) who demonstrated that children at lower developmental cognitive stages than Piaget's "preoperational stage" (6 years) had difficulty judging items as "louder" and "softer." Such children were more likely to yield what appeared to be poorer discrimination ability when forced to make such a judgment because they had not developed the relational structures on which to base the response. Therefore, it became more important, in the present study, to accommodate the younger subjects by using a procedure and response mode that would be appropriate to their age capabilities than to exactly replicate Harris' procedure for adults. The data yielded were similar to those of adult studies other than Harris; and except for subject response mode, were faithful to his methodology for measuring intensity difference limen.

The effect of sensation level of the stimulating tone on DL size was found to interact significantly with the age of the subject. That is the effect of sensation level decreased with increased age. The difference between mean DLI from 10 to 60 dB SL was 3.45 dB for the 4-year olds and 1.78 dB for the 12-year olds. Exactly why that should have occurred was not clear. Perhaps perception of loudness growth changes with the maturation of the auditory perceptual mechanism. The differences that were found for discrimination ability lent support to the hypothesis of developmental change. Therefore, such perceptual changes could also effect the perception of loudness growth. That possibility may be further supported by the fact that the difference in DL size between 4 and 12-year olds was 3.08 dB at 10 dB SL and was 1.32 dB at 60 dB SL. Further investigation into the development of the perception of loudness may yield an answer.

Table 20 is a display of the intensity levels at which DLI was measured in dB SPL. It can be seen that although the sensation levels were the same for all age groups, because of the difference in sensitivity between the groups the intensity levels at which DLI was measured were different. That is, the younger subjects always had DLI measured at a higher SPL value than did the older subjects. Perhaps the difference in DLI size was due to the difference in sensitivity and occurred because of the SPL influence. Further investigation into this area is needed.

Difference limen for frequency (DLF): The size of the difference limen for frequency decreased with increased age. The refinement of discrimination was seen in this study with DLI and was reported in early studies of pitch discrimination (Kidd and Kidd, 1966), where pitch was shown to improve with increased age between 5 and 10 years.

In his series of sub-tests designed to evaluate auditory perception, Abromovitz (1971) demonstrated that ability to discriminate between tone pairs, and tone patterns improved with age in normal subjects (5-10 years). Although he was not measuring DLF, he was assessing pitch discrimination and an age improvement was found. Eguchi (1976) demonstrated that DL for fundamental frequency decreased with increased age in normal hearing children between 7 and 11 years. Again this was not a measure of DLF but showed that pitch and frequency discrimination abilities were influenced by age, like the results of the present study. In the present study the 12-year old subjects tended to function like normal adults. Harris (1952) measured DLF with normal adults and found the mean DLF to be 4.6 Hz; the 12-year olds showed excellent agreement with this finding by yielding a mean DLF of 4.7 Hz.

The effect of frequency on DLF size and its interaction with age

Table 20. Intensity levels in dB SPL at which difference limen for intensity was measured.

Sensation Level(dB)	Age	Frequency (Hz)			
		500	1000	2000	4000
10	4	28.1	25.4	24.7	25.6
	6	27.8	21.1	23.3	24.8
	8	27.5	21.5	23.6	24.4
	10	26.5	22.9	21.8	21.2
	12	23.6	15.2	21.1	21.0
20	4	38.1	35.4	34.7	35.6
	6	37.8	31.1	33.3	34.8
	8	37.5	31.5	33.6	34.4
	10	36.5	32.9	31.8	31.2
	12	33.6	25.2	31.1	31.0
40	4	58.1	55.4	54.7	55.6
	6	57.8	51.1	53.3	54.8
	8	57.5	52.9	53.6	54.4
	10	56.5	52.9	51.8	51.2
	12	53.6	45.2	51.1	51.0
60	4	78.1	75.4	74.7	75.6
	6	77.8	71.1	73.3	74.8
	8	77.5	71.5	73.6	74.4
	10	76.5	72.9	71.8	71.2
	12	73.6	65.2	71.1	71.0

was found to be significant. For older subjects (8-10 years) DLF was smallest at 500-1000 Hz, increased with frequency at 2000 Hz and was the same or slightly increased at 4000 Hz. These findings were similar to Harris' normal adults, although he did not measure DLF at 4,000 Hz so a comparison could not be made at that frequency. The younger subjects (4-6 years) showed larger DLFs at 500 Hz than 1000 Hz or any of the other frequences. Two possible reasons could account for this: 1) As was indicated in the pure tone data, the younger children showed poorer sensitivity when compared to the older subjects. Since DLF was measured at 30 dB SL a reference was made to the individual thresholds and so the dB SPL was greater for the younger subjects than it was for the older subjects. This can be seen in Table 21 where the intensity in dB SPL at which DLF was measured is displayed. Perhaps the interaction of intensity and frequency on the perceived pitch was influencing the DLF of the younger subjects. 2) The greater effect of sensation level and its interaction with frequency on DLI size was observed for the younger subjects. Perhaps the fact that DLF was measured at 30 dB SL did not allow for the most sensitive measurement at 500 Hz for the younger children. Further investigation into the development of perceived pitch and its relation to intensity and DLF measured as various sensation levels may yield answers in this area.

