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Relations Among Selected Auditory Parameters and Age.

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ABSTRACT

The purpose of this study was to investigate changes in auditory behavior that occur as the auditory system ages. The relationships among differential sensitivity for frequency, differential sensitivity for intensity, aging and two of the most frequently used clinical diagnostic tests--pure tone air-conduction and speech discrimination--were investigated.

Fifty-four subjects composed of the following two age groups were used in this study: 20-29 and 45-79. There were 12 subjects in the control group (younger) and 6 subjects in each half decade in the older, or experimental group. Results of each subject's otological history and pure tone audiogram indicated a "normal" ear for his age. Each subject was administered a pure tone air- and bone-conduction threshold test, a speech reception threshold test, a speech discrimination test, frequency difference limen measurements at 500, 1000, 2000, and 4000 Hz and intensity difference limen measurements at 500, 1000, 2000, and 4000 Hz. The obtained measurements were analyzed through use of coefficients of correlation.

Results of the statistical analyses revealed a significant relationship between age and ability to perceive small changes in frequency. This relationship was noted at

all frequencies tested--500, 1000, 2000, and 4000 Hz. Also a significant relationship was found to exist between pure tone threshold and the ability to perceive small changes in frequency at these same frequencies.

The difference limen for intensity measurements showed no relationship with age. The lack of spread of DLI scores, for the various age groups, made it difficult to relate these measurements to other variables.

Although it was felt that a definite relationship between DLF and DLI was not demonstrated, a low positive correlation between these phenomena was noted at 2000 and 4000 Hz. There was little agreement between the observations regarding DLI and DLF in the present study with data obtained by other investigators. It was felt that differences in otological classification and psychophysical techniques could account for the lack of agreement among these data.

It was observed that the average pure tone responses obtained for the subjects included in the present study showed good agreement with the so-called "normal" presbycusic curves reported in the literature. Speech reception thresholds agreed very well with the three frequency average for all subjects. The speech discrimination scores were considerably better than may have been expected for subjects in the older groups. A tenable explanation for this finding may be the fact that these individuals were not drawn from a

clinical population but were included in this study because their pure tone audiogram and otological history indicated a "normal" ear for their respective ages. The discrimination scores obtained by older persons may be influenced to a large extent by the factors which bring them to the clinic.

There is increased evidence that auditory systems with confirmed pathologies respond differently than "normal" systems to DLF and DLI tasks. In order to utilize this new clinical information in diagnostic procedures for older patients it is necessary to distinguish a pathological condition from the normal changes that occur with aging. It is hoped that the present investigation has added to the body of basic knowledge regarding changes in auditory behavior that may be expected as the auditory system ages.

CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

STATEMENT OF THE PROBLEM

Professional workers in the field of communication disorders recognize that the communicative ability of the aging population must be maintained at the highest possible level if this segment of society is to remain active. One of the most prevalent communication disorders of the aged subject is poor speech discrimination. Although a slight progressing decrement in hearing sensitivity for pure tones is expected with each succeeding decade, frequently these subjects manifest abnormally poor speech discrimination which is out of proportion to what is expected from their degree of loss for pure tones. The basis of this discrimination problem is not clearly understood.

It seems reasonable to assume that speech discrimination depends, to a large extent, on the sensitivity of the individual to minute fluctuations in the nuances of speech which distinguish the various phonemic elements. One would suspect, therefore, that an individual must be able to discriminate small changes in frequency and intensity in order to discriminate speech well. A simple extension of

this expectation would predict that an individual who has difficulty in discriminating speech may manifest a deficit in one or both of these parameters.

Although numerous studies have investigated difference limen for frequency, difference limen for intensity and discrimination abilities few of them have addressed themselves to the problems of the aged or "presbycusic" subject. Those investigators who have included measurements for the aged, are not in agreement as to the findings. In most instances the psychophysical techniques used have differed so much that a comparison of data obtained is very difficult. None of the research reviewed by the present investigator studied both the relations among difference limen for frequency <u>and</u> intensity and speech discrimination ability of "aged" subjects. In view of the lack of related information regarding these phenomena it was felt that an investigation conducted to gather these data would be of considerable value.

Objectives of the Study

The present study was designed to accomplish the following major objectives:

1. To determine the relationships among differential sensitivity for frequency, differential sensitivity for intensity, aging and two of the most frequently used clinical diagnostic tests--pure tone air-conduction and speech discrimination.

2. To compare the present technique of evaluating difference limen for frequency and difference limen for intensity with techniques reported in the literature.

3. To determine whether the employed psychophysical techniques would have practical diagnostic value in a test battery for evaluating auditory function.

The following relationships were investigated:

1. The relationship between DLF and Aging. Three investigators have reported data on the relationship between DLF and age. Two of these--Konig (1957) and Ross et al. (1963) reported a significant relationship between DLF and age while more recently the third--Rupp (1964)--did not find a significant relationship. It is to be appreciated, however, that these studies utilized different psychophysical techniques and different subject selection criteria, therefore, it is difficult to compare these data.

2. The relationship between DLI and Aging. None of the studies reviewed reported data regarding this phenomenon; however, it would seem reasonable to assume that since there is a gradual decrease in sensitivity to pure tones with age

then there might likewise be a similar change in the ability to discriminate minimal changes in intensity presented at a supra-threshold level.

3. <u>The relationship between DLF and speech discrimination</u>. Two investigators reporting DLF data for presbycusic subjects included speech discrimination tests. Hayes (1951) used PB-50 lists to test two groups of patients who demonstrated an average sensorineural loss on the order of 46 dB. He concluded that when poor discrimination ability was super-imposed on sensorineural loss, a concomitant disturbance of DLF did not appear in all cases. Rupp (1964), on the other hand, compared the DLF obtained at 1000 Hz with PB max scores and reported a significant relationship. That is, as the size of the DLF became larger, group-by-group, the difficulty in understanding speech increased. Neither of these studies reported data for the "normal" aging ear across all of the speech frequencies. It would seem reasonable to expect that those patients who demonstrate difficulty in discriminating speech presented at a sensation level well above their thresholds would similarly have difficulty in discriminating minimal changes in the frequency of those pure

tones which contribute most to speech perception (i.e., 500, 1000 and 2000 Hz).

4. The relationship between DLI and speech discrimination. Data presented by Eby and Williams (1951), Huizing and Reyntjes (1952), and Palva (1952) suggest that patients with poor speech discrimination at high intensities are the ones that are supposed to have small difference limens and therefore an ability to detect small changes in intensity. Hirsh et al. (1954) investigated this relationship and concluded that the size of DLI was not related to speech discrimination scores. This conclusion has been further supported by a recent investigation conducted by Ross et al. (1963).

5. The relationship between DLF and pure tone air-conduction thresholds. It could reasonably be hypothesized that the structural correlate that accounts for reduced sensitivity to pure tones (i.e., raises threshold) might also effect suprathreshold tasks such as DLF for the same pure tones. However, the data which have been presented on this phenomenon reflect inconsistent findings. Meurmann (1954), who used a sinusoidal modulation technique for DLF measurements, reported that DLF grows proportionally

with the decrease in hearing; however, he did note wide variations in the relationship between pure tone hearing loss and DLF, especially at the higher frequencies. He did not find a consistent relationship between DLF and amount of hearing loss. Filling (1958) reported relationships between pure tone loss and DLF values for the following types of hearing problems: sensorineural; mixed conductive and perceptive; and conductive. She reported that DLF values were not related to the severity of hearing loss for the conductive and mixed conductive and perceptive groups but that the DLF tended to increase in relationship to the severity of loss for the group with sensorineural losses.

McCandless (1959), who studied DLF in three groups of subjects, through use of a discrete method of signal presentation, reported no consistent relationship between DLF and amount of hearing loss. In 1963 Ross *et al*. stated that DLF was correlated with pure tone thresholds in that larger DLF values were associated with greater hearing losses. More recently Rupp (1964) reported that DLF could not be correlated with air-conducted pure tones. However, he did observe highly significant correlations between

bone-conduction thresholds and DLF size for his various otologically classified groups of subjects. It should be pointed out that these studies did not look at the relationship between DLF and pure tone thresholds across different age groups who demonstrated "normal" hearing for their respective ages.

6. The relationship between DLI and pure tone air-conduction thresholds. Intuitively, one would suspect that a smaller DLI would be obtained at 4000 Hz than at either 500, 1000 or 2000 Hz in older patients. This assumption is based on the observation that older patients demonstrate the so-called recruitment phenomenon more readily than do younger subjects. In an experimental study based on 44 patients with a variety of types of hearing loss, and 18 normal subjects, Hirsh et al. (1954), concluded that DLI measurements do not distinguish recruiting and non-recruiting cases nor can the DLI distinguish hard-of-hearing from normal listeners when the DLI is measured with discrete tones at sensation levels of 5, 25, and 40 dB, relative to the person's threshold. This conclusion does not agree with an earlier study of Denes and Nauton (1950) who used essentially the same technique

on a small group of patients and reported that the DLI was different in recruiting and non-recruiting patients.

7. The relationship between DLF and DLI. In 1954 Meurmann studied both DLI and DLF function in the same patients and concluded that in end-organ lesions the DLF increases in contrast to the DLI which often diminishes. These data, however, when reviewed in detail, revealed that half of the test subjects in a group of older patients with neural deafness had normal DLI values and the other half had distinctly sub-normal values at high frequencies. Within these two groups there was no clear difference with regard to DLF. Ross et al. (1963), who investigated both DLI and DLF in a group of normal-hearing subjects, reported that subjects who demonstrated a wide or narrow DL for frequency at 500 and 4000 Hz in the right ear also tended to demonstrate a wide or narrow DL for intensity at 500, and 4000 Hz. This relationship was not observed at 2000 Hz. In the left ear this relationship was significant only at 500 Hz. A year later Rupp (1964) investigated DLF for nine groups of subjects with different otologically classified ears and included a SISI test for

each subject at 1000 and 4000 Hz. He reported that subjects who obtained low SISI scores at 4000 Hz also evidenced small DLF scores. This relationship was statistically significant at 4000 Hz but not at 1000 Hz.

REVIEW OF THE LITERATURE

The recent increase in the concern for the well being of the geriatric individual may be postulated as resulting from several factors. The fact that this segment of the population is increasing in rapidly mounting numbers is pointed up by several investigators (Goetzinger and Rousey, 1959; Morley, 1962; Gaitz and Warsaw, 1964; Alpiner, 1965). According to recent population estimates by 1975 the number of people in the United States over 65 years of age is expected to reach 21 million. This number will constitute slightly more than 10 percent of the total population (Goetzinger and Rousey, 1959; Gaitz and Warsaw, 1964).

There has been increasing concern for providing medical care for the elderly, for appropriate housing, and part-time employment, however, little attention has been given to the communication problems of this group. With the increasing services for the aged it is inevitable that there will be an increasing number of requests for speech, language, and hearing rehabilitation services.

The White House Conference on Aging in Washington, D.C., held January 9-12, 1961, was an impressive example of a nationally coordinated effort to meet the needs of the geriatric citizen. The conference was convened under a law authorizing the Secretary of Health, Education and Welfare to set up such a conference and for governors of the States to appoint appropriate delegates. A national advisory committee selected 20 subject matter areas, and detailed factual background papers in each field were prepared for use by all persons involved in the plans. State conferences were held in preparation for the national level conference (Morley, 1962).

The American Speech and Hearing Association's concern with the communication problems of the aging was pointed up in 1960 by the appointment of a committee to study the communication problems of this population. During the committee's first meeting it was decided that members would study the following areas of this problem: research, teaching, liaison with agencies concerned with problems of the aging, the family of the aging, and the motivation of the aging. These broad topics reflect the magnitude of the problem.

The most common communication problems of the aged population are:

1. Loss of hearing.
2. Aphasia--speech and language disturbances resulting from damage to the brain caused by strokes.
3. Loss of voice resulting from the removal of a cancerous larynx (Walle and Newman, 1967).

According to Gaitz and Warsaw (1964), loss of hearing is probably the most prevalent communication problem in the aged.

Pure Tone

Since Zwaardemaker (1894) stated that older people grow increasingly less sensitive to tones of high frequency, numerous investigators (Bunch, 1929; Public Health Service, 1938; Goetzinger et al., 1959; Glorig et al., 1961; Nixon et al., 1962), have reported the results of changes in auditory responses to pure tone stimuli. A summary of the pertinent findings include:

1. There is a progressive decrement in hearing sensitivity for pure tones with each succeeding decade.
2. There is a greater pure tone loss in the high frequencies.
3. There is a greater over-all loss in men than women.

Speech Discrimination

Although hearing sensitivity for pure tones is frequently utilized as a general index of one's auditory capacity, there is another major aspect of hearing which must be taken into consideration in addition to tonal hypocusis. This dimension of hearing is discrimination ability for speech. It is a well established clinical observation that individuals with identical hearing losses for pure tone may vary widely in their ability to understand speech once their hearing loss has been overcome by amplification. Also, frequently hearing losses as a result of presbyacousia, are characterized by abnormally poor speech discrimination which is out of proportion to what is expected from their degree of loss for pure tones (Goetzinger and Rousey, 1959; Hudson, 1960; Klotz and Kilbane, 1962; Miller and Ort, 1964; Alpiner, 1965).

These observations have been corroborated by data obtained by several investigators. In 1955, Pestalozza and Shore studied speech discrimination ability in a large group of elderly subjects and reported that:

1. Speech discrimination in older subjects is frequently very poor even in the presence of a mild hearing loss. They investigated a group of young subjects with the same amount and characteristics of hearing loss as the old individuals and found that the young subjects have better

discrimination. Scores for the younger group were always 9-20 percent better than that of the old subjects with the same amount of hearing loss.

2. No significant relationship was found between the slope of the audiogram and discrimination loss.

Goetzinger _et al_. (1959) also investigated discrimination in a group of older subjects by administering the W-22's (relatively easy) and Rush Hughes Test (difficult) in order to obtain a difference score between results of these two tests. Their conclusions were that, in general, auditory discrimination decreased while the difference score increased with advancing age.

Luterman _et al_. (1966) investigated auditory responses in a large number of elderly males. Sixty-two subjects whose age ranged from 74 to 89 years with a mean of 82 years were used. The mean speech discrimination score (W-22's at SRT + 40 dB) was 78 percent. This score was considerably below the discrimination scores obtained with younger subjects who evidenced similar mild sensorineural losses. Thirty percent of the older subjects did, however, obtain discrimination scores in excess of 90 percent.

Gaeth (1948) has termed the inordinate loss of speech discrimination ability experienced by some older subjects who have a mild loss for pure tones--"phonemic regression." As

previously mentioned the bases of these differences in discrimination ability are not clearly understood.

In an attempt to partial out those parameters which account for speech discrimination numerous investigators have studied pitch and loudness discrimination abilities in various groups of subjects over the years. The next section will review these studies with particular attention to those data which deal with the pitch, loudness, and speech discrimination abilities of the "presbycusic" subject.

Difference Limen for Frequency

The difference limen for frequency is defined as a just noticeable change in the perception of frequency at a specified frequency and at a given intensity.

In reporting differential sensitivity for frequency some investigators have reported their findings as absolute difference limen while others have reported relative difference limen. Absolute difference limen is defined as the cycles per second between the standard frequency and the variable frequency which has been perceived as just noticeably different. Relative difference limen may be defined as the ratio between the just noticeable difference and the base frequency to which it was compared. In this review, as well as in the section reporting measurements obtained by the present investigator, difference limen for frequency values are reported as absolute values in order to make

comparisons among studies easier. The abbreviation DLF is frequently used to indicate difference limen for frequency.

In reviewing the research prior to the use of electro-acoustical equipment, Vance (1914) provided a comprehensive review of the few studies that were reported. The following excerpts are taken from that review.

The first adequately described experiment of frequency DL's was made by Delezenne in 1827. He had a string 1,147 mm long, tuned to 120 Hz. A bridge placed at the middle gave him two halves, each tuned to 240 Hz. He found that good subjects, under the best conditions, could detect a difference in pitch if the bridge was moved 1 mm toward one end. That meant a limen of 0.42 Hz. Practically all of the subjects could notice the difference of 0.84 Hz when the bridge was moved 2 mm.

Preyer (1876) used an elaborate set of reeds constructed by Appunn. He confirmed results obtained by Delezenne and Seebeck. The limen that he reported was not a statistical quantity but the least difference observed under optimal conditions. Up until this time psychophysical method had not been used.

Luft (1888) used tuning forks with sliders to alter their pitch, and employed the method of limits. Max Meyer

(1898) objected to the method of limits for this purpose, and used tuning forks to determine the limens by the method of right and wrong cases. He only reported the frequency of right cases. These two studies introduced psychophysical method but were defective in that the tuning fork was actuated manually and they failed to control the intensity of the blow.

Stucker (1908) used forks up to 522 Hz, strings for 870 and 1740 Hz, and the Galton whistle above 3100 Hz. Instead of testing maximal sensitivity, he concerned himself with individual differences, with special interest in the musical training of his subjects. There is no evidence that he used a psychophysical technique.

Vance (1914) likewise concerned himself with individual differences and presented data for 50 subjects. He used tuning forks as a sound source, carefully and lightly struck, and measured limens by the method of right and wrong cases with the equal category excluded. Table 1 presents pertinent DLF values reported by these investigators. A review of these data reveals very small values for difference limen for frequency. Apparently the reason that these small DLF's were obtained was that transients and harmonics were produced whenever tones had an abrupt onset, such as when a tuning fork was struck sharply. These transient sounds produced auditory cues which aided in the detection of small incremental changes. A second weakness of the early studies

TABLE 1

DLF SCORES FOR NORMAL HEARING SUBJECTS PRIOR TO THE ADVENT OF ELECTRO-ACOUSTICAL EQUIPMENT (AVERAGE VALUES OF ABSOLUTE SENSITIVITY)

Investigator and year		Stimulus Source	Frequency Measured																		
			32	64	100	128	130.5	200	256	261	400	435	500	512	600	870	1000	1024	1200	1740	2048
Preyer	1876	Reeds											.3				.5				
Luft	1876	Tuning Forks		.15		.16			.23					.25				.22			.36
Meyer	1898	Tuning Forks			.54			.25			.28				.24				.69		
Stricker	1908	Tuning Forks Strings Whistle					1.0			1.3		1.4				2.5				7.7	
Schaefer	1910	Tuning Forks	3.4	2.9		1.3			1.5					1.8							6.7
Vance	1914	Tuning Forks		3.4		1.4			1.4					1.8				3.3			5.7

was that although there was good representation of frequencies tested, there was no ready means of controlling or measuring the intensity of the sound stimulus nor frequency increments.

The first investigator reported to use electro-acoustical apparatus for frequency difference limen measurements was Knudsen (1923). His stimulus was provided by a telephone receiver activated by a vacuum tube oscillator. He studied the frequency range of 50 to 6400 Hz. Twelve observers listened for a decreasing warble effect in the continuous tone to which they were listening. The threshold was the level at which the warble was no longer heard. Reporting his results as relative DLF he was the first researcher to note that the relative DLF decreased from 0.01 at 50 Hz to 0.003 at 600 Hz and then remained relatively constant through the 3200 Hz range.

In 1931 Shower and Biddulph provided the classical results through the use of thermionic oscillators. They objected to the hand-struck tuning fork because as previously mentioned, this method of activation introduces overtones and transients that can become, instead of the fundamental, the basis of the judgement. They chose to vary the frequency gradually, changing the properties of the circuit according to a smooth sinusoidal function of frequency change which was mechanically controlled. They reported that the smallest limens were obtained by a

frequency change of two times per second. They obtained the DLF by starting with equality and increasing the difference until there was a just noticeable difference. Five young subjects were tested using the range of 31 through 11,700 Hz. Several intensity levels were used and the sensation levels ranged from 5 dB to maximum tolerance for a given frequency. Their major conclusions were:

1. Observations on the relative DLF showed approximately constant value from 500 through 8000 Hz.
2. The DLF varied inversely with the sensation level as observed according to absolute DLF values.
3. The size of the DLF for frequencies below 500 Hz was due to the presence of transients in the signal.
4. The DLF was smaller when measured binaurally as compared with monaural measurements.
5. Monaural bone-conduction scores were smaller than air-conduction scores on the same ear.

