

COMPARISON OF PURE-TONE,  
WARBLE-TONE AND NARROW-BAND  
NOISE THRESHOLDS OF  
YOUNG NORMAL-HEARING CHILDREN

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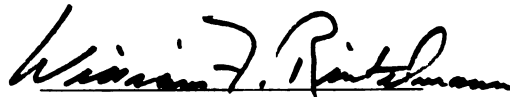


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## ABSTRACT

### COMPARISON OF PURE-TONE, WARBLE-TONE AND NARROW-BAND NOISE THRESHOLDS OF YOUNG NORMAL-HEARING CHILDREN

By

Daniel Joseph Orchik

The effect of auditory stimulus upon the threshold of hearing in young children was examined at four discrete age levels. Twenty normal-hearing children at each of the age levels of 3-1/2, 4-1/2, 5-1/2 and 6-1/2 were tested using pure tones, warble tones and narrow bands of noise. The 3-1/2 and 4-1/2 year-old children were tested at 500, 1000 and 2000 Hz, while the older children were examined at octave frequencies from 250 through 4000 Hz. For the warble-tone stimulus frequency deviations of  $\pm 3\%$  and  $\pm 10\%$  were employed with a single modulation rate of 8 per second. Two randomly selected test groups were used. While both groups were tested with pure tones and narrow bands of noise, Test Group I received the  $\pm 3\%$  warble tone and Test Group II received the  $\pm 10\%$  warble tone. In addition to the threshold comparisons made among the three types of stimuli, half of the subjects in each group were retested to obtain an estimate of clinical test-retest reliability for each of the stimuli.

The results showed a significant improvement in threshold as a function of age for all three stimuli. The stimuli were ranked

from most to least sensitive thresholds as follows: warble tones, pure tones and narrow bands of noise. Differences between any two of the three stimuli were 7 dB or less. However, warble-tone thresholds were generally more sensitive than pure-tone by 4 dB or less and narrow-band noise thresholds were poorer than pure-tone by 4 dB or less.

Thresholds obtained for the  $\pm 3\%$  warble tones were generally more sensitive for the two younger age categories while the  $\pm 10\%$  warble tones produced the more sensitive thresholds for the older children. However, the majority of differences in threshold between the two warble-tone conditions were 2.0 dB or less indicating that frequency deviation ( $\pm 3\%$  vs  $\pm 10\%$ ) had only minor effect upon threshold. Within this range of frequency deviation, it appears that warble tones on commercial audiometers can be employed clinically without concern for the effect of varying frequency deviation.

Clinical test-retest reliability was shown to be equivalent among the three stimuli. Not only were there no significant test-retest differences for any of the stimuli, but an examination of test-retest thresholds indicated that for all three stimuli, 88 percent or more of the comparisons were within  $\pm 5$  dB. Thus thresholds obtained clinically with pure tones, warble tones or narrow bands of noise should be equally reliable.

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## CHAPTER I

### INTRODUCTION

The importance of early detection and management of hearing loss in children as well as the detrimental effects of delayed identification and training have often been stressed in the literature (Lowell et al., 1956; Elliot and Vegely, 1968). In order to accomplish early identification of hearing loss precise information is required regarding the status of the auditory system. That is, before selection of amplification and application of an appropriate training program can be carried out, reliable information concerning hearing sensitivity must be obtained (Haug and Guilford, 1960; Wolski, Wiley and McIntire, 1964). However, until the child reaches an age when he can respond to conventional testing techniques, the acquisition of precise information concerning the hearing mechanism can be difficult. By the age of six to seven years, the child is generally able to respond to conventional pure-tone audiometry. Below age six, the test procedure usually requires some modification (Barr, 1955; Eagles et al., 1963; Langenback, 1965). The modification typically involves some form of what has been termed play audiometry.



The use of play audiometry with children has been reported with youngsters as early as eighteen months of age although the success rate drops sharply below three years of age. The success rate is generally reported to be maintained above 75% for the three to four age group, rising to 90% or better at four years and above. Along with an increased success rate, a gradual improvement in sensitivity has also been noted in children, with improved thresholds continuing through at least age seven (Barr, 1955; Haug and Guilford, 1960; Lowell et al., 1956; Eagles and Wishik, 1961).

The period from birth to three years is recognized as being critical to the acquisition of speech and language (Myklebust, 1954); but, it is during this age period that audiometric information important to identification and educational planning for the hard-of-hearing child can be most difficult to obtain. As a result the popularity of various objective techniques, such as cortical evoked response audiometry, has grown. However, behavioral audiometry has continued to remain a popular technique especially where auditory stimuli are presented via a sound-field and the audiologist determines the level of responsiveness of the child in an attempt to estimate hearing sensitivity.

A variety of stimuli have been suggested for use in behavioral audiometry: including bells, clackers, assorted noisemakers, white noise, complex noise, narrow-band noise, pure-tones, household sounds and environmental sounds including the human voice. Most of these stimuli, regardless of their attention-getting capabilities, have the significant problem of uncontrolled or inconsistent frequency

and intensity characteristics. Others, like white noise and broad band stimuli (including speech) do not provide information concerning threshold levels as a function of frequency.

Several individuals have suggested the use of pure tones in sound-field as a means of obtaining threshold information as a function of frequency (DiCarlo and Bradley, 1961; Bender, 1967). However, if one introduces a pure tone in a sound-field, the reflections from the boundaries of the test room may result in standing waves. As a result, some of the sounds will be reinforced and others cancelled as the subject moves about the room.

The problem of standing waves can be satisfactorily reduced by using warble tones. A warble tone is produced by frequency modulation. Frequency modulation refers to the periodic modification of a base or center frequency, with a variation of the base or center frequency to values either above, below or around it with amplitude held constant. The warble tone varies as a function of three basic parameters: (1) the center or base frequency, (2) the frequency deviation (FD), and (3) the modulation rate (MR).

The center frequency is the frequency around which the modulation takes place. Frequency deviation can be explained as follows: if the base frequency is 1000 Hz, then a  $\pm 5\%$  FD around the base or center frequency would produce a variation around 1000 Hz from 950 Hz to 1050 Hz, or a  $\pm 50$  Hz change. As this signal is repeated, the warbling sensation results. For a tone that warbles only above the base frequency, a 5% FD would produce a variation from 1000 Hz

to 1050 Hz. Thus, a  $\pm 5\%$  FD represents an actual nominal change of 10%.

The modulation rate (MR), or rate of frequency change, refers to the number of times per second the frequency varies (warbles) from one extreme of the frequency range to the other. Thus, a modulation rate of three per second and a frequency deviation of 5% for a 1000 Hz tone would mean that the tone would change from 1000 Hz to 1050 Hz three times per second.

Since its introduction into hearing testing, the warble-tone stimulus has been recommended for use with children in behavioral and play audiometry (Reilly, 1958a, 1958b; Miller and Rabanowitz, 1969; Carver, 1971). However, a survey by Staab and Rintelmann (1972) revealed a lack of information concerning the reliability and validity of the warble tone as an auditory stimulus, and they concluded that such information must be provided before warble tone can be seriously considered as a routine clinical tool.

Subsequent investigation by Staab (1971) as well as Rintelmann, Stephens and Orchik (1972) supported the reliability of warble tone as a stimulus for threshold measurement with normal hearing adults. However, at present the efficacy of warble-tone audiometry has not been systematically investigated with children, a population for whom its use was originally intended.

Another stimulus that has been suggested for use with children and other difficult-to-test subjects is narrow-band noise (Sanders and Josey, 1970). Narrow-band noise is credited with having similar attention-getting and fatigue-reducing properties to those associated with warble tones (Myers, 1957; Sanders and Josey, 1970).

The purpose of the present study is to provide data to effectively compare pure-tone, warble-tone and narrow-band noise thresholds in children as a function of chronological age. Test-retest reliability will also be examined. Until such information is obtained, arguments concerning the best stimulus for use with children remain speculative.

## CHAPTER II

### REVIEW OF THE LITERATURE

The following discussion is a review of the pertinent literature in the present area of investigation. Specific areas covered include: (1) the reliability of pure-tone audiometry with children as a function of age, (2) studies which deal with a comparison (direct or indirect) of warble-tone and conventional pure-tone thresholds, (3) warble-tone audiometry with children, and (4) narrow-band noise as an auditory stimulus.

#### Pure-Tone Audiometry With Children

The literature generally supports the contention that by the age of six to seven years children can be tested audiometrically using conventional pure-tone procedures. Using a modified technique usually referred to as some form of play audiometry, children can be tested as young as three years of age with a high percentage of success. Below age three, the success rate drops sharply, and below age two-and-a-half successful evaluation with play audiometry is found in only exceptional cases.

Barr (1955) evaluated the application of conventional and play audiometry with children. He reported that by age six to seven

years children were generally able to respond as adults to a conventional procedure. Below age six, Barr found that a modification in technique was required. Using play audiometry, he reported a 100% success rate with children 4 years of age and older. For the age range of 3-to-4 years, he found a success rate of more than 90%. In the 2-1/2-to-3 year group, the success rate fell to 60% and below age 2-1/2 success was achieved in only 20% of the children examined.

Lowell et al. (1956), in stressing the importance of early diagnosis of hearing loss, reported on a study with hard-of-hearing and normal-hearing children using a play audiometric procedure involving a conditioned response to a toy. Deaf children were tested initially at an average of 3 years 6 months using this technique and then reevaluated with the same procedure at an average age of 6 years 11 months. The results showed good test-retest reliability indicating the efficacy of the technique with deaf children as young as 3-1/2 years old.

Lowell et al. (1956) also reported the results obtained on a sample of children ranging in age from 2 years 6 months to 3 years 4 months who were presumed to have normal hearing but had not been previously tested. The audiometric findings confirmed the impression of normal hearing which implied, according to the authors, that their technique can be applied successfully to a high percentage of children above the age of 2-1/2 years.

In expressing the conviction that reliable audiometric data are required before an accurate diagnosis can be made, Haug and Guilford (1960) discussed the success obtained using their own device,

the Pediacoumeter. At the age of 4 years and above, their success rate was greater than 90% (94% for the ages 4 years to 4 years 11 months; 96% for the age range of 5 years to 5 years 11 months). For the age range of 3 years to 3 years 11 months the success rate was maintained at 82% (187 out of 227 cases). The percentage of successful examinations dropped to 47% for the ages of 2 years to 2 years 11 months, and 12% (3 of 25 children) for the ages 1 year to 1 year 11 months.

O'Neill, Oyer and Hillis (1961) reported a high correlation between the age of the child and his classification as easily-tested or difficult-to-test. They evaluated children using a variety of audiometric procedures and found that below the age of 40 months their success rate fell below 50% indicating that over half the children below 40 months of age could not be tested or gave responses so inconsistent as to be judged unreliable.

An investigation of the maturational aspects of pure-tone audiometry was reported by Myklebust (1954). His results showed a gradual improvement in threshold sensitivity through age 5-1/2 years. The average threshold improved toward audiometric zero and the standard deviations decreased as the age of the child increased. Myklebust also found a significant drop in the rate of successful tests below age 3-1/2, pointing out that one of the limitations of the pure-tone evaluation with young children is the fact that the stimulus employed is abstract and meaningless.

Statten and Wishart (1956), in comparing a modification of the peepshow to PGSR audiometry found the percentage of successes and

partial successes using the peepshow fell from 80% between the ages of 3 to 4 years to approximately 43% between the ages of 2 and 3 years. They further noted that the use of the peepshow is preferable to PGSR audiometry with children in all but a few cases.

Eagles and Wishik (1961) reported successful play audiometric procedures with children as young as 2 to 3 years. They gave no indication of the number of children on which play audiometry was attempted for this age group, but did report a consistent improvement in sensitivity from age 5 through age 12. The authors attributed the improvement in threshold to, among other factors, the improved behavior of the older children. Lenihan (1971) found a similar improvement in threshold with increasing age in children from 5 to 15 years of age. Lefanov (1971) reported improvement in sensitivity averaging 5 to 10 dB over a 2 to 3 year period. His results are from data gathered in a retest of 6 and 7 year old children who had been tested initially at the age of 3 to 4 years.

The preceding review indicates a well established and well supported correlation between the age of the child and the possibility of successful audiometric examination. Beyond age 3 the percentage of successes rises significantly to 75% or greater. There is a definite trend for improved thresholds as a function of increasing age beyond 3 years, continuing through at least age 6 to 7 years and possibly to age 12.

This improvement in sensitivity has been attributed to a number of factors including the behavior of the young child and the difficulties involved in maintaining his attention for such an



abstract signal. The indication seems clear that if a stimulus proposed for threshold measurement as an alternative to a pure tone is a better stimulus, in terms of being less abstract or a better attention-getter, then there is a margin for that stimulus to provide better thresholds in a normal-hearing group of children between the ages of 3 and 7 years.

#### Comparison of Warble-Tone and Conventional Pure-Tone Thresholds

Investigations of warble-tone and pure-tone stimuli employed for threshold measurement are discussed in this section. The investigations cited deal with research both directly and indirectly related to a comparison of thresholds obtained with warble tones and pure tones in adults. To the present time there has been no systematic comparison of the two stimuli with children.

Sivian and White in 1933 utilized warble tones and the psychophysical method of limits to determine the upper portion of the monaural minimum audible field (MAF) thresholds at 0° angle of incidence of 14 "normal" listeners. The reasons given for using warble tones were that they reduce fatigue and uncertainty on the part of the listener and also eliminate the residual standing wave patterns produced by reflections from the walls of the test room. They used a constant modulation rate of 10 per second and a frequency deviation that was progressively reduced from approximately  $\pm 4.6\%$  at 1100 Hz to approximately  $\pm 0.97\%$  at 15000 Hz. The results indicated no systematic differences between warble-tone and pure-tone thresholds.

Dallos and Tillman (1966) and Young and Harbert (1970) examined the possible effects of the modulation index (the ratio of frequency deviation to modulation rate) using Bekesy tracings. Both studies were specifically concerned with threshold changes in abnormally adapting ears but also included limited data obtained from normal listeners.

Dallos and Tillman (1966) used five different modulation rates (1, 2, 5, 10 and 25 per second) and three different frequency deviations (10, 63 and 250 Hz which were approximately  $\pm 1$ ,  $\pm 6$  and  $\pm 25\%$  respectively) at 500 Hz with one normal-hearing subject (one ear). The results showed that, in general, the hearing threshold improved slightly with increasing frequency deviation, and that consistently better thresholds were obtained for slower repetition rates. They suggested, however, that it is the modulation index which might be the critical variable in threshold sensitivity determination, and that under this condition, more sensitive thresholds are obtained with smaller frequency deviations. For example, while a frequency deviation (FD) of 40 Hz repeated 4 times per second and an FD of 100 Hz repeated 10 times per second yield the same modulation index, namely 10, more sensitive (better) thresholds would be obtained with the smaller deviation of 40 Hz.

Young and Harbert (1970) utilized four normal-hearing, trained listeners (four ears) and modulation rates of 1, 4, 10 and 25 per second with frequency deviations of  $\pm 10$ ,  $\pm 63$  and  $\pm 250$  Hz. Threshold values obtained by fixed frequency Bekesy audiometry at 1000 Hz showed that the thresholds remained about the same or improved

slightly with increased frequency deviation. As the modulation rate increased for a given frequency deviation the threshold became less sensitive (poorer). The greatest decibel change between combinations of frequency deviations and modulation rate was 7.1 dB. With respect to the modulation index, however, Young and Harbert agreed with Dallos and Tillman's observation that more sensitive thresholds are obtained for smaller frequency deviations.

The first systematic investigation of the relation between pure-tone and warble-tone thresholds was that by Staab (1971) in which he compared pure-tone and warble-tone thresholds for 30 different combinations of frequency deviation and modulation rate. He utilized frequency deviations of  $\pm 1, 3, 6, 10$  and 50% and modulation rates of 1, 2, 4, 8, 16 and 32 per second. Repeated thresholds for three normal listeners were examined for the octave frequency range of 250 through 8000 Hz. Staab's results indicate in general that warble-tone combinations up to and including  $\pm 10\%$  and modulation rates as fast as 32 per second show good agreement ( $\pm 5$  dB) with pure-tone thresholds. Frequency deviations were shown to exhibit more of an effect than modulation rates, and the modulation index, contrary to previous research, was found to have no systematic effect upon the dB difference scores at least for normal-hearing listeners.

Rintelmann, Orchik and Stephens (1972) compared warble-tone thresholds, obtained under earphones and in sound-field to pure-tone thresholds using a sample of 30 adult listeners with normal hearing. Their purpose was to substantiate the preliminary findings of Staab (1971) that warble-tone thresholds obtained using frequency

deviations up to and including  $\pm 10\%$  show good agreement with pure-tone thresholds. By using frequency deviations of  $\pm 3\%$  and  $\pm 10\%$  they were also able to gather data concerning warble-tone parameters currently available on commercial audiometers. The results of their experiment supported the contention of Staab concerning the agreement of warble-tone and pure-tone thresholds in that all differences were within  $\pm 5$  dB at all frequencies tested. As would be expected, sound field thresholds were better than those obtained under earphones (Sivian and White, 1933), although for the mid-frequency range (500 through 2000 Hz) agreement was close to a 5 dB differential. A second experiment (Rintelmann, Stephens and Orchik, 1972) examined the effects of change in azimuth ( $0^\circ$  vs  $90^\circ$ ) as well as occlusion versus non-occlusion of the nontest ear. The results indicated that changes in sound-field thresholds due to the above factors were less than 5 dB and thus were of little concern clinically. In addition, threshold test-retest agreement was equivalent for pure tones and warble tones.

It is obvious from the preceding review that good agreement has been demonstrated with normal hearing adult listeners between warble-tone and pure-tone thresholds for frequency deviations up to and including  $\pm 10\%$ . Equally clear is the fact that although warble-tone has been suggested as a preferable stimulus for testing children, threshold comparisons using the two stimuli in this population have yet to be investigated.

### Warble-Tone Audiometry With Children

At present, no study has systematically explored the effect of frequency modulation upon threshold measurement in children. Warble tone has been suggested for use by a number of authors primarily because it is believed to possess attention-getting properties and it eliminates residual standing wave patterns when used in a sound-field. This section includes a review of the literature suggesting warble tone as an auditory stimulus for use with children.

As a measure of behavioral response to warble-tone stimuli, Huizing in 1953 (cited in Jerger, 1963) reported success with a technique which involved the moving of a block as the conditioned response in children between 30 months and 7 years of age. This procedure was also used in a sound-field as an introductory test to threshold measurement which involved pure-tones delivered through earphones.

