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DIFFERENTIAL SENSITIVITY TO DURATION OF

MONAURAL PURE-TONE AUDITORY STIMULI

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DIFFERENTIAL SENSITIVITY TO DURATION OF MONAURAL PURE-TONE AUDITORY STIMULI

CHAPTER I

INTRODUCTION

A major goal of audiology is the establishment of relationships between physical parameters of acoustic stimuli and man's response to them. Such relationships supply the basis of our knowledge of auditory function and permit inferences to be drawn about the way in which man analytically derives meaning from his rather complex acoustical environment.

One method of obtaining indicants of this analytical ability is the measurement of difference limens (DLs) for various stimulus parameters. More specifically, the determination of the least discriminable differences among stimuli is an index of the limiting capabilities of man's acoustic analysis and is indispensable to an understanding of total auditory function.

The primary parameters of sound, as related to the perceptual ability of the auditory system, are frequency, intensity, duration, and phase. The last of these parameters, phase, is relatively unsuited to a behavioral study of precise differential judgment, whereas, the parameters of frequency and intensity lend themselves readily to exploration of stimulus thresholds and difference thresholds. As a consequence, extensive experimental work has been devoted to defining the characteristics of auditory sensation to parameters of frequency and intensity.

In contrast, the amount of information available on differential sensitivity to the duration of auditory stimuli is extremely limited. A search of the literature reveals only a few investigations addressed specifically to a study of the least discriminable differences between auditory stimuli of different durations. Some few additional studies permit the extrapolation of data for the computation of a duration DL. A comparison of the results of these studies presents a confusing picture. The findings are contradictory between experiments and, at times, within individual studies.

The importance of obtaining a reliable estimate of the ability to discriminate differences in stimulus duration is two-fold. First, a systematic specification of man's differential sensitivity to this basic parameter should add to our understanding of the perceptual processes of the human auditory system. Secondly, the possibility always exists that such information might become clinically useful as have similar data that were obtained relative to the parameters of frequency and intensity. Investigations of the sensitivity of the auditory system to small changes in intensity resulted ultimately in the development of audiological tests which have proven to be of value in the audiological and otological clinic (14, 32, 42).

The present investigation was designed to provide basic information regarding the difference limen for tonal duration under various combinations of acoustic conditions. Specific conclusions are to be drawn regarding: the size and constancy of the duration DL over a restricted range of stimulus durations; the effect of stimulus sensation level on the DL; and, the size of the DL at different stimulus frequencies.

A discussion of experimental work related to this study of differential sensitivity to duration as well as the procedural variables which may affect such a study are presented in the following review of literature.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Differential sensitivity of the human ear to auditory stimuli has been of interest to psychologists and research workers in related fields for many years. However, the work carried out since 1923 is of particular interest to a study of differential sensitivity to the duration of acoustic stimuli. Prior to this time, the investigation of auditory perception was largely done without the benefit of electronic control of the stimulus. As a result, studies involving duration were limited primarily to measurements of time perception and utilized relatively gross instrumentation by present standards. The introduction of more exact methods of producing and controlling auditory stimuli has since resulted in data in which very short durations have been treated as a controlled variable.

The purpose of the present study was to obtain a differential limen of duration as an estimate of the ability of normal-hearing humans to differentiate among acoustic stimuli on the basis of duration presentation. A primary objective was to secure measurements of the DL representative of the maximal capability of a normal-hearing subject to detect differences in tonal duration. Data were gathered using several combinations of frequency, sensation level, and duration.

The interests of this investigation are best served by presenting the review of past experimental work related to a study of differential sensitivity to auditory stimulus duration in three major divisions. The first of these, differential sensitivity to frequency and intensity, is important to an understanding of the differences in findings which result from the employment of different psychophysical procedures or the choice of naive rather than experienced subjects. The second division of the review of literature, discrimination of differences in duration, is presented in order to report those investigations concerned with the ability of the auditory mechanism to respond to differences in stimulus duration. These several works demonstrate the relationship of the parameter of duration to frequency and intensity. The third area of interest, differential limen for duration, is employed to present those investigations concerned with the assessment of the smallest change in duration which the human ear can detect. These studies provide a "standard" of Weber ratios which may be utilized as comparative data for the measurements of differential sensitivity to duration obtained by the present experiment.