In 1948 and 1952, Harris published two research articles in the area of pitch perception of particular interest in the present study. Initially, he was concerned with the effect of ambient noise on DLF's. He measured the DLF for 500 and 800 Hz in quiet and in the presence of complex masking noise. The DLF's obtained in quiet were 3.61 and 3.33 for 500 and 800 Hz, respectively, and 4.19 and 6.11 in noise. In 1948 he reported that if a signal tone was

presented at a level 15 dB greater than the noise level the pitch discrimination thresholds were as efficient as those obtained in a quiet environment. Table 2 presents the DLF scores obtained by Knudsen, Shower and Biddulph, and Harris. DLF data are also included in Table 2 that were obtained from studies whose primary objective was measurement of DLF in pathological ears but which included data on "normal-hearing" subjects in addition to their clinical populations.

The first comprehensive study of the DLF in non-normal ears was reported by Shutts in 1950. He compared the DLF's of a group of 20 normal hearing subjects with a mean age of 30 years with a group of 20 subjects who demonstrated sensorineural losses. The mean age of the sensorineural subjects were 37 years. The frequencies of 500, 1000 and 2000 Hz were studied at sensation levels of 10, 25, and 45 dB. Shutts reported that the DLF's were consistently larger for the sensorineural subjects. As previously mentioned, the data for the 20 normal-hearing subjects included in this study are presented in Table 2.

In 1951, Hayes conducted a study to explore the question, "If phonemic regression is superimposed on perceptive hearing loss is there a concomitant disturbance in pitch discrimination?" He compared the DLF size with the ability to discriminate speech in three groups of subjects all exhibiting sensorineural hearing losses at about a 46 dB level. His first group consisted of 14 subjects under 50

TABLE 2

DLF SCORES FOR NORMAL-HEARING SUBJECTS FOLLOWING THE ADVENT OF ELECTRO-ACOUSTICAL EQUIPMENT
(Values Reported as Absolute Units)

Investigator and Year	Method Used	Sensation Level	Measure Employed	Number of Subjects	Frequency Measured					
					250	500	1000	2000	3000	4000
Knudsen 1923	Electro-Acoustical Apparatus Sinusoidal Mod.	20 dB	MEAN	12	1.0	1.6	3.0	6.0	9.0	
Shower and Biddulph 1931	Thermionic Oscillators Sinusoidal Mod.	40 dB	MEAN	5	2.5	2.6	3.6	3.8		9.2
Harris 1952	Constant Stimuli	30 dB	MEDIAN	328	1.3	2.1	3.6	8.3		21.1
Shutts 1950	Constant Stimuli	45 dB	MEAN	20		3.3	4.5	8.9		
Meurmann 1954	Sinusoidal Modulation	20 dB	MEAN	52	3.0	3.0	6.7	12.3		33.7
Konig 1957	Constant Stimuli	40 dB	MEAN	10	1.6	2.4	3.6	6.8	12.3	21.2
Filling 1958	Sinusoidal Modulation	20 dB	MEAN	10	1.8	3.4	6.0	12.0		23.0
McCandless 1959	Method of Limits	45 dB	MEAN	9		2.3		4.4		9.6
Ross, Huntington, Newby, and Dixon 1963	Constant Stimuli	30 dB	MEAN	31		6.0		19.4		64.0
Rupp 1964	Constant Stimuli	25 dB	MEAN	22	4.8		7.5		21.8	30.9

years-of-age who had good phonetic discrimination. A second group of 15 subjects was over 50 years-of-age and had good discriminatory abilities. The third group of 14 subjects was over 50 years-of-age and had poor discrimination ability. Conclusions reached by Hayes included:

1. In terms of absolute difference limen the two groups with good discrimination ability were equivalent populations. Age alone was not responsible for a modification in the difference limen for frequency.
2. The older group of subjects who reflected "phonemic regression" did not demonstrate that poor discrimination ability was invariably associated with a poor DLF score. While it was true that poor DLF may have been a factor in poor speech discrimination, it was also true that those with poor discrimination might have had DLF values which were better than average.
3. The older group with poor discrimination ability did have larger DLF values than the two groups with good phonemic discrimination ability. This may have been a primary factor in some phonemic regression.

His main conclusion was that when "phonemic regression" was superimposed on sensorineural hearing loss, a concomitant disturbance of the DLF did not appear in all cases.

In 1954, Meurmann employed a method of continuous sinusoidal modulation to determine the DLF at 250, 500, 1000 2000, and 4000 Hz. The test tone was modulated two times per second. He obtained measures on five groups of subjects whose hearing had been categorized as:

1. Normal
2. Conductive loss
3. Sensorineural loss (young subjects)
4. Sensorineural loss (old subjects)
5. Meniere cases

The DLF scores obtained for 52 normal hearing subjects for 250, 500, 1000, 2000, and 4000 Hz were 3.0, 3.0, 6.7, 12.3, and 33.7 Hz, respectively.

In 1957, Konig compared the DLF scores of 70 subjects across an age range of 20 to 89 years. The older groups who were included in the study had to manifest a "normal" presbycusic curve. His investigation was concerned with the effects of frequency and loudness on pitch discrimination for a group of 10 untrained young observers and the differential sensitivity to frequency for various age-groups of non-clinical subjects. A discontinuous method of tone presentation was used. The tones were of 1.4 second duration and were separated by 1 second silent intervals. The DLF's were measured for seven frequencies at a sensation level of 40 dB. Included in his conclusions were:

1. The size of the absolute difference limens gradually diminishes with frequency (i.e., as

the frequency becomes lower the limens become smaller).

2. The sensitivity to frequency differences increases with sensation level up to a level of 40 dB above threshold, above which the size of the limen remains practically the same when the sound intensity increased.

3. Sensitivity for DLF began to be affected in all audible frequency ranges as early as the fourth decade.

4. There was an abrupt drop in DLF awareness after the sixth decade.

In 1957, Filling reported a study of DLF involving five groups of subjects with different auditory sensitivity. These groups included:

1. Ten normal-hearing subjects.
2. Eighteen patients with perceptive hearing losses.
3. Nine with mixed losses.
4. Ten conductive losses.
5. A group of presbycusics.

A modulated tone was used as the signal source. The tone was presented at 20 dB sensation level with two modulations per second. The subject reported when he detected the presence of a warble effect in the continuous signal, Filling's conclusions were:

1. For the group with sensorineural loss, there was an increase in the DLF values at the high end of the frequency scale with less pronounced changes in the DLF at the low end of the scale. The values of the DLF tended to increase in relationship to the severity of the loss.
2. For the group showing mixed conductive and perceptive losses, the DLF values were larger than normal for all frequencies tested with very large DLF values for the frequencies at the high end of the frequency scale. In opposition to the sensorineural group, the values of the DLF were not directly related to the severity of loss.
3. For the group with conductive hearing losses, the DLF values were normal or only slightly increased and the DLF results were not dependent on the severity of the hearing loss.

In 1959, McCandless studied the DLF in three groups of subjects whose hearing was classified as:

1. Normal.
2. High-frequency loss localized near 4000 Hz.
3. Mild to moderate gradually sloping perceptive type loss.

His major conclusions were:

1. The perceptive group had much larger DLF than the normal-hearing or high-frequency loss group.
2. A relationship between degree of hearing loss and DLF size was not demonstrated.

One of the sub-goals of a study reported by Ross, et al. in 1963 was the DLF measurement of a group of normal-hearing subjects and a group of sensorineural losses. Results of their study suggested that:

1. DLF was related to age.
2. DLF was correlated with the pure tone threshold in that larger DLF values were associated with greater hearing losses.
3. DLF scores were significantly higher for the hearing-impaired group.

In 1964, Rupp investigated the differential sensitivity for frequency in normal-hearing subjects and for subjects exhibiting nine different otological classifications of impaired hearing. His conclusions included:

1. Subjects with sensorineural and retrocochlear hearing losses were less sensitive to frequency change, as tested over a wide frequency range, than were subjects who demonstrated normal hearing ability.
2. The median DLF scores showed large observable differences between groups with conductive

losses and groups with sensorineural or retrocochlear losses.

3. Highly significant relationships between bone-conduction thresholds and the DLF size were found as group values were compared.
4. As group PB max scores were compared with the group DLF performances at 1000 Hz, a significant relationship was found. The size of DLF became larger, group by group, as the difficulty in understanding speech increased.
5. He could find no relationship between size of DLF and age.
6. The development of a usable DLF test could eventually lead to its wide use in diagnostic centers.

Table 3 contains the mean DLF score for presbycusic subjects reported by Hayes, Meurmann, Konig, Filling, and Rupp. Only Konig's study was designed specifically to determine the relationship of DLF and age. Hayes, Meurmann, Filling, and Rupp included "presbycusics" in their studies as subgroups, or in the case of Hayes, for the purpose of investigating a particular phenomenon--phonemic regression.

Of the five investigators who reported DLF's for presbycusic subjects only two included discrimination tests. Hayes, who used PB-50 discrimination lists to test the

TABLE 3

MEAN DLF SCORES FOR OLDER SUBJECTS REPORTED BY FIVE INVESTIGATORS

Investigator and Year		Age Group	Frequency Measured					
			250	500	1000	2000	3000	4000
Hayes	1951	50+		7.6	14.4	24.6		
		50+		15.5	18.7	31.5		
Meurmann	1954	40-80	4.4	6.1	11.1	24.6		60.9
Konig	1957	50-59	3.7	5.0	7.8	16.4	32.1	64.0
		60-69	5.6	7.1	10.2	22.2	39.0	89.2
		70-79	6.0	7.8	11.8	28.6	48.0	
Filling	1958	50-59	2.4	6.0	12.5	22.9		79.8
		60-69	3.3	6.5	12.4	25.0		84.0
		70-79	2.8	5.7	13.2	29.1		80.0
Rupp	1964	55-65	8.6		17.4		55.0	126.3
		66-81	13.3		30.2		80.3	127.3

discrimination abilities of his two sensorineural groups, concluded that when poor discrimination ability (phonemic regression) was superimposed on sensorineural hearing loss, a concomitant disturbance of the DLF did not appear in all cases. He did not include a normal-hearing group as a control but used Shutt's normative data since they both utilized the same psychophysical technique. Rupp administered PB lists, taken from the group developed by the psycho-acoustics laboratory and reported by Eagan, to test the discrimination of the nine otologically classified groups in his study. He compared only the DLF obtained at 1000 Hz by his groups with the PB max scores. He reported that as group scores were compared a significant relationship was found. As the size of the DLF became larger, group by group, the difficulty in understanding speech increased.

A review of the studies reporting data on frequency difference limen would seem to warrant the following conclusions:

1. In the normal-hearing ear an exact DLF value may not exist. The method of measurement and amount of practice may be expected to influence the scores; therefore, a comparison of DLF's obtained by different groups within a study would probably be of more value than a comparison of data obtained through use of different psychophysical methods.

2. In the normal-hearing ear there is a tendency for the size of the absolute DLF to increase with the frequency under test.
3. Intensity plays an important role in the determination of the DLF. Within each method, the DLF decreased in size from near threshold to about 40 dB above threshold. Rupp has suggested that a sensation level of 20 dB may be optimum for frequencies of 1000 Hz and higher.
4. There is disagreement as to the effect of age on DLF size. Konig and Ross et al. report a significant relationship while Rupp does not.
5. The limited data reported by Hayes and Rupp on the relationship of discrimination scores and DLF for presbycusic subjects are inconclusive and will not permit conclusions to be drawn at this time.
6. There is evidence that pathological ears demonstrate different sensitivity to frequency change, depending on the type of disorder.
7. Since previous research did not show specific unalterable results, additional study should have value. If the essential requirements for a study in pitch perception is fulfilled, the information obtained should add to the knowledge of difference limen for frequency.

Difference Limen for Intensity

The smallest change in intensity that can just be detected by a listener is referred to as the difference limen for intensity. The abbréviation DLI is frequently used to indicate difference limen for intensity.

The pre-electronic age of loudness discrimination has been summarized by Knudsen (1923) who collected DLI data in addition to that already presented on DLF. He obtained DLI values for pure tones that were smaller than those of most subsequent experiments. Apparently this was due to the fact that he used an abrupt transition from one intensity level to another, and therefore the listener could base his response not only on the change in intensity but also on the by-products of the abrupt changes, such as added frequencies.

Riesz (1928) overcame this problem in stimulus control by mixing the output of two oscillators at slightly different frequencies and obtaining a tone of intermediate frequency whose intensity fluctuated at a rate that corresponded to the difference between the two frequencies. The listener was required to judge whether the tone sounded constant in loudness or whether its loudness fluctuated, that is, whether beats were heard. The changes in intensity were made gradually and periodically. The rate was about three beats per second. Figure 1 shows the change in DLI as a function of frequency for different sensation-levels. It is to be noted that at around 40 dB SL there is little

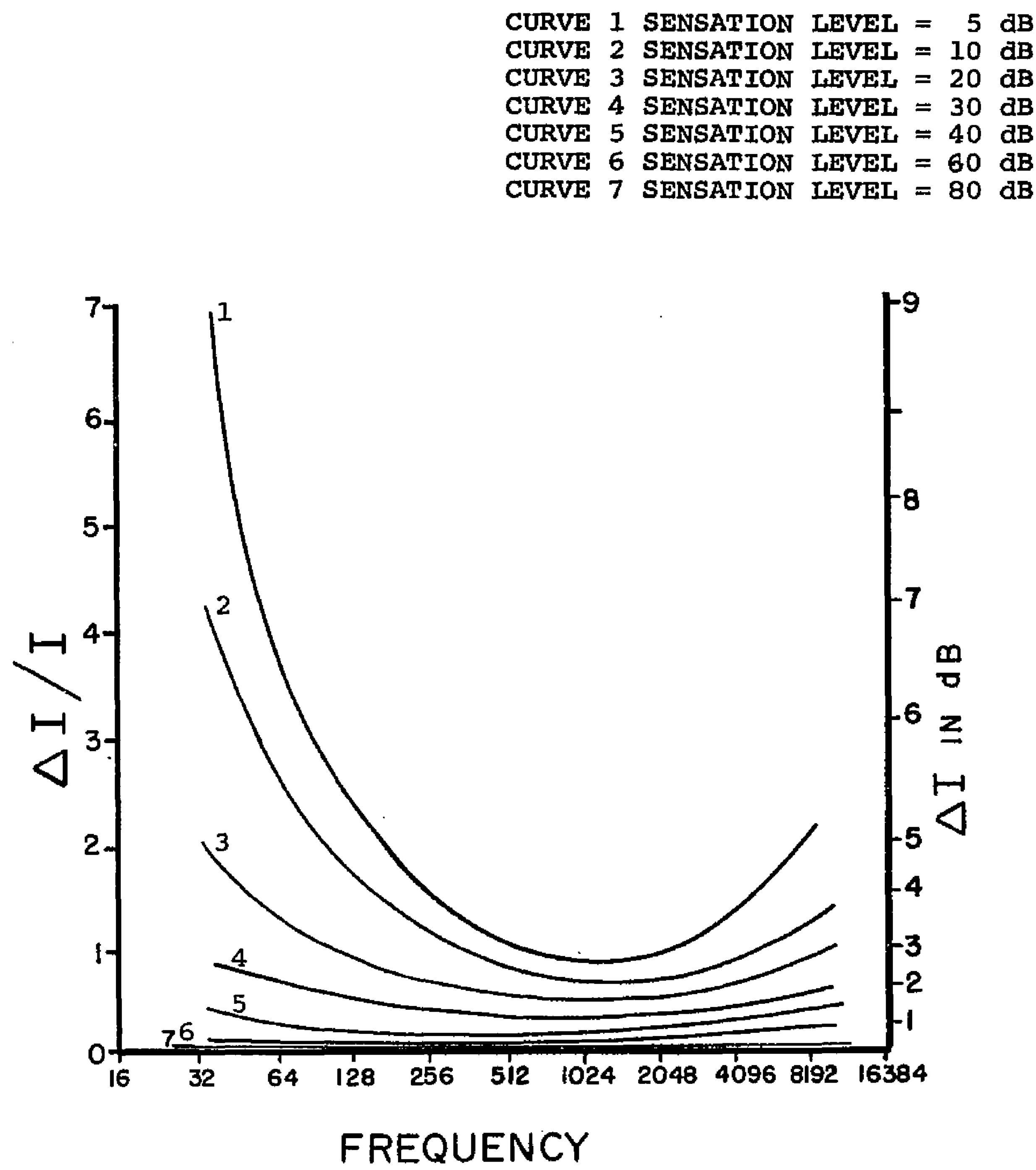

FIGURE 1. CHANGE IN DLI AS A FUNCTION OF FREQUENCY FOR DIFFERENT SENSATION-LEVELS. (RIESZ, 1928)

difference in DLI's for the various frequencies. Also at high sensation levels the absolute DL for all frequencies was never larger than 3 dB. Although subsequent experiments have not all agreed with Riesz's results, particularly with the small size of the DL's obtained, Harris (1963) in his very comprehensive study of DLI stated that ". . . there is very little effect of overall loudness except at the very weakest sensation-levels."

Renewed interest in difference limen for intensity was precipitated in the late 1940's and early 1950's due to the fact that several investigators (Halm, 1949; Denes and Nauton, 1950; Bangs and Mullins, 1953) reported that certain types of hearing losses are apparently accompanied by unusually keen differential sensitivity. Initially, these studies were concerned with determining whether or not recruitment was present for the listener. Recruitment may be defined as a more-rapid-than-usual increase in loudness in relation to the actual change in magnitude of the physical dimension of intensity. In many studies it was assumed that recruitment was reflected in unusually small difference limens for intensity.

In 1947, von Békésy described a new audiometer which provided for a slow continuous change in the test frequency from low to high and a continuous change in the intensity of the test tone. A graph was made by the listener pressing a button to control the intensity output. The excursion

between the just-heard and the just-not-heard intensity gives an indication of the listener's variability about his absolute threshold. von Békésy showed that a small variability was associated with recruitment. This variability was interpreted as an extrapolated measure of the DL at threshold. Hirsh et al. (1954) have questioned whether this assumption is true or not. They contend that variability about an absolute threshold is not a true measure of DL.

In 1948, Luscher and Zwislocki published their first paper on the measurement of differential sensitivity with a tone whose intensity was alternated between two levels by an amplitude modulator. This method was actually a modification of the technique used by Riesz. In their research, intensity was changed quite abruptly. The normative data of Luscher and Zwislocki compare well with those of Riesz, being large at low intensities and becoming smaller at high intensities. They recommended that the DL measurement be made at 40 dB sensation level since the DL does not change substantially if intensity is increased further, or if the frequency is changed. Results of their study suggest that at 40 dB sensation level a normal DL would lie between 10 and 16 percent modulation, a partially recruiting DL would be somewhere between 6 and 8 percent, and complete recruitment would be indicated by a DL of less than 6 percent.

Attempts to validate Luscher and Zwislocki data were made by Liden and Nilsson (1950) and Lund-Iversen (1952).

Liden and Nilsson reported that the range of the DL values both in normal subjects and clinical populations were too large to assign certain values to different diagnoses. Lund-Iversen compared the DL measurements with recruitment results obtained from loudness-balance tests. The loudness-balance results differentiated among diagnostic categories; however, the DL measurements were equivocal and more or less the same from group-to-group.

In 1948, Doerfler made a comparison of the differential sensitivity of a group of normal subjects with that of a group of patients with perceptive deafness. He used a sinusoidal modulation similar to that of Riesz' study and reported the DL's for the perceptive group to be between 0.5 and 0.1 dB lower than that of the normal subjects.

In 1952, Jerger utilized a modification of the Luscher-Zwislocki technique to measure the DL for intensity at 15 dB and 40 dB sensation level. In his study, however, instead of permitting a rapid change between the modulated and unmodulated tones, Jerger made a gradual transition from no modulation to that value that appears to be pulsing. He later modified his technique so that the difference between the DL obtained at 10 dB sensation level and 40 dB sensation level could be investigated in terms of their differences.