Reilly (1958a), who was influenced by the work of Huizing, developed an instrument for sound-field threshold measurement in children which he called the "audio-frequency wobulator." The instrument was based on Huizing's apparatus and employed a warble-tone stimulus. It provided for output to two sets of speakers: one set was portable and the other fixed to the arms of a chair in which the subject was seated. Reilly suggested that testing with warble tones in a sound-field could begin as early as 6 months of age, while play audiometry did not become possible until at least 21 months of age. Reilly introduced children older than 33 months to warble tone while they played at a table, and, as familiarity with the test signal increased, the children were taken to the test chair. Audiograms were

then obtained by means of play audiometric techniques using warble tone introduced through speakers at a fixed distance from the child's head. Pure-tones were later substituted for the warble tone and audiograms again obtained. Finally, the child was introduced to the earphones. According to Reilly with the experience the child has had from sound-field testing, he will tolerate the earphones at an earlier age. As a result, pure-tone audiograms can be recorded at an earlier age. Reilly commented that the youngest child for whom he had been able to obtain a warble-tone audiogram was just under two years of age. He added that children responded to warble tones of much less intensity than for pure-tones of the same frequency. He also found this difference for both behavioral and play audiometry. He further suggested that the difference in thresholds might be "a cortical phenomenon," but that further research was required. What was meant by "cortical phenomenon" was not discussed.

Lagenbeck (1965) stated that if the audiometer has a provision for the continuous alteration of frequency with intensity maintained constant, it should be utilized to help determine the threshold curve. He further wrote that with respect to children, especially those from about age 5 to 7 years, the tester can be just as successful as he is with adults if he can make the "game" more interesting for the child.

Heron and Jacobs (1969) described a procedure employing warble-tone stimuli to be used with neonates. The procedure employs three frequency ranges (250-500 Hz, 1000-2000 Hz and 4000-8000 Hz) with frequency deviations up to one-third of the center frequency.

They used modulation rates of 1 to 10 per second. Using a minimal level of 40 dB, they reported good success in examining neonates.

Liden and Kankkunen (1969) reported on a visual reinforcement procedure in testing young deaf children that utilized a warble tone. The apparatus was primarily designed for obtaining the sound-field thresholds for warble-tones. They used slides projected on a frosted glass screen as the visual reinforcer, and reported reliable results for children as young as 8 months of age using a level of 30 dB in sound-field as the limit of normal hearing.

Finally, Carver (1971) suggested warble tones as a possible alternative to pure tones as stimuli for testing children. He contended that a warble tone attracts and holds a child's attention better than a simple pure tone.

To the present, warble tones have been used in a variety of ways to assess hearing in young children ranging in age from a few months through seven years of age. Advocates point to superior attention-getting properties as a major advantage of the warble-tone stimulus. Also, in at least one instance, better thresholds have been related to a possible cortical phenomenon although the phenomenon is unspecified. However, despite its widespread clinical use with children, experimental evidence is lacking. Specifically, the effects of frequency modulation upon threshold have not been systematically explored in the young child.

#### Narrow-Band Noise as an Auditory Stimulus

Narrow-band noise has been suggested as a stimulus for threshold determination for many of the same reasons given for the

use of warble tone; namely, elimination of standing waves, and provision of a more distinct stimulus for young subjects, the elderly and patients with tinnitus (Myers, 1957; Harris, 1963).

Myers (1957) presented narrow bands of noise recorded on a disc and centering around the octave frequencies from 500 through 4000 Hz to 12 subjects ranging in age from 11 to 62 years of age. He employed the psychophysical method of limits and found good agreement between pure-tone thresholds and narrow-band noise thresholds. In discussing the results of his research, Myers concluded that there was no particular advantage to either stimulus but contended that narrow-band noise might be preferable in certain cases, such as providing information about hearing within a particular frequency region rather than at discrete frequencies when a Bekesy audiometer might not be available.

Harris (1963) enumerated reasons for not using pure tones exclusively as threshold measuring stimuli. The reasons included:

1. The inherently erratic nature of standing waves in the earphone-eardrum coupling, and the dependency of the standing wave pattern on frequency.
2. The sharp irregularities at higher frequencies of the earphone's frequency response curve.
3. The dependence upon frequency of the impedance for which earphone is used.

Harris suggested stimulus tones modulated in frequency from 2% to 5% or narrow bands of noise centered on the usual test frequencies as an alternative to pure tones.

Thresholds obtained using narrow bands of noise and pure tones with a Bekesy audiometer were compared for normal-hearing and sensorineural hearing loss subjects by Simon and Northern (1966).



The noiseband signals employed (190-310, 400-600, 800-1200, 3800-4200 Hz) had arithmetic centers at each of the five usual test frequencies. Thresholds for 35 normal-hearing and a group of 121 sensorineural subjects were compared for both pure tones and narrow bands of noise. The results indicated no significant differences in thresholds for the normal-hearing group. The sensorineural group exhibited significantly better thresholds for the narrow-band noise (ranging from 10 to 20 dB) at 2000 and 4000 Hz. Simon and Northern explained the difference as either representing an average of sensitivity for the frequency band of the noise or, more probably, sensitivity at the most acute frequency region within the passband.

An investigation of the reliability and validity of using narrow bands of white noise as a threshold measuring stimulus was reported by Sanders and Josey in 1970. Three groups of subjects were employed: (1) 10 normal-hearing young adults ranging in age from 18 to 26 years, (2) 10 hearing impaired children ranging in age from 3 to 6-6 years of age, and (3) 10 mentally retarded children ranging in chronological age from 5-5 to 13-10 years with mental ages ranging from 2-5 to 4-10 years.

The adult group was used primarily for calibration purposes, while the hearing impaired children served as a measure of validity as they all had previous audiometric data which enabled their pure-tone audiograms to serve as a validity measure. The 10 mentally retarded children were utilized in an examination of the test-retest reliability of pure-tone and narrow-band noise thresholds. The results of the examination indicated that narrow-band noise

audiometry is a valid and reliable method for assessing auditory sensitivity. The results further indicated that when compared to pure-tone audiometry, narrow-band noise audiometry is as good or better a method for evaluating hearing. Finally, Sanders and Josey pointed out that the results obtained with the mentally retarded group suggested that attending to narrow-band noise stimuli was an easier listening task and therefore applicable to a larger population than pure-tone audiometry.

The relatively limited research in the area of narrow-band noise audiometry indicates that narrow bands of noise have yielded reliable results when used with normal-hearing adult subjects. The results further indicate that with a difficult-to-test population, narrow-band noise may be a more desirable stimulus. However, a systematic comparison of pure-tone, warble-tone and narrow-band noise audiometry has not been made. Thus, the question regarding which, if any of the stimuli (pure tones, warble tones or narrow bands of noise) is a more effective stimulus with the young child remains unanswered.

### Summary

While warble-tone has been suggested as a preferred stimulus for threshold measurement in children, a systematic comparison of pure-tone and warble-tone audiometry with young children has not been carried out.

Narrow-band noise audiometry has also been suggested as an alternative to pure-tone audiometry and, at least in a difficult-to-test population, has been shown to be more effective as a stimulus

for threshold determination. However, a comparison of the two suggested alternatives to pure-tone audiometry, warble-tone and narrow-band noise audiometry, has not been undertaken in a sample of normal-hearing young children.

Pure-tone audiometry has been shown to be successful with a large percentage of children over the age of three years. However, threshold responses in children have been shown to improve progressively with increasing age, indicating that pure-tone stimuli may not result in the best possible threshold. If the differences in threshold are related to behavioral changes in the young child and the abstractness of the test signal, then there would appear to be a margin for better thresholds to be obtained using a more effective stimulus.

The present study was conducted to compare threshold responses of children in discrete age categories for pure-tone, warble-tone and narrow-band noise stimuli.

The following questions were examined with reference to 3-1/2, 4-1/2, 5-1/2, and 6-1/2 year old children:

1. Do threshold responses vary with age for the three types of stimuli?
2. For each of the age groups listed above, how do threshold responses obtained with the three types of signals compare?
3. Does the relationship among the three stimuli vary as a function of age?
4. How do thresholds for the three stimuli compare in terms of test-retest reliability?
5. Does any of these three stimuli provide consistently better thresholds and thus gain support as the most effective stimulus for use with children?

## CHAPTER III

### EXPERIMENTAL PROCEDURES

Information concerning subjects, instrumentation, calibration, stimuli employed and the experimental procedures utilized are presented in this chapter.

#### Subjects

The subjects of this study were 80 normal-hearing children equally distributed among the discrete age categories of 3-1/2, 4-1/2, 5-1/2 and 6-1/2 years of age. Each age category encompassed a 5 month period; for example, the 3-1/2 year group included children ranging in age from 3 years 6 months to 3 years 11 months. Thus there was a minimum age difference of 7 months between the oldest child in one age category and the youngest child in the succeeding age group. As the age range was identical at all age levels (i.e., 3 years 6 months to 3 years 11 months) only the mean ages for the four age categories are shown in Table 1. The subjects were subdivided into Test Groups I and II according to the experimental design employed which will be explained later in this chapter.

Normal hearing was defined as passing a pure-tone screening at 20 dB (ANSI, 1969) at the test frequencies employed in the study.

Table 1.--Mean age of children in Test Groups I and II in the four age categories examined.

| Age Level | Group I     | Group II    |
|-----------|-------------|-------------|
|           | Mean Age    | Mean Age    |
| 3-1/2     | 3 yrs 8 mos | 3 yrs 8 mos |
| 4-1/2     | 4 yrs 9 mos | 4 yrs 9 mos |
| 5-1/2     | 5 yrs 8 mos | 5 yrs 8 mos |
| 6-1/2     | 6 yrs 9 mos | 6 yrs 7 mos |

If the subject passed the screening in only one ear, then that ear was used as the test ear. All subjects were utilized in such a way as to achieve an equal number of right and left ears at each age level.

### Instrumentation

All equipment employed during the testing, with the exception of the earphones, was located in the control room of the test suite. A block diagram of the equipment used is shown in Figure 1.

Maico Ma-24 Audiometer.--The Ma-24 is a dual channel instrument which allows for testing 11 different half-octave and octave frequencies from 125 through 8000 Hz, and also has a Hearing Threshold Level (HTL) Range from -25 dB to 110 dB re ANSI-1969. This audiometer was used for obtaining the pure-tone air conduction thresholds, warble-tone and narrow-band noise thresholds in 5 dB steps of attenuation. It was also used to administer the screening test to prospective subjects. In addition, the narrow-band noise stimuli utilized were generated by the Ma-24. The bandwidths and filter slopes for the narrow-band noise are shown in Table 2. These data are displayed graphically in Appendix C.

Oscilloscope and Spectrum Analyzer.--The type 564B Tektronix Storage Oscilloscope with Auto Erase is designed to store cathode ray tube displays for viewing or photographing up to an hour after application of the input signal. In addition, the instrument can be operated as a conventional oscilloscope and was used in this way to

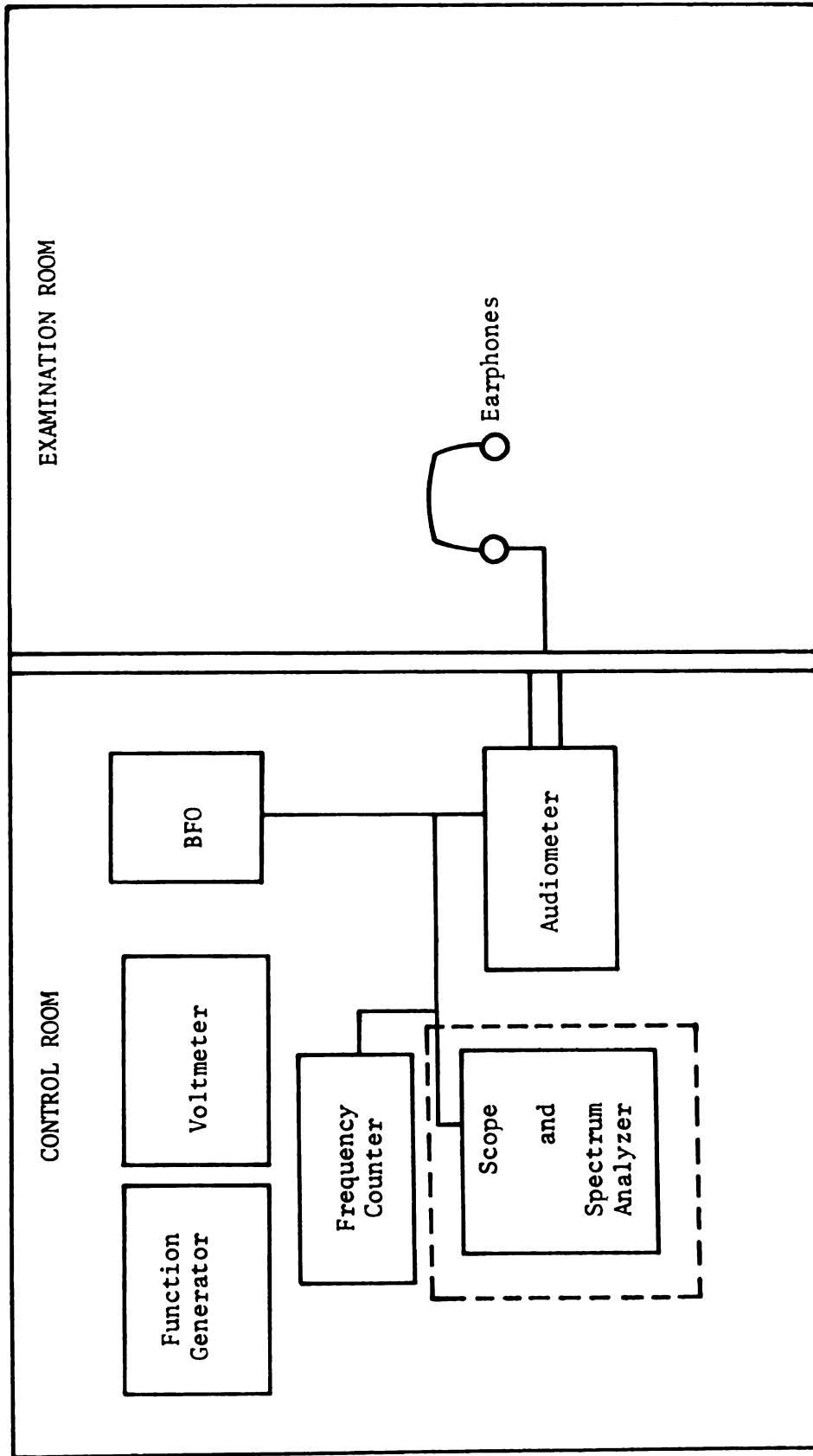


Figure 1.--Block diagram of equipment used in present study.

Table 2.--Center frequencies, bandwidths and rejection rates for the narrow-band noise signals generated by the Maico Ma-24 audiometer.

| Center Frequency | Bandwidth    | Rejection Rate in dB/octave |       |
|------------------|--------------|-----------------------------|-------|
|                  |              | Lower                       | Upper |
| 255 Hz           | 240- 290 Hz  | 25                          | 20    |
| 500 Hz           | 475- 550 Hz  | 23.5                        | 21.5  |
| 1020 Hz          | 950-1090 Hz  | 23                          | 23    |
| 2050 Hz          | 1900-2300 Hz | 20                          | 24    |
| 4080 Hz          | 3800-4400 Hz | 19                          | 25    |



measure the stimulus rise and decay times. The oscilloscope is compatible with the Tektronix plug-in units and, hence, a Spectrum Analyzer, Model 3L5, was utilized to measure the warble-tone frequency deviations desired in a manner first described by Staab (1971).

Function Generator.--The Hewlitt-Packard 3310 Function Generator is a voltage-controlled generator which allows for low distortion and high stability sine wave generation over a frequency range of 0.0005 Hz to 5 MHz in 10 decade ranges. The frequency of the sine wave generation determined the modulation rates and its output voltage was instrumental in determining the desired frequency deviation.

Voltmeter.--A Bruel and Kjaer Type 2409 Electronic Voltmeter allowed for the fine adjustments of the output voltages of the function generator. This instrument is a vacuum tube voltmeter for AC measurements in the frequency range from 2 Hz to 200,000 Hz. Eleven voltage ranges allow for full scale deflection from 10 millivolts to 1000 volts.

Frequency Counter.--The Bekman Eput and Timer, Model 6148, is a 100 MHz unit which can measure frequency, time interval, period, multiple period, ratio, multiple ratio, and which counts random events. It has a stability of  $\pm 3$  parts in  $10^9$  parts per day. Visual measurements are presented in an eight digit, inline, numerical display utilizing glow tubes. The display unit contains an automatically-positioned decimal point and an indication of units of measurement. This initially was used to determine the accuracy of

the frequency of modulation rates and then during the experiment to monitor the center frequencies of the test stimuli.

Beat-Frequency Oscillator.--A Bruel and Kjaer (B&K) Beat-Frequency Oscillator, Model 1013, was used as the main source for the generation of the warble tones. This instrument is designed for measurements in the frequency range from 200 Hz to 200,000 Hz and consists of an oscillator, mixer and an amplifier section. It works on the heterodyne principle using two high-frequency oscillators, one of which operates on a fixed frequency, while the frequency of the other can be varied by means of a variable capacitor. The required signal base frequency is obtained as the difference between the two high frequencies and can be read off a large illuminated scale, the pointer of which is connected to the variable capacitor. The oscillator also allows for frequency modulation of the output signal.

#### Test Environment

Subjects were tested in an Industrial Acoustics Corporation (IAC) Series 1600-ACT sound-treated room combination consisting of a 400 Series control room and a 1200 Series test booth. All threshold testing was conducted monaurally via earphone (Telephonics TDH-39/10Z) mounted in an MX-41/AR cushion with the nontest ear covered by the opposite earphone.

The ambient noise levels of the test room were measured in accordance with the criteria set forth by the American Standards Association for background noise in audiometer test rooms (ASA-S3.1-1960). The levels measured and the instrumentation involved are

recorded in Appendix B. The levels recorded met the criteria set forth by ASA and thus were sufficiently low so as not to interfere with threshold measurement.

### Calibration

Calibration of all test equipment took place at the beginning and at the end of the experiment. Specifically, the Maico Ma-24 was calibrated or checked at the frequencies employed in the study for frequency, harmonic distortion and SPL output. In addition, it was also checked for attenuator linearity and rise and decay times of the stimulus. The instruments utilized in generation and measurement of the warble tones (beat-frequency oscillator and spectrum analyzer) were also calibrated according to the procedures specified in their respective operating manuals. Measurement of the signal to be warbled, including its center frequency, SPL output and harmonic distortion were also measured at the earphone after it had been routed through the "Accessory Input" of the Maico Ma-24 audiometer.