Developmental differences: In general, it can be seen that auditory sensitivity and discrimination improved with increased age. The agreement among these findings and those of studies of vision and tactile stimulation indicated that the sensory perceptual mechanism changes with age. There is a question of whether the significant age differences were a result of increased motivation and attention of the older

Table 21. Intensity levels in dB SPL at which difference limen for frequency was measured.

Age	Frequency (Hz)			
	500	1000	2000	4000
4	48.1	45.4	44.7	45.6
6	47.8	41.1	43.3	44.8
8	47.5	41.5	43.6	44.4
10	46.5	42.9	41.8	41.2
12	43.6	35.2	41.1	41.0

children as opposed to true developmental peripheral and perceptual changes. In the present study, an attempt was made to control for these factors by using a constant schedule of tangible reinforcement. The subjects received tokens at presecribed intervals and were allowed to use those tokens in a trade for toys at the end of each session. Such procedures were to control for differences in motivation among subjects which might have occurred without tangible reinforcement. The subjects were also given rest periods every 15 minutes or on request, although they had to work for at least seven consecutive minutes. Again, such a procedure was used in order to control for the difference in attention span among the subjects.

The possibility that intelligence rather than chronological age influenced the results of this study could not be ruled out by merely demonstrating age differences. The older child's responses were most likely influenced by his expanded experience. The mere fact of attending school longer made the older child more experienced at manipulating stimuli and making refined discriminations than the younger child. Jenkins and Fealock (1960) using mentally retarded children demonstrated that the degree of perceptual constancy improved with increased chronological age as opposed to increased mental age. Although a generalization to the present study may be made from their work, further documentation to fully evaluate the role of intelligence in change in auditory perception is needed.

That the change in auditory perception found in the present study may have arisen from differences in the peripheral system's ability to respond differentially to stimuli which were physically different, or the differences in the way the neural system made use

of the differentiated input at a higher level was pointed out by Dember (1965).

It is feasible that Dember's first choice, difference in peripheral sensitivity was the underlying basis for all the developmental changes demonstrated in the present study. Since the three psychoacoustic tasks were related directly or indirectly to sensitivity than those improved thresholds between 4 and 12 years may have resulted in the improved temporal integration thresholds and differential sensitivity for intensity and frequency that was found. Further investigation into this area is needed to more fully understand the hypothesized relationship.

Prediction Model

It was possible to question the validity of the psychoacoustic tasks employed in the present study when considering the youngest subjects. Through the prediction model (main-effects-only) the validity of the tasks was predicted from the main effects. Residual points were obtained by comparing the reconstructed estimates calculated from the observed data and any extreme points were evaluated.

Pure tone sensitivity: The mean pure tone data indicated that the validity of the tasks was good. That is, individual subject scores were well predicted by the main-effects-only model for all age groups. The individual subject scores showed that the lower frequencies tended to yield extreme thresholds for all age groups. The other extreme residuals tended to be demonstrated by the 4 and 12-year olds, a finding not unusual in light of the observation of Leninhan et al. (1971) that individual subject differences easily effected their data. With the

4 and 12-year olds being at either extreme of the age range, it was not peculiar that an individual would fall away from the group norm. That is, finding a 4-year old with greater sensitivity and a 12-year old with poorer sensitivity than the rest of their age group.

Temporal integration: The mean residuals of the temporal integration thresholds demonstrated good prediction of mean thresholds for all age groups by the main-effects-only model. That was indicated by the fact that there were no extreme scores. The validity of the task appeared good. The individual subject residuals indicated that the extreme points were caused by individual subject differences rather than from a particular task condition. Again subject variability was expected when individual thresholds rather than mean scores were used.

Difference limen for intensity: Mean residuals of difference limen for intensity indicated that age was the main effect which was the poorest predicter of mean subject scores when the main-effects-only model was used. That is, the 4-year olds yielded two significantly different (two standard deviations away from 0 residual) points. The individual subject residuals indicated that the extreme scores of the 4-year olds were obtained at 10 and 60 dB SL. The main effect of sensation level on DLI for 4-year olds yielded extreme scores unlike those found for any other age group or for any other condition.