The studies reported up to this point utilized a tone whose amplitude is continuously changed about two or three times per second. However, according to most

definitions of the DL for intensity, a listener should compare two tones that differ with respect to intensity and judge whether they have the same or different loudness. Normative data for this type of judgment was provided by Dimmick and Olson (1941). They reported a DL 50% of about 4.5 dB at 10 dB SL, but even at the loudest levels their DL's were never smaller than 2.3 dB. The clinical use of this DL technique was first proposed by Denes and Nauton (1950) who referred to Luscher and Zwislocki's work and pointed out that sinusoidal modulation introduces sidebands such that the patient is asked to judge not only on the basis of cues for loudness but also on the basis of cues for pitch and "quality." This criticism of intensity modulation techniques is similar to that made by Harris (1952) and Kock (1937) in reference to frequency modulation.

In 1954, Hirsh, Palva and Goodman reviewed the problems of previous DL studies and chose for their investigation a variant of the constant method in which the patient had to judge whether two discrete tones were different or same in loudness. These investigators obtained data at 5, 25, and 40 dB sensation levels for 22 ears showing recruitment and 11 ears not showing recruitment. They concluded that measures of intensity DL were almost useless in identifying recruiting-type ears because of the large overlap among their groups. One interesting aspect of their investigation, however, was that in attempting to narrow

down characteristics of hearing that are related to the size of DL they attempted to separate within the recruitment category patients with high speech discrimination scores from those with low discrimination scores. The same was done in the nonrecruitment group. They concluded that such a separation yielded no constant relation to the size of the DLI. It was felt, however, that a low discrimination score was associated with recruitment for cases in which recruitment was accompanied by a hearing loss for speech of more than 20 dB.

The Denes-Nauton test for DL measurement is an above-threshold method in which the DLI is found by applying two sounds of the same frequency to the same ear in alternate fashion. Initially the two tones are considerably separated in intensity (10 dB) and are gradually brought together. The patient signals when he thinks that the two tones are equal in loudness, then when one is not as loud as the other. This sound is then increased until it sounds just perceptibly louder than the other. The difference limen is the difference between the point of less loud to just loud. Measurements are made at 4 and 44 dB sensation levels. Results of their investigation led them to contend that the DL decreases with intensity for nonrecruiting ears but either increases or remains constant with intensity for recruiting ears. Several contradictions between the results of Denes and

Nauton and other investigators have been pointed up. One of the most notable differences was that some of the DL values of Denes and Nauton obtained at 44 dB sensation level in recruiting cases are higher than those obtained for conductive cases, a result which completely contradicts the results of Luscher and Zwislocki and others who tested at 40 dB sensation level.

It seems apparent at this time that the results of any measure of differential intensity sensitivity will depend upon the technique used to measure it. It is further noted that there are not just two techniques--one for amplitude modulation and the other for two-tone comparison--but rather there are several techniques due to the fact that patterns of amplitude modulation are not all the same, nor are the time relations in the two-tone comparisons the same. As Harris (1963) pointed out, loudness-memory and loudness-modulation do not deal with the same psychoacoustic trait.

A review of these studies reporting data on difference limen for intensity would seem to warrant the following conclusions:

1. The size of the DL for intensity is extremely dependent on the method by which it is measured. For this reason a comparison of absolute sizes of DLI obtained for different groups within the same study would be of more value than a comparison of data obtained through use of different psychophysical methods.

2. Recruitment may or may not be associated with an unusually small difference limen for intensity.
3. The differential sensitivity of the ear increases with the intensity at the same time as its dependence upon the frequency decreases. In the normal ear, maximum sensitivity is reached at about 40 dB sensation level.
4. Little data have been presented regarding the relationship of DLI and discrimination ability. Hirsh _et al_. (1954) could not demonstrate a constant relationship between speech discrimination scores and DLI. This conclusion was supported by a more recent investigation by Ross _et al_. (1963).

Difference Limens for Both Frequency and Intensity

A review of the literature reveals three studies that have included both a measure of DLI and DLF as part of their investigation.

In 1954, Meurmann studied difference limen for frequency in five groups of subjects whose hearing had been categorized as normal, conductive loss, sensorineural loss (young subjects), sensorineural loss (old subjects), loss associated with Meniere's disease and also included a measure of difference limen for intensity. Results of this investigation led the author to conclude that ". . . in end-organ lesions the difference limen of frequency increases in

contrast to the difference limen of intensity which often diminishes." Half of the test subjects in the group of older subjects with neural deafness had distinctly subnormal DLI values at high frequencies. However, these two groups did not differ clearly with regard to DLF. In a few cases in which the DLI appeared normal the DLF values were distinctly increased but there were also cases in which in spite of distinct recruitment, the DLF was only slightly increased. It should be noted that the DLI for each patient in this study was determined by the width of the envelope of a Békésy audiogram. As already stated, Hirsh et al. (1954) have contended that a Békésy tracing does not measure a difference limen but rather measures the variability about the absolute threshold. Ross et al. (1963), who investigated auditory parameters in a group of hearing-impaired subjects, included measurements of DLI and DLF for a group of normal-hearing subjects whose ages ranged from 30 to 56 years of age. These investigators used a discontinuous method of stimulus presentation and obtained measurements at 500, 2000 and 4000 Hz. They stated that their normal-hearing subjects who reported a wide or narrow DL for intensity at 500 and 4000 Hz in the right ear also tended to demonstrate a wide or narrow DL for frequency at these two frequencies. This relationship was not evident at 2000 Hz. In reviewing data for the left ears the relationship was significant only at 500 Hz. For their hearing-impaired group, left ear only, a

significant relationship between DL's for frequency and intensity was noted at 4000 Hz. These investigators felt that this single correlation could have occurred by chance.

More recently Rupp (1964), who investigated frequency difference limens for nine groups of subjects with different otologically classified ears included a SISI test for each of his subjects at 1000 and 4000 Hz. He reported that subjects who obtained low SISI scores at 4000 Hz also evidenced small DLF scores. This relationship was statistically significant at 4000 Hz but not at 1000 Hz. He did not compare the SISI values with discrimination scores obtained in this study.

Summary of the Findings of Previous Studies Reporting Data for Aged Subjects Regarding DLF, DLI and Speech Discrimination

This section contains a brief summary of those studies reviewed by the present investigator which seemed to be particularly significant to the present investigation.

Six previous investigators included measurements of difference limen for frequency for older subjects in their studies. These were Hayes (1951); Meurmann (1954); Konig (1957); Filling (1958); Ross *et al*. (1963); and Rupp (1964). Of these six, three reported the relationship between DLF and age. Only Konig's study was designed *specifically* to determine the relationship of DLF and age. However, Ross *et al*. and Rupp did look at this relationship as a sub-goal

of their studies. These three investigators were not in agreement as to the relationship between DLF and size and age. Konig and Ross *et al*. report a significant relationship while Rupp's data did not demonstrate a significant relationship. It is to be appreciated, however, that these studies utilized different psychophysical techniques and different subject selection criteria. The present review of the literature revealed no data on DLI size and age.

Three investigators--Meurmann, Ross *et al*., and Rupp--reported both a measure of DLI and DLF as part of their investigation. Meurmann (1954) stated that in cases with end-organ lesions small DLI's are accompanied by large DLF's. Ross *et al*. (1963) reported that there was a tendency for their normal-hearing subjects who demonstrated small or large DLI's to also demonstrate small or large DLF's at 500 and 4000 Hz. This relationship between DLF and DLI was not observed at 2000 Hz. Rupp (1964) reported that subjects who obtained low SISI scores, at 4000 Hz only, also evidenced small DLF scores. His findings are not in disagreement with Meurmann's data although they are stated differently. That is, a low SISI score would suggest the absence of the ability to detect small changes in intensity. Therefore, it may be assumed that the DLI's were average *or* possibly large. Although this reasoning would not contradict Meurmann's findings it would likewise not substantiate them.

Of the investigators who reported DLF data for _presbycusic_ subjects only two included discrimination tests. Hayes (1951), who used PB 50 discrimination lists to test his two sensorineural groups, concluded that when poor discrimination ability was super-imposed on sensorineural hearing loss, a concomitant disturbance of the DLF did not appear in all cases. Rupp (1964) compared only the DLF obtained at 1000 Hz with PB max scores. He reported that as group scores were compared, a significant relationship was found. That is, as the size of the DLF became larger, group by group, the difficulty in understanding speech increased. It would appear that these limited data are inconclusive regarding the relationship of DLF size and discrimination ability.

Hirsh, Palva and Goodman (1954) attempted to separate within a recruitment category patients with high speech discrimination scores from those with low discrimination scores. The same was done in a nonrecruiting group. They concluded that such a separation yielded no constant relation to the size of the DLI. They did feel, however, that low discrimination score that was accompanied by hearing loss for speech of more than 20 dB would be associated with a small DLI. Results of an investigation by Ross _et al._ (1963) supported Hirsh's conclusion that the size of the DL for intensity was not related to the speech discrimination score.

None of the studies reviewed had as its major objective the investigation of the relationships of all four of these parameters--difference limen for frequency, difference limen for intensity, speech discrimination and age.

Histopathology of "Presbycusis"

Several investigators have reported data obtained from studies whose purpose was to correlate structural changes with auditory behavior of older patients.

The first report of a comprehensive study of the temporal bones of older patients was made by Crowe, Guild, and Palvogt (1934). They sectioned the temporal bones of 79 aged patients with high-tone hearing loss. Their findings revealed degeneration of the spiral ganglion in the basal end of the cochlea and atrophic changes in the stria vascularis in some areas of the cochlea.

In 1937, Saxen (Schuknecht, 1955) likewise reported atrophy of the spiral ganglion in the basal turn of the cochlea. Angiosclerotic changes of the inner ear characterized by degeneration in the sub-epithelial tissue of the membranous cochlea was also observed.

More recently Schuknecht (1955) presented findings obtained from a number of histopathologic studies of aged temporal bones. He grouped his findings into several groups including those temporal bones characterized by atrophy of the organ of Corti and the spiral ganglion of the auditory

nerve along the first few millimeters of the basal coil of the cochlea; atrophy of the stria vascularis along the entire length of the cochlea duct; and stiffening and calcification of the basilar membrane throughout the cochlea.

In 1965, Hansen and Reske-Nielsen reported the histopathology of 12 elderly persons. They sampled the entire auditory system of their subjects. Their findings indicated that the majority of the histopathologic changes were in the central auditory pathways at the level of the dorsal cochleanuclei, the inferior colliculi, and the auditory cortices of the temporal lobes. They noted few pathological changes in the temporal bones. In correlating the auditory behavior with structural changes they concluded that the amount of hearing loss observed in these patients could hardly be due to the small histopathologic changes observed in the cochlea but was due also, perhaps primarily to the pathological processes in the brain.

In 1967, Feldman hypothesized that if a generalized central factor were operative in the discrimination problem experienced by "presbycusics" the speech function score would show significant correlations with tests of central function. He investigated visual, tactile, and auditory reaction time as it related to speech discrimination. He reported high correlations between discrimination scores and pure tone thresholds at 250 and 1,000 Hz and between discrimination scores and tactile and auditory time. It was

his conclusion that the discrimination problem of the "presbycusics" is due to a composite of both peripheral and central factors.

The data presented by Hansen and Reske-Nielsen and more recently by Feldman show increasing evidence that some, if not the greater part, of the discrimination problems accompanying age are due to generalized central nervous system dysfunction.

EXPERIMENTAL HYPOTHESES

The following specific hypotheses were investigated:

1. There is no significant relationship between DLF and Aging.
2. There is no significant relationship between DLI and Aging.
3. There is no significant relationship between DLF and Speech Discrimination.
4. There is no significant relationship between DLI and Speech Discrimination.
5. There is no significant relationship between DLF and Pure Tone Thresholds.
6. There is no significant relationship between DLI and Pure Tone Thresholds.
7. There is no significant relationship between DLF and DLI.

CHAPTER II

METHOD

<u>Subjects</u>

Fifty-four subjects were used in this study. The total number of subjects was composed of two major age groups as follows: 20-29 and 45-79. The younger group consisted of 12 subjects and served as a control group. Data obtained from these subjects were compared with that reported for young normal-hearing subjects in other studies. The 45-79 year group (experimental group) consisted of 42 subjects. The following half-decades consisted of six subjects each: 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, and 75-79. The males and females in both the control and experimental groups were equal. No person was selected if he had taken part in previous difference limen experiments.

<u>Case history</u>. In order for a subject to be included in the study his case history had to reveal that he met the following criteria:

1. No knowledge of a hearing loss prior to age 50 and/or that any hearing loss experienced after age 50 was gradual and had not postdated drug therapy, infected ears, accident, illness or noise trauma.

2. No frequent ear infection that may have contributed to hearing loss.
3. Engaged in occupations which minimized the risk of noise injury.
4. The family history revealed little probability of hereditary sensorineural deafness.
5. The subject did not appear to be suffering from senile dementia.
6. The subject was in relatively good health.

Most of the subjects used in both the control and experimental groups were employed by the Louisiana State Department of Health. Their occupations included: health education, secretarial work, purchasing, program administration, and other similar office duties. A few of the older subjects were retirees who had previously worked as salesmen, realtors, and secretaries.

Auditory Thresholds. The subjects in the youngest group had pure tone thresholds that were within 20 dB (ISO) of audiometric zero for the frequencies of 250 - 8000 Hz. The average pure tone loss for the older subjects was on the same order as the well-known "normal" presbycusic curves (Glorig and Davis, 1961; Corso, 1962). The term presbycusic as used in reference to the subjects selected for the present study, simply refers to the reduction of auditory sensitivity that accompanies the aging process.

The audiometric curve for the older group was usually no more than 10-15 dB per octave drop across the speech frequencies (500 - 2000 Hz) and 25-30 dB per octave from 2000 - 8000 Hz. The air-bone gap was no more than 10 dB at any frequency. Figure 2 presents a composite audiogram showing the average pure tone air-conduction thresholds for subjects in various age groups. Table 4 shows the mean age, SRT, and three-frequency average for all subjects used in the present study. A Grason-Stadler speech audiometer Model 162 was used to administer the Speech Reception Threshold (SRT) and discrimination tests. This audiometer was equipped with a high-fidelity Model 86 Viking tape recorder.

All speech stimuli were presented in recorded form, using the Central Institute for the Deaf Auditory Tests W-1 and W-22 for SRT and discrimination testing, respectively. A high quality magnetic tape was used to record list W-1 (SRT) and list 2A of the W-22's (discrimination) for use in this study. The discrimination tests were administered at 40 dB above speech reception thresholds. The usual four second interval between presentation of the PB words was increased to five seconds in order to give the older patients additional response time.

Pure Tone and Speech Tests Equipment

The following equipment was used for pure tone and speech tests: TDH-39 earphones; Beltone audiometer Model

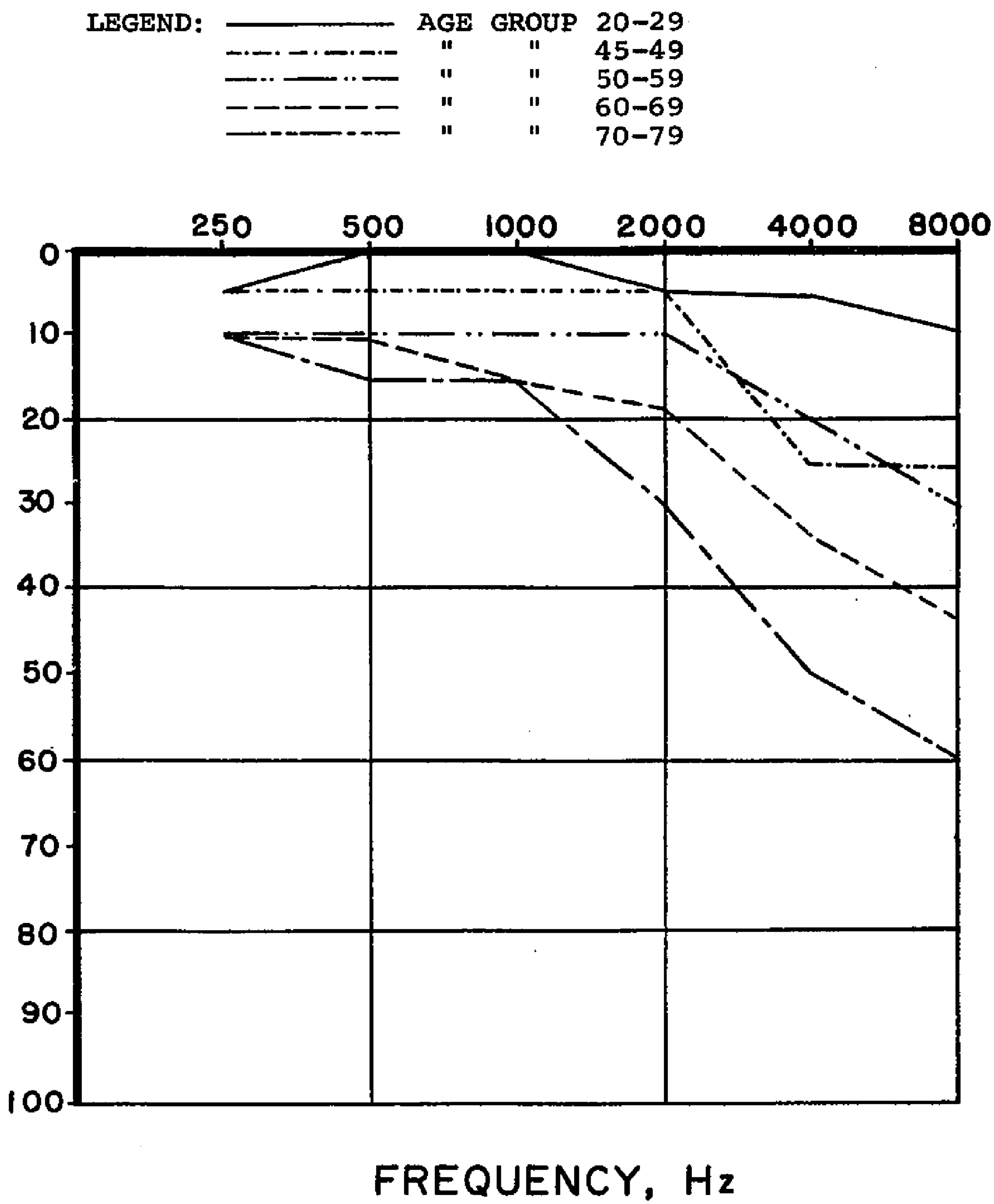

FIGURE 2. COMPOSITE AUDIOGRAM SHOWING THE AVERAGE PURE TONE AIR-CONDUCTION THRESHOLDS FOR SUBJECTS IN VARIOUS AGE GROUPS.

TABLE 4

MEAN AGE, SRT, and THREE-FREQUENCY AVERAGE FOR ALL SUBJECTS IN THE PRESENT STUDY

Group	Age	SRT	3-Frequency Average
20-24	22.5	3.0	2.5
25-29	27.2	2.0	1.0
45-49	47.3	5.3	5.0
50-54	53.5	7.2	9.0
55-59	55.2	10.3	10.0
60-64	62.3	12.0	11.7
65-69	67.7	15.3	13.3
70-74	71.7	19.3	20.0
75-79	76.5	22.3	24.2

15-C and a Grason-Stadler speech audiometer, Model 162. The acoustic output of the Beltone 15-C was checked through use of a type 2203 Bruel and Kjaer precision sound level meter, a type 1613 Bruel and Kjaer octave filter set, and a type 4132 Bruel and Kjaer condenser microphone. The sound pressure reading met the present ISO standards. The acoustic output of the Grason-Stadler speech audiometer was checked according to the GS instruction manual 162-21. The SPL reference was 22 dB. All audiometric testing was conducted in an I.A.C. sound suite, Model 1600 A.