Center frequency, bandwidth and filter slopes for the narrow-band noise signals were checked as well as the SPL output at the test frequencies employed.

In addition to the above, daily calibration checks were made of the SPL output for the three stimuli employed at the test frequencies. Calibration for the pure-tone stimuli was consistent with the American National Standards Institute (ANSI) 1969 "Specifications For Audiometers." Calibration of the warble-tone stimuli followed the rationale and method developed by Staab (1971) which is given in

Appendix C. The method for calibration of the narrow-band noise stimuli was similar to that reported by Sanders and Josey (1970) which is given in Appendix D.

The instrumentation and procedures involved in the calibration checks and the results of those measurements are reported in Appendices E through K.

### Test Stimuli

Stimuli employed during the experiment consisted of pure-tone, warble-tone and narrow-band noise signals. For the warble-tone stimuli, the base frequency (a pure tone) was frequency modulated so that the frequency deviation occurred in a sinusoidal manner both above and below the center frequency. Frequency deviations of  $\pm 3\%$  and  $\pm 10\%$  and a constant modulation rate of 8 per second were utilized. The pure-tone and narrow-band noise signals consisted of those generated by the Maico Ma-24 audiometer. The specific test stimuli varied by subject test group and are reported below.

### Experimental Procedures

The 20 subjects in each age category (3-1/2, 4-1/2, 5-1/2 and 6-1/2) were randomly assigned to one of two groups. Test Group I consisted of children tested with pure tones, narrow bands of noise and warble tones with a  $\pm 3\%$  frequency deviation. Children in Test Group II were tested using pure tones, narrow bands of noise and warble tones with a  $\pm 10\%$  frequency deviation.

In addition to random assignment of children to Test Groups I and II, the order in which the subject was presented a particular

type of stimulus (pure tone, warble tone or narrow band of noise) was also randomly determined. Finally, within each stimulus type, the order of test frequency presentation was also randomized.

Forty subjects were retested to gain an estimate of test-retest reliability. Five children in each age group from both Test Groups I and II were selected. The time interval between tests was never less than one-half an hour and never more than one week. For these subjects the randomized order of stimulus and frequency presentation established at the initial test session was maintained for the retest.

Threshold Determination.--Thresholds were determined at 500, 1000 and 2000 Hz for the 3-1/2 and 4-1/2 year old groups. For the 5-1/2 and 6-1/2 year old children thresholds were obtained at each octave frequency from 250 Hz through 4000 Hz. This was accomplished for pure-tone, warble-tone and narrow-band noise thresholds and all were established using the ascending method described by Carhart and Jerger (1959). Briefly the method was as follows:

1. The auditory stimulus was initially presented at 20 dB Hearing Threshold Level (HTL).
2. The intensity was decreased in 10 dB steps until the subject failed to respond.
3. The signal intensity was then increased in 5 dB steps until a response was obtained.
4. The signal intensity was again decreased 10 dB and step "3" repeated.
5. Threshold was defined as the lowest point where two responses were obtained upon ascending trials.

The 3-1/2 and 4-1/2 year old children were tested with the assistance of a clinical audiologist on the staff of Michigan State University. She assisted in the play audiometry conditioning procedure which in this instance consisted of the child either dropping a block into a box or placing a ring on a peg in response to a test stimulus.

The 5-1/2 and 6-1/2 year old children were alone in the test room and the response for these subjects consisted of raising their hand upon hearing a test stimulus.

## CHAPTER IV

### RESULTS AND DISCUSSION

In this chapter the results are presented for the comparison of pure-tone, warble-tone and narrow-band noise thresholds relative to the questions under investigation.

The data were analyzed descriptively and inferentially. Inferential analysis consisted of a repeated measures analysis of variance to compare the variables of test stimulus, frequency, age level and their appropriate interactions. A separate analysis of variance was utilized to compare test-retest thresholds. The analysis of variance results for the above analyses are displayed in Tables A1 and A2.

#### Thresholds as a Function of Age

The threshold responses of the children examined in this study showed an improvement with increasing age. As shown in Table A1 the main effect for the age variable was significant ( $p < 0.01$ ) for both Test Groups I and II.

Although a comparison of thresholds at 3-1/2 and 6-1/2 years-of-age always yielded a difference in the direction of more sensitive thresholds for the older age group, the improvement in sensitivity

was not constant at all test frequencies. This interaction of age and frequency was significant in Test Group I ( $p < 0.01$ ) but not in Group II.

The frequency by age interaction is illustrated for the test stimuli in Figures 2A through 4B. It can be seen that an interaction of age and frequency did not take place between the youngest and oldest age groups (the 3-1/2 and 6-1/2 year-old children). That is, the threshold curves for these two age groups remained separated for all three types of stimuli and at all frequencies tested. However, there was some overlapping in mean threshold scores between adjacent age groups for each of the three types of stimuli. For the most part, the interactions were between the 3-1/2 and 4-1/2 year-old groups or between the 5-1/2 and 6-1/2 year-old groups. In one instance there was an interaction between the 4-1/2 and 5-1/2 year-old age groups. This is pointed out further when the individual test stimuli are examined in the discussion below.

The mean pure-tone thresholds at each of the four age levels are presented in Table 3 and illustrated graphically in Figure 2A and 2B. The findings revealed a consistent improvement in pure-tone threshold with age for both test groups. The difference in mean thresholds between the 3-1/2 and 6-1/2 year-old children was greatest at 500 Hz for both test groups (6.5 dB for Group I and 6 dB for Group II) and least at 2000 Hz (4.5 dB for Group I and 2 dB for Group II).



Table 3.--Mean pure-tone thresholds in dB SPL\* as a function of age for Test Groups I and II.

| Group I            |      |      |      |      |      |
|--------------------|------|------|------|------|------|
| Frequency in Hertz |      |      |      |      |      |
| Age                | 250  | 500  | 1000 | 2000 | 4000 |
| 3-1/2              | ---+ | 23.3 | 15.1 | 16.9 | ---  |
| 4-1/2              | ---  | 23.3 | 15.6 | 12.9 | ---  |
| 5-1/2              | 36.3 | 17.8 | 10.2 | 7.5  | 14.9 |
| 6-1/2              | 32.3 | 16.8 | 9.2  | 11.5 | 12.9 |
| Group II           |      |      |      |      |      |
| 3-1/2              | ---  | 23.8 | 14.6 | 12.4 | ---  |
| 4-1/2              | ---  | 22.3 | 12.1 | 14.4 | ---  |
| 5-1/2              | 36.3 | 21.3 | 11.6 | 10.4 | 17.4 |
| 6-1/2              | 33.8 | 17.8 | 10.6 | 10.4 | 13.9 |

\*re 0.0002 dynes/cm<sup>2</sup>

+did not test

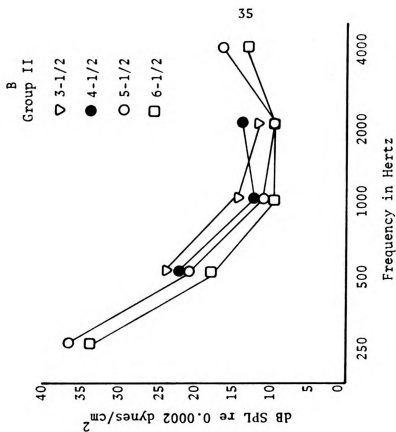
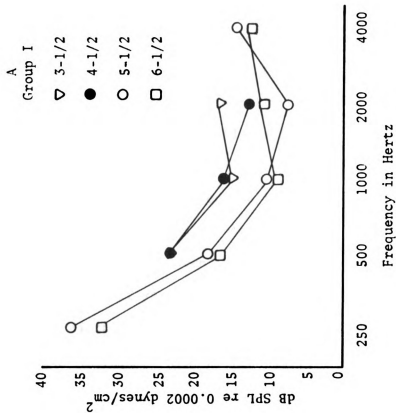


Figure 2.--Mean pure-tone thresholds in dB SPL as a function of age. The mean thresholds for Test Group I are shown in 2A while 2B displays the thresholds for Test Group II.

Figure 2A and 2B shows the frequency by age interaction as being between the 3-1/2 and 4-1/2 year-old age categories or between the 5-1/2 and 6-1/2 year-old categories.

The mean warble-tone thresholds at each of the four age levels are presented in Table 4 and displayed graphically in Figure 3A and 3B. The results for both test groups demonstrated a gradual improvement in sensitivity from age 3-1/2 through 6-1/2. Again, the greatest difference in threshold between the 3-1/2 and 6-1/2 age groups was at 500 Hz (6.5 dB for Group I and 7 dB for Group II) and the smallest difference was at 2000 Hz (3.5 dB for Group I and 3.9 dB for Group II).

The frequency by age interaction for warble tones was between the 3-1/2 and 4-1/2 year-old groups and between the 5-1/2 and 6-1/2 year-old groups in Test Group I while the interaction in Test Group II was between the 3-1/2 and 4-1/2 year-old age categories only.

The mean narrow-band noise thresholds at each of the four age levels are listed in Table 5 and illustrated in Figure 4A and 4B. A gradual improvement in threshold was again in evidence for both test groups with the greatest difference (improvement) in threshold at 500 Hz and the smallest difference in threshold at 2000 Hz.

The frequency by age interaction for the narrow-band noise thresholds was found between the 3-1/2 and 4-1/2 as well as between the 5-1/2 and 6-1/2 year-old age categories in Test Group I while in Test Group II there was an interaction only between the 4-1/2 and 5-1/2 year-old age categories.

Table 4.--Mean warble-tone thresholds in dB SPL\* as a function of age for Test Groups I and II.

| Group I            |                  |      |      |      |      |
|--------------------|------------------|------|------|------|------|
| Frequency in Hertz |                  |      |      |      |      |
| Age                | 250              | 500  | 1000 | 2000 | 4000 |
| 3-1/2              | --- <sup>+</sup> | 20.9 | 13.7 | 12.9 | ---  |
| 4-1/2              | ---              | 23.4 | 11.2 | 9.5  | ---  |
| 5-1/2              | 34.4             | 18.4 | 9.2  | 7.4  | 13.1 |
| 6-1/2              | 28.9             | 14.9 | 8.2  | 9.4  | 12.1 |
| Group II           |                  |      |      |      |      |
| 3-1/2              | ---              | 25.9 | 14.7 | 11.9 | ---  |
| 4-1/2              | ---              | 23.4 | 11.7 | 12.9 | ---  |
| 5-1/2              | 35.9             | 21.4 | 11.2 | 8.4  | 15.1 |
| 6-1/2              | 32.4             | 18.9 | 8.7  | 8.0  | 12.6 |

\*re 0.0002 dynes/cm<sup>2</sup>

<sup>+</sup>did not test

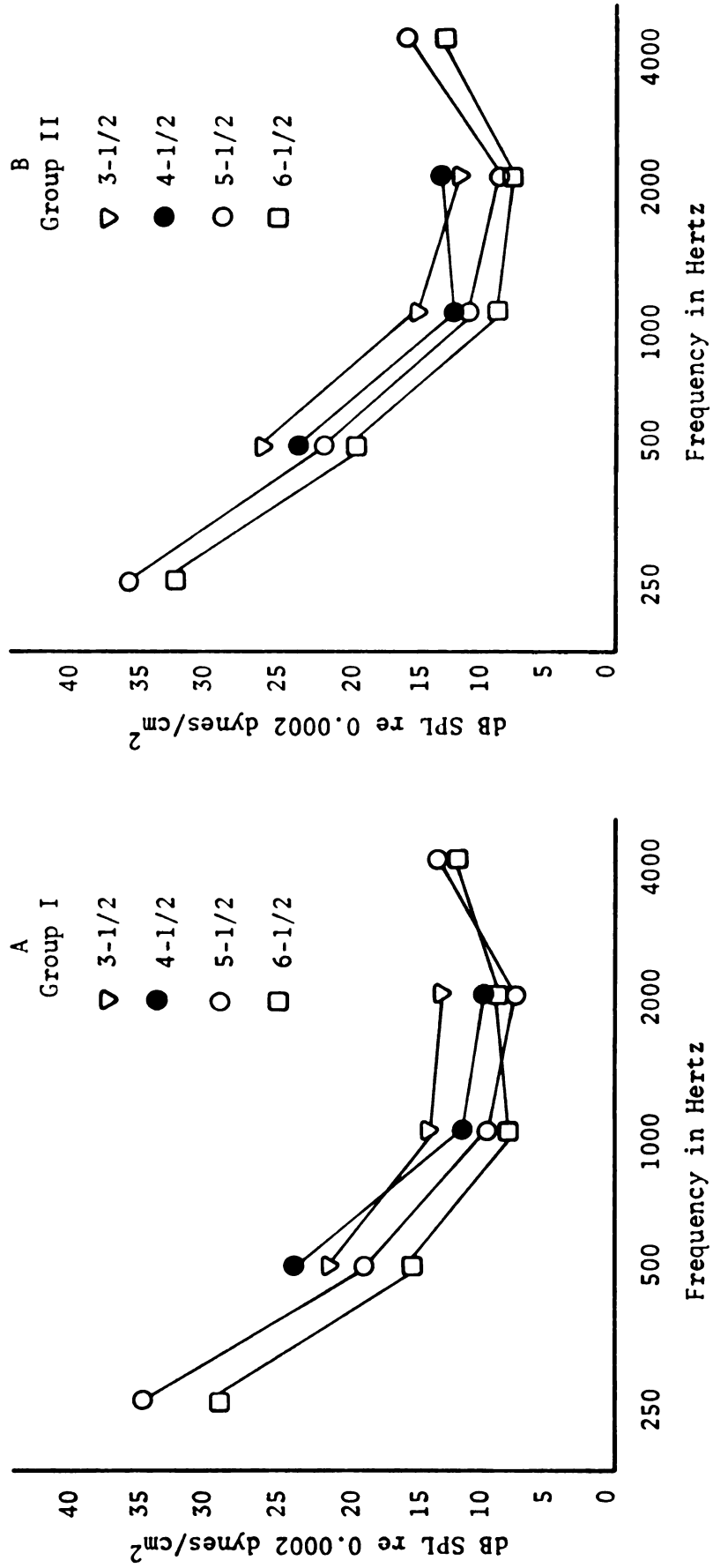


Figure 3.--Mean warble-tone thresholds in dB SPL as a function of age. The mean thresholds for Test Group I are shown in 3A while 3B displays the thresholds for Test Group II.

Table 5.--Mean narrow-band noise thresholds in dB SPL\* as a function of age for Test Groups I and II.

| Group I            |                  |      |      |      |      |
|--------------------|------------------|------|------|------|------|
| Frequency in Hertz |                  |      |      |      |      |
| Age                | 250              | 500  | 1000 | 2000 | 4000 |
| 3-1/2              | --- <sup>+</sup> | 26.6 | 18.2 | 19.4 | ---  |
| 4-1/2              | ---              | 26.6 | 17.7 | 14.8 | ---  |
| 5-1/2              | 36.3             | 21.2 | 12.9 | 10.4 | 16.3 |
| 6-1/2              | 35.8             | 20.2 | 11.9 | 13.9 | 14.8 |
| Group II           |                  |      |      |      |      |
| 3-1/2              | ---              | 27.1 | 18.7 | 16.8 | ---  |
| 4-1/2              | ---              | 24.1 | 14.7 | 14.8 | ---  |
| 5-1/2              | 38.8             | 24.6 | 15.2 | 14.3 | 18.8 |
| 6-1/2              | 35.5             | 19.9 | 12.2 | 9.8  | 13.8 |

\* re 0.0002 dynes/cm<sup>2</sup>

<sup>+</sup>did not test

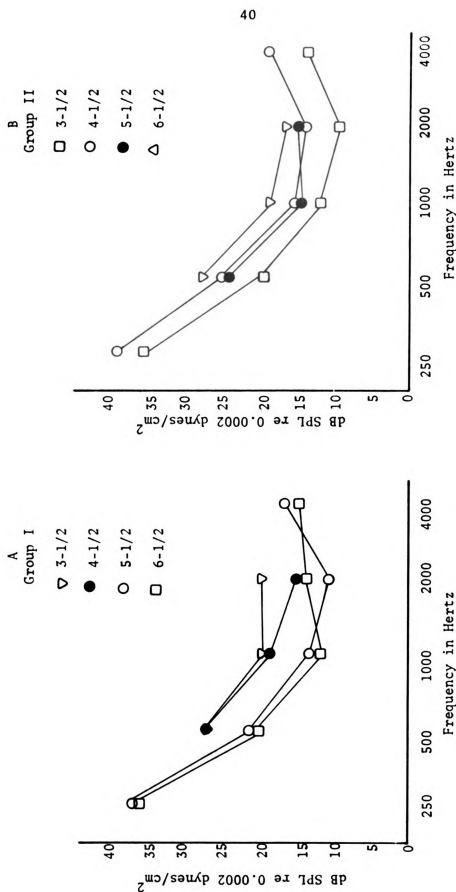


Figure 4.--Mean narrow-band noise thresholds in dB SPL as a function of age. The mean thresholds for Test Group I are shown in 4A while 4B displays the thresholds for Test Group II.

Comparison of Pure-Tone, Warble-Tone  
and Narrow-Band Noise Thresholds

The probability of the F statistic for the main effect of stimulus was significant ( $p < 0.01$ ). Table 6 and Figure 5A and 5B illustrate the relationship of the mean three frequency average (500, 1000 and 2000 Hz) thresholds as a function of age for each of the three test stimuli. Several relationships are readily apparent.

First, as was previously pointed out, there is an improvement in sensitivity as a function of increasing age for all three stimuli. The three frequency average shows an improvement across stimuli ranging from 5.0 dB to 6.1 dB in Test Group I and 4.0 dB to 7.1 dB in Test Group II over the age range of 3-1/2 through 6-1/2 years.

Second and more important from the standpoint of stimulus comparison, is the relationship found among the three types of stimuli as a function of age. Based on the three frequency average, the stimuli were ranked from most to least sensitive thresholds: warble-tone, pure-tone and narrow-band noise. The only exception was in Test Group II at the 3-1/2 year age level where the pure-tone average threshold was approximately 0.5 dB more sensitive than the warble-tone average threshold. The mean thresholds for the three stimuli as a function of frequency will be compared by age level in the discussion to follow.