Difference limen for frequency: The mean residuals of the difference limen for frequency obtained from the main-effects-only model indicated that mean scores were well predicted by the model. Individual subject residuals demonstrated that the main effect which yielded extreme scores were significantly different from the reconstructed estimates.

In general, individual subject variability was expected. In the present study, it was found that subject variability tended to decrease with increasing age. The mean scores, fitted to the main-effects-only model, indicated that the main effects were good predicters of subjects' scores for the tasks employed. That is, the responses obtained were not significantly different from those which would be predicted from the reconstructed estimates. Therefore, the tasks employed were assumed to be valid measures of the development of psychoacoustic performance in children.

The data obtained in the present study demonstrated a trend which was consistent with Fior's (1972) hypothesis of "maximum maturity" of auditory perception occurring between 10 and 13 years of age. These data demonstrated that there was still a tendency for improved sensitivity and discrimination between 10 and 12 years. Perhaps if an age group older than 12 had been used in this study, a plateau of performance would have been demonstrated, but certainly, it can be seen that age differences continued with improvement in auditory perceptual abilities through 12 years. The mean differences between adjacent age groups for all tasks can be seen in Table 22. Regardless of the fact that an actual plateau in performance could not be demonstrated, the trend of maturation of psychoacoustic performance with a maximum at 12 years was found. That tendency supports Fior's hypothesis.

Learning, thinking and motivation all depend on making use of perceptual skills. The developmental trends demonstrated in audition lead to the consideration of the interaction between auditory development and that of speech perception and production. Gibson and Levin

Table 22. Mean threshold change between adjacent age groups for all tasks.

Task	Age Range (years)			
	4-6	6-8	8-10	10-12
Pure tone Sensitivity	1.5 dB	0.6 dB	1.9 dB	1.5 dB
Temporal Integration	2.4 dB	0.9 dB	0.3 dB	5.5 dB
Intensity DL	1.4 dB	0.4 dB	0.1 dB	0,3 dB
Frequency DL	3.9 Hz	3.4 Hz	2.3 Hz	1.4 Hz

(1975) pointed out that increased specificity of audition is primary to hearing and for producing phonemic, syntactic and semantic variations. In order to more fully understand how auditory perception and its development relates to language learning and development of academic skills, further study must be made. How this area influences the skills of the mentally retarded, hearing impaired, learning disabled and language disordered child must be thoroughly investigated.

Chapter VI

Summary and Conclusions

The results of the present study may be summarized as follows:

1) Pure tone sensitivity increased with increased age between 4 and 12 years with the thresholds of the 12-year olds showing the greatest sensitivity and being most like normal adult values. The frequency sensitivity of the ear to threshold tones was the same for all age groups and was like that of normal adults.

2) Temporal integration thresholds, like pure tone thresholds, improved with increased age. Like normal adult temporal integration thresholds, they decreased with increased duration. A 15.31 dB mean shift in threshold was found for durational changes of 25 through 200 msec; above 200 msec a smaller mean threshold shift (5.5 dB) was found. The configuration of the functions did not change with age and was slightly steeper that that found for normal adults.

3) Intensity difference limen decreased in size with increased age. Like normal adult data DLI size decreased with increased sensation level. The frequency effect for these data was also like adult data; DLI was largest at 500 Hz, decreased with increased frequency until 2000 Hz and increased again with increased frequency.

4) Frequency difference limen decreased in size with increased age. For older subjects (8-12 years) DLF was smallest at 500 and 1000 Hz and increased in size with increased frequency. For the younger subjects (4-6 years) DLF was larger at 500 than 1000 Hz, deviating

from what had been found with the older subjects and for normal adults.

In general, an improvement in auditory sensitivity and discrimination with increased age has been found. Several questions have been raised about the developing auditory percpetual mechanism which may be answered by future research.

The possibility of the change in auditory sensitivity being the underlying basis for changes found in temporal integration thresholds and frequency and intensity difference limen thresholds must be more carefully examined. One could evaluate that by using differerent subjects, that is, mentally retarded children who vary in both mental and chronological age. One would want to demonstrate an improvement in sensitivity and discrimination with increased chronological age, rather than increased mental age. If such a result was found then the hypothesis of interdependence between sensitivity and discrimination would be supported.

It also seems necessary to demonstrate objectively that true threshold changes are occurring rather than behavioral or motivational changes. Objective audiometric techniques such as EEG techniques, should be employed to evaluate the peripheral mechanism.