Frequency Difference Limen Equipment Used in Previous Investigations

A review of the literature on differential sensitivity for pitch revealed two basic psychophysical methods that have been used for measurements since the advent of electroacoustical instruments. One method, which has been used by several European investigators (Meurmann, 1954; Filling, 1958), utilizes a single oscillator with a frequency modulating device that permits the rate of modulation to be gradually increased or decreased until the subject reports hearing a warble from a steady state tone. Harris (1952) felt that this technique does not lend itself well to pitch discrimination. He further stated that it has been repeatedly shown that sudden alternation of two frequencies introduced stimulus artifacts and that even with a smooth alternation artifacts may be introduced. Years before

Harris' research, Koch (1937) contended that the discrimination data obtained by an approximately sinusoidal transition from one frequency to another could be predicted from the nature of the stimulus and that the same data would be obtained by this method even if the ear were possessed of infinitely good discrimination.

A second method that has been used by numerous investigators (Harris, 1948; Shutts, 1950; Hayes, 1951; Rosenblith and Stevens, 1953; Butler and Albrite, 1956; Konig, 1957; McCandless, 1959; Rupp, 1964) utilizes two oscillators as signal sources. One is set at a base frequency by a frequency counter. The second or variable oscillator is changed in such a way that a comparison can be made by the subject as to whether the tone produced by the variable oscillator is higher or lower than that produced by the standard or base oscillator. An oscilloscope is used to determine if the two oscillators are synchronized. Synchronization is indicated by the presence of a zero lissajous figure on the scope. Also a separate interval-timer and electronic switch is used to control the output of each oscillator. A tape recorder may be utilized if taped stimuli are pre-recorded and programmed to be presented to the subject.

Frequency Difference Limen Equipment Used in the Present Investigation

Figure 3 shows a block diagram representing the equipment used in the present investigation. An inspection

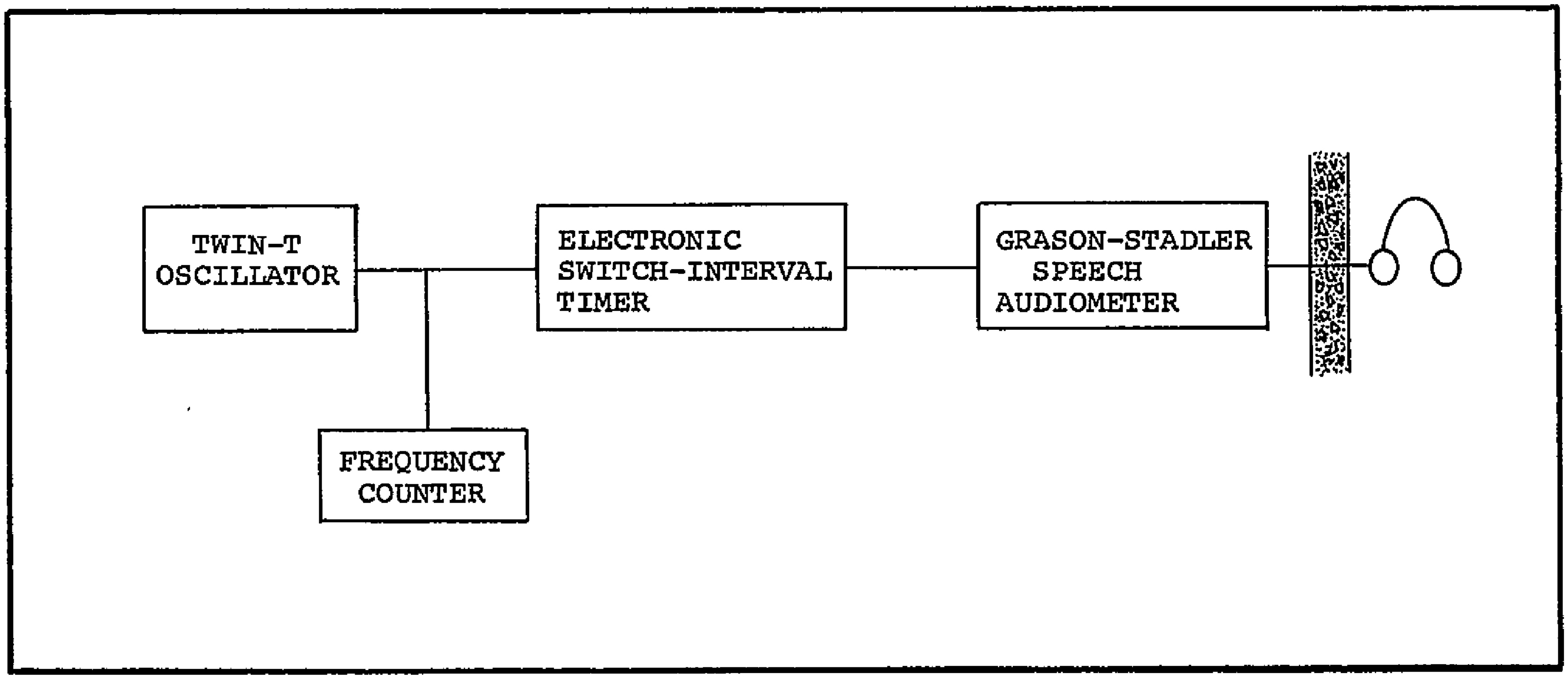

FIGURE 3. SIMPLIFIED BLOCK DIAGRAM OF THE EXPERIMENTAL APPARATUS USED FOR DLF MEASUREMENTS.

of this diagram reveals that the source for both the standard and comparison tone was provided by a single oscillator constructed specifically for use in this study. This oscillator was a one transistor, selective frequency, Twin-T type. A panel outline and a circuit diagram for this oscillator are included in the appendix. This single unit replaced the two pure tone oscillators used in previous studies which utilized a discontinuous method of signal presentation. With the Twin-T oscillator the standard tone (base frequency) may be either 500 Hz, 1000 Hz, 2000 Hz, or 4000 Hz, depending on the position of the base frequency selector. Fine adjustment of the base frequency is possible through use of four knobs attached to the base frequency potentiometers located in the rear of the oscillator. A three-position switch located in the upper right corner of the control panel provided the option of using the oscillator as simply a signal source for four frequencies (500, 1K, 2K and 4K Hz) (Manual A) or as a variable oscillator (Manual B), depending on the increment selected, or a combined automatic program controlled by an outside source. The two-position switch located in the center of the panel gave the option of presenting the standard tone first (normal) or the variable tone first (reverse). The small two-position switch located in the upper right corner permitted any increment presented at 4000 Hz to be reduced by 3 Hz. A separate single unit containing both an electronic

switch and interval timer determined (1) the rise and decay time of each signal, (2) the duration of the standard and variable tone, and (3) the interval between these two tones. A panel outline and circuit diagram for this unit are included in the appendix. This piece of equipment was constructed to replace two electronic switches and two interval timers used in several previous investigations (Harris, 1948; McCandless, 1959; Rupp et al., 1964).

The output of the Twin-T oscillator was monitored through use of a model 5211-B Hewlett-Packard frequency counter and passed through the electronic switch and interval timer and finally channeled through a Grason-Stadler speech audiometer. The volume of the signal was controlled by adjusting the attenuator of the speech audiometer to the required intensity level. The signal was presented to the subject via a TDH-39 earphone mounted on a headset with an inactive earphone on the opposite side. The experimenter monitored the presentation of the stimuli through use of a separate earphone. Some investigators (Rosenblith and Stevens, 1953; Konig, 1957; McCandless, 1959) have controlled the signal output of the oscillators directly while others (Shutts, 1950; Hayes, 1951; Rupp, 1964) have used taped stimuli. The present investigator used a direct control presentation in order to have more flexibility in signal presentation and also to avoid possible problems that could arise with the use of taped signals (i.e., tape stretching, signal distortion, etc.).

EXPERIMENTAL METHOD FOR DLF

1. Psychophysical Technique.--Rosenblith and Stevens (1953) measured DL's for frequency using both the AX and ABX methods. They found that the AX method yielded smaller DLF's provided the method was used consistently throughout a single experiment.

In the present study the DLF thresholds for criteria of 75 percent correct detection of change of frequency was determined through use of the single comparison standard procedure (AX). Each subject was required to report whether the pitch of the variable second signal (X) was higher or lower than the preceding reference (first) signal (A). Turnbull (1944) studied pitch discrimination as a function of tonal duration and reported that DLF size was largely independent of the duration for most frequencies if the duration exceeds .04 seconds. For a tone of 1024 Hz at 60 dB above threshold the effect of the stimulus duration on pitch discrimination was slight until the duration was reduced to 0.1 seconds. At 8192 Hz, he found that duration had little effect until the stimulus time became less than .25 seconds. He stated that it was almost impossible to discriminate differences at any frequencies when the stimulus tones were shorter than .03 seconds. The duration of each signal in the present study was 1.5 seconds. Konig (1957) suggests that a sound of this duration is adequate for testing frequency DL's for subjects

up to 89 years of age. Harris (1948) studied the effect of the silent interval between the comparison and variable tone on frequency DL's. He measured intervals from .1 to 25 seconds and found no significant difference in the size of the DLF. He also found that intervals as short as .06 seconds between test tones have little effect. A 1 second interval was used between the standard and variable tone (Konig, 1957). The duration of the interval between successive pairs of tones was approximately 5 seconds. The present study utilized rise and decay times of 100 and 150 msec, respectively. Results of previous experiments (Harris et al., 1948; Rosenblith, 1953; Konig, 1957), suggest that a slow rise and decay time should minimize the possibility that the ear will be responding to transients in the signal.

Listening was monaural; the best ear of each subject was tested. When both ears were identical the test ear was selected randomly. The variable signal preceded the standard tone half of the time and the base tone was presented first for half of the presentations. The order of presenting the standard or variable frequency first was determined through use of random numbers. For each presentation of eight pairs at any given increment, four pairs were presented with the standard frequency first, followed by the variable frequency or vice versa. Frequent rest periods were provided to minimize the effect of fatigue on the responses of all subjects. Particular attention was given to signs of fatigue

among the older subjects. The following paradigm represents a single stimulus sequence:

		STIMULUS		STIMULUS		
METHOD	500 Hz	A		X	510 Hz	CORRECT
AX		1.5 sec.	1.0 sec.	1.5 sec.	5.0 sec.	RESPONSE HIGHER

2. Signal Presentation.--The sensation level was set at 40 dB above threshold (Konig, 1957). Four males in the older age group reported that a 40 dB sensation level was uncomfortably loud at 4000 Hz in which case the DLF was obtained at 20 dB SL. Two of these four males were tested at 20 dB SL at both 2000 and 4000 Hz for the same reason. Two tones with a constant difference between them were presented as eight successive pairs. The difference between the standard and variable frequencies was gradually reduced until the DLF was obtained. This procedure was continued until the number of correct responses were as near as possible to six, but not less than six. The difference in Hz between the two tones when 75 percent, or six, correct responses were obtained was called the DLF with this method.

a. Test familiarization and DLF approximation.--The subjects were inexperienced in studies of this kind and also had an unknown DLF. The instructions to each subject was as follows:

At this time you will be presented with several pairs of tones. You will hear one tone, followed by a short, silent interval, then the second tone. Your job is to

> listen to the pitch of the two tones and report whether the second tone is higher or lower in pitch than the first tone. Remember you are to report higher or lower but never the same. (At this point the examiner whistled a pair of tones, and the subject indicated verbally whether the second tone was higher or lower in pitch.) Keep in mind that you are comparing the second tone of each pair to the first tone. Your only response will be higher or lower and you are talking about the second tone. Even if the two tones seem to be equal, or the same, you have to make a choice either that the second tone is higher or that it is lower.

The subjects were familiarized with the listening task by being presented three of the largest incremental pairs for a given frequency. For example, at 500 Hz the subject was presented with three pairs of 500 Hz (base frequency) and 522 Hz (largest increment). He responded higher or lower to each of the three signal presentations. If all three of his responses were correct the size of the increment was reduced in steps of 4 Hz to 518 Hz, etc. This decrease in steps of 4 Hz was continued until the subject responded incorrectly to one of the three presentations, then the test series was begun at the previous smallest increment where no incorrect response was made.

It was felt that the use of an approximation series was a factor in reducing fatigue for all subjects and the time required for listening on the test series was noticeably reduced through the use of this procedure.

b. The test series.--The number of pairs presented was dependent upon the test familiarization and approximation

series; however, for each incremental pair eight presentations were made and the size of the increment was reduced in sequence. The order of presentation of the four frequencies was determined through use of random numbers. For each of the four frequencies under observation, there were 22 incremental pairings of the test series as follows:

Increment	500 Hz	1000 Hz	2000 Hz	4000 Hz
22	522	1060	2093	4187
21	521	1057	2089	4178
20	520	1055	2084	4170
19	519	1052	2080	4161
18	518	1049	2076	4153
17	517	1046	2071	4143
16	516	1043	2067	4133
15	515	1040	2062	4123
14	514	1037	2058	4115
13	513	1035	2054	4107
12	512	1032	2050	4099
11	511	1030	2046	4091
10	510	1027	2041	4083
9	509	1025	2037	4075
8	508	1022	2033	4066
7	507	1019	2028	4056
6	506	1016	2024	4048
5	505	1014	2020	4040
4	504	1011	2016	4032
3	503	1008	2012	4023
2	502	1005	2007	4015
1	501	1003	2004	4007

In addition to the 22 increments shown, 22 additional increments were available for 4000 Hz. These increments could be utilized by switching an additional resistor into the regular resistor line. The introduction of this added resistance reduced the selected increment by 3 Hz. For example 4187 Hz could be reduced to 4184; 4178 could be reduced to 4175, etc.

c. Summary of the experimental procedure for DLF.--The DLF for a single frequency was determined as follows: Three pairs of tones (standard, followed by variable or vice-versa) consisting of the base frequency (i.e. 500 Hz) and the largest increment (i.e. 522 Hz) were presented to the listener. If he responded correctly (higher or lower) to all three presentations the size of the variable tone was reduced by 4 increments (518 Hz) and three more pairs were presented. This reduction of the variable tone was continued in 4 increment steps until the subject failed to respond correctly to one of the three pairs. At this time the test series was begun at the last increment where all three pairs were correctly identified. From this point on, eight pairs were presented to the listener at each increment. If he responded correctly to six or more (75% or greater) of the pairs the increment was decreased one step (increment) and eight more pairs were presented. This reduction was continued, one increment at a time (8 pairs) until the subject failed to respond correctly to at least 6 of 8 pairs (less than 75%). The smallest increment where the subject could obtain a 75% correct response was judged to be his DLF.

3. Recording.--The responses of each subject were recorded on a response sheet for each frequency. Responses were recorded for each subject as absolute difference limens.

Absolute difference limen was noted as the difference in cycles per second between the reference frequency and the variable frequency which was perceived as just noticeably different, according to above criteria. A copy of the response sheet is included in the appendix.

Intensity Difference Limen Equipment Used in Previous Investigations

A review of the literature on differential sensitivity for intensity revealed that just as in the case of frequency DL measurements two basic psychophysical methods have been utilized. One method, such as the one used by Reisz (1928), Doerfler (1948), and Luscher and Zwislocki (1951) utilizes a tone whose amplitude is modulated to produce intensity changes. A second technique, such as that used by Dimmick and Olson (1941), Denes and Nauton (1941) and Hirsh, Palva, and Goodman (1954) utilizes a discontinuous method of presenting two sounds of the same frequency to the same ear in alternate fashion.

Intensity Difference Limen Equipment Used in the Present Investigation

The present study used a discontinuous presentation because of the objections to the amplitude modulated technique raised by several investigators. Additionally, von Békésy (1960) has recently suggested that because of the possible effect of fatigue it is better to measure the difference limen for loudness by presenting two brief tones

in immediate succession than to use the procedure of gradually increasing the variations of a continuous tone until it becomes noticeably different.

An inspection of Figure 4 will be of assistance in understanding how the signal was presented to the listener. The output of an Eico 378 audio oscillator was monitored through use of a model 5211-B Hewlett-Packard frequency counter before being split between two attenuators by the switching action of the single unit containing both an electronic switch and an interval timer. This unit also determined:

1. The rise and decay time of each signal.
2. The duration of the standard intensity signal and variable intensity signal.
3. The interval between these tones.

The intensity of one attenuator remained constant while the other was adjusted to the desired incremental output. The signal was finally channeledtthrough a Grason-Stadler speech audiometer before being presented to the subject via a TDH-39 earphone.

The present investigator used a direct control presentation in order to have more flexibility in signal presentation.

EXPERIMENTAL METHOD FOR DLI

1. Psychophysical Technique.--The same method used for the DLF measurements (AX) was used to obtain measurements

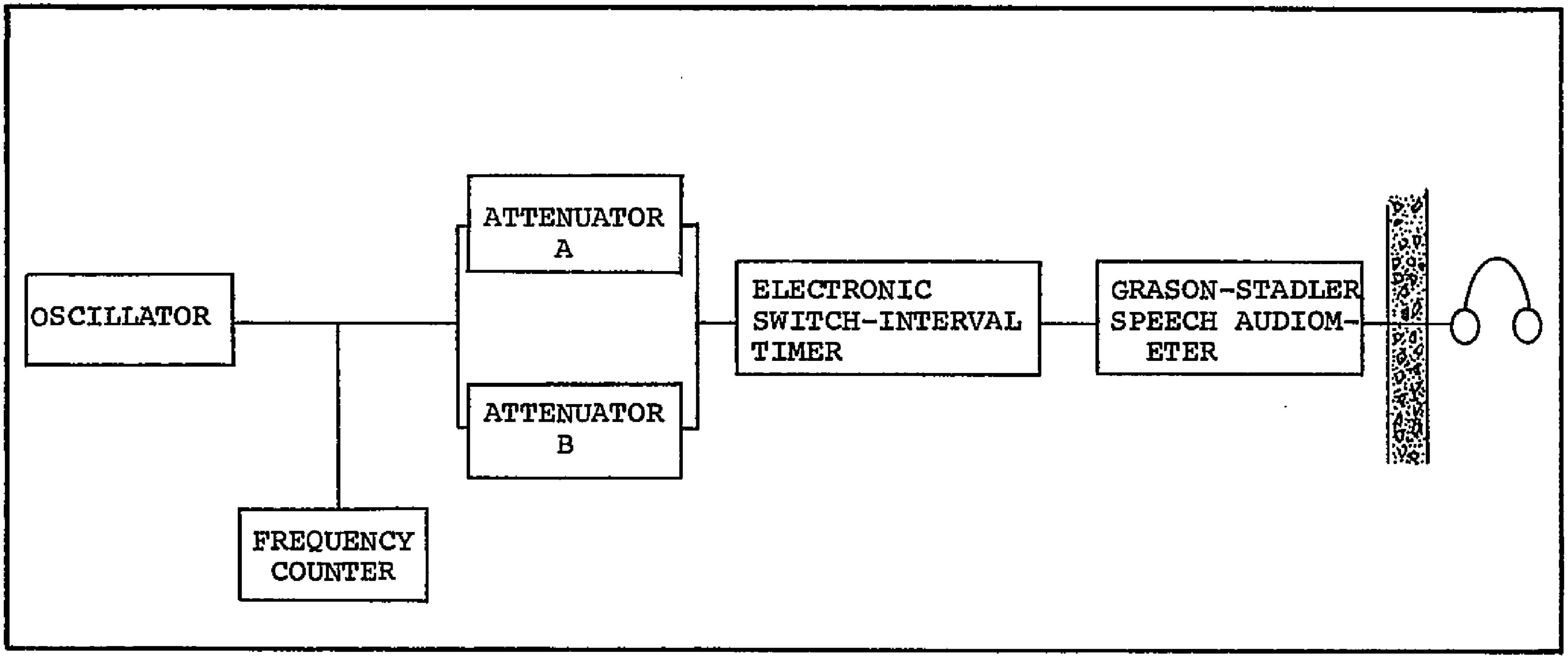

FIGURE 4. SIMPLIFIED BLOCK DIAGRAM OF THE EXPERIMENTAL APPARATUS USED FOR DLI MEASUREMENTS.

for DLI. DLF measurements were obtained prior to the DLI measurements for one-half of the subjects and the reverse order was used in testing the other half.

In the present study the criteria for DLI thresholds of 75 percent correct detection of change of intensity was determined through use of the single comparison standard procedure (AX). Each subject was required to report whether the variable intensity (second) signal (X) was louder or softer than the preceding reference (first) signal (A).