Figure 6A and 6B illustrates the stimulus comparisons for Test Groups I and II respectively at the 3-1/2 year age level. In Test Group I warble tone provided the most sensitive thresholds at all frequencies followed by the progressively poorer thresholds using pure tones and narrow bands of noise. In Test Group II the warble



Table 6.--Comparison of mean threshold SPL in dB\* (three frequency averages<sup>†</sup>) obtained for the three test stimuli as a function of age for Test Groups I and II.

| Three Frequency Average |           |             |                   |
|-------------------------|-----------|-------------|-------------------|
| Group I                 |           |             |                   |
| Age                     | Pure Tone | Warble Tone | Narrow-Band Noise |
| 3-1/2                   | 18.4      | 15.8        | 21.4              |
| 4-1/2                   | 17.2      | 14.7        | 19.7              |
| 5-1/2                   | 11.8      | 11.6        | 14.8              |
| 6-1/2                   | 12.5      | 10.8        | 15.3              |
| Group II                |           |             |                   |
| 3-1/2                   | 16.9      | 17.5        | 20.8              |
| 4-1/2                   | 16.3      | 16.0        | 17.8              |
| 5-1/2                   | 14.4      | 13.6        | 18.0              |
| 6-1/2                   | 12.9      | 11.8        | 13.7              |

\*re 0.0002 dynes/cm<sup>2</sup>

<sup>†</sup>500, 1000 and 2000 Hz

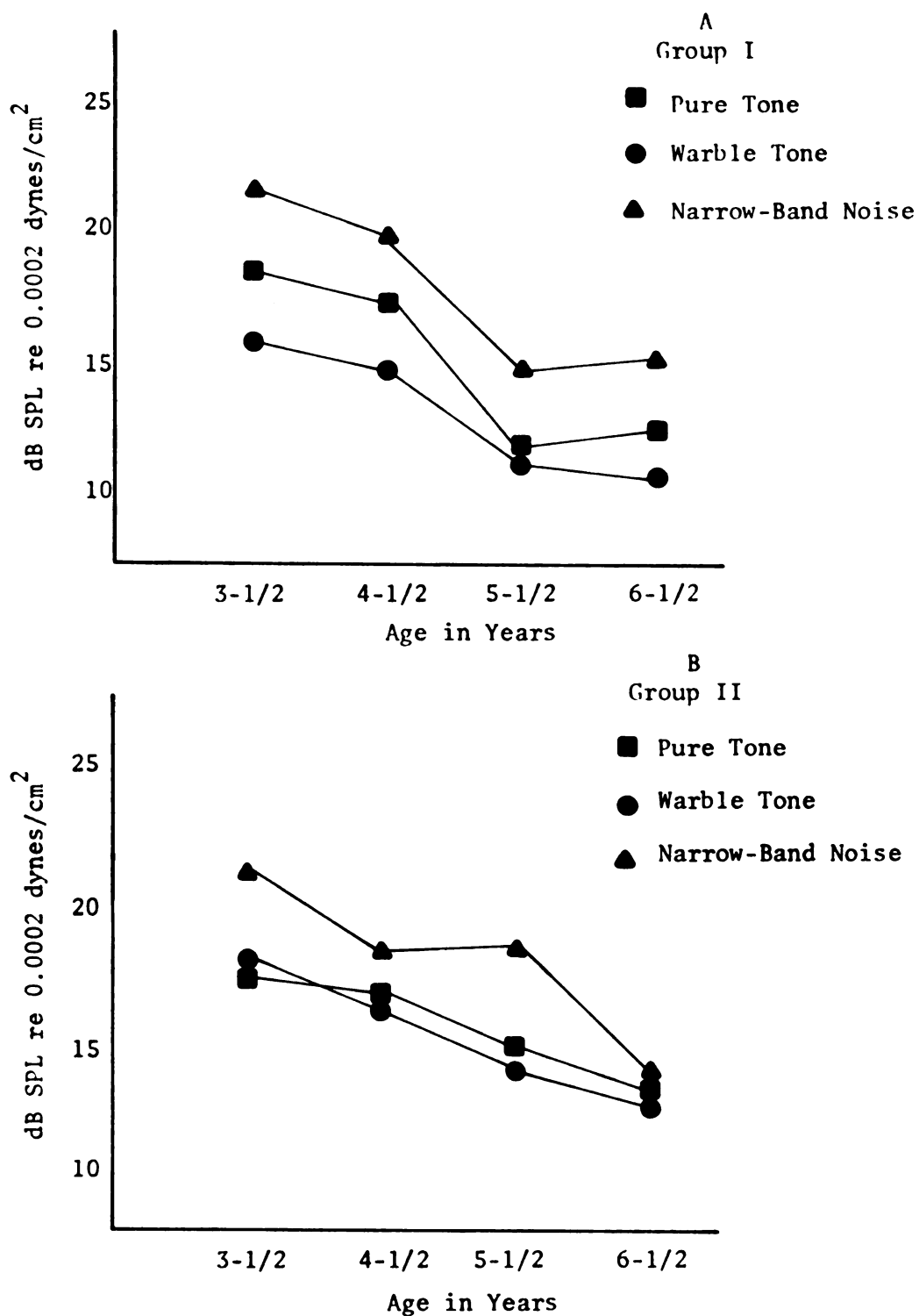


Figure 5.--Mean thresholds (three frequency averages) for the three types of stimuli as a function of age. The three frequency averages for Test Group I are shown in 5A while 5B displays the three frequency averages for Test Group II.

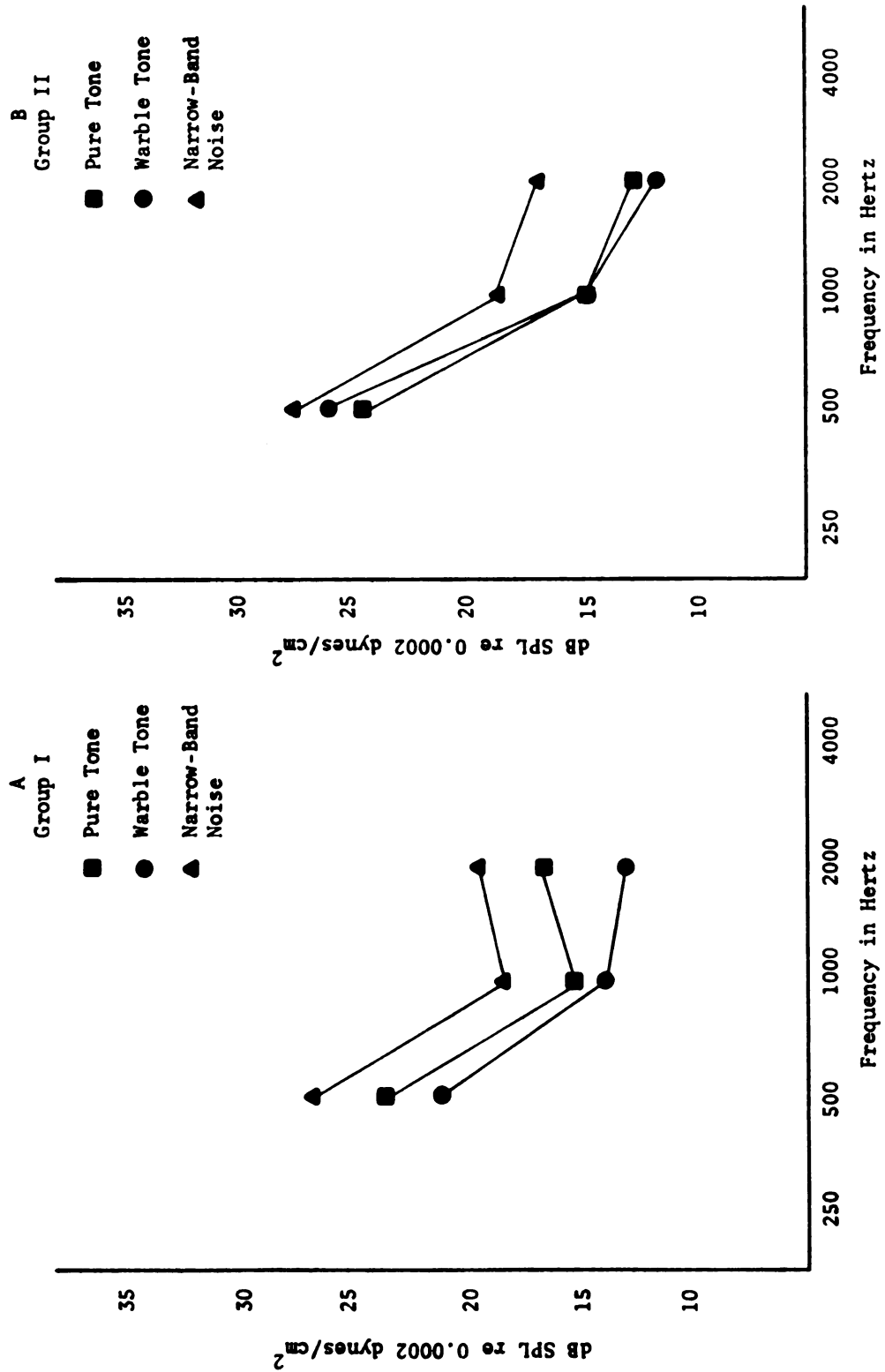


Figure 6.--Mean thresholds in dB SPL for the three types of stimuli at the 3-1/2 year age level. The mean thresholds for Test Group I are shown in 6A while 6B displays the mean thresholds for Test Group II.

tones and pure tones exhibited equivalent results with the pure-tone threshold more sensitive at 500 Hz, the warble-tone threshold more sensitive at 2000 Hz while the two stimuli provided essentially equal thresholds at 1000 Hz. The narrow-band noise thresholds were the least sensitive at all frequencies.

At 4-1/2 years-of-age as shown in Figure 7A and 7B, similar results were found for both test groups. That is, in Test Groups I and II mean pure-tone thresholds were most sensitive at 500 Hz while mean warble-tone thresholds were most sensitive at 1000 and 2000 Hz. Narrow-band noise thresholds were again the least sensitive at all frequencies.

The 5-1/2 year-old children were tested at the octave frequencies from 250 through 4000 Hz and, as illustrated in Figure 8A and 8B, warble-tone thresholds were superior in both Test Groups I and II at all frequencies tested with the exception of 500 Hz where the pure-tone thresholds were again more sensitive. With the exception of 250 Hz in Test Group I where the mean narrow-band noise and pure-tone thresholds were identical, narrow-band thresholds were the least sensitive at all frequencies.

For the oldest age group examined, 6-1/2 years, Figure 9A and 9B shows that warble-tone thresholds were most sensitive at all frequencies for Test Group I, while for Test Group II warble-tone thresholds were most sensitive at all frequencies except 500 Hz where the mean pure-tone threshold proved most sensitive. Although narrow-band noise thresholds were the poorest at all frequencies in Test

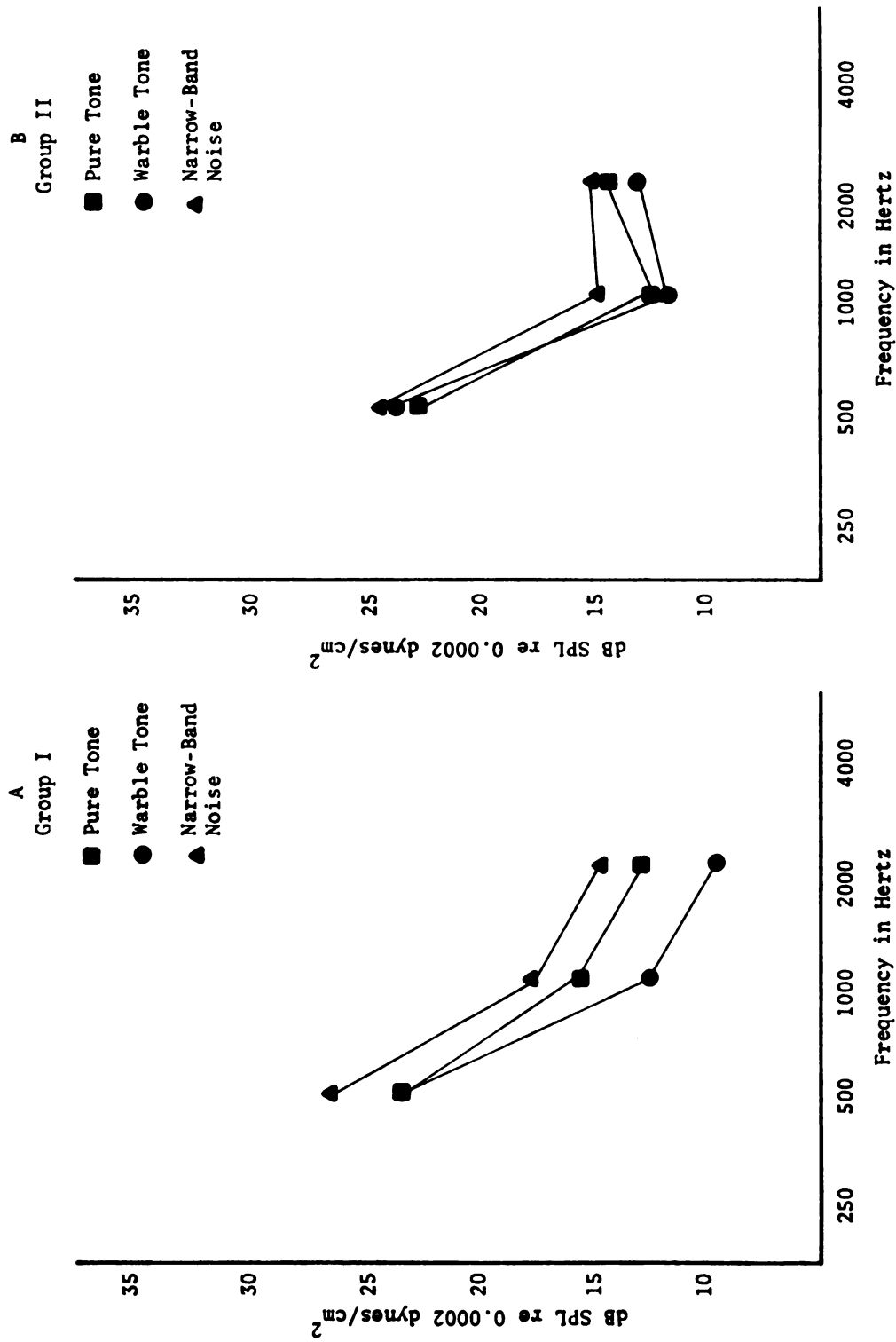


Figure 7.--Mean thresholds in dB SPL for the three types of stimuli at the 4-1/2 year age level. The mean thresholds for Test Group I are shown in 7A while 7B displays the mean thresholds for Test Group II.

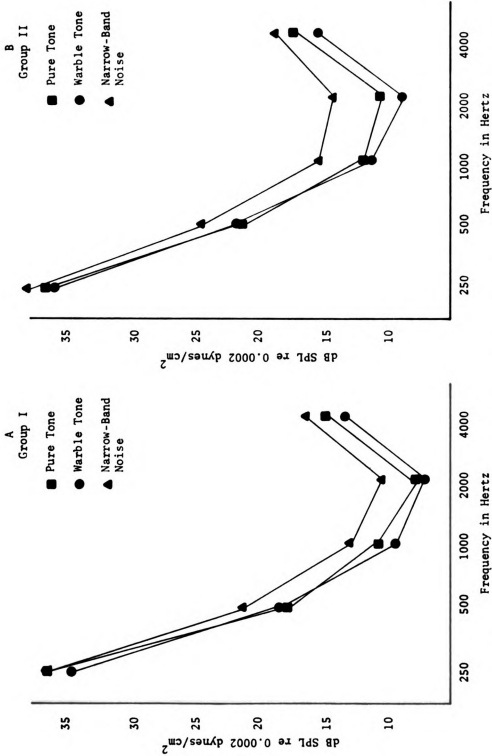


Figure 8.--Mean thresholds in dB SPL for the three types of stimuli at the 5-1/2 year age level. The mean thresholds for Test Group I are shown in 8A while 8B displays the mean thresholds for Test Group II.

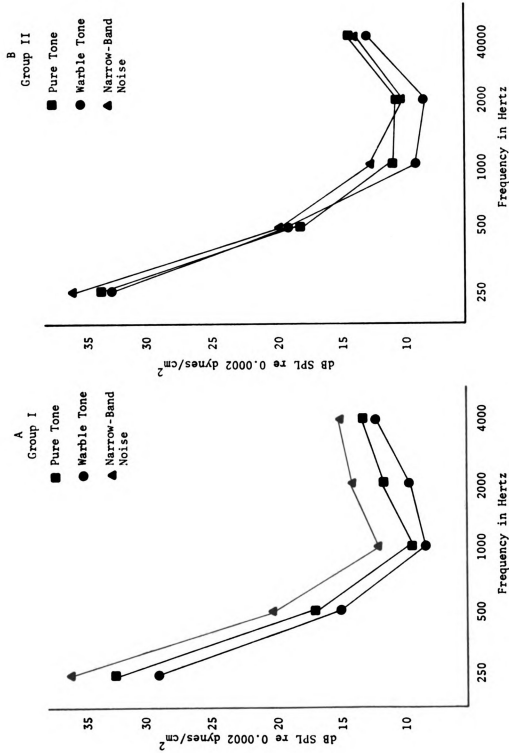


Figure 9.--Mean thresholds in dB SPL for the three types of stimuli at the 6-1/2 year age level. The mean thresholds for Test Group I are shown in 9A while 9B displays the mean thresholds for Test Group II.

Group I, they were slightly better than the pure-tone thresholds at 2000 Hz and 4000 Hz in Test Group II.

In summary, in comparing the three stimuli at each of the age levels as a function of frequency the same relationship noted earlier with the three frequency average was found. Namely, warble-tone thresholds were slightly more sensitive than pure-tone thresholds and that narrow-band noise produced the least sensitive thresholds among the three types of stimuli.

#### Comparison of $\pm 3\%$ and $\pm 10\%$ Warble-Tone Thresholds

Recall, the warble-tone stimulus for Test Group I had a frequency deviation of  $\pm 3\%$  while the warble tone with a  $\pm 10\%$  frequency deviation was employed with Test Group II. The two warble-tone parameters were compared by examining the threshold differences in dB between the warble-tone and pure-tone thresholds for Test Groups I and II. These differences are displayed graphically in Figure 10. The dB difference scores are presented in Table 7.

For the 3-1/2 and 4-1/2 year-old children, the  $\pm 3\%$  warble-tone provided better (more sensitive) thresholds at all frequencies. At the 5-1/2 and 6-1/2 age levels, there appears to be an interaction between warble-tone condition and frequency. For the 5-1/2 year-old children, the  $\pm 10\%$  warble tone provided better thresholds at 500, 2000 and 4000 Hz while the  $\pm 3\%$  warble tone provided better thresholds at 250 Hz and 1000 Hz.

At the 6-1/2 year level, the  $\pm 10\%$  warble tone provided more sensitive thresholds at 1000, 2000 and 4000 Hz while more sensitive thresholds were found for the  $\pm 3\%$  warble tone at 250 and 500 Hz.