Differential Sensitivity to Frequency and Intensity

Early studies of the DLs of frequency employed strings, Galton whistles, and tuning forks to produce the acoustic stimuli. Of interest historically is the work of Preyer, Luft, Meyer, and Schaefer which is reported by Vance (60). Boring (4, 5, 6) has also presented an excellent review of the work of Sauveur, Delezenne, and Vance, among others, with regard to the determination of the frequency DL. Knudsen (34) was one of the first investigators to employ electronic equipment to study differential sensitivity of the ear to small changes in frequency. His circuit was designed so that the frequency of the output tone could be changed periodically and abruptly through a motor-controlled relay. The stimuli were presented by means of an earphone at a 20-db SL (sensation level). The data obtained from twelve subjects reveal that the sensitivity of the ear to small changes in frequency varies with the frequency of the stimulus. The average Weber ratios, interpolated from graphic data, are shown in Table 1. Included also in Table 1 are the data of several other authors which are to be discussed subsequently. The data of Knudsen are characterized by a decrease in the Weber ratio as frequency is increased. Relatively little change is seen in the size of the ratio for those stimulus frequencies above 400 cps.

Differential pitch sensitivity of the ear was investigated by Shower and Biddulph (55) utilizing both sinusoidal

TABLE 1

RELATIVE DIFFERENCE LIMEN OF FREQUENCY AS A FUNCTION OF STIMULUS FREQUENCY

	Relative Difference Limens				
Frequency (cps)	Knudsen (20-db SL)	Shower and Biddulph (40-db SL)		Koester (moderate intensity level)	Harris (30-db SL)
		Sinusoidal	Abrupt		
31		.0395	.0160		
50	.0100				
62		.0490	.0160		
100	.0066				
125		.0258	.0120		.0030
200				.0034	
250		.0100	.0075		.0031
400	.0032				
500		.0070	.0030	.0023	.0021
800	.0030				
1000		.0040	.0025	.0016	.0011
2000		.0025	.0024	.0011	.0010
2500				.0010	
3000				.0011	
3200	.0030				
4000		.0026	.0025	.0013	.0025
8000		.0025	.0024		
10000		.0026	.0025		

and abrupt frequency variation. The data obtained from five subjects at a 40-db SL are included in Table 1. It can be seen that the values found with either method of stimulus variation follow the same general trend, i.e., the size of the Weber ratio decreases as the frequency of the stimulus increases. A comparison of these data with those of Knudsen (34) reveals differences in the size of the Weber ratio for stimulus frequencies below 500 cps with the abrupt variation technique and below 2000 cps in the case of the sinusoidal variation of the stimulus. Like Knudsen, Shower and Biddulph also obtained smaller ratios using an abrupt variation technique. However, both studies emphasize the fact that the ratio becomes smaller as the stimulus frequency is increased.

Koester (36) reported smaller Weber ratios for frequency than either Knudsen (34) or Shower and Biddulph (55). He used a modified method of constant stimulus difference to obtain frequency DLs from three experienced subjects at a "moderate" intensity level. The standard and variable stimuli, each approximately one second in duration, were separated by a five-second interval. These were presented in groups of twenty paired stimuli. The frequency of the variable stimulus of one-half the group (ten pairs) was higher than the standard stimulus by a discrete step, but was lower by a discrete step in the other half of the group presentations (ten pairs). The order of presentation of the higher or lower step was random. The trend of the data, shown in Table 1, is similar to that of Knudsen as well as that of Shower and Biddulph in that values vary as a function of frequency.

A more recent study of differential sensitivity to frequency was performed by Harris (26) who reports DLs of the same general magnitude as those obtained by Koester (36). Three experienced listeners were required to judge the second (variable) tone as higher or lower in pitch than the first (standard) tone. Tonal duration was 1.4 sec at the half-power point with standard and variable tones separated by an interval of 1.4 sec. The rise-decay time of the stimuli were set between 15 and 40 msec, depending on the frequency of the tone. Judgment sessions were limited to approximately eight minutes. The Weber ratios, shown in Table 1 for a 30-db SL, follow the same general trend over frequency that Koester observed, i.e., the limens become smaller as stimulus frequency is increased through 1000 cps. However, there is an increase in the size of the limen at the stimulus frequency of 4000 cps. A slight increase in the size of the DLs above 4000 cps is also noted in Koester's data and in Shower and Biddulph's (55) results for the sinusoidal variation.

The work cited in the foregoing review permits some general conclusions to be drawn relative to the differential sensitivity of the ear to small changes in frequency. Despite the differences in relative DLs at specific frequencies, each study shows a definite frequency effect. A general characteristic of these studies is a reduction in the Weber ratio as the stimulus frequency is increased to approximately 2000 cps. Beyond the stimulus frequency of 2000 cps, there is a tendency for the Weber ratio to increase as the stimulus frequency is increased. Constancy of the Weber ratio over frequency does not appear to extend appreciably to those frequencies below 500 or above 2000 cps.