Kohler (1949), who studied the effect of tonal duration on perceived loudness, reported that even weak tones reach maximum loudness in 0.3 seconds. In order to keep the DLF and DLI psychophysical techniques as similar as possible a duration of 1.5 seconds was used for the standard and variable intensity. Experiments by von Békésy (1960) have demonstrated that for untrained subjects changing the interstimulus interval from 0.25 seconds to 5.0 seconds has very little effect on the size of the difference limen for intensity. Rise and decay times were the same as that used in the DLF measurements (100 and 150 msec). The main objective of controlling the rise and decay times in both measurements was to avoid a <u>click</u> in the signal presentation which could give an extraneous cue to the listener. Listening was monaural. The same ear selected for DLF measurements was administered the DLI. The following paradigm represents a single stimulus sequence:

		STIMULUS		STIMULUS		
METHOD	40 dB	A		X	50 dB	CORRECT
AX		1.5 sec.	1.0 sec.	1.5 sec.	5.0 sec.	RESPONSE LOUDER

2. Signal Presentation.--The sensation level was set at 40 dB above threshold. Three males in the older age groups reported that a 40 dB sensation level was uncomfortably loud at 4000 Hz in which cases the DLI was obtained at 20 dB SL. For the same reason, two additional males were tested at 20 dB SL for both 2000 and 4000 Hz. Two tones with a constant difference between them were presented as eight successive pairs. The difference between the standard and variable intensities was gradually reduced until the DLI was obtained. Such a procedure was continued until the number of correct responses were as near as possible to six but not less than six. The difference in dB between the two tones when 75 percent, or six, correct responses were obtained was called the DLI with this method.

a. Test familiarization and DLI approximation.--The instructions to each subject was as follows:

At this time you will be presented with several pairs of tones. You will hear one tone, followed by a short, silent interval, then the second tone. Your job is to listen to the loudness of the two tones and report whether the second tone is louder or softer than the first tone. Remember, you are to report louder or softer, but never the same. (At this point the examiner whistled a pair of tones, and the subject indicated verbally whether the second tone was louder or softer.) Keep in mind that you are comparing the second tone of each pair to the first tone. Your only response will be

louder or softer, and you are talking about the second tone. Even if the two tones seem to be equal, or the same, you have to make a choice either that the second tone is louder or that it is softer.

The subjects were familiarized with the listening tasks by giving two presentations of the largest incremental pair for a given frequency. For example, at 500 Hz the subject was presented two pairs of 500 Hz at 40 dB and at 50 dB. He responded louder or softer to both of the two signal presentations. If both of his responses were correct the size of the increment was reduced in steps of 2 dB (i.e. 48 dB), until the subject responded incorrectly to one of the two presentations or until the smallest two increments were reached. At this point the test series was begun. It was felt that the approximation procedure reduced the time needed for obtaining the DLI considerably.

b. The test series.--The number of pairs presented was dependent upon the test familiarization and approximation series; however, for each incremental pair eight presentations were made and the size of the increment was reduced in sequence. As was done in the DLF measurements, the order of presentation of the four frequencies were determined through use of random numbers. For each of the four frequencies under observation, there were 10 incremental pairings available. The order of presenting the standard or variable intensity increment first was

determined through use of random numbers. The incremental pairings of the test series were as follows:

Increment	500 Hz 40 dB SL	1000 Hz 40 dB SL	2000 Hz 40 dB SL	4000 Hz 40 dB SL
10	50 dB	50 dB	50 dB	50 dB
9	49 dB	49 dB	49 dB	49 dB
8	48 dB	48 dB	48 dB	48 dB
7	47 dB	47 dB	47 dB	47 dB
6	46 dB	46 dB	46 dB	46 dB
5	45 dB	45 dB	45 dB	45 dB
4	44 dB	44 dB	44 dB	44 dB
3	43 dB	43 dB	43 dB	43 dB
2	42 dB	42 dB	42 dB	42 dB
1	41 dB	41 dB	41 dB	41 dB

c. Summary of the experimental procedure for DLI. The DLI for a single frequency was determined as follows: Two presentations of the largest loudness increment were presented to the listener (i.e. 40 dB tone followed by a 50 dB tone, or vice-versa). If he responded correctly (louder or softer) to both presentations the size of the increment was reduced by 2 dB and two more pairs were presented. This reduction in two dB steps was continued until either (1) the subject failed to respond correctly to one of the pairs or (2) until the smallest two increments of the series were reached. At this point the test was begun and eight pairs were presented to the listener at each increment. If he responded correctly to six or more (75% or greater) the increment was decreased by one dB and eight more pairs were presented. This reduction was continued, one dB at a time (8 pairs), until the subject did not respond correctly to at least

6 of the 8 pairs (less than 75%). The smallest dB increment where the subject could obtain a 75% correct response was judged to be his DLI.

3. Recording.--The responses of each subject was recorded on a response sheet for each frequency. Responses for each frequency were scored in dB. The DLI was recorded as the minimal difference in intensity between the standard and variable increment that could be detected 75 percent of the time. A copy of the response sheet is included in the appendix.

SUMMARY OF THE METHOD

Fifty-four subjects composed of the two following major age groups were used in this study: 20-29 and 45-79. The older or experimental group consisted of six subjects in each half-decade. Each subject was administered a pure tone air- and bone-conduction threshold test, a speech reception test, a speech discrimination test, frequency difference limen measurements at 500, 1K, 2K, and 4K Hz and intensity difference limen measurements at 500, 1K, 2K, and 4K Hz.

ANALYSIS OF THE DATA

1. Descriptive statistics were utilized to show means and variability. Two dimensional plots were used to present the mean DLF for each age

group, the mean speech discrimination score for each group, and the relationship between DLF and Pure Tone Thresholds.

2. Correlation coefficients were computed to determine if there is a statistically significant relationship between:

   A. DLF and aging

   B. DLF and pure tone thresholds

   C. DLI and pure tone thresholds

   D. DLI and DLF

3. The mean DLF values obtained in the present study for the young normal-hearing and "presbycusic" subjects were compared with data presented by previous investigators.

CHAPTER III

RESULTS AND DISCUSSION OF THESE DATA

The major objective of the present study was to obtain measurements of differential sensitivity for frequency, differential sensitivity for intensity, pure tone thresholds, and speech discrimination across a large sample of "normal-hearing" subjects in order to study the relationships among these phenomena and the aging process.

The data obtained in this investigation are discussed in the following order:

1. Difference limen for frequency as a function of age;
2. Difference limen for intensity as a function of age;
3. Relationships between speech discrimination, difference limen for frequency, and difference limen for intensity;
4. Difference limen for frequency and its relationship to pure tone air-conduction thresholds;
5. Difference limen for intensity and its relationship to pure tone air-conduction thresholds; and,
6. Relationships between difference limen for frequency and difference limen for intensity.

Difference Limen for Frequency and Age

The mean DLF and standard deviation values obtained at 500, 1000, 2000 and 4000 Hz are presented in Table 5. Even a cursory inspection of these data reveals that the mean DL increases with frequency and age. Figure 5 presents the grand means for the DLF at 500, 1000, 2000 and 4000 Hz and for the various age groups. These data provide further evidence of the change in DLF as a function of age.

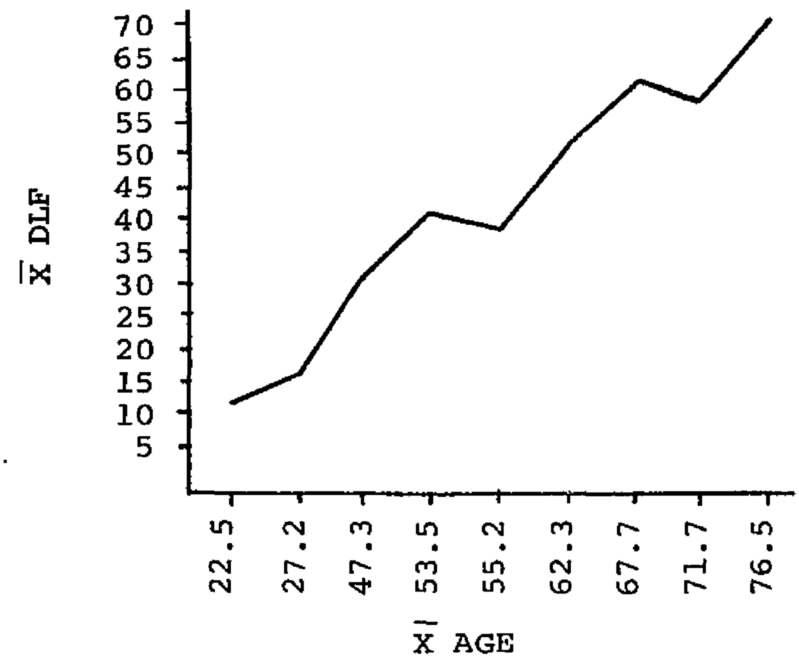

FIGURE 5. MEAN AGE AND DLF FOR ALL GROUPS.

The relationship between DLF and age was determined through coefficients of correlation. A significant relationship was found to exist between DLF at all frequencies tested--500, 1000, 2000 and 4000 Hz--and age. A rho value of +.64 was obtained when the relationship between the DLF at 500 Hz and age was tested. In order to determine the proportion of the variance in DLF accountable for by the variance in age the

TABLE 5

MEAN DLF AND STANDARD DEVIATION VALUES AT 500, 1000, 2000 and 4000 Hz

N = 6 Subjects in each age group

AGE GROUP	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
20-24	4.3	1.70	9.3	7.08	11.8	5.30	30.5	16.59
25-29	4.3	1.97	9.2	8.59	16.8	12.42	36.3	24.80
45-49	5.0	3.65	10.8	6.57	25.2	12.63	*84.3	48.20
50-54	7.8	2.97	16.3	6.26	33.2	9.77	107.5	55.44
55-59	10.5	4.96	18.8	12.09	36.5	25.26	*80.3	54.12
60-64	12.2	3.89	21.8	12.16	42.2	27.84	*130.2	40.32
65-69	13.5	5.92	27.2	16.34	57.0	22.34	*148.5	51.66
70-74	11.7	4.23	25.2	12.04	48.8	15.61	*144.8	46.63
75-79	13.8	2.54	29.2	4.67	57.7	15.00	*181.3	12.67

*A few subjects were unable to meet DL criterion of 75% even at the largest increment. The data for these subjects were tabulated at the maximum increment.

correlation of determination was computed. r^2 = .4096 signifying that at 500 Hz age accounted for 41% of the variability in DLF. A scatter plot and regression line depicting these variables are presented in Figure 6. An r of +.55 was obtained between DLF at 1000 Hz and age. r^2 = .3025 at this frequency. The scatter plot and regression line for these scores are presented in Figure 7. When DLF at 2000 Hz and age were compared an r value of +.63 was obtained. r^2 at 2000 Hz = .3969. Figure 8 presents the scatter plot and regression line for age versus this frequency. The largest r value for the group (+.73) was obtained when the coefficient of correlation between the DLF at 4000 Hz and age was ascertained. A coefficient of determination of .5329 suggested that age accounted for over one-half of the variability in DLF at this frequency. The regression line in Figure 9 provides a visual representation of this significant relationship. The relationships between difference limen for frequency measured at 500, 1000, 2000 and 4000 Hz and age were all significant at the .01 level of confidence.

These findings support those reported by Konig (1957) and Ross (1963), who also found a significant relationship between DLF and age. They do not substantiate one of the conclusions drawn by Rupp (1964)--that there is

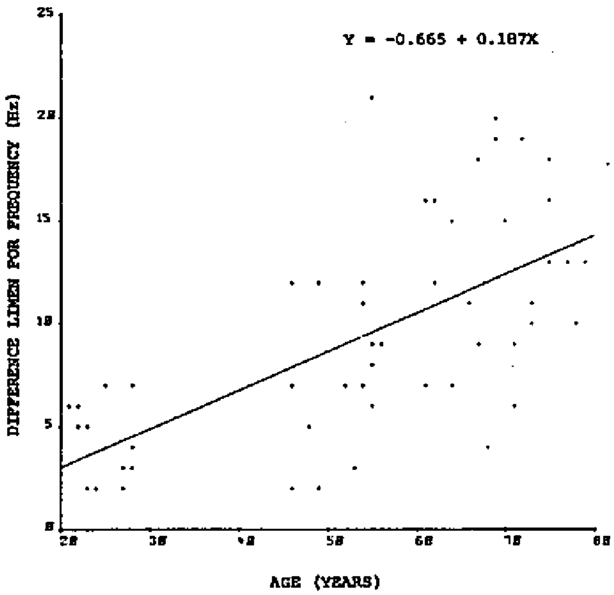

FIGURE 6. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND AGE AT 500 Hz

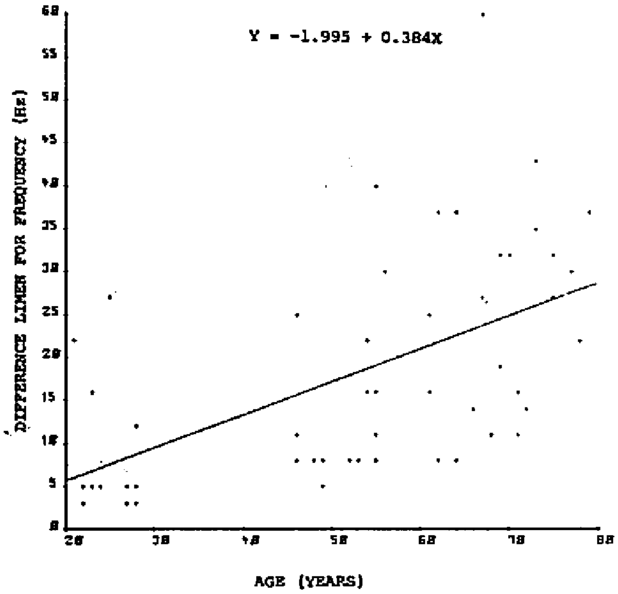

FIGURE 7. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND AGE AT 1000 Hz

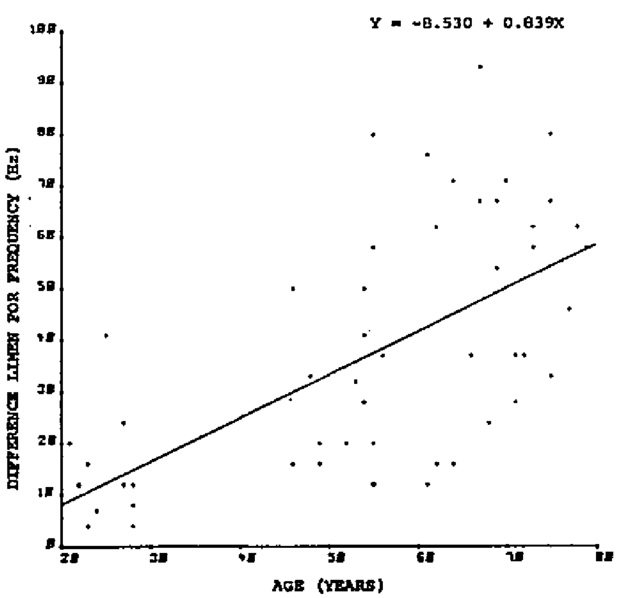

FIGURE 8. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND AGE AT 2000 Hz

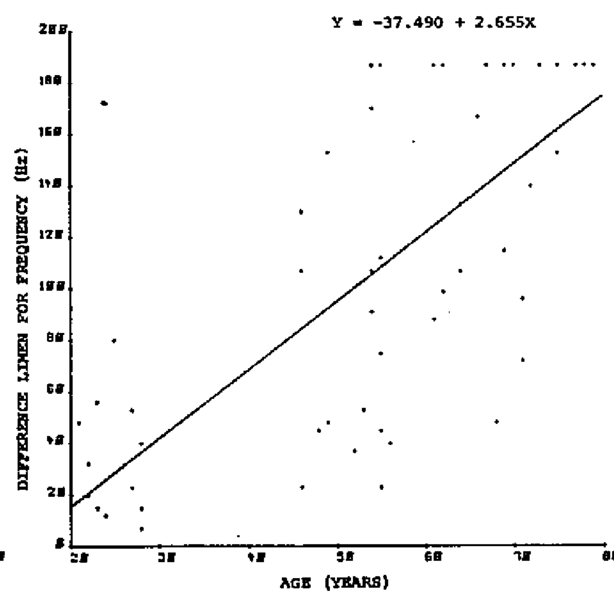

FIGURE 9. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND AGE AT 4000 Hz

no relationship between DLF and age for normal-hearing subjects. Although the conclusion reached by the present investigator regarding DLF and age for normal-hearing subjects does not agree with Rupp much of the data obtained by the two studies are in close agreement. First, it should be pointed out that Rupp's investigation involved measurements on ten groups of subjects who were classified primarily according to otological findings and not according to audiometric configurations. He drew his conclusions regarding DLF and age according to measurements obtained for these differently classified otological groups and not across a large age range of subjects who had normal hearing for their respective age. His conclusion regarding the relationship between DLF and age for normal-hearing subjects was drawn from a group of 21 subjects whose ages ranged only from 18 to 43 years of age. Similarly, he obtained coefficients of correlation between DLF and age for subjects classified as having the following types of hearing impairment: sensorineural losses of unspecified origin; sensorineural losses due to Meniere's disease; and losses due to acoustic trauma. He found no significant correlations for these two variables for any of the three groups. The only significant correlation that he found between age and DLF

for air-conducted pure tones was at 250 Hz for his oldest age group (66-81 years of age).

Table 6 presents the DLF's obtained for the control group (20-29 years) in the present study along with those obtained for normal-hearing subjects studied in other recent research. Although different psychophysical techniques and sensation levels were used in these studies, the measurements obtained in the present study compare favorably with previous findings. It can be noted that in all of the studies DLF increases as the test frequency increases. While the size of the DL's obtained in the present study are somewhat larger than those reported by earlier investigators, they agree very well with the recent data reported by Rupp for his normal-hearing subjects.

The data presented in Table 7 for older subjects tested in the present study generally agree with previous research. Although data for the older subjects in the present study were obtained by half decades, two age groups--45 to 64 and 65 to 79--are used in Table 7 in order to make a comparison with other studies easier. It should be pointed out that just as in the case of the younger subjects the size of the DLF increases with the frequency under test. The size of the DL's for these subjects also compare very closely with that presented by the most recent investigators.

TABLE 6

DLF SCORES FOR NORMAL-HEARING SUBJECTS REPORTED BY RECENT INVESTIGATORS

Investigator and Year		Method Used	Sensation Level	Number of Subjects	Frequency Measured					
					250	500	1000	2000	3000	4000
Shutts	1950	Constant Stimuli	40 dB	20		3.3	4.5	8.9		
Harris	1952	Constant Stimuli	30 dB	328	1.3	2.1	3.6	8.28		21.1
Meurmann	1954	Sinusoidal Modulation	20 dB	52	3.0	3.0	6.7	12.3		33.7
Konig	1957	Constant Stimuli	40 dB	10	1.6	2.4	3.6	6.8	12.3	21.2
Filling	1958	Sinusoidal Modulation	20 dB	10	1.8	3.4	6.0	12.0		23.0
McCandless	1959	Method of Limits	45 dB	9	[illegible]	2.3		4.4		9.6
Ross, Huntington, Newby and Dixon	1963	Constant Stimuli	30 dB	31		6.0		19.4		64.0
Rupp	1964	Constant Stimuli	25 dB	22	4.8		7.5		21.8	30.9
Present Study		Constant Stimuli	40 dB	12		4.3	9.0	14.3		33.4

TABLE 7

MEAN DLF SCORES FOR OLDER SUBJECTS REPORTED BY RECENT INVESTIGATORS

Investigator and Year		Age Group	Frequency Measured 250	500	1000	2000	3000	4000
Hayes	1951	50+ 50+		7.6 15.5	14.4 18.7	24.6 31.5		
Meurmann	1954	40-80	4.4	6.1	11.1	24.6		60.9
Konig	1957	50-59 60-69 70-79	3.7 5.6 6.0	5.0 7.1 7.8	7.8 10.2 11.8	16.4 22.2 28.6	32.1 39.0 48.0	64.0 89.0
Filling	1958	50-59 60-69 70-79	2.4 3.3 2.8	6.0 6.5 5.7	12.5 12.4 13.2	22.9 25.0 29.1		79.8 84.0 80.0
Rupp	1964	55-65 66-81	8.6 13.3		17.4 30.2		55.0 80.3	126.3 127.3
Present Study		45-64 65-79		8.8 13.0	17.0 27.2	34.2 54.4		101.4 158.2

Hypothesis number one--that there is no significant relationship between DLF and aging--was rejected. Results of the test demonstrated a significant relationship between all of the test frequencies--500, 1000, 2000 and 4000 Hz--and age. The data were significant at the .01 level of confidence.