When measuring DLI in the present study it was found that sensation level had a much stronger influence on DL size for the younger subjects than for the older subjects. Such a finding could be related to possible changes in loudness perception with increased age. In order to more carefully evaluate if such changes take place in the developing auditory mechanism, one would have to assess the perception of loudness

growth, perhaps by obtaining phon curves on normal children.

The possibility that changes in loudness perception are related to the development of the auditory percpetual mechanism may also be related to a result obtained from measurements of the frequency difference limen. In the present study DLF was measured at 30 dB SL as suggested by Harris (1952). If loudness growth is different for the younger than for the older subjects and for adults, 30 dB SL may not have been the most sensitive level at which to measure DLF for the younger children. In order to determone the accuracy of such a theory one would have to measure DLF at various sensation levels for different age groups.

The major findings of the present study indicated that a change in age from 4 to 12 years produced a concomittent change in performance on psychoacoustic tasks. Auditory sensitivity, measured through pure tone sensitivity and temporal integration methods and auditory discrimination,measured with difference limen for intensity and frequency improved with increased age.

APPENDIX I

Raw Data

Pure Tone Sensitivity:

Subject	Age	Frequency (Hz)					
		250	500	1000	2000	4000	8000
AA	4	44.5	28.0	27.5	22.0	21.5	31.5
JB	4	29.5	14.0	11.5	8.5	16.0	17.0
CH	4	31.0	12.5	10.5	14.0	16.0	9.0
JN	4	37.5	21.0	17.5	16.5	9.5	10.5
AR	4	30.0	15.0	10.0	12.5	15.0	12.5
DA	6	32.0	16.0	6.5	11.0	14.0	15.5
JE	6	36.0	21.0	11.5	17.0	14.5	18.5
CG	6	35.0	15.5	12.0	13.5	16.5	17.5
EH	6	30.0	21.0	15.5	11.0	14.0	14.5
TW	6	30.0	15.5	10.0	14.0	15.0	13.0
LB	8	32.5	16.0	12.0	8.5	11.5	15.5
JBR	8	28.5	11.5	6.5	11.5	7.5	7.5
ME	8	35.5	22.0	15.0	14.5	19.5	10.5
BBK	8	27.5	16.5	14.5	17.0	18.5	20.5
LR	8	32.0	21.5	9.5	16.5	15.0	15.0
TE	10	29.5	12.5	7.5	10.5	11.5	11.0
BGK	10	34.5	18.5	11.5	11.5	6.5	12.5
MM	10	30.0	13.5	16.5	6.5	19.0	7.5
AR	10	22.0	18.5	17.0	16.5	9.0	10.0
SW	10	25.5	19.5	12.0	14.0	10.0	7.0
PE	12	26.5	12.5	0.0	9.5	5.5	9.5
BH	12	25.5	11.5	1.0	10.0	6.5	10.0
TM	12	29.5	14.5	8.5	10.5	11.0	11.0
PS	12	30.0	18.0	10.0	16.0	12.5	12.5
JW	12	29.0	11.5	6.5	9.5	19.5	19.5

Difference Limen for Intensity:

Subject	Age	Frequency				Sensation Level
		500	1000	2000	4000	
AA	4	6.2	5.7	6.0	6.0	10
		4.6	3.8	3.9	4.5	20
		3.4	3.2	3.4	3.0	40
		2.3	1.9	2.3	1.9	60
JB	4	5.4	5.0	5.0	4.9	10
		4.7	4.1	3.9	4.2	20
		3.7	3.4	3.3	3.1	40
		2.7	2.3	2.2	2.2	60
CH	4	6.0	5.5	5.8	5.9	10
		4.9	4.6	4.2	4.4	20
		3.6	3.3	3.2	3.2	40
		2.2	1.8	1.9	2.2	60
JN	4	6.3	6.3	5.8	6.1	10
		4.8	4.2	4.1	4.0	20
		3.6	3.2	3.2	3.1	40
		2.7	2.2	2.4	2.0	60
AR	4	5.9	5.9	6.1	5.7	10
		4.4	4.1	3.9	4.3	20
		3.0	3.4	3.1	2.9	40
		2.9	2.2	2.4	2.2	60
DA	6	3.8	4.0	3.6	3.8	10
		3.0	3.2	2.9	2.6	20
		2.3	2.0	2.6	2.8	40
		1.7	1.8	1.4	1.5	60
JE	6	4.0	2.7	3.1	3.7	10
		3.2	2.0	2.5	2.4	20
		2.1	2.0	1.9	2.1	40
		1.2	1.9	1.2	1.4	60
CG	6	3.7	3.9	3.1	3.3	10
		3.1	2.9	2.2	2.8	20
		1.8	2.2	2.0	1.7	40
		1.7	1.2	1.8	1.2	60
EH	6	3.6	3.3	3.1	3.2	10
		2.9	2.7	3.0	2.6	20
		2.2	2.1	2.1	1.9	40
		1.8	1.8	1.5	1.7	60
TW	6	3.7	3.2	3.2	3.0	10
		2.8	2.6	2.2	2.2	20
		2.1	2.0	1.9	1.8	40
		1.8	1.4	1.3	1.5	60
JBR	8	3.7	3.3	3.2	3.1	10
		3.2	2.7	2.4	2.9	20
		2.3	2.2	2.1	2.3	40
		2.0	1.7	1.7	1.5	60