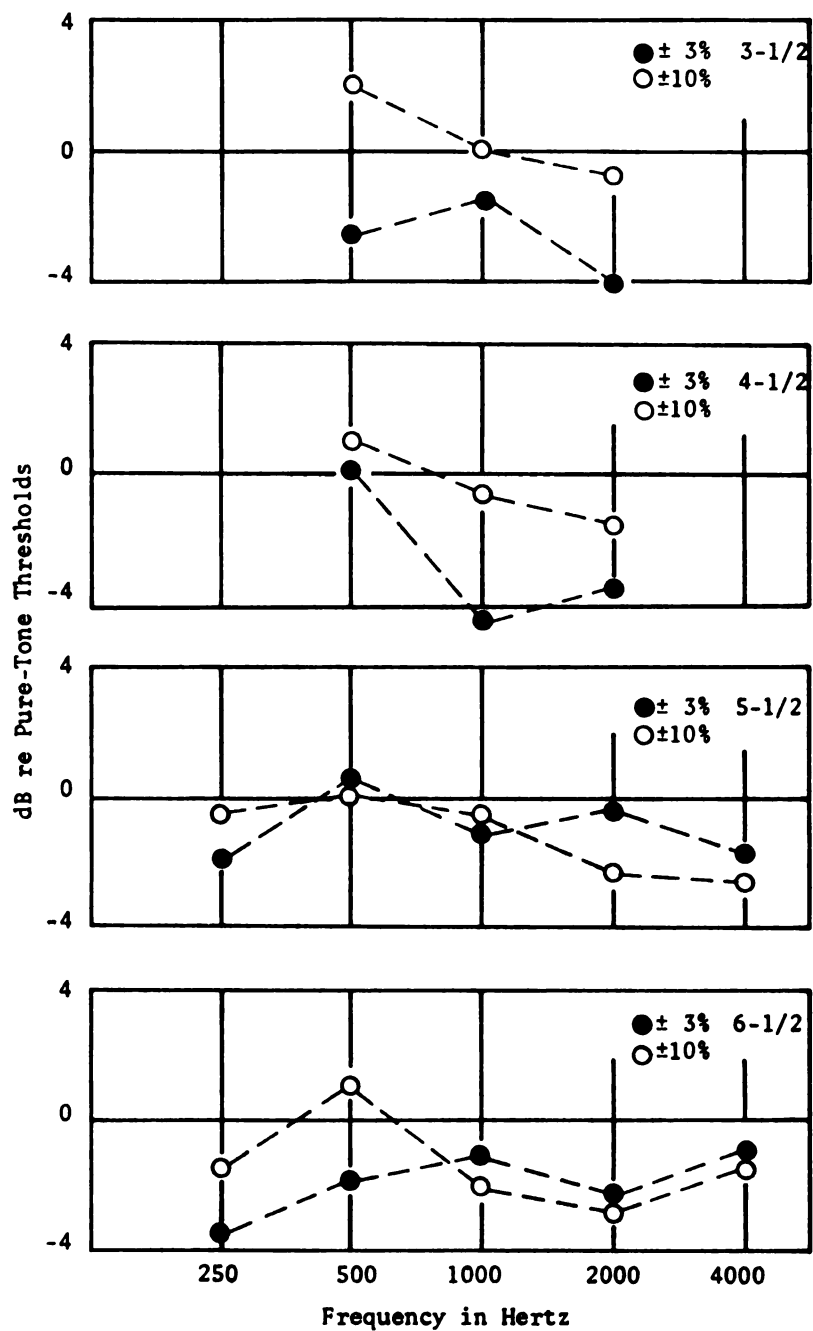


Figure 10.--Comparison of mean warble-tone thresholds for the  $\pm 3\%$  and  $\pm 10\%$  frequency deviations with their respective pure-tone thresholds.\* Baseline (0dB) represents the pure-tone thresholds.

\*Negative values indicate that warble-tone thresholds were more sensitive than pure-tone thresholds, whereas, positive values indicate that warble-tone thresholds were less sensitive.

Table 7.--Decibel difference scores\* for the  $\pm 3\%$  and  $\pm 10\%$  warble-tone thresholds.

| Age   | FD         | 250              | 500  | 1000 | 2000 | 4000 |
|-------|------------|------------------|------|------|------|------|
| 3-1/2 | $\pm 3\%$  | --- <sup>+</sup> | -2.4 | -1.4 | -4.0 | ---  |
|       | $\pm 10\%$ | ---              | 2.1  | 0.1  | -0.5 | ---  |
| 4-1/2 | $\pm 3\%$  | ---              | 0.1  | -4.4 | -3.5 | ---  |
|       | $\pm 10\%$ | ---              | 1.1  | -0.4 | -1.5 | ---  |
| 5-1/2 | $\pm 3\%$  | -1.9             | 0.6  | -1.0 | -0.1 | -1.8 |
|       | $\pm 10\%$ | -0.4             | 0.1  | -0.5 | -2.1 | -2.3 |
| 6-1/2 | $\pm 3\%$  | -3.4             | -1.9 | -1.0 | -2.1 | -0.8 |
|       | $\pm 10\%$ | -1.4             | 1.1  | -2.0 | -2.6 | -1.3 |

\*Difference scores were obtained by subtracting from each warble-tone threshold its respective pure-tone threshold. A negative value indicates the warble-tone threshold was more sensitive than the pure-tone sensitive while a positive value indicates the pure-tone threshold was more sensitive.

<sup>+</sup>Did not test.

In summary, a comparison of thresholds obtained with  $\pm 3\%$  and  $\pm 10\%$  warble tones indicated  $\pm 3\%$  yielded slightly better thresholds for the younger age groups while  $\pm 10\%$  thresholds were slightly better for the two older age groups in the majority of instances. Finally, in comparing the  $\pm 3\%$  to  $\pm 10\%$  warble-tone thresholds, all differences were 4.5 dB or less and in 75 percent of the comparisons differences were 2.0 dB or less.

#### Thresholds as a Function of Frequency

An analysis of thresholds as a function of frequency also provided a significant main effect with the probability of the F statistic less than 0.01. Since thresholds were recorded in sound pressure level, re 0.0002 dynes/cm<sup>2</sup>, such an effect would be expected. It is well established that the threshold of audition in SPL varies as a function of frequency. The findings in the present investigation are consistent with data reported in the literature (Sivian and White, 1933), namely that greater SPL is required to reach threshold at 250 and 500 Hz than at 1000, 2000 and 4000 Hz.

#### Comparison of Right and Left Ear Thresholds

As stated in the procedure section, an equal number of right and left ears were tested. However, it must be pointed out that no attempt was made to select the test ear at random. Moreover, no attempt was made to determine laterality.

Mean thresholds for right and left ears were compared across frequency and test stimuli at each age level for Test Groups I and II. Table 8 displays the difference in dB between the right and left ear

Table 8.--Differences in dB\* between the right and left ear thresholds across frequency and stimuli at each of the four age levels.

| Age   | Test Group I  | Test Group II |
|-------|---------------|---------------|
|       | dB Difference | dB Difference |
| 3-1/2 | 2.7           | 0.5           |
| 4-1/2 | 1.4           | 0.6           |
| 5-1/2 | 1.1           | -0.2          |
| 6-1/2 | 1.4           | -0.2          |

\*A positive difference means right ear thresholds were more sensitive.

thresholds at each age level, Note that all differences were 2.7 dB or less. With the exception of the 3-1/2 year level in Test Group I differences were less than 1.5 dB. The majority of differences were in the direction of more sensitive thresholds for the right ear and differences between ears tended to be smaller for Test Group II.

#### Test-Retest Threshold Comparisons for the Three Test Stimuli

Five subjects were retested at each age level in both test groups. The subjects retested were selected primarily on the basis of availability for retest and absence of any overt symptoms of illness which might introduce an artifact of transient conductive hearing loss into the test-retest comparison.

Mean test and retest threshold differences were within  $\pm 5$  dB at all frequencies tested across age levels for each of the stimuli employed. Analysis of variance revealed no significant test-retest differences as shown in Table A2.

Table A2 also illustrates main effects of stimulus, frequency and age for test-retest data in Test Group I, and a frequency by age interaction as found in the test data analysis.

A stimulus by frequency interaction is also in evidence ( $p=0.01$ ). Observation of the raw data indicated the reason for the interaction was primarily a greater degree of overlap between the warble-tone and pure-tone thresholds at 500 Hz in the subjects selected for retest.

The test-retest analysis for Test Group II showed significant main effects for stimulus and frequency but not for age ( $p>0.01$ ).

The frequency by age interaction was in evidence for the test-retest data in Test Group II, whereas it was not for the test data.

Table 9 displays the test and retest thresholds for the three stimuli across frequencies and age levels, while Table 10 gives the test-retest comparison for the three stimuli across age levels as a function of frequency.

Examination of test-retest differences across frequency and age levels indicated differences were 2.0 dB or less for all stimuli. When comparisons were made as a function of frequency, differences were 1.5 dB or less at all frequencies with the exception of the warble-tone comparison in Test Group II where the test-retest difference was 3.7 dB. The larger difference in this one instance cannot be explained.

Since clinical reliability is generally accepted as threshold agreement within  $\pm 5$  dB, an examination was made of the number of test-retest threshold comparisons which fell within this generally accepted limit. Table 11 shows the test-retest results for the three stimuli employed. A total of 80 threshold comparisons were made in each of the two test groups. Examination of Table 11 indicates that across groups threshold differences were within  $\pm 5$  dB for 88% or more of the comparisons for all three stimuli. Further, Table 11 also shows that none of the three stimuli were superior to the others in terms of clinical test-retest reliability.

## DISCUSSION

The results of the present investigation indicate that significant effects upon the hearing threshold of young children are

Table 9.--Mean test and retest thresholds in dB SPL\* across frequency and age categories for the three stimuli utilized for Test Groups I and II.

| Test Group I      |      |        |
|-------------------|------|--------|
| Stimulus          | Test | Retest |
| Pure Tone         | 15.2 | 15.5   |
| Warble Tone       | 12.8 | 13.4   |
| Narrow-Band Noise | 17.6 | 17.3   |
| Test Group II     |      |        |
| Pure Tone         | 14.1 | 14.0   |
| Warble Tone       | 14.9 | 12.9   |
| Narrow-Band Noise | 16.7 | 16.6   |

\*re 0.0002 dynes/cm<sup>2</sup>

Table 10.--Mean test and retest thresholds in dB SPL\* as a function of frequency across age categories for the three test stimuli examined in Test Groups I and II.

| Test Group I      |        |        |         |        |         |        |
|-------------------|--------|--------|---------|--------|---------|--------|
| Stimulus          | 500 Hz |        | 1000 Hz |        | 2000 Hz |        |
|                   | Test   | Retest | Test    | Retest | Test    | Retest |
| Pure Tone         | 19.8   | 20.0   | 12.6    | 12.9   | 13.2    | 13.7   |
| Warble Tone       | 18.9   | 20.1   | 10.2    | 10.7   | 9.4     | 9.4    |
| Narrow-Band Noise | 23.1   | 22.1   | 16.0    | 15.8   | 13.8    | 14.1   |
| Test Group II     |        |        |         |        |         |        |
| Pure Tone         | 20.0   | 20.8   | 11.1    | 11.1   | 11.1    | 10.2   |
| Warble Tone       | 21.6   | 19.9   | 11.7    | 11.2   | 11.4    | 7.7    |
| Narrow-Band Noise | 22.6   | 22.1   | 14.4    | 13.3   | 13.0    | 14.5   |

\*re 0.0002 dynes/cm<sup>2</sup>



Table 11.--Comparison of test-retest thresholds across frequencies and age categories for the three stimuli employed in Test Groups I and II.

| Test Group I  |             |             |                   |
|---------------|-------------|-------------|-------------------|
| dB Difference | Pure Tone   | Warble Tone | Narrow-Band Noise |
| 0 dB          | 37* (46.5%) | 34 (42.5%)  | 28 (35%)          |
| ±5 dB         | 38 (47.5%)  | 36 (45.5%)  | 47 (58.5%)        |
| ±10 dB        | 5 (6%)      | 10 (12%)    | 5 (6%)            |
| Test Group II |             |             |                   |
| 0 dB          | 32 (40.5%)  | 38 (47.5%)  | 41 (51%)          |
| ±5 dB         | 42 (52.5%)  | 40 (50%)    | 32 (40.5%)        |
| ±10 dB        | 6 (7%)      | 2 (2.5%)    | 7 (8.5%)          |

\*Value represents the number of test-retest threshold comparisons that fell within the dB difference denoted.

observed related to the factors of age, frequency and stimulus employed. The effects of these variables shall be discussed individually in the sections to follow as well as other findings of interest.

#### The Effects of Age Upon Threshold

Over the age range examined there was a significant improvement in hearing sensitivity with increasing age. This finding is in agreement with previous research which has pointed to the maturational aspects of hearing in children (Kennedy, 1957; Eagles et al., 1963; Siegenthaler, 1969).

The improvement was consistent across stimuli as thresholds for all stimuli examined displayed improved sensitivity as the age level of the children tested increased. The effect was somewhat less consistent across frequency. That is, the degree of improvement in hearing as a function of age (3-1/2 to 6-1/2 years) seems to be greater for low frequency stimuli. However, as thresholds for high frequency stimuli were more sensitive initially (age 3-1/2) when compared to the minimum audible thresholds for adults (re ANSI-1969 reference thresholds) there was less margin for improved thresholds in the high frequencies,

The findings of Eagles et al. support the concept of greater improvement in threshold for low frequency pure tones. Eagles and his associates examined an older population of children; but, in comparing his results with 5 year-old children to 13 year-old children, one notes an improvement in threshold of 8 dB and 6.2 dB at 250 and 500 Hz respectively while the improvement in threshold was 3.1 dB at 2000 Hz and 4000 Hz. Eagles' data were for children

screened to eliminate otoscopic abnormalities and, thus, rule out the possible influence of increased conductive pathology upon low frequency thresholds in the younger age groups.

Even though the maturational aspect seems clearly established, it is open to question whether one is observing the maturation of auditory abilities or simply the maturation of the child in terms of modification of behavior and improved attention or listening skills.

The significant interaction of frequency and age can be viewed as a further indication that the improvement in sensitivity does not occur at the same rate at all frequencies, although the improvement is always observable when the 3-1/2 and 6-1/2 age levels are compared. This finding is not without precedent as Eagles et al. (1963) showed a similar finding with an older population of children.

#### The Effects of Frequency Upon Threshold

The difference found in threshold as a function of frequency is consistent with previous investigations. The minimum audible threshold is generally accepted as being poorer at frequencies below 1000 Hz and above 4000 Hz than it is in the mid-frequency region. This differential sensitivity as a function of frequency has been attributed to a number of anatomical and physiological aspects of the auditory system such as the resonance characteristics of the external auditory meatus (Wever and Lawrence, 1955) and increased neural density toward the basal end of the cochlea (Schuknecht, 1960).

### The Effect of Stimulus Upon Threshold

With young children, the stimulus employed had a small yet significant effect upon the threshold obtained, with the warble-tone stimulus in general providing the most sensitive thresholds. This effect is maintained across age levels, especially when the three frequency average is used as the measure of comparison.

When the examination is expanded to include discrete test frequencies, pure-tone thresholds were at times slightly better than warble-tone thresholds, but a significant interaction was not in evidence for the test data. Differences between any two of the three stimuli were 7 dB or less. However, warble-tone thresholds were generally more sensitive than pure-tone by 4 dB or less and narrow-band noise thresholds were poorer than pure-tone by 4 dB or less. Thus, when testing under earphones is possible, pure tones, warble tones and narrow bands of noise might be expected to give clinically equivalent results. However, if testing in a sound-field becomes necessary, such as when a child refuses to wear earphones, an alternative to pure tones must be used, and in this case warble tone would be the preferred stimulus. Data are available to correct sound-field to earphone thresholds using warble tones as the stimulus (Rintelmann, Orchik and Stephens, 1972); however, similar correction data are not presently available for narrow-band noise thresholds.

Further, in contrast to the findings of Sanders and Josey (1970), the results of the present investigation revealed that narrow-band noise thresholds were almost invariably the poorest and, thus, at least for this age range and population would be least preferred

as a stimulus for threshold measurement. Sanders and Josey found narrow-band noise thresholds more sensitive than pure-tone for a group of mentally retarded children. Obviously with the difference in populations between the two studies, generalizations are difficult to make.

Another problem (not encountered in the present study) could result from the use of narrow-band noise when testing persons with sensorineural hearing loss, especially those with sharply sloping configurations.

In previous research (Sanders and Josey, 1970; Simon and Northern, 1966) the bandwidth of the narrow-band noise signal had been stressed as important to threshold validity especially when the effect of audiometric slope is considered. A parameter not generally considered has been the variable of filter slope, sometimes termed rejection rate. Simon and Northern have suggested that the narrow-band noise threshold represents the best hearing within the bandwidth of the noise signal. However, in the case of an individual with a sharply sloping configuration and a stimulus that utilizes a filter slope of 10 or 15 dB per octave, a response might conceivably be obtained as much as two octaves below the center frequency rather than simply anywhere within the bandwidth of the noise (computed at a point 3 dB below the center frequency).

Table 12 illustrates narrow-band noise signals previously reported in the literature (Sanders and Josey, 1970; Sanders and Rintelmann, 1964). It should be noted that the narrow-band noise in the Sanders and Rintelmann study was being used as a masking noise and not as a threshold measuring stimulus.

Table 12.--Narrow-band noise signals employed in earlier studies.  
Rejection rates are given for above and below the center frequencies.

| Test Frequency | Sanders and Josey<br>(1970)<br>Rejection Rate<br>dB/octave |        | Sanders and Rintelmann<br>(1964)<br>Rejection Rate<br>dB/octave |        |
|----------------|------------------------------------------------------------|--------|-----------------------------------------------------------------|--------|
|                | Lower                                                      | Higher | Lower                                                           | Higher |
| 250 Hz         | 11.4                                                       | 19.0   | 19                                                              | 23     |
| 500 Hz         | 11.0                                                       | 19.0   | 5                                                               | 16     |
| 1000 Hz        | 11.0                                                       | 18.0   | 8                                                               | 16     |
| 2000 Hz        | 11.0                                                       | 11.0   | 18                                                              | 36     |
| 4000 Hz        | 17.6                                                       | 33.2   | 8                                                               | 44     |

If signals such as those shown in Table 12 were used for testing young children in a sound-field, obvious complications could result. Without steep rejection rates, the narrow-band noise signals would create similar problems, but of a smaller magnitude than broadband signals (e.g. white noise or speech) as a test stimulus in behavioral audiometry.