Difference Limen for Intensity and Age

The mean age, DLI and standard deviation values for all groups are presented in Table 8.

TABLE 8

MEAN AGE, DLI AND STANDARD DEVIATION VALUES FOR ALL GROUPS REPORTED IN dB

GROUP		AGE	500Hz	1KHz	2KHz	4KHz
20-24	$\overline{X}$	22.5	1.8	2.0	1.7	2.8
	S		.38	.81	.46	.83
25-29	$\overline{X}$	27.2	1.5	2.0	2.3	1.7
	S		.50	.57	.74	.46
45-49	$\overline{X}$	47.3	1.5	1.8	2.7	2.5
	S		.76	.69	.11	1.26
50-54	$\overline{X}$	53.5	1.8	1.8	2.0	2.0
	S		1.39	1.12	.71	.81
55-59	$\overline{X}$	55.2	1.8	2.0	2.2	1.8
	S		.37	1.0	.89	.89
60-64	$\overline{X}$	62.3	2.5	2.3	2.8	2.3
	S		.76	1.10	1.07	.74
65-69	$\overline{X}$	67.7	2.3	2.0	2.7	2.3
	S		1.38	1.0	1.70	.94
70-74	$\overline{X}$	71.7	2.0	2.5	2.2	2.3
	S		.81	.95	.68	1.27
75-79	$\overline{X}$	76.5	3.2	3.0	2.7	3.0
	S		1.06	1.15	1.65	1.63

By inspection of the data presented in Table 8 it can be seen that no relationship exists between DLI and age. For example, it can be noted that the mean DLI obtained by the 20-24 year group at 500 Hz was 1.8 dB. Similarly a measurement of 1.8 dB was obtained for the 50-54 year old group while the 70-74 year group did essentially as well with a 2.0 dB response. At 1000 Hz the 20-24 year group and the 65-69 group both obtained a DLI of 2.0 dB. Other scores obtained at this frequency were also similar. For 2000 Hz three groups--45-49; 65-69; and 75-79--all scored 2.7 dB. The 20-24 year and 75-79 year group obtained essentially the same score with 2.8 and 3.0 dB, respectively. Because of the obvious lack of relationship between age and DLI these data were not subjected to additional statistical analyses.

Hypothesis number two--that there is no significant relationship between DLI and aging--was not rejected. A comparison of the DLI scores obtained for the various age groups demonstrated no relationship between these two variables.

Relationships between Speech Discrimination, Difference Limen for Frequency, and Difference Limen for Intensity

Figure 10 shows the mean age and speech discrimination score for the various age groups. With the subjects tested in this study, mean speech discrimination scores of 97% or better were obtained until the age of 65, at which point discriminatory ability started to decline. Because

the study included only 18 subjects 65 years of age and older a definitive statement concerning speech discrimination and advanced age cannot be made. The data obtained by most investigations of discriminatory ability of older subjects have indicated a trend of decreasing speech discrimination ability with age. The subjects for these studies have, in many instances, been selected from patients who have presented themselves at a Speech and Hearing Clinic with a complaint of being hard-of-hearing or from among hospital patients who had other health problems.

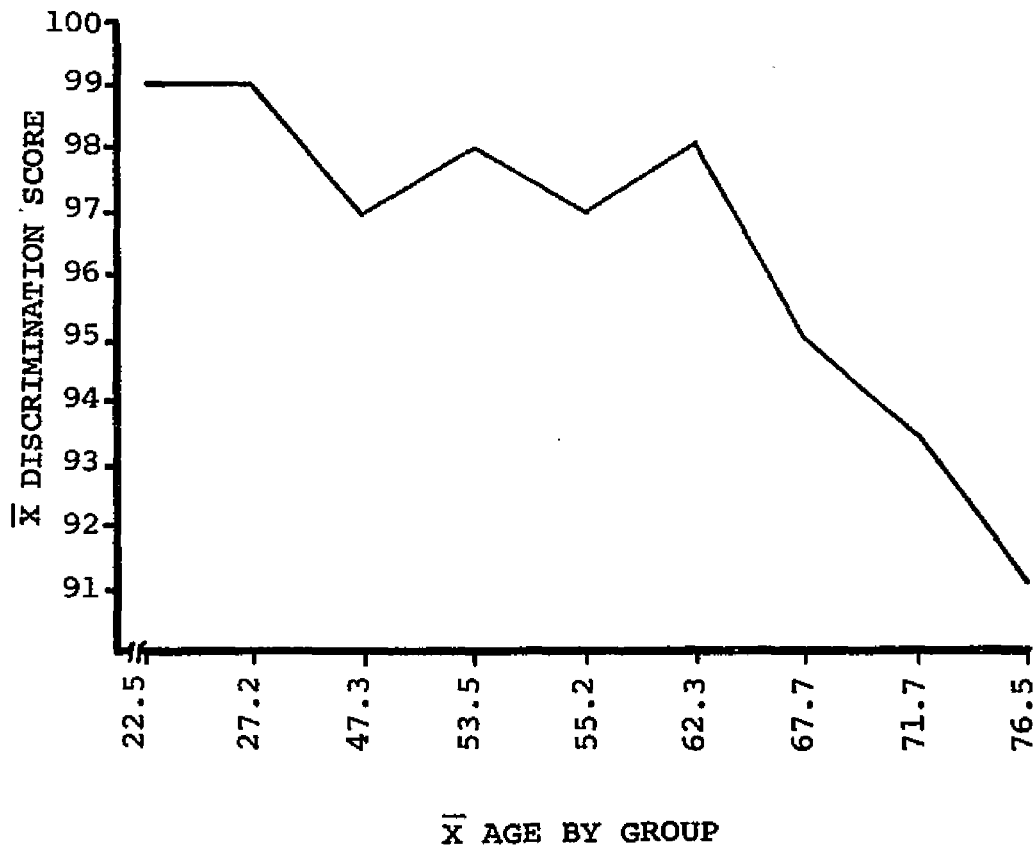

FIGURE 10. MEAN AGE AND SPEECH DISCRIMINATION SCORE

It would seem reasonable to think that many older persons who have no history of ear disease and who are active socially or vocationally may not experience the decrease in discriminatory ability frequently associated with age. It should be noted that although there was a noticeable decline in speech discrimination ability of the subjects in the present study after the age of 65, all of the older individuals still achieved very good discrimination scores. As previously suggested the good discriminatory ability, observed in the present investigation while not expected, may be explained by the fact that these subjects did not present themselves at the clinic with a complaint but rather were "sought out" by the investigator and were studied because their pure tone audiogram and otological history indicated a "normal" ear for their age. With few exceptions, even the oldest subjects were active enough to come to the clinic unaccompanied.

Ross _et al_. (1963), who investigated speech discrimination abilities in a group of normal-hearing subjects whose ages ranged from 30 to 56 reported that no significant correlations were obtained between age and speech discrimination measures.

Luterman (1966), who investigated auditory responses in a large group of octogenarian males reported that thirty percent of his older subjects obtained discrimination scores in excess of 90 percent.

Table 9 presents the mean age, discrimination score, difference limen for intensity, and difference limen for frequency for the nine age groups studied. Because the obtained data show little relationship between speech discrimination and aging any attempt to relate discrimination scores at various ages with changes in DLF and DLI performance is precluded.

Accordingly, hypothesis number three--that there is no relationship between DLF and speech discrimination--was not rejected.

For the same reason hypothesis number four--that there is no significant relationship between DLI and speech discrimination--was not rejected.

Difference Limen for Frequency and Pure Tone Air-Conduction Thresholds

Significant relationships were noted between DLF and pure tone air-conduction thresholds at all frequencies tested. r values of +.48; +.44; +.42; and +.58 were attained at 500, 1000, 2000, and 4000 Hz, respectively. Although these relationships were all significant at the .01 level of confidence, it should be noted that r^2 for the highest r value (+.58 at 4000 Hz) accounted for only 34% of the variance. Scatter plots and regression lines for these four relationships are shown in Figures 11, 12, 13, and 14.

Of the studies reviewed by the present investigator five have reported data on the relationship between DLF and

TABLE 9

MEAN AGE, DISCRIMINATION SCORE, DLI, AND DLF FOR ALL GROUPS

GROUP	AGE	DISCRIMINATION SCORE	DIFFERENCE LIMEN FOR INTENSITY 500 Hz	1000 Hz	2000 Hz	4000 Hz	DIFFERENCE LIMEN FOR FREQUENCY 500 Hz	1000 Hz	2000 Hz	4000 Hz
20-24	22.5	99	1.8	2.0	1.7	2.8	4.3	9.3	11.8	30.5
25-29	27.2	99	1.5	2.0	2.3	1.7	4.3	9.2	16.3	36.3
45-49	47.3	97	1.5	1.8	2.7	2.5	5.0	10.8	25.2	84.3
50-54	53.5	98	1.8	1.8	2.0	2.0	7.8	16.3	33.2	107.5
55-59	55.2	97	1.8	2.0	2.2	1.8	10.5	18.8	36.5	80.3
60-64	62.3	98	2.5	2.3	2.8	2.3	12.2	21.8	42.2	130.2
65-69	67.7	95	2.3	2.0	2.7	2.3	13.5	27.2	57.0	148.5
70-74	71.7	93	2.0	2.5	2.2	2.3	11.7	25.2	48.8	144.8
75-79	76.5	91	3.2	3.0	2.7	3.0	13.8	29.2	57.7	181.3

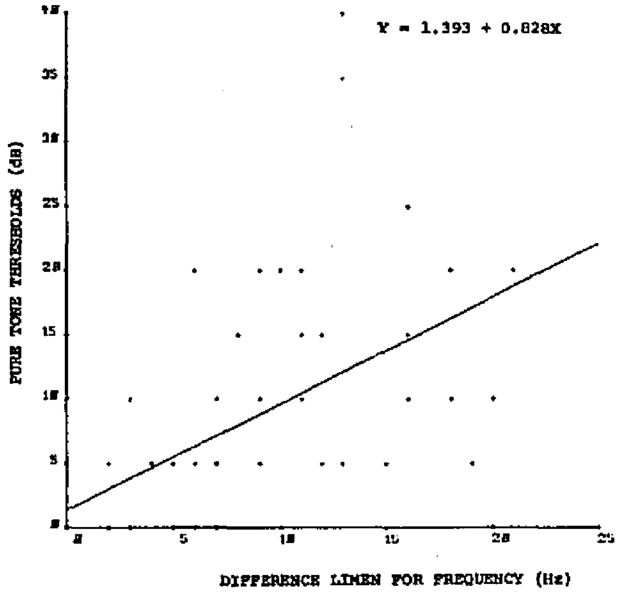

FIGURE 11. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND PURE TONE THRESHOLDS AT 500 Hz

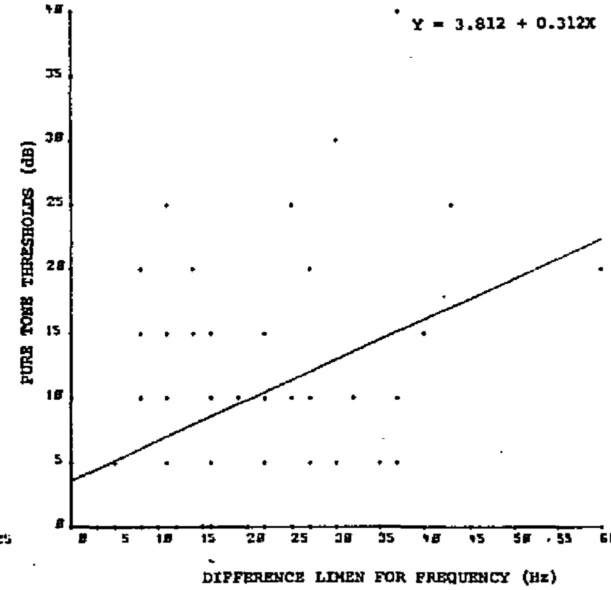

FIGURE 12. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND PURE TONE THRESHOLDS AT 1000 Hz

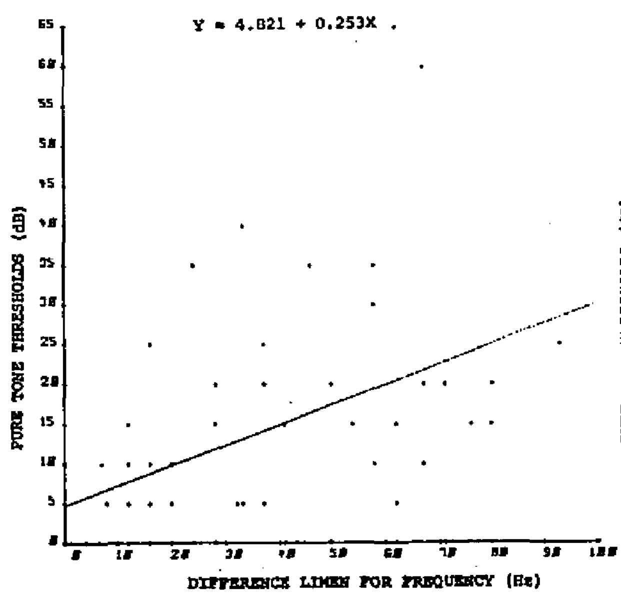

FIGURE 13. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND PURE TONE THRESHOLDS AT 2000 Hz

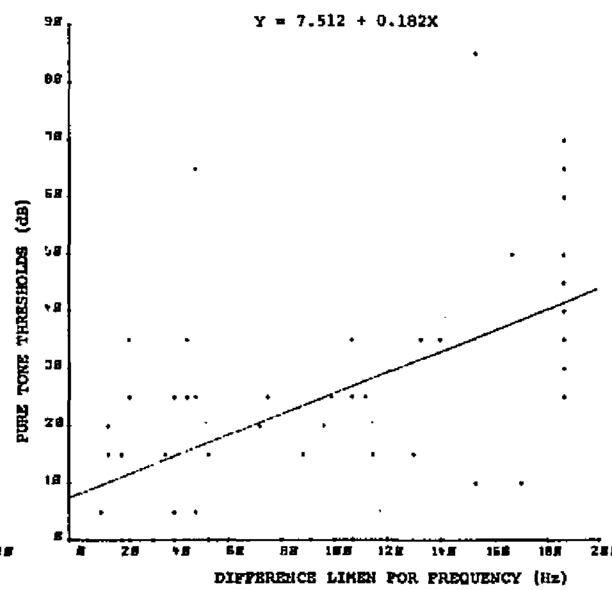

FIGURE 14. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR FREQUENCY AND PURE TONE THRESHOLDS AT 4000 Hz

pure tone air-conduction thresholds. Three of these (Meurmann, 1954; Filling, 1958; Ross et al., 1963) observed a significant relationship between these phenomena for sensorineural losses while the other two (McCandless, 1958; Rupp, 1964) did not report a significant relationship for any of their groups.

Meurmann (1954) compared DLF values of his normal-hearing subjects with conductive and sensorineural problems and concluded that DLF values for the conductive group were not significantly different from the normals. Although it was observed that in many of the subjects with sensorineural problems the DLF grew proportionally with the decrease in hearing, this investigator felt that wide variations observed for many of the subjects made it impossible to predict the size of the DLF by the amount of hearing loss. In 1958, Filling studied the relationship of DLF size and hearing loss and like Meurmann reported that for sensorineural losses the values of DLF tended to increase with the severity of the loss; however, she noted that the DLF for conductive and mixed problems were not directly related to severity of loss. Ross et al. (1963) reported the relationship between degree of hearing loss and DLF size for a group of subjects with sensorineural losses and found a statistically significant relationship at 500, 2000 and 4000 Hz in the right ear and at 500 and 2000 Hz in the left. They did

note, however, that while the correlations were significant they were low and there were many wide variations.

McCandless (1959) investigated DLF values in relationship to degree of loss for (1) a group of subjects who demonstrated a high-frequency loss localized near 4000 Hz and (2) a group with mild to moderate gradually sloping perceptive type losses. He did not demonstrate a relationship between degree of hearing loss and DLF size. Rupp (1964) investigated DLF values for ten different otological classifications and stated that he could not demonstrate definite relationships between degree of hearing loss for air-conducted sounds and DLF size within any single classification. He did find a highly significant relationship between bone conduction thresholds and DLF size as group values were compared.

The different conclusions reached by these investigators regarding the relationship between DLF and pure tone air-conduction thresholds could possibly have resulted from several factors. Namely, different audiometric criteria, different otological diagnoses, and different psychophysical techniques. It should be pointed out that while normal-hearing subjects were included in these studies, Meurmann, Filling, McCandless, and Ross _et al_. did not report this relationship for their normal-hearing subjects. Additionally, it should be noted that although Rupp reported findings regarding his normal-hearing subjects, their ages

ranged from 18 to 43 years with a median of 25 years.

It is difficult to compare the data of the present study with those just discussed. Although all of the subjects in the present study were classified as having normal-hearing for their age, some of them would probably have been classified as mild sensorineural losses according to the criteria of other investigators. Although the relationships observed between DLF and pure tone thresholds in the present study were low, they were significant and support those previous investigators who observed a relationship between DLF and sensorineural losses. It should be pointed out, however, that both McCandless and Rupp, who included mild-to-moderate sensorineural losses in their study, did not demonstrate this relationship. Figure 15 provides a visual presentation of the relationship of difference limen for frequency and pure tone thresholds at all four frequencies (mean data) obtained in the present study.

Hypothesis number five--that there is no significant relationship between DLF and pure tone air-conduction threshold--was rejected.