DLI continued

LB	8	3.4	3.3	2.5	3.1	10
		2.1	1.7	2.1	1.8	20
		1.9	1.6	1.5	1.5	40
		1.4	1.2	1.3	1.2	60
ME	8	3.1	2.5	2.8	2.8	10
		2.0	2.1	1.9	1.7	20
		1.3	1.0	1.2	1.3	40
		1.3	1.3	1.3	1.3	60
BBK	8	3.3	3.0	2.8	2.5	10
		2.4	2.0	2.2	2.0	20
		1.9	1.6	1.5	1.8	40
		1.4	1.2	1.3	1.3	60
LR	8	3.2	2.8	2.6	2.5	10
		2.4	2.3	2.3	2.3	20
		2.1	2.8	1.6	1.7	40
		1.4	1.3	1.2	1.1	60
TE	10	3.6	3.1	2.8	3.3	10
		2.2	2.2	2.0	2.4	20
		2.1	1.8	1.9	1.3	40
		1.3	1.5	1.2	1.1	60
BGK	10	3.1	2.9	2.9	2.8	10
		2.6	2.2	2.5	2.5	20
		2.1	2.1	1.7	1.8	40
		1.7	1.1	1.1	1.2	60
MM	10	3.0	3.2	2.8	3.2	10
		2.2	2.3	2.6	2.7	20
		1.7	1.8	2.2	1.8	40
		0.9	1.2	1.4	1.2	60
AR	10	3.2	3.5	3.4	3.8	10
		2.7	2.7	2.1	2.6	20
		2.2	2.0	2.2	2.2	40
		1.6	1.2	1.2	1.4	60
SW	10	2.9	2.5	2.7	2.8	10
		2.1	2.8	2.8	2.4	20
		1.8	1.6	1.2	1.6	40
		1.2	1.0	1.0	1.0	60
PE	12	2.7	2.2	2.5	2.5	10
		2.3	2.1	2.2	2.2	20
		1.3	1.2	1.2	1.1	40
		0.7	0.5	0.7	0.7	60
BH	12	3.2	3.1	2.9	2.8	10
		2.3	1.9	2.0	2.2	20
		1.8	1.2	1.2	1.2	40
		1.3	1.3	0.8	0.7	60
TM	12	3.0	2.3	2.1	2.4	10
		2.2	2.0	2.4	1.9	20

DLI continued

TM	12	1.4	1.5	1.6	1.2	40
		1.0	0.8	0.5	0.7	60
PS	12	3.0	3.0	2.7	2.8	10
		2.3	2.3	2.2	2.1	20
		2.2	1.7	2.1	1.9	40
		1.6	1.2	0.8	0.8	60
JW	12	2.8	2.8	2.7	2.4	10
		2.1	2.8	2.2	2.1	20
		1.6	1.3	1.2	1.9	40
		0.9	1.5	1.0	0.8	60

Temporal Integration:

Subject	Age	Duration (msec)						Frequency (Hz)
		25	50	100	200	400	800	
AA	4	27.5	23.3	21.6	15.8	12.5	10.0	500
		25.8	20.0	15.0	8.3	10.8	7.5	1000
		23.3	16.6	14.1	9.1	10.0	8.3	2000
		25.5	20.8	12.5	10.0	8.3	5.8	4000
JB	4	20.0	14.1	14.4	5.0	0.8	-1.6	500
		21.6	9.2	5.0	2.5	-2.5	-10.0	1000
		15.8	13.3	5.0	2.5	-0.8	-1.6	2000
		12.5	8.3	0.8	-0.8	-0.8	-0.8	4000
CH	4	26.6	19.2	13.3	11.6	7.5	6.6	500
		22.5	11.6	9.2	5.8	5.0	2.5	1000
		17.5	9.2	6.6	5.0	2.5	0.0	2000
		23.3	11.6	9.2	3.3	-3.3	-3.3	4000
JN	4	25.0	21.6	14.6	11.6	10.8	2.5	500
		25.0	22.5	13.3	7.5	5.8	0.8	1000
		21.6	17.5	11.6	10.0	7.5	5.8	2000
		25.8	16.6	15.0	12.5	10.8	7.5	4000
AR	4	26.6	20.0	13.3	10.0	2.5	5.0	500
		22.5	13.3	6.6	5.0	5.0	3.3	1000
		18.3	9.2	6.6	5.0	4.2	0.8	2000
		25.8	10.0	7.5	3.3	-3.3	1.6	4000
DA	6	25.0	17.5	14.2	12.5	8.3	7.5	500
		21.6	15.0	5.0	-0.8	0.0	0.0	1000
		26.6	16.6	10.0	5.8	5.8	0.0	2000
		23.3	9.2	2.5	-2.5	-5.0	-6.6	4000
JE	6	27.5	19.2	15.0	11.6	12.5	10.8	500
		22.5	17.5	10.0	5.8	3.3	0.0	1000
		24.2	15.0	13.3	5.0	7.5	7.5	2000
		23.3	13.3	5.8	5.8	0.8	-2.5	4000
CG	6	20.8	11.6	11.6	7.5	5.8	-3.3	500
		17.5	10.8	4.2	1.6	0.0	0.0	1000
		18.3	10.0	5.0	1.6	4.2	-3.3	2000
		18.3	12.5	8.3	0.8	1.6	-4.2	4000
EH	6	18.3	13.3	10.0	5.0	4.2	-3.3	500
		18.3	10.8	3.3	3.3	2.5	0.0	1000
		17.5	10.0	5.8	3.3	4.2	-2.5	2000
		17.5	11.6	8.3	1.6	1.6	-1.6	4000
TW	6	25.0	14.2	9.2	9.2	0.8	1.6	500
		20.0	13.3	8.3	5.8	1.6	3.3	1000
		15.0	7.5	7.5	5.8	-2.5	-4.2	2000
		17.5	8.3	7.5	10.0	-3.3	-10.8	4000
JBR	8	20.8	13.3	10.8	7.5	3.3	-0.8	500
		20.8	13.3	8.3	7.5	1.6	0.8	1000
		20.8	11.6	12.5	8.3	1.6	-1.6	2000
		18.3	12.5	8.3	3.3	-0.8	-2.5	4000

Temporal Integration continued

LB	8	19.2	15.0	10.8	4.2	1.6	-0.8	500
		16.6	12.5	9.2	6.6	0.8	-3.3	1000
		19.2	11.6	6.6	2.5	-0.8	-1.6	2000
		18.3	11.6	12.5	3.3	-1.6	-7.5	4000
ME	8	17.5	12.5	11.6	8.3	2.5	-0.8	500
		16.6	13.3	5.8	1.6	-1.6	0.0	1000
		16.6	12.5	7.5	5.0	-1.6	-3.3	2000
		15.0	12.5	4.2	4.2	0.0	-1.6	4000
BBK	8	22.5	15.0	9.2	3.3	1.6	0.8	500
		21.6	12.5	8.3	5.0	1.6	1.6	1000
		21.6	16.6	13.3	5.0	0.8	-1.6	2000
		21.6	14.2	8.3	4.2	0.8	0.0	4000
LR	8	19.2	12.5	8.3	3.3	0.8	-1.6	500
		17.5	10.8	7.5	5.0	2.5	-2.5	1000
		15.8	8.3	5.8	1.6	-2.5	-3.3	2000
		15.8	9.2	10.0	5.0	0.8	-11.6	4000
TE	10	20.8	15.0	8.3	7.5	2.5	-3.3	500
		20.8	13.3	7.5	2.5	-0.8	-2.5	1000
		21.6	12.5	7.5	-0.8	-1.6	-0.8	2000
		23.3	8.3	6.6	3.3	-1.6	-2.5	4000
BGK	10	21.6	17.5	11.6	7.5	0.0	-5.0	500
		20.0	13.3	10.0	5.0	5.0	-5.0	1000
		22.5	12.5	8.3	2.5	1.6	-6.6	2000
		20.4	10.8	9.2	4.2	2.3	-5.8	4000
MM	10	20.0	15.8	12.5	7.5	1.6	-1.6	500
		17.5	15.8	6.6	3.3	2.5	-2.5	1000
		19.2	14.2	7.5	3.3	-0.8	-6.6	2000
		20.0	13.3	5.8	4.2	-1.6	-7.5	4000
AR	10	18.3	18.3	2.5	12.5	4.2	0.8	500
		20.0	16.6	9.2	1.6	4.2	4.2	1000
		19.2	14.2	8.3	1.6	8.3	-3.3	2000
		6.6	5.8	-5.0	-13.3	-13.3	-15.0	4000
SW	10	24.2	17.5	9.2	5.8	8.3	3.3	500
		18.3	14.2	10.0	9.2	6.6	4.2	1000
		12.5	10.8	10.0	9.2	1.6	0.0	2000
		14.2	9.2	6.6	-2.5	0.8	-5.8	4000
PE	12	15.0	11.6	4.2	3.3	1.6	1.6	500
		10.8	0.8	-2.5	-5.8	-8.3	-9.2	1000
		10.8	6.6	0.0	-5.0	0.8	0.8	2000
		6.6	5.0	0.8	-6.6	-10.0	-4.2	4000
BH	12	16.6	13.3	2.5	2.5	1.6	-6.6	500
		12.5	-0.8	0.8	-5.0	-5.0	-8.3	1000
		14.2	7.5	1.6	-0.8	0.8	-0.8	2000
		9.2	7.5	2.5	-7.5	-8.3	-5.8	4000