An important aspect of these studies is the relatively wide variation of the DLs reported for the stimulus frequencies below 500 cps. Knudsen (34) pointed out that the introduction of noise from switch contacts made questionable an exact determination of the limen at the low frequencies. Although Shower and Biddulph (55) attempted to overcome the problem of transients by using a filter to eliminate the effect of switching noises, they report that the differences between the sinusoidal and the abrupt variation methods within their study probably were due to the transients introduced by the abrupt variation of the stimulus. Koch (35) has pointed out that the experimental methods employed in these two studies may have resulted in effects which masked the true differential pitch sensitivity of the ear. From his analysis of the experimental methods, Koch was able to state that the DLs found by Shower and Biddulph for the low frequencies were too high, due to the technique of frequency modulation. Koch also stated that the "square top wave type modulation" used by Knudsen reduced the uncertainty of pitch recognition and consequently the DLs obtained at the lower frequencies were probably more accurate than those of Shower and Biddulph.

It may also be noted that the two studies which showed the least variation at the lower frequencies, those of Koester (36) and Harris (26), utilized experienced subjects. Knudsen (34) and Shower and Biddulph (55) obtained their measurements from inexperienced subjects. It is likely that the difference in variability of DLs among these studies is attributable, at least in part, to a practice effect. More specifically, in a measurement of DLs, inter-subject variability is likely to be reduced through practice in the experimental task (6, 11, 26, 28, 31, 64, 65). Furthermore, such practice can be expected to enhance a subject's performance through a firm establishment of judgmental criteria (17, 26).

The preceding discussion has been concerned with the variations of the DL of frequency among several studies. A similar diversity may be noted in the case of difference limens of intensity.

Studies of the differential sensitivity of the ear to small changes in intensity performed by Knudsen (34) and by Riesz (53) present data which were obtained with different procedures. Knudsen utilized an intensity-modulated tone which alternated fifty times a minute. The average Weber ratios obtained from sixteen normal-hearing subjects are displayed in Table 2. Also included in Table 2 are the data from several studies which will be discussed presently. The DLs of Knudsen are of the same general magnitude across frequency, the largest relative DL not exceeding .120. Included in Table 2 also are the data obtained by Riesz who employed a beating tone as a stimulus. An estimate of the limen was found by setting one oscillator at a specific sensation level and then adjusting the second until the subject reported that he heard beats. These results, unlike those of Knudsen, indicate that the ear is less sensitive (the ratios were larger) to small changes in intensity at low frequencies than at the high frequencies.

It has been suggested that the method of "beating-tones" employed by Riesz (53) did not result in a true difference limen for intensity, but rather that the method provided a measurement of the ability of the subject to detect just noticeable beats. Twenty years after Riesz's study, Doerfler (16) employed a similar procedure. Doerfler's results, also included in Table 2, conform to the general trend of Riesz's data. Doerfler employed the same technique as Riesz but used a different group of subjects which suggests that the variation in the intensive limen between the studies of Knudsen (34) and Riesz and of Doerfler were due, at least in part, to the differences in experimental techniques employed by Knudsen and Riesz.

TABLE 2

RELATIVE DIFFERENCE LIMEN OF INTENSITY AS A FUNCTION OF STIMULUS FREQUENCY

Frequency (cps)	Relative Difference Limens			
	Knudsen (20-db SL)	Riesz (40-db SL)	Doerfler (40-db SL)	Dimmick and Olson (41-db SL to 52-db SL)
35		.50		
70		.30		
100	.105			
128				1.34
200	.100	.25		
256				1.65
400	.103			
440				.78
500			.26	
540				.91
800	.105			
1000		.20	.28	1.19
1600	.107			
2000			.20	
3200	.110			
4000		.15	.18	
4800	.120			
7000		.23		
10000		.25		

Dimmick and Olson (15) were interested in supplementing Riesz's (53) data and attempted to measure the intensive DL for the mid-range of frequencies. They employed a psychophysical method of constants and presented the stimulus by means of a speaker mounted ten feet in front of the subject. Their results, obtained from five trained listeners, are shown in Table 2. These data do not agree closely with those of the other investigators. The DLs reported by Dimmick and Olson are larger than those reported by other investigators and the data indicate that the ear is less sensitive to intensity changes of a moderately intense stimulus of 1000 cps than to one of 440 cps. This is the reverse of the trend shown by the results of Riesz and of Doerfler (16).

In general, these studies present a rather confusing picture of the magnitude of the intensive DL for moderate sensation levels. Montgomery (45) has pointed out, however, that a wide divergence of results can be expected between investigations when identical procedures are not employed. This phenomenon is demonstrated by a comparison between data gathered by Montgomery and that obtained by Churcher, King, and Davies (9). These investigations were each concerned with the differential sensitivity of the ear to small changes of intensity. However, procedures differed between the studies. Montgomery employed one experienced subject who was allowed to switch between the stimuli until he was ready to make a decision as to which was louder. Churcher, King, and Davies used discrete, as well as cyclic, changes in intensity. Both incremental and decremental changes in the stimulus were employed with the discrete intensity technique. The results of these two investigators, displayed in Table 3, are shown to differ significantly. First, Montgomery's DLs are consistently the smaller of the two and secondly, the range of DLs over sensation level found by Montgomery is considerably smaller than that shown in the data of Churcher, King, and Davies. It is the opinion of Harris (28) and of Loeb and Hawkes (40) that differences of this nature may be the result of procedural variations between two studies. Harris (28) has stated:

> ...that either a real difference in psychophysical method or in the acoustic manner of presenting S with an intensity change, may create a truly new test which may yield a ΔI more or less sensitive to overall loudness and to frequency as the case may be.