Difference Limen for Intensity and Pure Tone Air-Conduction Thresholds

The relationship between difference limen for intensity and pure tone air-conduction thresholds was studied through use of coefficients of correlation. Pearson r values

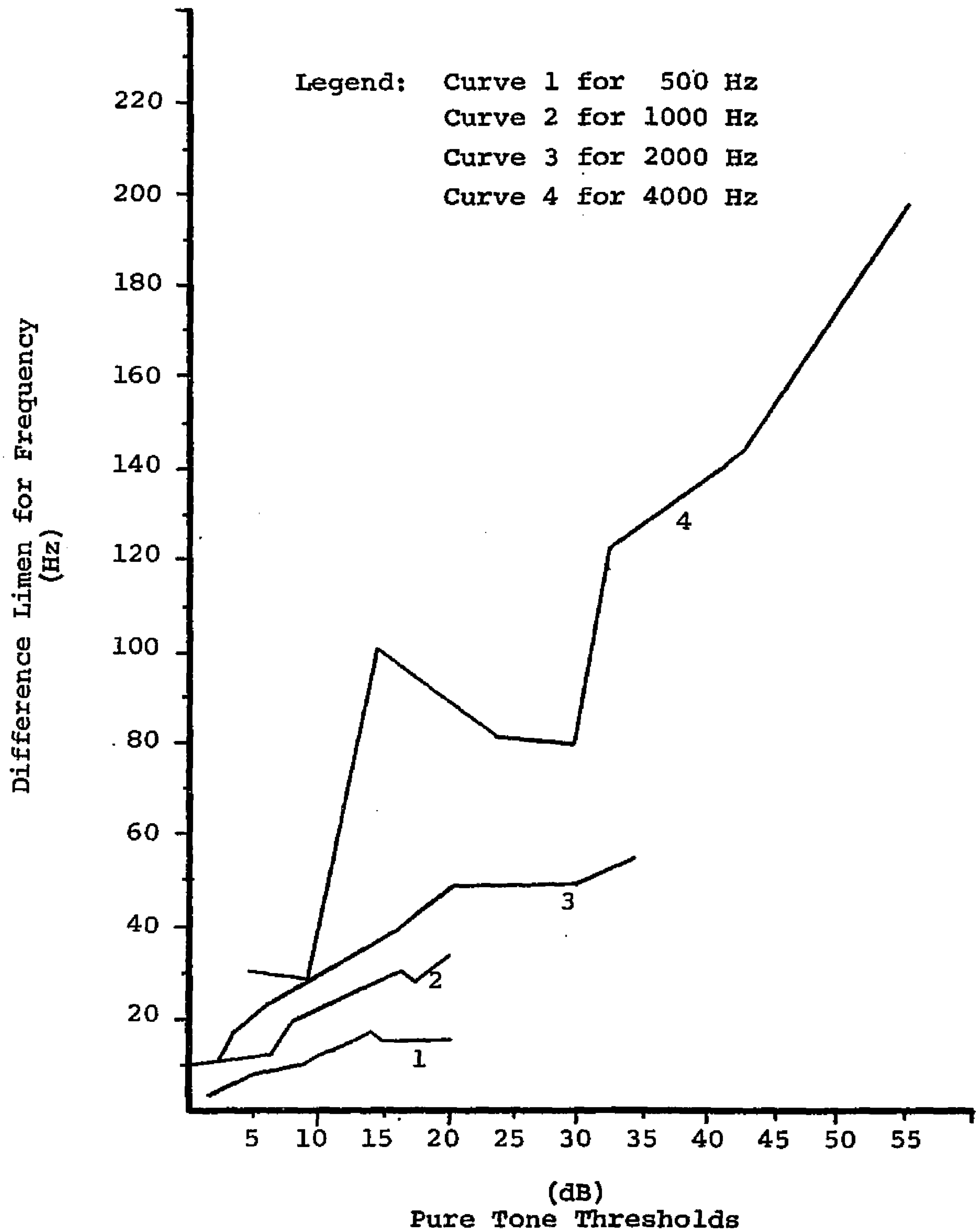

FIGURE 15. RELATIONSHIP OF DLF AND PURE TONE THRESHOLD AT 500, 1000, 2000 and 4000 Hz.

of +.21; -.03; -.10; and -.09 were obtained for DLI and pure tone thresholds at 500, 1000, 2000 and 4000 Hz, respectively. None of these values was significant at the .01 or .05 levels of confidence. A summary of the data is presented in Figures 16, 17, 18 and 19.

In view of these coefficients of correlation hypothesis number six--that there is no significant relationship between DLI and pure tone thresholds--was not rejected.

Difference Limen for Frequency and Difference Limen for Intensity

When the relationship between DLF and DLI was tested r values of +.26, +.16, +.32 and +.30 were obtained at 500, 1000, 2000 and 4000 Hz respectively. None of these relationships was significant at the .01 level of confidence; however, the values of +.32 and +.30, obtained at 2000 and 4000 Hz, were significant at the .05 level of confidence. r^2 for 2000 and 4000 Hz were .1024 and .0900 indicating that a significant but very weak relationship exists. Figures 20, 21, 22, and 23 show the scatter plots and regression lines for these measurements.

Due to the fact that three previous studies, which included both a measurement of DLF and DLI, used subjects with different otological and audiological classifications, a comparison with the present data is difficult. The difference in psychophysical techniques imposes an additional

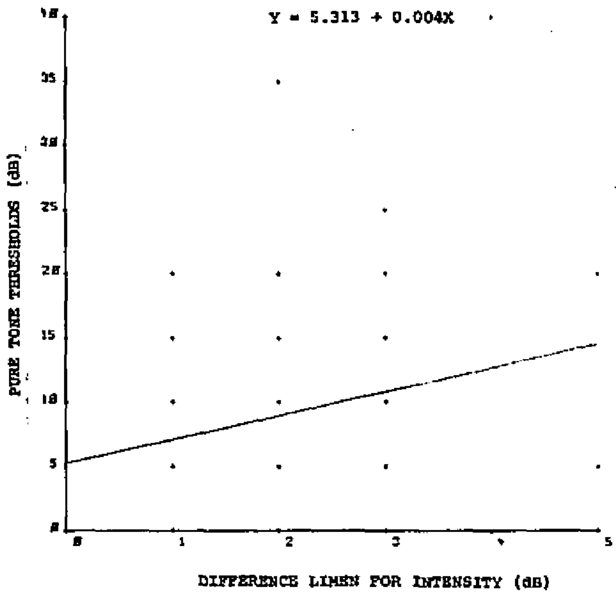

FIGURE 16. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND PURE TONE THRESHOLDS AT 500 Hz

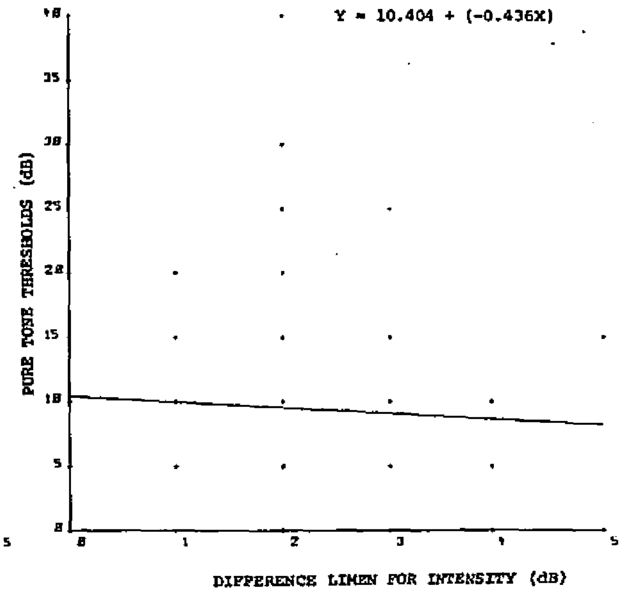

FIGURE 17. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND PURE TONE THRESHOLDS AT 1000 Hz

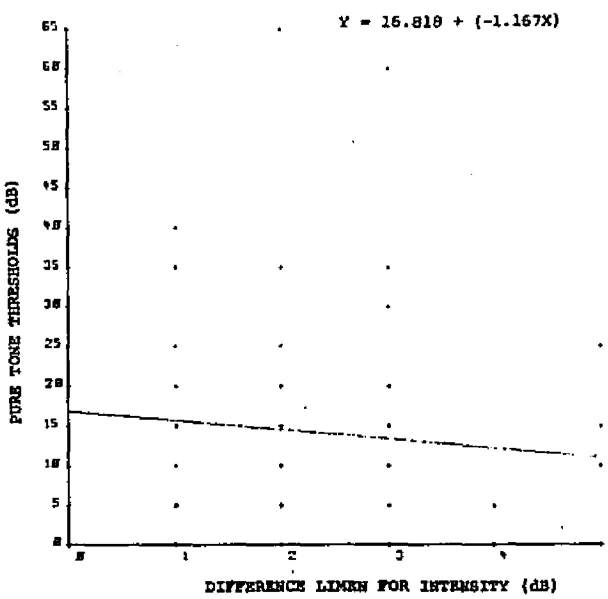

FIGURE 18. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND PURE TONE THRESHOLDS AT 2000 Hz

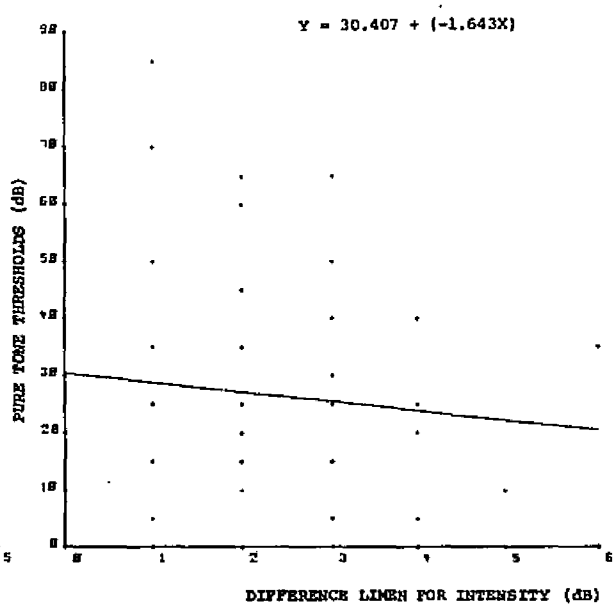

FIGURE 19. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND PURE TONE THRESHOLDS AT 4000 Hz

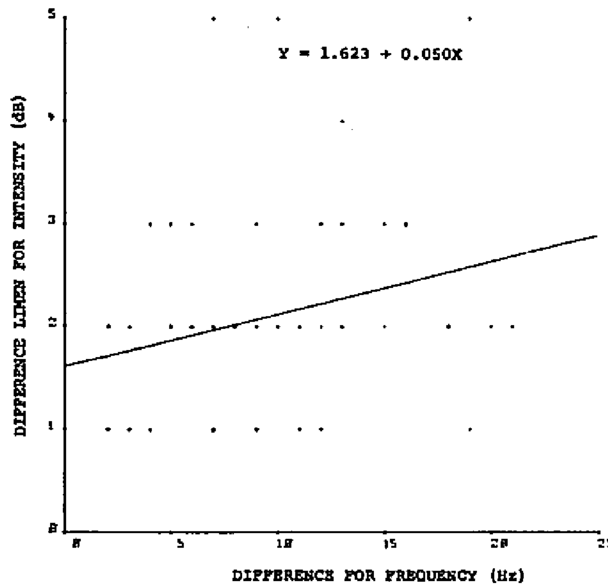

FIGURE 20. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND DIFFERENCE LIMEN FOR FREQUENCY AT 500 Hz

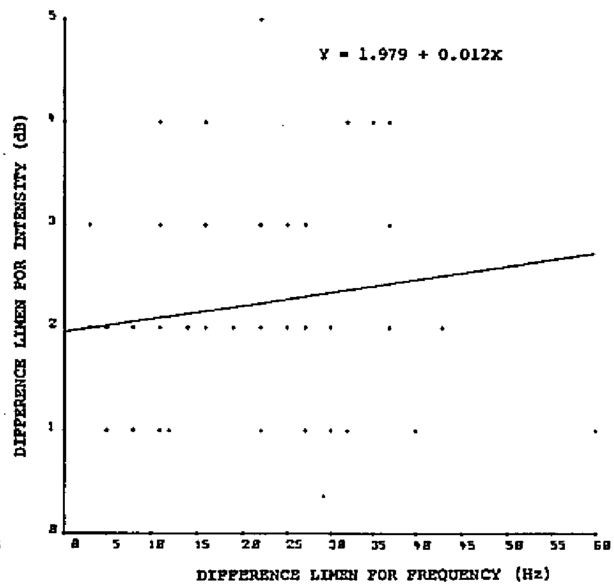

FIGURE 21. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND DIFFERENCE LIMEN FOR FREQUENCY AT 1000 Hz

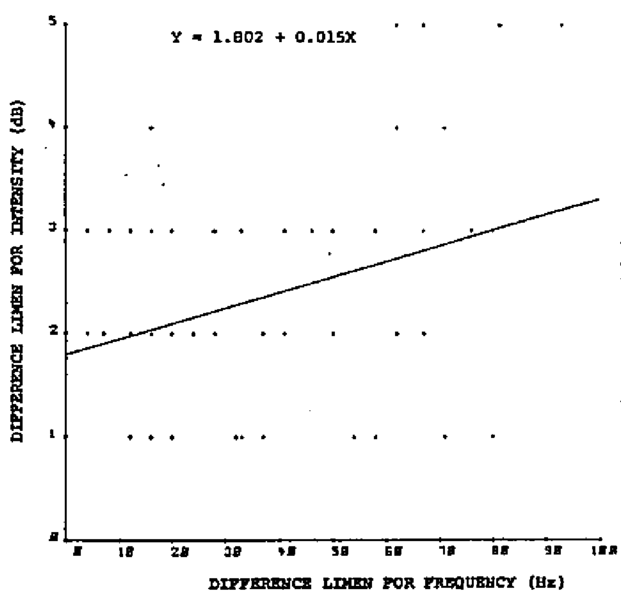

FIGURE 22. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND DIFFERENCE LIMEN FOR FREQUENCY AT 2000 Hz

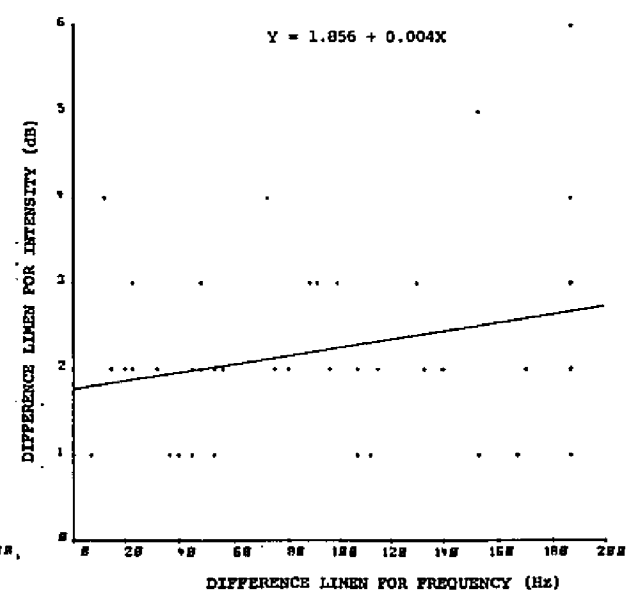

FIGURE 23. RELATIONSHIP BETWEEN DIFFERENCE LIMEN FOR INTENSITY AND DIFFERENCE LIMEN FOR FREQUENCY AT 4000 Hz

variable. Meurmann (1954) who used a sinusoidal modulation technique to obtain DLF's and a Békésy curve for DLI measurements, stated that in cases of end-organ lesions small DLI's are accompanied by large DLF's, or that a negative correlation between DLI and DLF was observed.

Ross et al. (1963), who used a discontinuous method of stimulus presentation for measurements of DLI and DLF, reported that for their normal-hearing subjects small or large DLF's at 500 and 4000 Hz tended to be accompanied by small or large DLI's at these two frequencies, indicating a direct or positive relationship. These investigators felt that no significant relationship could be demonstrated between DLF and DLI for their hearing-impaired subjects.

Rupp (1964), who used a SISI test as a means of determining differential sensitivity for intensity, reported DLF data for nine groups of subjects with confirmed otological pathologies. He used median group scores to compare the size of DLI and DLF for 1000 and 4000 Hz. This positive correlation between the size of SISI and DLF scores (i.e., large DLF scores are accompanied by large SISI scores and small DLF scores are accompanied by small SISI scores) at 4000 Hz suggests a reverse or negative relationship between the abilities to detect DLI and DLF. That is, a high, or large, SISI score indicates that the subject can hear small increments in intensity whereas a large DLF score means that it takes a large incremental change in frequency to be

perceived by the listener. Rupp reported that small DLF scores were accompanied by low SISI scores at 4000 Hz for normal-hearing subjects and those with conductive losses. Subjects with sensorineural losses obtained high SISI scores and large DLF's.

To summarize, the findings of the present study show little agreement with previous research regarding the relationship between DLI and DLF. The present study demonstrated a significant relationship between DLF and DLI at 2000 and 4000 Hz. However, the correlations were low and the trend was in a positive direction (i.e., as DLF becomes larger, DLI likewise becomes larger). The positive relationship observed between DLI and DLF at 4000 Hz agrees with a similar finding reported by Ross et al. who also noted a positive relationship at 500 Hz. The subjects and psychophysical technique used by the present investigator and Ross et al. seem to be in closer agreement than those used by the present and other investigators. Both reported data for normal-hearing subjects and used a discontinuous method of signal presentation for the DLF and DLI tasks. Meurmann, on the other hand, used a modulation technique and Békésy tracing for DLF and DLI respectively. He reported a negative correlation for patients with end-organ disease. Rupp, who used a discontinuous technique and SISI test for DLF and DLI respectively likewise reported a negative correlation

between these phenomenon when group scores were compared. It is to be appreciated that few of his subjects had normal hearing whereas many had a diagnosis of end-organ disease or other similar pathology related to a sensorineural hearing loss. He also reported that as the hearing loss increased the predictibility of the relationship between DLI and DLF increased.

On the basis of these data it seems reasonable to conclude that while there is a tendency for a negative relationship to be observed between DLI and DLF performance with patients who have a hearing loss due to some types of otological pathology, subjects with normal hearing will possibly demonstrate a positive relationship for these same tasks.

Although a significant relationship (.05 level of confidence) was observed at two of the frequencies tested it is felt that a positive statement regarding this phenomenon should be held in abeyance; therefore, hypothesis number seven--that there is no significant relationship between DLI and DLF--<u>was not rejected</u>.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The objectives of this study were:

1. To determine the relationships among differential sensitivity for frequency, differential sensitivity for intensity, aging and two of the most frequently used clinical diagnostic tests--pure tone air-conduction and speech discrimination.
2. To compare the present technique of evaluating difference limen for frequency and difference limen for intensity with techniques reported in the literature.
3. To determine whether the employed psychophysical technique would have practical diagnostic value in a test battery for evaluating auditory function.

The following experimental procedure was used: fifty four subjects composed of two major age groups were used in this study: 20-29 and 45-79. There were 12 subjects in the control group (younger) and 6 subjects in each half decade in the older, or experimental group. Results of each subject's otological history and pure tone audiogram indicated a "normal" ear for his age. Each subject was administered a pure tone air- and bone-conduction threshold test, a

speech discrimination test, frequency difference limen measurements at 500, 1000, 2000 and 4000 Hz and intensity difference limen measurements at 500, 1000, 2000 and 4000 Hz. The obtained measurements were analyzed through use of coefficients of correlation.

It was observed that the pure tone responses obtained for the subjects included in the present study agreed very well with the so-called "normal" presbycusic curves reported in the literature. Speech reception thresholds showed good agreement with the three frequency average for all subjects. The speech discrimination scores were considerably better than may have been expected for subjects in the older groups. A tenable explanation for this finding may be the fact that these individuals were not drawn from a clinical population but were included in this study because their pure tone audiogram and otological history indicated a "normal" ear for their respective ages. The discrimination scores obtained by older persons may be influenced to a large extent by the factors which bring them to the clinic.

DLF's obtained in the present study support previous research which has demonstrated that when the intensity level is kept constant the size of absolute DLF increases as the test frequency increases. The difference limens for frequency measurements were somewhat larger than those presented by early investigators; however, they compared favorably with more recent DLF studies. As mentioned

previously, different psychophysical techniques may be expected to yield different results. Instructions to subjects, amount of practice, otological diagnoses, and other variables account for considerable differences in DLF size. Some studies, which reported data for normal-hearing subjects, did not concern themselves with the age of the subject as long as he met a specified audiometric criterion. Other investigators did not report the age of their normal-hearing population. Since results of the present study demonstrated that age influences the size of DLF, this variable must be taken into account when reporting DLF data for normal-hearing populations.

It was hoped that the data obtained in the present investigation would add to present knowledge regarding speech discrimination ability of the older or "presbycusic" population. The relationships between speech discrimination ability and responses of the auditory system to minimal changes in the basic units of speech--pitch and loudness--were to be examined. Due to the good discriminatory ability of the subjects used in the present study, there were not enough subjects with poor speech discrimination or "phonemic regression" to permit this comparison.

Results of the statistical analyses revealed a significant, although relatively weak relationship between age and ability to perceive small changes in frequency.

This relationship was noted at all frequencies tested--500, 1000, 2000, and 4000 Hz. Also a significant relationship was found to exist between pure tone threshold and the ability to perceive small changes in frequency at these same frequencies.

The difference limen for intensity measurements showed no relationship with age. The lack of spread of DLI scores, for the various age groups, made it difficult to relate these measurements to other variables.

Although it was felt that a definite relationship between DLF and DLI was not demonstrated, a low positive correlation between these phenomena was noted at 2000 and 4000 Hz. There was little agreement between the observations regarding DLI and DLF in the present study with data obtained by other investigators. It was felt that differences in otological classification and psychophysical techniques could easily account for the lack of agreement among these data. Results of data obtained by Ross _et al._, and the present investigator did, however, indicate that for normal-hearing subjects a positive correlation between DLI and DLF may exist at 4000 Hz.