The warble tone, by contrast, is used to examine a range only as wide as its frequency deviation which in the present study was as small as  $\pm 3\%$  around the center frequency. Thus, at 2000 Hz, this particular warble tone can be used to examine the frequency range from 1940 to 2060 Hz. With the use of pure tones contraindicated in sound-field because of the problem of standing waves, warble tones and narrow bands of noise are the two most likely alternatives. Considering the preceding discussion, warble tones would appear to present less risk of invalidly estimating threshold.

#### The Effects of Frequency Deviation Upon Thresholds

There is no apparent indication in the present study of any significant differences in threshold attributable to the frequency deviation of the warble tone up to and including  $\pm 10\%$ . Although the  $\pm 3\%$  frequency deviation provided better thresholds for the younger age groups, the  $\pm 10\%$  frequency deviation generally provided better thresholds for the older age groups. The majority of the threshold differences were 2.0 dB or less. This finding is in agreement with previous research by Rintelmann, Orchik and Stephens (1972) who demonstrated only slight differences in warble-tone thresholds for normal-hearing

adults using the same frequency deviations. Further, the results of this investigation suggest that warble-tone parameters presently available commercially, as outlined by Staab and Rintelmann (1972), are equally applicable to testing young children.

#### Test-Retest Agreement

Examination of the test-retest data indicated that neither stimulus showed consistently better test-retest agreement, and thus in terms of clinical reliability all three stimuli were essentially equivalent.

Rintelmann, Orchik and Stephens (1972) found comparable test-retest reliability between pure-tone and warble-tone thresholds with normal-hearing adults employing the same warble-tone parameters as in the present investigation. The results of the present study with normal-hearing young children are in slight contrast to the report of Sanders and Josey (1970) who suggested that narrow-band noise audiometry might be more reliable with a difficult-to-test population such as mentally retarded children. The difference in populations may again account for the conflicting results. The relative efficiency for warble tone and narrow-band noise cannot be assessed until they are studied simultaneously in a number of populations.

In terms of choosing an alternative stimulus to pure tones, warble-tone and narrow-band noise thresholds appear to be of equivalent clinical reliability for young normal-hearing children.



### Summary

Evidence in the present investigation indicates that warble tone is a preferable stimulus for hearing threshold measurement in young children. Normal-hearing children tested with warble tones consistently displayed more sensitive thresholds than for pure tones or narrow-band noise over the age range of 3-1/2 years through 6-1/2 years. Children tested using narrow bands of noise almost invariably had the least sensitive thresholds of the three stimuli used.

In agreement with previous research, a significant improvement in hearing sensitivity with increasing age was also in evidence. An interaction of frequency and age indicated the maturational phenomenon was not constant across frequency; rather, low frequencies were found to produce a greater improvement in threshold sensitivity as a function of age than the middle or high frequencies.

Finally, a comparison of test-retest threshold agreement showed that the three stimuli employed, pure tones, warble tones and narrow-band noise were essentially equivalent in terms of clinical reliability.

### Clinical Implications

The clinical impact of the present research is most apparent in terms of the choice of stimulus for threshold testing, particularly in instances where an alternative stimulus to pure tone is desirable. For example, when testing in a sound-field is necessary, an alternative to pure tone must be employed because of the standing wave problem. Based upon the results of this investigation, the use of

warble-tone audiometry is recommended. Not only should warble tone provide the most sensitive thresholds, but also this stimulus reduces the risk of invalidly estimating the pure-tone threshold, since the frequency range sampled is restricted to the warble-tone frequency deviation.

If warble tone is not available and narrow-band noise is to be employed, the clinician should be aware of its limitations. First, the subject may give less sensitive responses than he would for either warble tones or pure tones. Secondly, the clinician must be aware of the stimulus parameters of the narrow-band noise, especially the filter slopes. If they are inadequate, threshold could be substantially underestimated, especially for individuals with sharply sloping high-frequency sensorineural hearing losses.

Even in circumstances where testing via earphone is possible, the clinician might find the use of warble tones preferable to conventional pure tones. The results of this investigation showed young children 3-1/2 through 6-1/2 years of age gave consistently more sensitive thresholds to warble tones. Two assumptions logically follow. First, warble tone might provide a more valid estimate of hearing in young children and other difficult-to-test populations. Second, if children who can be tested by pure-tone and warble-tone audiometry give more sensitive thresholds to warble tones, perhaps warble-tone audiometry offers a greater probability of success with the difficult-to-test.

## CHAPTER V

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### Summary

The effect of stimulus type upon the threshold of hearing in young children was examined at four discrete age levels. Twenty normal-hearing children at each of the age levels of 3-1/2, 4-1/2, 5-1/2 and 6-1/2 were tested using pure tones, warble tones and narrow bands of noise. The 3-1/2 and 4-1/2 year-old children were tested at 500, 1000 and 2000 Hz while the older children were examined at octave frequencies from 250 through 4000 Hz. For the warble-tone stimulus, frequency deviations of  $\pm 3\%$  and  $\pm 10\%$  were employed with a constant modulation rate of 8 per second. At each age level the subjects were randomly assigned to one of two test groups. Test Group I was evaluated using pure tones, narrow bands of noise and warble tones utilizing a  $\pm 3\%$  frequency deviation. Test Group II was examined using pure tones, narrow bands of noise and warble tones with a  $\pm 10\%$  frequency deviation. All subjects were examined audiometrically using all three stimuli and threshold comparisons were made. In addition, half of the subjects at each age level were re-examined to enable a test-retest reliability comparison among the three stimuli.

The data were analyzed both descriptively and inferentially. The results showed a significant improvement in threshold as a function of age for all stimuli. The stimuli were ranked from the most to the least sensitive thresholds as warble tones, pure tones and narrow bands of noise. Differences were small yet significant. Comparison of warble-tone thresholds as a function of frequency deviation ( $\pm 3\%$  vs  $\pm 10\%$ ) showed the majority of threshold differences were 2.0 dB or less. Clinical test-retest reliability was equivalent among the three test stimuli.

### Conclusions

The following conclusions seem warranted:

1. Auditory thresholds of young children for pure tones, warble tones and narrow bands of noise showed an improvement in sensitivity with increasing age over the range from 3-1/2 to 6-1/2 years.
2. With normal-hearing young children, the type of auditory stimulus had a definite effect upon the absolute threshold obtained. The stimuli were ranked from most to least sensitive thresholds as follows: warble tones, pure tones and narrow bands of noise.
3. The inter-relationships of the three types of stimuli employed with reference to threshold sensitivity remained constant as a function of age.

4. Only slight differences in warble-tone thresholds were observed as a function of frequency deviation ( $\pm 3\%$  vs  $\pm 10\%$ ). Thus, it appears that one can employ frequency deviations up to and including  $\pm 10\%$  without altering thresholds. Within this frequency deviation range thresholds obtained with stimulus parameters presently available commercially should show close agreement.
5. Threshold test-retest reliability for pure tones, warble tones and narrow bands of noise were essentially equivalent ( $\pm 5$  dB) and were clinically acceptable.

#### Recommendations for Future Research

In the present investigation a significant effect upon the threshold of normal-hearing young children was exerted by the type of stimulus employed. The present study should be replicated for subjects with sensorineural hearing loss to determine if the same relationships hold. The effect of audiometric slope might substantially influence the absolute thresholds obtained for narrow-band noise. This notion should be investigated employing a sensorineural population with varying degrees of audiometric slope.

Although differences among thresholds for the stimuli employed were statistically significant, they were small from a clinical standpoint. It must be kept in mind, however, that the population sampled had hearing within normal limits and, thus, there was not a great margin for finding differences in threshold. An examination of a difficult-to-test population, such as mentally retarded children

or children in younger age categories than those presently investigated, would provide opportunity for greater differences to be found. Sanders and Josey (1970) examined thresholds for pure tones and narrow bands of noise in a mentally retarded group of 10 children of various mental ages. This study should be replicated with the addition of warble tone.

The age range in the present study was selected because of the high probability of successful threshold testing for children above three years of age. In examining a younger population one would have the opportunity of comparing success rate of the three types of stimuli as well as threshold differences. To accommodate the younger child obvious changes in experimental design would be required such as restricting the test frequency range examined.

Stimuli such as warble tones and narrow bands of noise have been suggested as alternatives to pure tones especially with young children because they are felt to be better attention-centering stimuli and, thus, capable of producing more sensitive thresholds. Because differences in thresholds were small in the present investigation, it would be desirable to determine whether the differences found were simply a function of signal parameter or if either warble tones or narrow bands of noise are more readily distinguished than pure tones by young children. A signal detection task with perhaps embedding pure tones, warble tones and narrow bands of noise in a competing signal, should help answer the question as to which of the stimuli is more capable of attracting the attention of young children.

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## APPENDICES

# APPENDIX A

## ANALYSIS OF VARIANCE TABLES

Table A1.--Analysis of variance of the test data for Test Groups I and II.

| Source         | SS       | dF  | MS       | F ratio | Probability of Statistic |
|----------------|----------|-----|----------|---------|--------------------------|
| Group I        |          |     |          |         |                          |
| <u>Within</u>  |          |     |          |         |                          |
| Stimulus (A)   | 126126.2 | 2   | 63063.1  | 48.3    | 0.0005*                  |
| Frequency (B)  | 598279.7 | 2   | 299139.8 | 229.2   | 0.0005*                  |
| AB             | 2391.8   | 4   | 597.9    | 0.4     | 0.766                    |
| AC             | 7123.9   | 6   | 1187.3   | 0.9     | 0.488                    |
| ABC            | 6928.5   | 12  | 577.3    | 0.4     | 0.945                    |
| BC             | 42215.0  | 6   | 7035.8   | 5.3     | 0.0005*                  |
| Within Error   | 375766.7 | 288 | 1304.7   |         |                          |
| <u>Between</u> |          |     |          |         |                          |
| Age (C)        | 237706.6 | 3   | 79235.5  | 6.5     | 0.001*                   |
| Between Error  | 436753.3 | 36  | 12132.0  |         |                          |
| Group II       |          |     |          |         |                          |
| <u>Within</u>  |          |     |          |         |                          |
| Stimulus (A)   | 57619.5  | 2   | 28809.7  | 20.6    | 0.0005*                  |
| Frequency (B)  | 797662.5 | 2   | 398831.2 | 285.3   | 0.0005*                  |
| AB             | 10219.0  | 4   | 2554.7   | 1.8     | 0.1                      |
| AC             | 13190.6  | 6   | 2198.4   | 1.5     | 0.155                    |
| ABC            | 3797.9   | 12  | 316.4    | 0.2     | 0.9                      |
| BC             | 15942.3  | 6   | 2657.0   | 1.9     | 0.081                    |
| Within Error   | 402506.7 | 288 | 1397.5   |         |                          |
| <u>Between</u> |          |     |          |         |                          |
| Age (C)        | 150220.7 | 3   | 50073.5  | 5.4     | 0.003*                   |
| Between Error  | 329273.3 | 36  | 9146.4   |         |                          |

\*p<0.01

Table A2.--Analysis of Variance Table for test-retest comparison of  
Test Groups I and II.

| Test Group I    |          |     |          |         |                             |
|-----------------|----------|-----|----------|---------|-----------------------------|
| Source          | SS       | dF  | MS       | F ratio | Probability<br>of Statistic |
| <u>Within</u>   |          |     |          |         |                             |
| Test-Retest (A) | 374.1    | 1   | 374.1    | 0.27    | 0.6                         |
| Stimulus (B)    | 114999.6 | 2   | 57499.8  | 43.0    | 0.0005*                     |
| Frequency (C)   | 519373.9 | 2   | 259686.9 | 194.2   | 0.0005*                     |
| AB              | 1414.9   | 2   | 707.4    | 0.5     | 0.5                         |
| AC              | 24.9     | 2   | 12.4     | 0.009   | 0.9                         |
| BC              | 17712.7  | 4   | 4428.1   | 3.3     | 0.011                       |
| ABC             | 1505.7   | 4   | 376.4    | 0.28    | 0.89                        |
| AD              | 7272.4   | 3   | 2424.1   | 1.8     | 0.14                        |
| BD              | 6781.2   | 6   | 1130.2   | 0.8     | 0.5                         |
| CD              | 65744.2  | 6   | 10957.3  | 8.1     | 0.0005*                     |
| ABD             | 8644.8   | 6   | 1440.8   | 1.07    | 0.37                        |
| ACD             | 13088.1  | 6   | 2181.3   | 1.6     | 0.13                        |
| BCD             | 4854.3   | 12  | 404.5    | 0.3     | 0.9                         |
| ABCD            | 8783.7   | 12  | 731.9    | 0.54    | 0.882                       |
| Within Error    | 363706.1 | 272 | 1337.1   |         |                             |
| <u>Between</u>  |          |     |          |         |                             |
| Age (D)         | 314699.2 | 3   | 104899.7 | 5.9     | 0.006*                      |
| Between Error   | 282465.0 | 16  | 17654.0  |         |                             |

\*p<0.01

Table A2--(Continued)

| Test Group II   |          |     |          |         |                          |
|-----------------|----------|-----|----------|---------|--------------------------|
| Source          | SS       | dF  | MS       | F ratio | Probability of Statistic |
| <u>Within</u>   |          |     |          |         |                          |
| Test-Retest (A) | 4188.8   | 1   | 4188.8   | 2.9     | 0.085                    |
| Stimulus (B)    | 57780.6  | 2   | 28890.3  | 20.0    | 0.0005*                  |
| Frequency (C)   | 716858.6 | 2   | 358429.3 | 248.7   | 0.0005*                  |
| AB              | 7482.9   | 2   | 3741.4   | 2.59    | 0.076                    |
| AC              | 548.0    | 2   | 274.0    | 0.19    | 0.8                      |
| BC              | 7718.3   | 4   | 1929.5   | 1.33    | 0.256                    |
| ABC             | 9843.0   | 4   | 2460.7   | 1.7     | 0.14                     |
| AD              | 4110.4   | 3   | 1370.1   | 0.95    | 0.4                      |
| BD              | 5862.1   | 6   | 977.0    | 0.67    | 0.6                      |
| CD              | 31950.0  | 6   | 5325.0   | 3.69    | 0.002*                   |
| ABD             | 8881.5   | 6   | 1480.2   | 1.02    | 0.4                      |
| ACD             | 7954.5   | 6   | 1325.7   | 0.9     | 0.4                      |
| BCD             | 5309.7   | 12  | 442.4    | 0.3     | 0.9                      |
| ABCD            | 3752.0   | 12  | 312.6    | 0.21    | 0.9                      |
| Within Error    | 391942.8 | 272 | 1440.9   |         |                          |
| <u>Between</u>  |          |     |          |         |                          |
| Age (D)         | 174071.5 | 3   | 58023.8  | 2.87    | 0.069                    |
| Between Error   | 322568.4 | 16  | 20160.5  |         |                          |

\*p&lt;0.01

## APPENDIX B

### AMBIENT NOISE LEVELS IN TEST ROOM

Table A3.--Octave band and C-scale measurement of ambient noise levels in the examination room (fan on) in dB SPL according to the standards set forth by the American Standards Association (ASA S3.1-1960).

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|            |   |              |  |                    |   |          |
|------------|---|--------------|--|--------------------|---|----------|
| Test Room  | = | IAC 1200-ACT |  | Sound Level Meter  | = | B&K 2204 |
| Microphone | = | B&K 4145     |  | Octave Band Filter | = | B&K 1613 |

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|         |                           |      |    |     |     |     |      |      |      |
|---------|---------------------------|------|----|-----|-----|-----|------|------|------|
|         | Center Frequency in Hertz |      |    |     |     |     |      |      |      |
|         | C-Scale                   | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| dB SPL* | 50                        | 45   | 50 | 34  | 12  | <10 | <10  | <10  | <10  |

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\*re 0.0002 dynes/cm<sup>2</sup>



## APPENDIX C

### PROCEDURE FOR CALIBRATION OF THE WARBLE-TONE SIGNAL

#### Calibration of Warble Tone

There are no accepted or consistent standards on which to base warble-tone calibration (Staab and Rintelmann, 1972). The procedure employed in this study was based upon that first described by Staab in 1971. In Staab's procedure, the center or base frequency of the tone to be warbled was calibrated through the ACCESSORY INPUT of the Maico Ma-24 audiometer without any warble in a manner similar to that advocated by the American National Standards Institute (S3.6-1969). The effect of this procedure was that the sound pressure level (SPL) outputs obtained were not the same for those obtained for the pure tones because the ACCESSORY INPUT of the Maico Ma-24 audiometer was calibrated to 19 dB SPL at "0" VU. Thus for ease of comparison, thresholds were recorded in SPL for warble tone as well as the other stimuli employed.

During testing it was essential that the exact center frequency, modulation rate and frequency deviation be specified for the test frequency employed. This was accomplished in the following manner:

Calibration of Center Frequency. This refers to the unmodulated center frequency obtained from the B&K 1013 Beat-Frequency

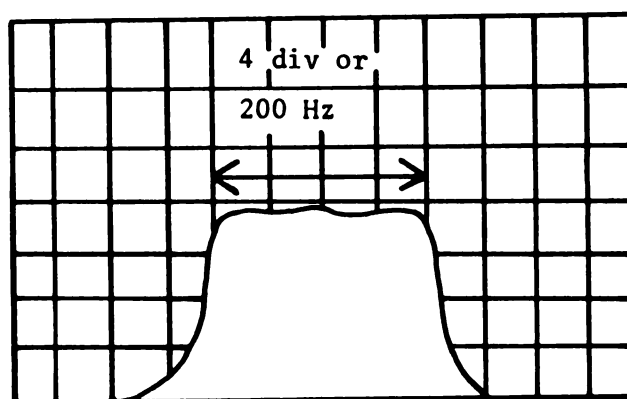
Oscillator. Since it was a sine wave the frequency counter (Bekman Eput and Timer, Model 6148) was utilized to set the frequency by varying the fine scale adjustment of the beat-frequency oscillator until the frequency counter recorded the desired frequency.

Calibration of the Modulation Rate. An independent function generator (Hewlett-Packard Model 1033A) externally drove the beat-frequency oscillator to generate the modulation rate used. In this experiment, an 8 Hz signal was utilized from the function generator thus producing a modulation rate of 8 per second. The modulation rate was easily checked by reading a frequency counter connected to the output of the function generator.

Calibration of the Frequency Deviation. Calibration of the frequency deviation was performed using a Tektronix 3L5 Spectrum Analyzer designed for use with the Tektronix type 564B Model 121N Oscilloscope. The analyzer displayed signal amplitude as a function of frequency. The desired frequency deviation can be obtained by adjusting the output voltage of the Hewlett-Packard Function Generator.