Temporal Integration continued

TM	12	14.2	12.5	5.0	3.3	0.8	-1.6	500
		10.8	6.6	-3.0	-1.6	-9.2	-6.6	1000
		10.0	3.3	-7.5	-11.6	-12.5	-10.8	2000
		15.0	12.5	7.5	4.2	-3.3	-3.3	4000
PS	12	16.6	11.6	3.3	3.3	2.5	-1.6	500
		13.3	7.5	-0.8	-1.6	-4.2	-7.5	1000
		11.6	5.8	-2.5	-10.0	-10.8	-8.3	2000
		15.8	12.5	6.6	3.3	-2.5	-5.8	4000
JW	12	16.6	5.0	0.8	-7.5	-4.2	-11.6	500
		16.6	8.3	7.5	0.0	-4.2	-12.5	1000
		9.2	9.2	-0.8	-4.2	-15.0	-7.5	2000
		15.0	8.3	4.2	-3.3	-13.3	-15.0	4000

Difference Limen for Frequency:

Subject	Age	Trial			Frequency
		1	2	3	
AA	4	15.8	16.0	15.9	500
		11.6	12.0	11.8	1000
		16.8	16.2	16.5	2000
		17.6	17.8	17.7	4000
JB	4	15.0	16.0	15.5	500
		12.6	12.2	12.4	1000
		16.6	17.2	16.9	2000
		17.2	18.0	17.6	4000
CH	4	15.8	16.2	16.0	500
		12.2	12.2	12.2	1000
		17.2	17.0	17.1	2000
		18.4	17.8	18.1	4000
JN	4	16.2	15.8	16.0	500
		11.2	11.8	11.5	1000
		17.6	17.6	17.6	2000
		18.0	17.4	17.7	4000
AR	4	15.6	16.2	15.9	500
		12.8	12.0	11.9	1000
		17.2	16.8	17.0	2000
		18.2	18.6	18.4	4000
DA	6	10.6	11.0	10.8	500
		9.2	9.2	9.2	1000
		11.4	11.0	11.2	2000
		13.0	13.4	13.2	4000
JE	6	11.2	11.2	11.2	500
		9.2	8.4	8.8	1000
		12.8	13.2	13.0	2000
		14.6	13.8	14.2	4000
CG	6	12.0	11.8	11.9	500
		10.4	10.0	10.2	1000
		12.8	13.6	13.2	2000
		15.0	14.8	14.9	4000
EH	6	12.0	12.2	12.1	500
		10.4	9.8	10.1	1000
		12.0	12.0	12.0	2000
		14.0	13.6	13.8	4000
TW	6	11.4	12.6	12.0	500
		10.0	9.2	9.6	1000
		12.0	11.8	11.9	2000
		15.0	14.6	14.8	4000
LB	8	8.6	7.8	8.2	500
		7.8	6.8	7.3	1000
		11.6	11.0	11.3	2000
		6.8	7.0	6.9	4000