The present technique for evaluating difference limen for frequency seems to compare favorably with those described in the literature. The equipment used in the present investigation appeared to offer two major advantages

over that used in previous studies which have utilized a discontinuous method of signal presentation. First, the Twin-T oscillator used in the present investigation produced both the standard tone (base frequency) and a comparison tone (variable frequency) whereas previous investigators have used one signal source for the standard tone and another for the comparison tone. Furthermore, when two signal sources are used there must be constant concern that one instrument does not drift and change the size of the DL or that two signals do not produce an electronic or acoustic interaction. A second advantage of the present equipment was that a single unit provided the necessary timing and switching for the signal presentation whereas other investigators have frequently utilized two interval timers and two electronic switches.

Although the equipment did offer these advantages, due to the amount of time required to obtain the DLF for a single frequency and also the difficulty experienced in explaining the listening task to some of the subjects, the present investigator would have reservations about recommending this specific testing procedure as part of a routine audiometric test battery. Since it appears that regardless of the psychophysical technique employed considerable time is required for DLF measurements, future investigators may want to consider testing fewer frequencies. Due to the

importance of auditory responses at 4000 Hz for sensori-neural losses and potentially valuable information that may be obtained at 250 or 500 Hz regarding conductive losses, Meniere's disease, and acoustic neuromas, it is recommended that future studies consider DLF measurements at 4000 Hz and either 250 or 500 Hz.

Although the DLI test required much less time and was easier to administer, due to the fact that limited conclusions were drawn regarding the data obtained a statement regarding the adequacy of the equipment and psycho-physical technique for determining DLI will be held in abeyance.

There is increasing evidence that auditory systems with confirmed pathologies respond differently than "normal" systems to DLF and DLI tasks. In order to utilize this new clinical information in diagnostic procedures for older patients it is necessary to distinguish a pathological condition from the normal changes that occur with aging. It is hoped that the present investigation has added to the body of basic knowledge regarding changes in auditory behavior that may be expected as the auditory system ages.

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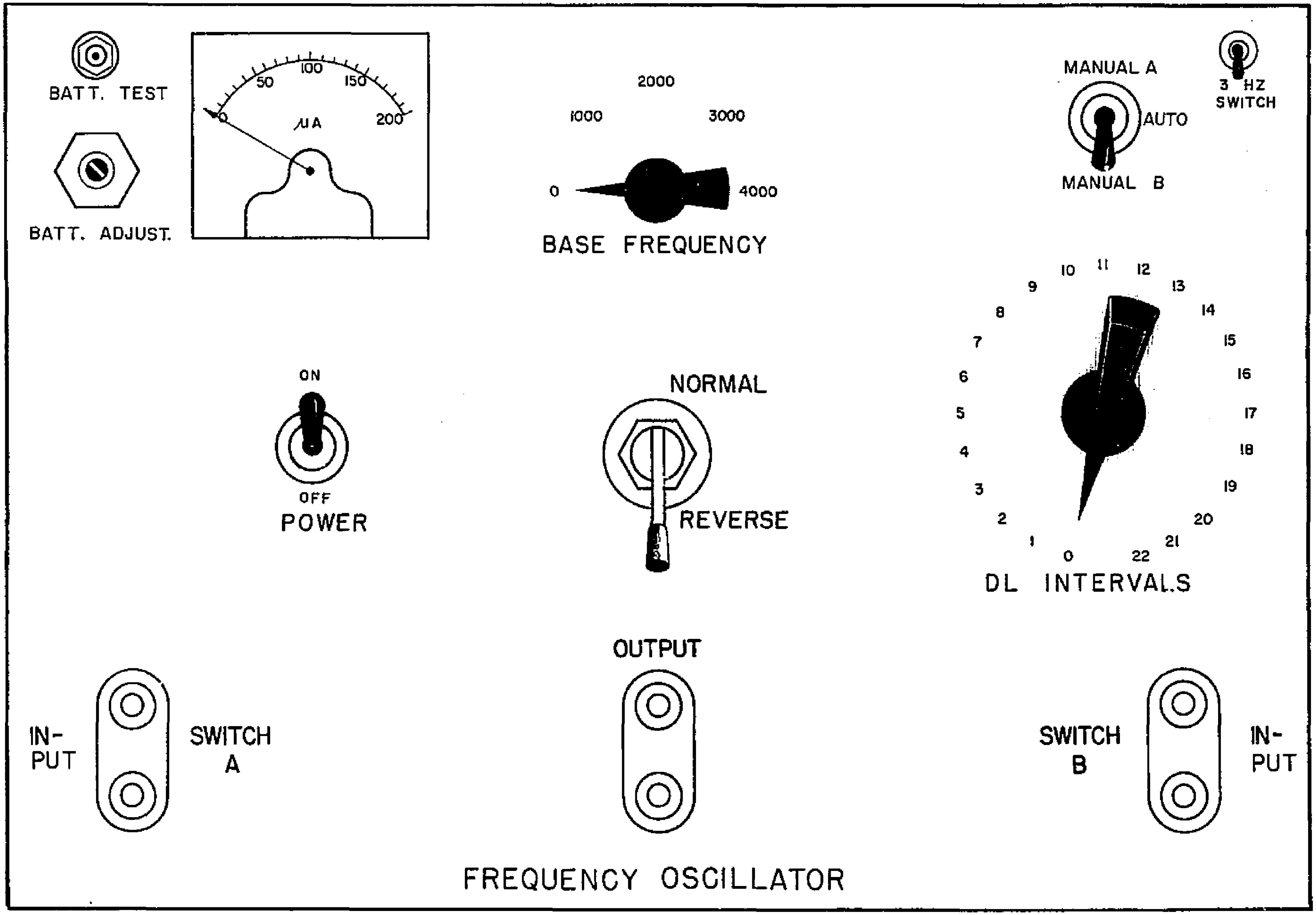
APPENDICES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10 11 12 13 14 15 16 17 18 19 20 21 22 0 1 2 3 4 5 6 7 8 9
DL INTERVALS
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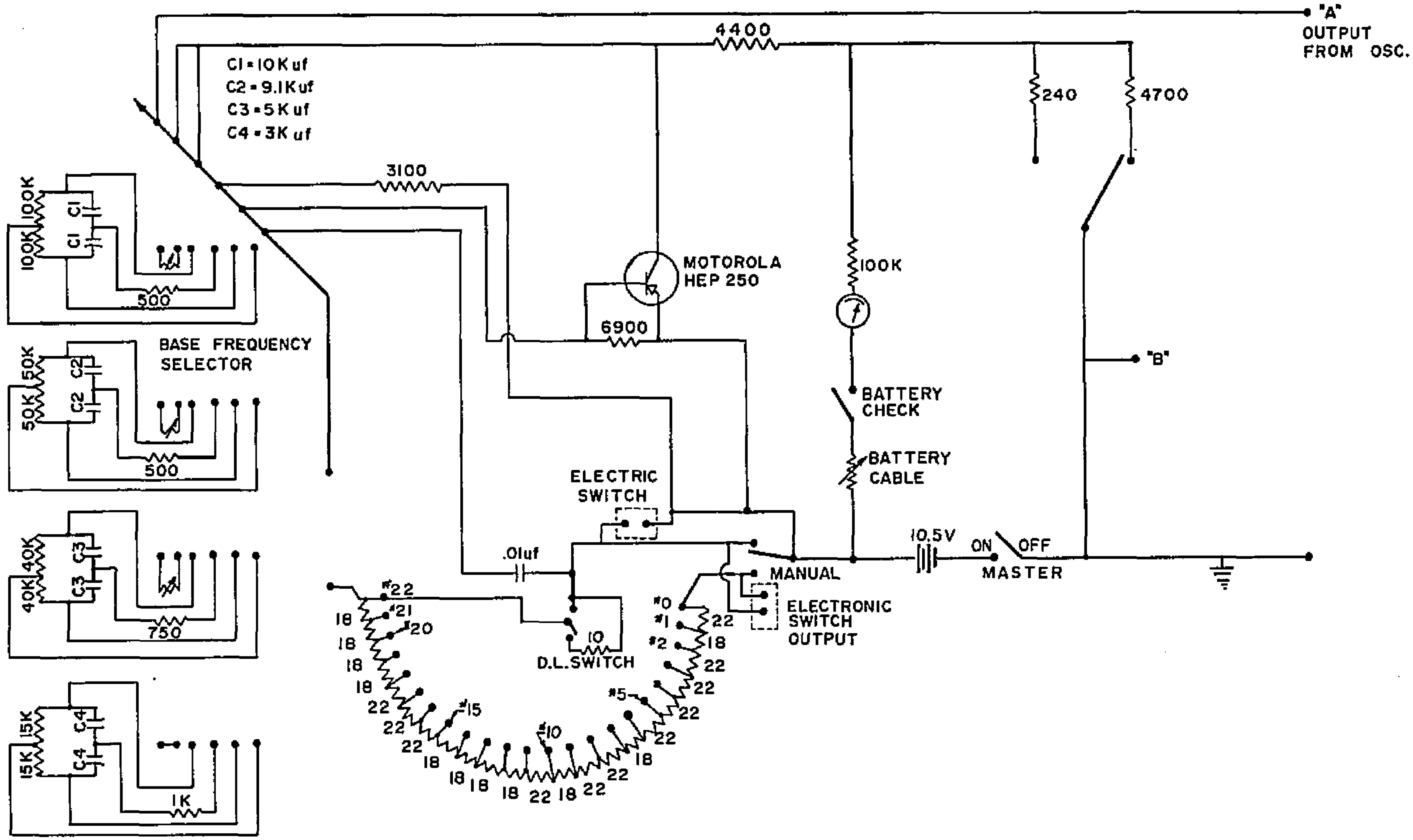
FREQUENCY OSCILLATOR



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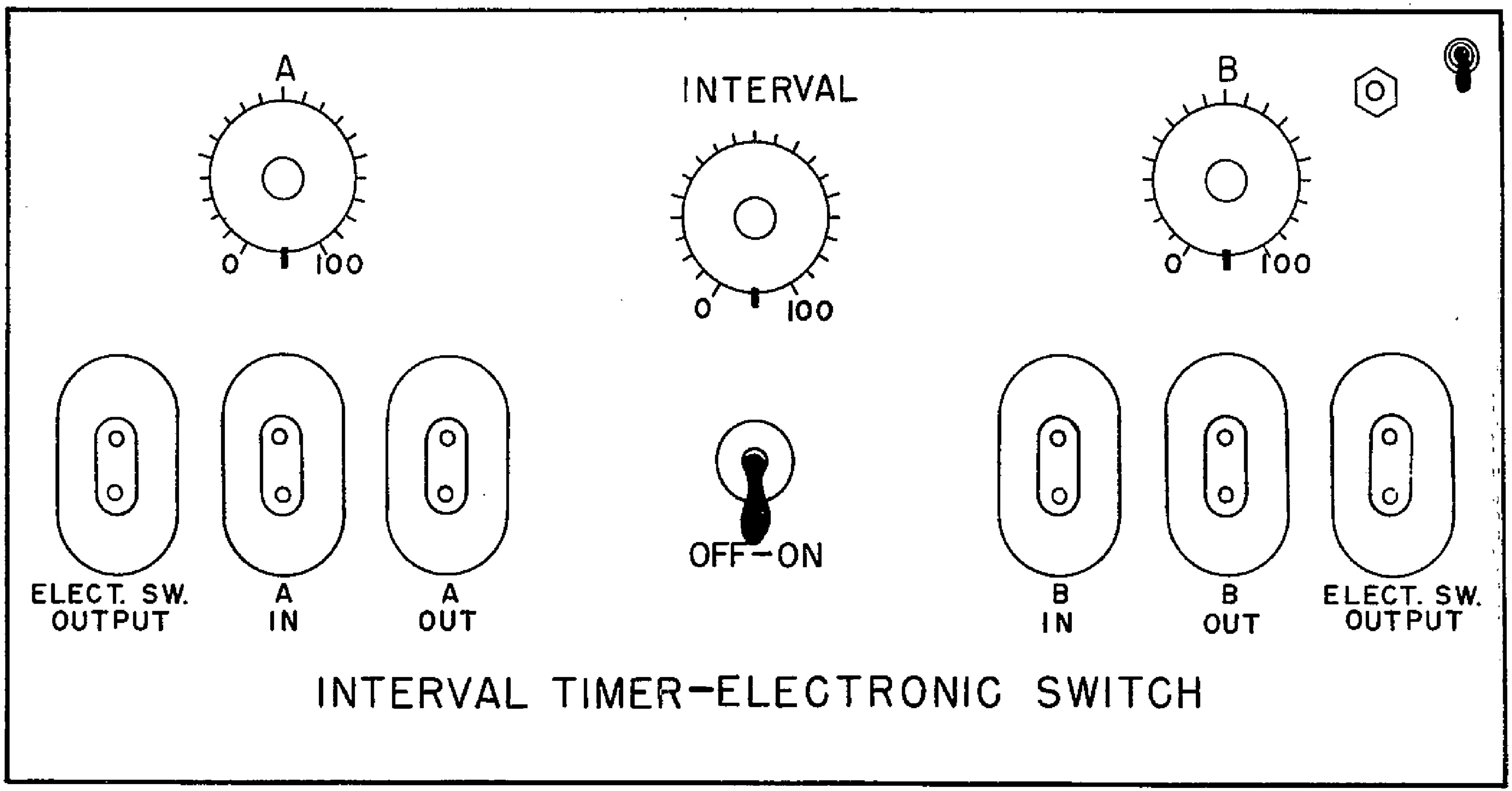
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100
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100
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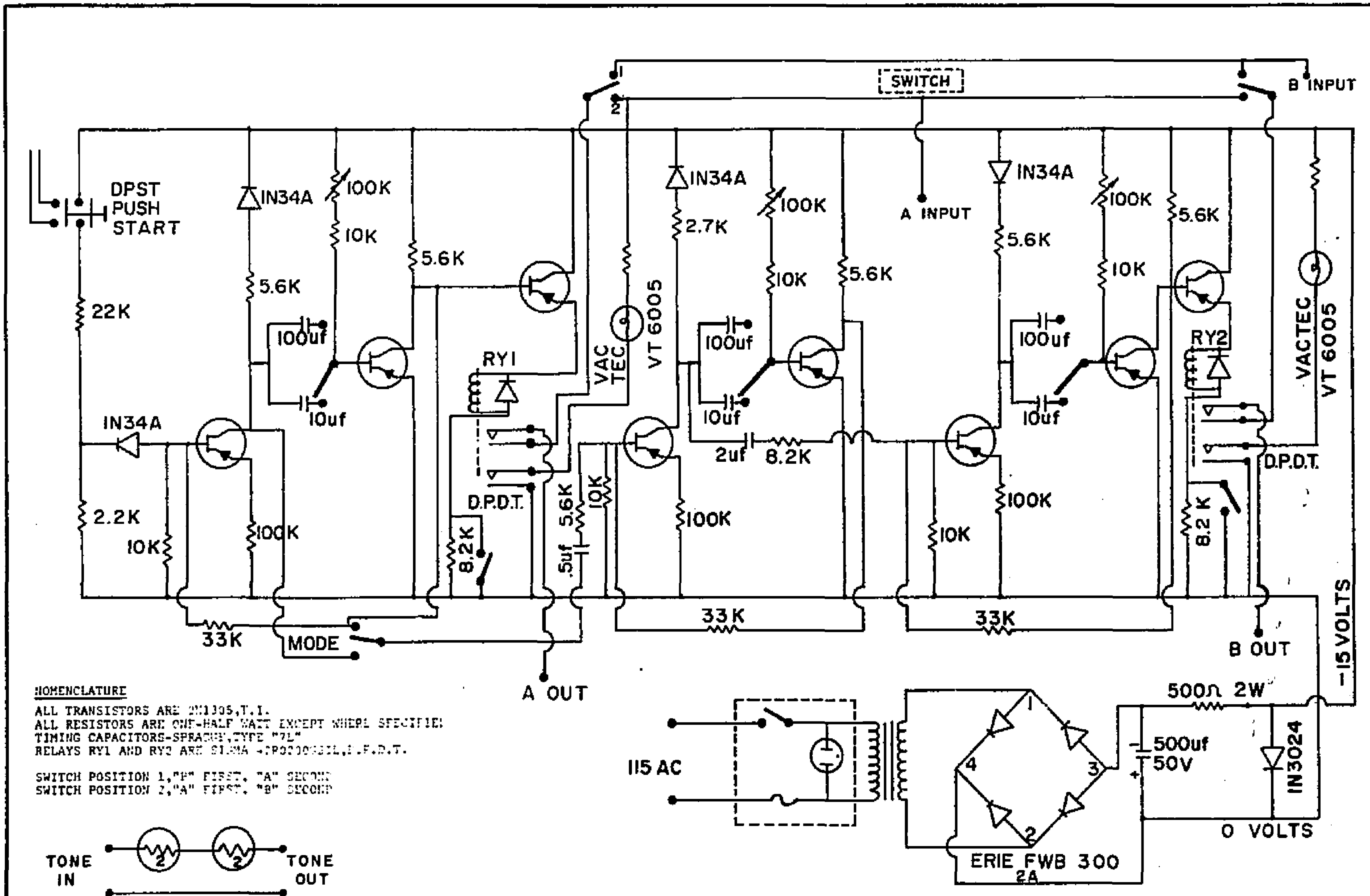
100
ELECT. SW.
OUTPUT
A
IN
A
OUT
OFF—ON
B
IN
B
OUT
ELECT. SW.
OUTPUT
INTERVAL TIMER—ELECTRONIC SWITCH



INTERVAL TIMER—ELECTRONIC SWITCH CIRCUIT

FREQUENCY DL RESPONSE SHEET

SUBJECT____________________ DATE____________________

FREQUENCY____________________ AGE____________________

INTERVAL

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1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L
2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L
3. H L	3. H L	3. H L	3. H L	3. H L	3. H L	3. H L	3. H L	3. H L	3. H L	3. H L
4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L
5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L
6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L
7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L
8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L

12	13	14	15	16	17	18	19	20	21	22
1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L	1. H L
2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L	2. H L
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4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L	4. H L
5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L	5. H L
6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L	6. H L
7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L	7. H L
8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L	8. H L

INTENSITY DL RESPONSE SHEET

SUBJECT__________________ DATE________________

AGE________________

FREQUENCY____________

dB INCREMENT

1	2	3	4	5	6	7	8	9	10
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2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S
3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S
4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S
5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S
6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S
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8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S

FREQUENCY____________

dB INCREMENT

1	2	3	4	5	6	7	8	9	10
1. L S	1. L S	1. L S	1. L S	1. L S	1. L S	1. L S	1. L S	1. L S	1. L S
2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S	2. L S
3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S
4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S	4. L S
5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S	5. L S
6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S	6. L S
7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S
8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S

FREQUENCY____________

dB INCREMENT

1	2	3	4	5	6	7	8	9	10
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3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S
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FREQUENCY____________

dB INCREMENT

1	2	3	4	5	6	7	8	9	10
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3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S	3. L S
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7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S	7. L S
8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S	8. L S

VITA

Troy Jerry Cox was born at Woodville, Mississippi on October 9, 1933. After attending the public elementary schools and Monticello High School, he enrolled in Southeastern Louisiana College in 1951 and studied there until he entered the United States Air Force in 1952. He was honorably discharged on June 3, 1956, and resumed his studies at Southeastern Louisiana College where he was awarded the B.A. degree in 1959. In the same year he enrolled in the graduate school of Louisiana State University where he was awarded a Master of Arts degree in 1961. From 1961 until 1964 he was employed as a Speech and Hearing Consultant with the Louisiana State Department of Health until he enrolled in the doctoral program in the Department of Speech at Louisiana State University. After completion of the course requirements for the doctoral degree, he returned to the Health Department as Administrator of the Communicative Disorders Program in which capacity he is presently serving.

EXAMINATION AND THESIS REPORT

Candidate: Troy Jerry Cox

Major Field: Speech

Title of Thesis: RELATIONS AMONG SELECTED AUDITORY PARAMETERS AND AGE

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

April 27, 1970