The basic procedure utilized in frequency deviation determination involved the manipulation of the DISPERSION knob on the spectrum analyzer which allowed for the selection of a certain value of Hz/DIVision on the visual display area of the oscilloscope. The value of the warble-tone frequency deviation desired

was manually varied by manipulating the frequency deviation knob on the beat-frequency oscillator with the output voltage of the function generator until the display fell within the predetermined scale selected on the oscilloscope and outlined by the graticule divisions. Figure A1 gives an example of a  $\pm 10\%$  frequency deviation at 1000 Hz.



DISPERSION = 50 Hz/DIV

Frequency Deviation = 200 Hz

Figure A1.--Visual display on an oscilloscope produced by a spectrum analyzer showing a  $\pm 10\%$  frequency deviation centered around a base frequency of 1000 Hz.

## APPENDIX D

### CALIBRATION OF NARROW-BAND NOISE SIGNAL

Pre-experimentally, ten normal-hearing subjects between the ages of 18 and 25 years were tested using the Maico Ma-24 audiometer employed in this study. Pure-tone and narrow-band noise thresholds were measured at octave intervals from 250-4000 Hz. The differences between the pure-tone and narrow-band noise thresholds represented corrections that would be necessary to relate narrow-band noise thresholds to audiometric zero. This procedure was employed by Sanders and Josey (1970).

Table A4 presents the mean thresholds in dB HTL for pure tones and narrow bands of noise with the threshold differences at each test frequency.

Graphical displays of the narrow-band noise signals employed in the present study are shown in Figures A2 through A6.

Table A4.--Mean thresholds in dB HTL for pure tones and narrow bands of noise with the threshold difference at each test frequency.

| Test Frequency | Stimulus  |             |                      |
|----------------|-----------|-------------|----------------------|
|                | Pure Tone | Narrow-Band | Threshold Difference |
| 250 Hz         | 1.5       | 17.5        | 16.0                 |
| 500 Hz         | 0.5       | 7.0         | 6.5                  |
| 1000 Hz        | 1.5       | 5.0         | 3.5                  |
| 2000 Hz        | 1.0       | 11.0        | 10.0                 |
| 4000 Hz        | 2.0       | 11.5        | 9.5                  |

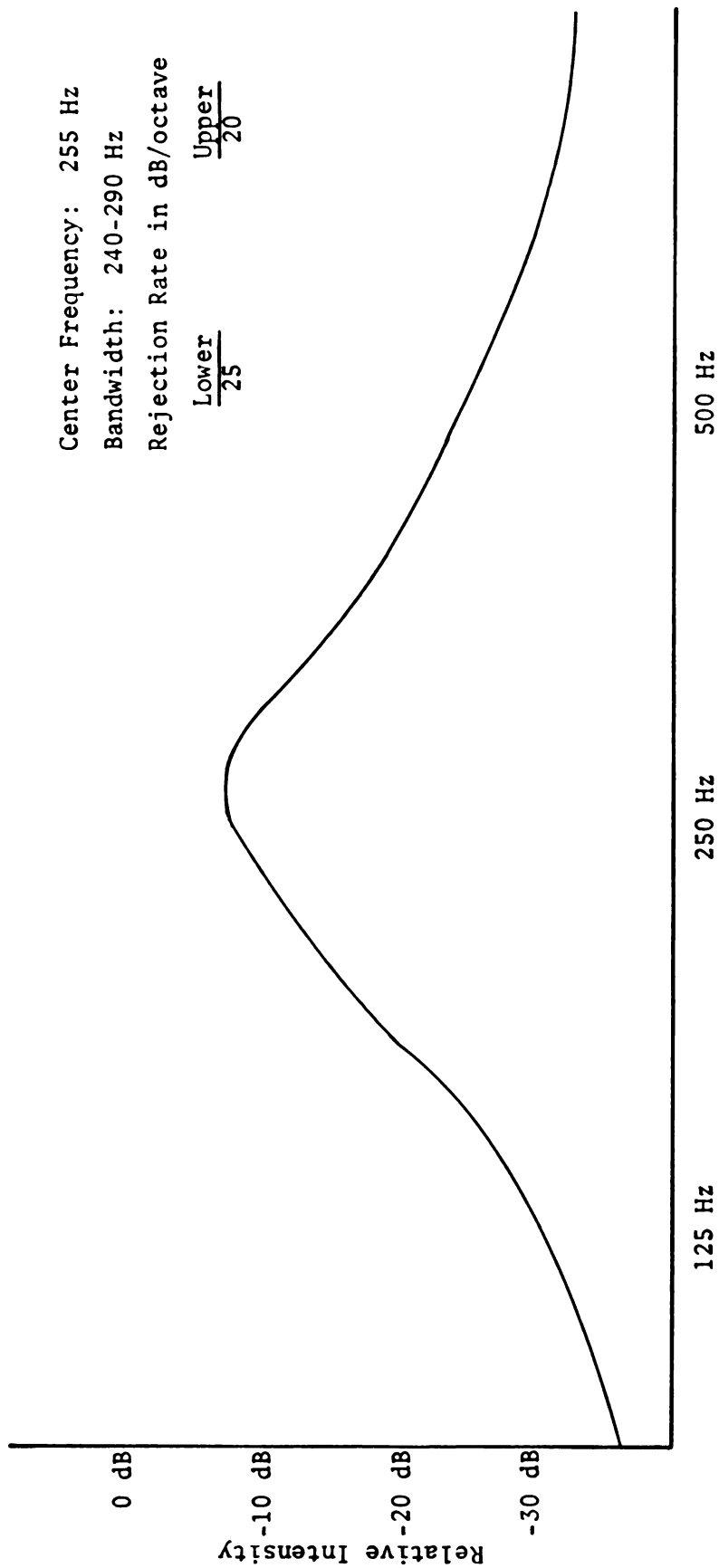


Figure A2.--Spectrum of the narrow band of noise centered around 250 Hz.

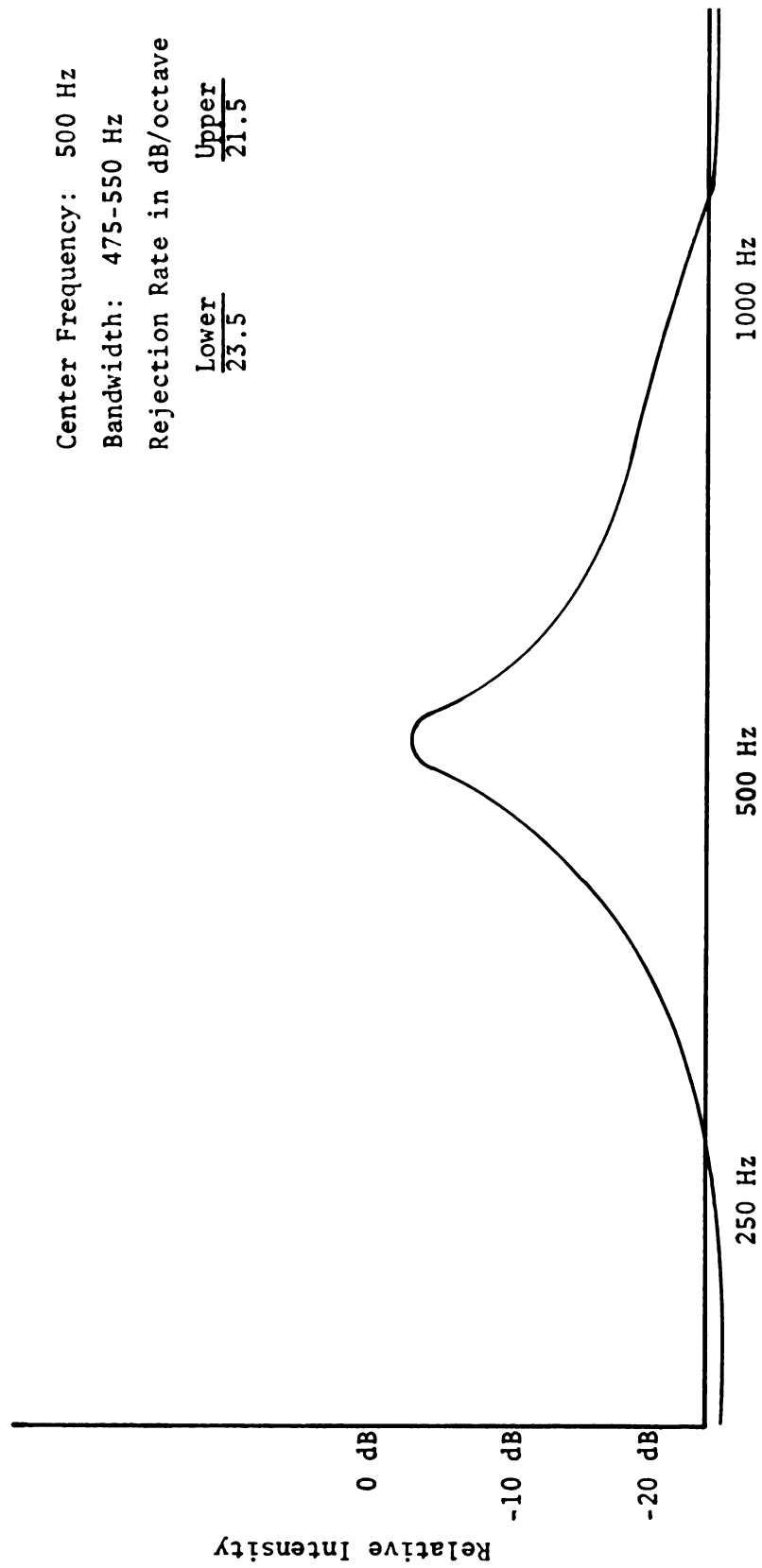


Figure A3.--Spectrum of the narrow band of noise centered around 500 Hz.



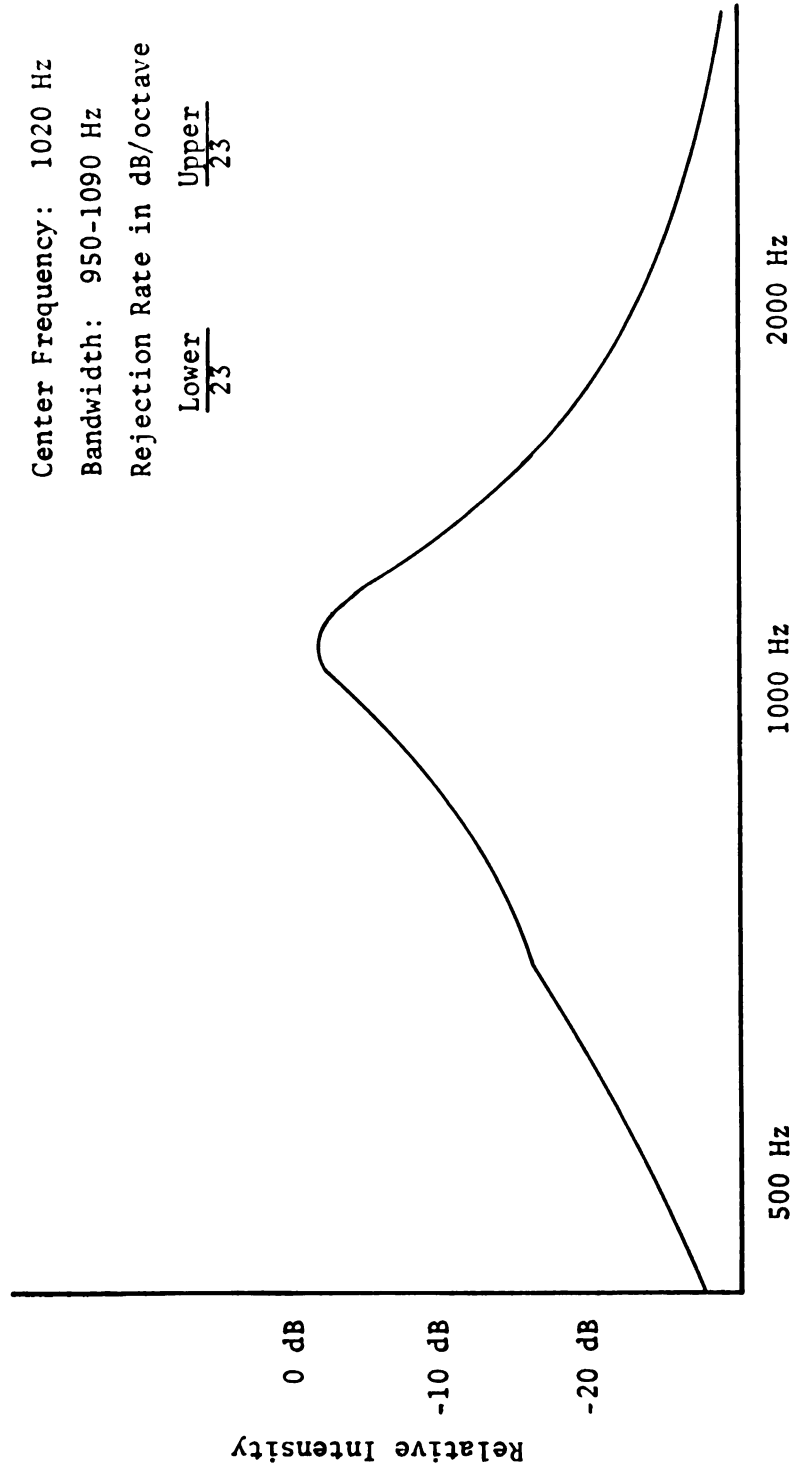


Figure A4.--Spectrum of the narrow band of noise centered around 1000 Hz.

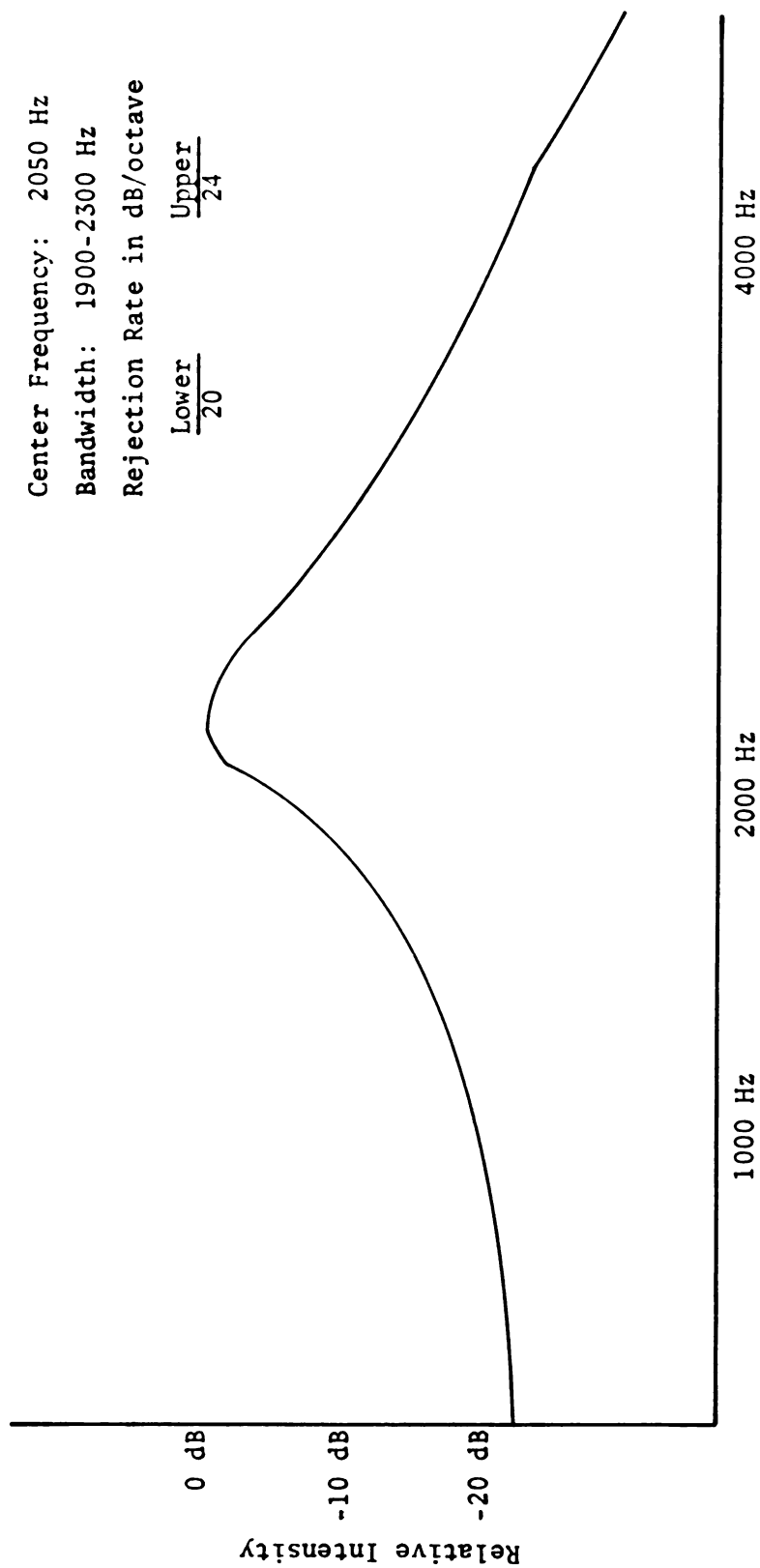


Figure A5.--Spectrum of the narrow band of noise centered around 2000 Hz.