DLF continued

JBR	8	7.2	8.4	7.8	500
		6.2	6.6	6.4	1000
		8.8	8.6	8.7	2000
		11.8	10.4	11.1	4000
ME	8	7.6	7.0	7.3	500
		6.6	6.6	6.6	1000
		9.4	9.8	9.6	2000
		12.0	11.4	11.7	4000
BBK	8	6.8	7.0	6.9	500
		6.0	6.4	6.2	1000
		8.8	8.0	8.4	2000
		10.4	11.2	10.8	4000
LR	8	6.6	6.6	6.6	500
		9.2	8.6	8.9	1000
		11.0	11.8	11.4	2000
		8.0	7.8	7.9	4000
TE	10	5.2	5.4	5.3	500
		4.4	4.6	4.5	1000
		7.0	7.6	7.3	2000
		10.2	10.4	10.3	4000
BGK	10	5.4	6.2	5.8	500
		4.6	5.0	4.8	1000
		6.6	6.4	6.5	2000
		9.8	9.4	9.6	4000
MM	10	5.2	5.4	5.3	500
		5.0	4.6	4.8	1000
		6.4	6.4	6.4	2000
		9.2	8.8	9.0	4000
AR	10	4.4	4.6	4.5	500
		3.8	4.2	4.0	1000
		5.6	5.0	4.3	2000
		8.2	8.2	8.2	4000
SW	10	4.6	4.8	4.7	500
		4.4	4.0	4.2	1000
		5.4	5.2	5.3	2000
		8.2	7.8	8.0	4000
PE	12	4.8	4.6	4.7	500
		3.8	3.8	3.8	1000
		4.8	5.2	5.0	2000
		5.2	5.4	5.3	4000
BH	12	4.4	4.4	4.4	500
		4.0	3.6	3.8	1000
		5.8	5.2	5.5	2000
		5.0	4.8	4.9	4000
TM	12	4.6	4.6	4.6	500
		3.4	3.6	3.5	1000

DLF continued

TM	12	5.2	5.4	5.3	2000
		4.2	4.2	4.2	4000
PS	12	5.0	5.0	5.0	500
		3.4	4.0	3.7	1000
		6.8	6.6	6.7	2000
		5.8	6.2	6.0	4000
JW	12	5.0	4.6	4.8	500
		4.0	3.6	3.8	1000
		5.4	4.6	5.0	2000
		5.2	5.6	5.4	4000

APPENDIX II

Demographic Information

Subject	Age	Sex	Siblings	Parents' Education	Residence
AA	4	F	2	Father: M.A. Mother: B.A.	Flushing, New York
JB	4	M	1	Father: B.A. Mother: B.A.	Flushing, New York
CH	4	M	3	Father: H.S. Mother: H.S.	Seaford, New York
JN	4	M	3	Father: Ll.D. Mother: M.A.	Flushing, New York
AR	4	M	1	Father: M.A. Mother: B.A.	Paramus, New Jersey
DA	6	F	2	Father: M.A. Mother: B.A.	Jamaica, New York
JE	6	M	3	Father: B.A. Mother: B.A.	Flushing, New York
CG	6	F	1	Father: M.A. Mother: B.A.	Flushing, New York
EH	6	F	2	Father: B.A. Mother: H.S.	Kew Gardens, New York
TW	6	M	1	Father: B.A. Mother: B.A.	East Meadow, New York
JBR	8	M	1	Father: M.A. Mother: B.A.	Flushing, New York
LB	8	F	3	Father: H.S. Mother: B.A.	Seaford, New York
ME	8	M	3	Father: B.A. Mother: B.A.	Flushing, New York
BBK	8	M	2	Father: B.A. Mother: H.S.	Laurelton, New York

LR	8	F	3	Father: H.S. Mother: B.A.	Seaford, New York
TE	10	M	3	Father: B.A. Mother: B.A.	Flushing, New York
BGK	10	F	2	Father: B.A. Mother: H.S.	Laurelton, New York
MM	10	M	2	Father: H.S. Mother: H.S.	Seaford, New York
AR	10	M	3	Father: H.S. Mother: B.A.	Seaford, New York
SW	10	F	1	Father: B.A. Mother: M.A.	Westbury, New York
PE	12	F	2	Father: M.A. Mother: M.A.	Westbury, New York
BH	12	M	2	Father: B.A. Mother: M.A.	Jamaica, New York
TM	12	M	1	Father: B.A. Mother: M.A.	Flushing, New York
PS	12	F	3	Father: M.A. Mother: B.A.	Jamaica, New York
JW	12	F	1	Father: B.A. Mother: M.A.	Westbury, New York

APPENDIX III

Release Form and Schedule Letter

Dear

At an earlier request for subjects for my dissertation, you kindly offered the services of a child you know.

I am presently in the process of arranging times at which I can collect data and would therefore appreciate it if you would indicate a convenient time in the space provided. This initial session will take approximately one hour. Later dates will also be needed but we can arrange them at another time. All of the testing will take place at Queens College Speech and Hearing Center. If you need transportation, it can be provided.

Thanks very much for your time and cooperation.

Sincerely,

Toni Maxon

Child's Name	Age	Date	Time	Phone Number

Please sign this form as a release for me to:
1) use your child as an experimental subject
2) report and publish the results of these experiments.

If you have any questions, you can contact me by phone: 520-7358.

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