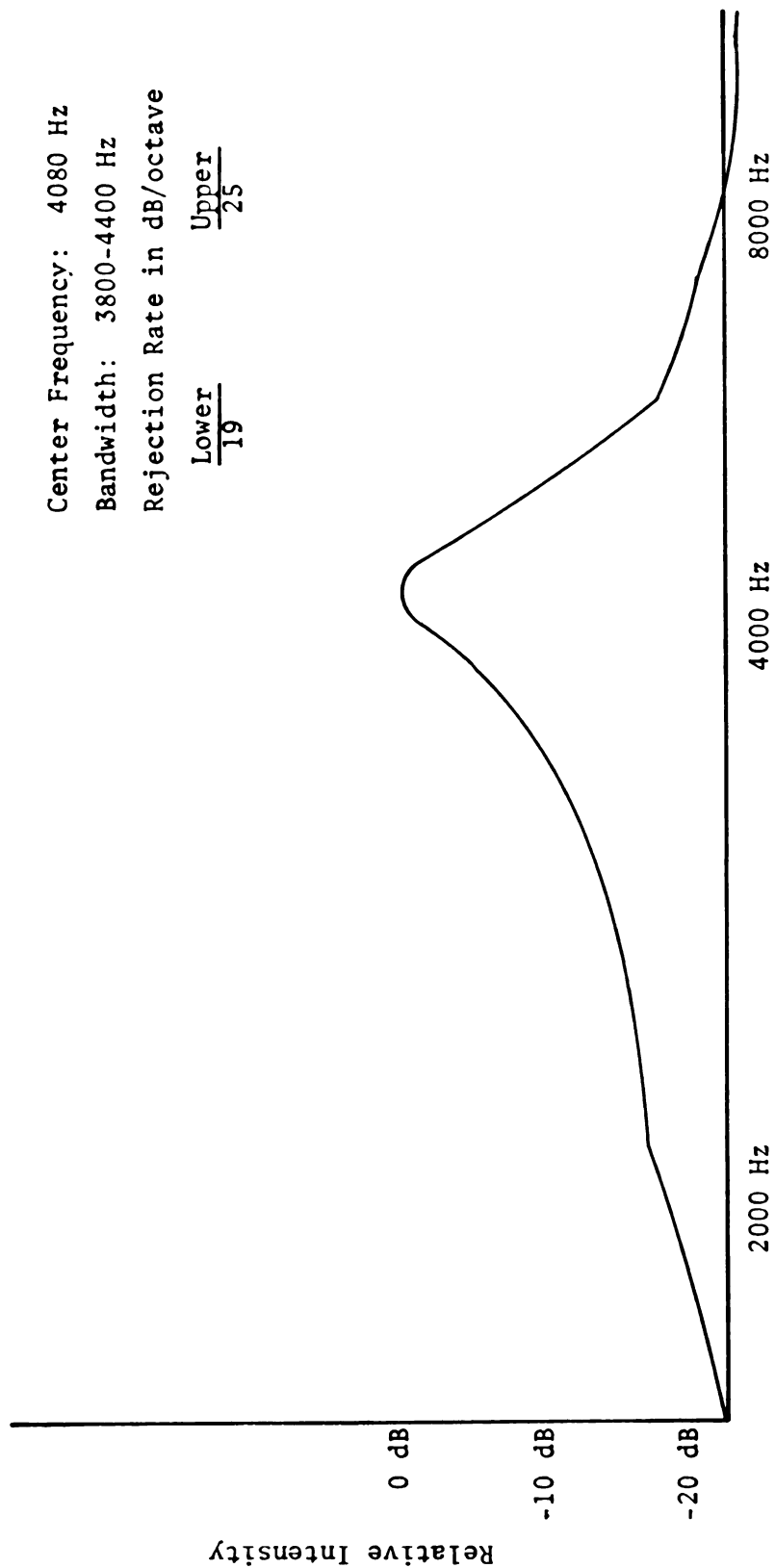


Figure A6.--Spectrum of the narrow band of noise centered around 4000 Hz.

## APPENDIX E

### LINEARITY OF THE MAICO MA-24 AUDIOMETER ATTENUATOR

The linearity of the Ma-24 attenuator was checked pre- and post-experimentally at 1000 Hz. The measurements were made acoustically with the test earphone attached to a B&K artificial ear and associated sound level meter and octave-band filter set.

The results of this linearity check are shown in Table A5 and were found to be well within the acceptable tolerance limits according to ANSI S3.6-1969.

Table A5.--Pre- and post-experimental linearity check of the Maico Ma-24 audiometer attenuator made acoustically at the test earphone.

Audiometer = Maico Ma-24  
 Audiometer Channel = Right  
 Earphone = Right (TDH-39/10Z)  
 Earphone Cushion = Mx-41/AR

Artificial Ear = B&K 4152  
 Sound Level Meter = B&K 2204  
 Microphone = B&K 4144  
 Octave Band Filter = B&K 1613

| dB HTL | Pre-Experiment |        | Post-Experiment |        |
|--------|----------------|--------|-----------------|--------|
|        | 1000 Hz        |        | 1000 Hz         |        |
|        | dB SPL         | dB dif | dB SPL          | dB dif |
| 100    | 106.8          |        | 106.4           |        |
| 90     | 96.9           | 9.9    | 96.4            | 10.0   |
| 80     | 87.0           | 9.9    | 86.5            | 9.9    |
| 70     | 77.5           | 9.5    | 76.6            | 9.9    |
| 60     | 67.2           | 10.3   | 66.6            | 10.0   |
| 50     | 58.2           | 9.0    | 56.8            | 9.8    |
| 40     | 48.4           | 9.8    | 46.8            | 10.0   |
| 30     | 38.5           | 9.9    | 36.9            | 9.9    |
| 20     | 28.3           | 10.2   | 26.8            | 10.1   |
| 10     | 17.5           | 10.8   | 17.0            | 9.8    |
| 0      | 7.7            | 9.8    | 7.3             | 9.7    |

APPENDIX F  
EARPHONE OUTPUT DATA

Table A6.--Output data for pure-tone stimuli of the Maico Ma-24 audiometer (right channel, right earphone). Measurements were in accordance with American National Standards Institute (ANSI S3.6-1969).

Audiometer = Maico Ma-24  
Earphone = TDH-39/10Z  
Cushion Type = MX-41/AR

Microphone = B&K 4144  
Artificial Ear = B&K 4152  
Sound Level Meter = B&K 2204  
Octave Band Filter = B&K 1613

| Frequency<br>in Hertz | Pre-Experiment          | Mean* | Post-Experiment         |
|-----------------------|-------------------------|-------|-------------------------|
|                       | Output<br>(70 dB Input) |       | Output<br>(70 dB Input) |
| 250                   | 96.0                    | 95.8  | 96.0                    |
| 500                   | 82.0                    | 82.3  | 82.4                    |
| 1000                  | 78.2                    | 77.2  | 77.3                    |
| 2000                  | 79.0                    | 78.0  | 78.1                    |
| 4000                  | 79.2                    | 78.4  | 78.8                    |

\*Mean SPL from daily calibration based on 27 daily measurements.

Table A7.--Output data for the beat-frequency oscillator routed through the Maico Ma-24 audiometer (right channel, right earphone). Levels were obtained by measuring the SPL output for the unmodulated warble-tone center frequency at "0" VU with 70 dB HTL input through the ACCESSORY INPUT of the Maico Ma-24.

Audiometer = Maico Ma-24  
 Earphone = TDH-39/10Z  
 Cushion Type = MX-41/AR  
 Beat-Frequency Oscillator = B&K 1013

Microphone = B&K 4144  
 Artificial Ear = B&K 4152  
 Sound Level Meter = B&K 2204  
 Octave Band Filter = B&K 1613

| Frequency<br>in Hertz | Pre-Experiment          | Mean* | Post-Experiment         |
|-----------------------|-------------------------|-------|-------------------------|
|                       | Output<br>(70 dB Input) |       | Output<br>(70 dB Input) |
| 250                   | 91.5                    | 91.9  | 91.8                    |
| 500                   | 91.5                    | 92.4  | 92.3                    |
| 1000                  | 91.0                    | 92.2  | 92.2                    |
| 2000                  | 88.4                    | 88.4  | 88.5                    |
| 4000                  | 94.0                    | 94.1  | 94.4                    |

\*Mean SPL from daily calibration based on 27 daily measurements.

Table A8.--Output data for narrow-band noise signals from the Maico Ma-24 audiometer measured acoustically at 70 dB input on the Hearing Threshold Level dial.

Audiometer = Maico Ma-24  
 Earphone = TDH-39/10Z  
 Cushion Type = Mx-41/AR

Microphone = B&K 4144  
 Artificial Ear = B&K 4152  
 Sound Level Meter = B&K 2204  
 Octave Band Filter = B&K 1613

| Frequency<br>in Hertz | Pre-Experiment          | Mean* | Post-Experiment         |
|-----------------------|-------------------------|-------|-------------------------|
|                       | Output<br>(70 dB Input) |       | Output<br>(70 dB Input) |
| 250                   | 80.0                    | 79.8  | 80.5                    |
| 500                   | 78.0                    | 76.2  | 77.0                    |
| 1000                  | 74.8                    | 73.4  | 74.3                    |
| 2000                  | 69.8                    | 68.4  | 69.2                    |
| 4000                  | 70.9                    | 69.8  | 70.8                    |

\*Mean SPL from daily calibration based on 27 daily measurements.



APPENDIX G  
EARPHONE FREQUENCY RESPONSE

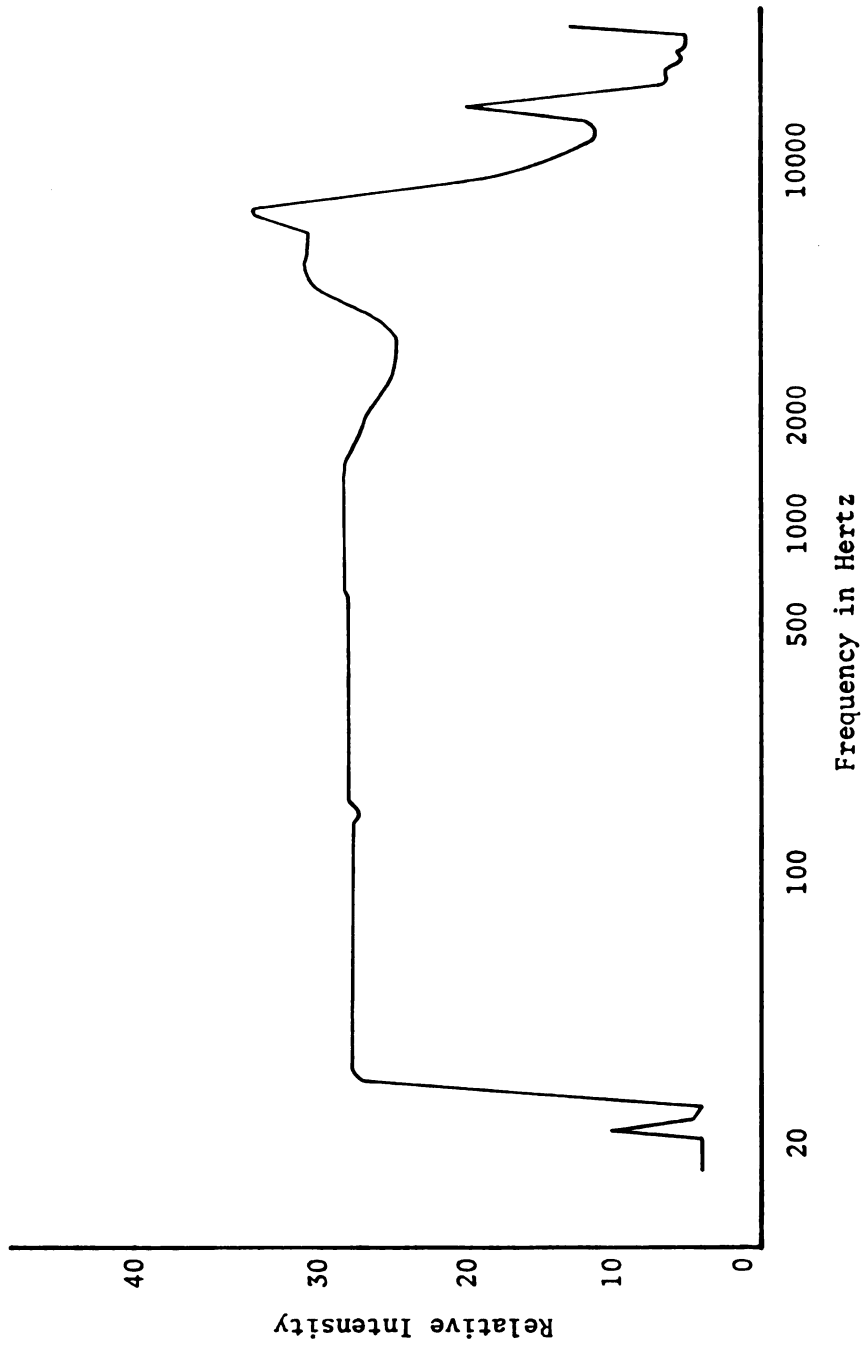


Figure A7.--Frequency response of test earphone.

# APPENDIX H

## HARMONIC DISTORTION DATA

Table A9.--Pre- and post-experimental harmonic distortion measurements of the fundamental for the test frequencies used. Measurements were made for the right channel of the Ma-24 audiometer in accordance with the American National Standards Institute standard (ANSI S3.6-1969).

Audiometer = Maico Ma-24  
Audiometer Channel = Right

Frequency Analyzer = B&K 2107

| Frequency<br>in Hertz | SPL of<br>Fundamental | SPL with<br>Fundamental<br>Rejected* | Difference<br>in dB |
|-----------------------|-----------------------|--------------------------------------|---------------------|
| Pre-experiment        |                       |                                      |                     |
| 250                   | 102                   | 67.5                                 | 34.5                |
| 500                   | 109                   | 65.5                                 | 33.5                |
| 1000                  | 105                   | 70.0                                 | 35.0                |
| 2000                  | 108                   | 73.0                                 | 35.0                |
| 4000                  | 104                   | 68.0                                 | 36.0                |
| Post-experiment       |                       |                                      |                     |
| 250                   | 104                   | 72.0                                 | 32.0                |
| 500                   | 111                   | 75.0                                 | 36.0                |
| 1000                  | 104                   | 73.0                                 | 31.0                |
| 2000                  | 109                   | 79.0                                 | 30.0                |
| 4000                  | 104                   | 70.0                                 | 34.0                |

\*These values represent the total SPL remaining after the fundamental had been rejected.

Table A10.--Pre- and post-experimental harmonic distortion measurements of the fundamental of the warble-tone center frequencies used. Measurements were made for the output of the beat-frequency oscillator, routed through the right channel of the Ma-24 audiometer, in accordance with the American National Standards Institute standard (ANSI S3.6-1969).

Audiometer = Maico Ma-24

Frequency Analyzer = B&K 2107

Beat-Frequency Oscillator = B&K 1013

| Frequency<br>in Hertz | SPL of<br>Fundamental | SPL with<br>Fundamental<br>Rejected* | Difference<br>in dB |
|-----------------------|-----------------------|--------------------------------------|---------------------|
| Pre-experiment        |                       |                                      |                     |
| 250                   | 104                   | 72                                   | 32                  |
| 500                   | 105                   | 75                                   | 30                  |
| 1000                  | 107                   | 74                                   | 33                  |
| 2000                  | 106                   | 73.5                                 | 32.5                |
| 4000                  | 107                   | 72                                   | 35                  |
| Post-experiment       |                       |                                      |                     |
| 250                   | 103                   | 73                                   | 30                  |
| 500                   | 103                   | 73                                   | 30                  |
| 1000                  | 102                   | 70                                   | 32                  |
| 2000                  | 103                   | 72                                   | 31                  |
| 4000                  | 103.5                 | 73                                   | 30.5                |

\*These values represent the total SPL remaining after the fundamental had been rejected.

# APPENDIX I

## RISE AND DECAY TIMES

Table All.--Pre- and post-experimental rise and decay time\* as measured for pure tones generated by the Maico Ma-24 audiometer. The times were measured utilizing a storage oscilloscope in accordance with the American National Standards Institute standard (ANSI S3.6-1969).

Audiometer = Maico Ma-24  
 Earphone Jack = Right  
 Storage Oscilloscope = Tektronix Type 564B

### Rise and Decay Times for Pure-Tone Signals (in milliseconds)

|                 | Frequency in Hertz |     |      |      |      |
|-----------------|--------------------|-----|------|------|------|
|                 | 250                | 500 | 1000 | 2000 | 4000 |
| Pre-experiment  |                    |     |      |      |      |
| Rise            | 50                 | 60  | 50   | 45   | 40   |
| Decay           | 60                 | 70  | 75   | 80   | 70   |
| Post-experiment |                    |     |      |      |      |
| Rise            | 40                 | 38  | 45   | 35   | 35   |
| Decay           | 80                 | 70  | 65   | 75   | 75   |

\*Rise time = Time for SPL to rise from -20 dB to -1 dB re its steady value.

Decay time = Time for SPL to decay by 20 dB.

APPENDIX J  
TEST FREQUENCY CHECKS

Table A12.--Pre- and post-experimental checks of the test frequencies of the Maico Ma-24 audiometer\* performed in accordance with the American National Standards Institute standard (ANSI S3.6-1969).

| Audiometer = Maico Ma-24   |                       | Frequency Counter = Bekman 6148 |                          |
|----------------------------|-----------------------|---------------------------------|--------------------------|
| Audiometer Channel = Right |                       |                                 |                          |
| Test Frequency<br>in Hertz | Measured<br>Frequency | Difference<br>in Hertz          | Difference<br>in Percent |
| Pre-experiment             |                       |                                 |                          |
| 250                        | 249                   | -1                              | 0.4%                     |
| 500                        | 501                   | 1                               | 0.2%                     |
| 1000                       | 993                   | -7                              | 0.7%                     |
| 2000                       | 2006                  | 6                               | 0.3%                     |
| 4000                       | 4033                  | 33                              | 0.7%                     |
| Post-experiment            |                       |                                 |                          |
| 250                        | 247                   | -3                              | 1.2%                     |
| 500                        | 500                   | 0                               | 0.0%                     |
| 1000                       | 991                   | -9                              | 0.9%                     |
| 2000                       | 2005                  | 5                               | 0.3%                     |
| 4000                       | 4031                  | 31                              | 0.7%                     |

\*The unmodulated center frequencies of the warble tones produced by the beat-frequency oscillator were observed during all testing and manually varied to be within 3% of the indicated frequency.

# APPENDIX K

## WARBLE-TONE FREQUENCY DEVIATION REQUIREMENTS

Table A13.--The frequency deviation (FD) setting on the beat-frequency oscillator as well as the volt scale (VS) and output voltage (V) on the function generator required to produce the desired warble-tone frequency deviations.

| Center<br>Frequency<br>in Hertz | Frequency<br>in<br>Percent | Deviation<br>in<br>Hertz | FD  | VS | V    |
|---------------------------------|----------------------------|--------------------------|-----|----|------|
| 250                             | ± 3                        | 15                       | 100 | 1  | 0.60 |
|                                 | ±10                        | 50                       | 100 | 3  | 1.80 |
| 500                             | ± 3                        | 30                       | 100 | 3  | 1.20 |
|                                 | ±10                        | 100                      | 100 | 10 | 3.40 |
| 1000                            | ± 3                        | 60                       | 100 | 3  | 2.00 |
|                                 | ±10                        | 200                      | 160 | 10 | 4.60 |
| 2000                            | ± 3                        | 120                      | 100 | 10 | 3.60 |
|                                 | ±10                        | 400                      | 400 | 10 | 3.40 |
| 4000                            | ± 3                        | 240                      | 250 | 10 | 3.60 |
|                                 | ±10                        | 800                      | 630 | 10 | 3.40 |

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