In summary, it may be pointed out that the studies presented above do not provide a uniform DL of intensity under a specific set of physical conditions, but rather, they present evidence that the intensive difference limen is, to some degree, a function of the procedural technique utilized to obtain the measurement.

Discrimination of Differences in Duration

The preceding review has presented a discussion of experimental work devoted to differential sensitivity of the ear to small changes in frequency and intensity. In this

TABLE 3

SENSITIVITY OF THE EAR TO INTENSITY AS SHOWN BY TWO STUDIES USING DIFFERENT PROCEDURES

Sensation Level (db)	Relative Difference Limen			
	Churcher, King, and Davies (800-cps tone)			Montgomery (1000-cps tone)
	Discrete		Cyclic	
	Decrement	Increment		
10	.247	.210	.256	
11				.069
20	.106	.076	.100	
21				.025
30	.062	.042	.053	
40				.009
50	.026	.022	.024	
70	.018	.008	.008	
80				.002
90	.008	.004	.004	

discussion, an attempt was made to point out that the differences shown by the several investigators were due, at least in part, to variations in the psychophysical methods they employed.

Thus far, the discussion has been related to experimental work in which the duration of the stimuli utilized was long enough so that the duration of the tone was not a variable. Under other conditions, however, such as those in which the stimulus is a short pulse, duration becomes a critical factor in the judgment of pitch and loudness. Experimental work has shown, for example, that the pitch of a tone changes as the duration of the sound is progressively reduced to very small values. Stevens and Davis (58) have described three principal states of sensation which can exist for a tone as it is increased from a very short (two to three msec) to a moderately long duration (400 msec). The first state is a click which is devoid of pitch. A second stage is that point at which the sound just acquires a characteristic of pitch. The third stage is reached when pitch can not only be assigned, but will not change if the duration of the tone is increased.

Similar evidence of the effect of duration on the perception of pitch has been presented by Doughty and Garner (16, 17) who investigated the pitch characteristics of short duration tones. They defined two thresholds for pitch, each related to duration. The shortest duration at which the sound attained enough pitch quality to allow it to be distinguished from another sound with a different central component was defined as click-pitch threshold. It was determined that the duration required to establish threshold for click-pitch remained relatively constant (between 4.0 and 4.6 msec) for the higher frequencies (1000, 2000, 4000, and 8000 cps). However, the durations required to establish threshold in the case of the lower frequencies were of greater magnitude and became progressively larger as frequency was decreased. These durations were 17.9, 10.5, and 5.8 msec respectively for the frequencies 125, 250, and 500 cps. Tone-pitch threshold was defined as the shortest duration at which the sound assumed a pitch quality that was very nearly identical with the pitch of a tone of the same frequency but of longer duration. The duration necessary to establish tone-pitch threshold was found to be a function of the frequency of the test tone. The duration remained relatively constant (between 8.8 and 10.2 msec) for the higher frequencies. However, the durations required in the case of the lower frequencies increased in size as frequency was decreased.

Bekesy (3) and, subsequently, Turnbull (59) have presented evidence that the duration of a stimulus affects the size of the difference limen for frequency. Bekesy used two subjects, a standard tone of 800 cps, and held the sensation level constant at 40 db. The average Weber ratio (interpolated from graphic data) increased from .0028 to .0097 as duration of the stimulus tone was decreased from 370 msec to 10 msec.

Turnbull (59) has reported that the ability to perceive small differences in frequency is a function of tonal duration. He used three frequencies (128, 1024, and 8192 cps) with several variable durations which ranged from 507.3 to 17.3 msec in discrete steps. All judgments were made at a sensation level of 60 db. As with the results obtained by Bekesy (3), the Weber ratios became larger as duration was decreased. This trend was present at each of the frequencies but it was not linear over reference duration. The Weber ratio increased more rapidly at durations below 100 msec than at longer reference durations.

These findings are corroborated by those of Liang and Chistovich (37) who investigated the dependence of frequency-difference limens on duration utilizing the psychophysical method of adjustments. Their data for three frequencies (250, 1000, and 4000 cps) show that the DL increased in size as duration was decreased. They, too, found that the rate of change in the DL was not linear and describe three separate relationships between the magnitude of the DL and reference duration at each of the three tonal frequencies employed. In the case of short durations (from approximately 3.0 to 40.9 msec), the DL was reduced in direct proportion to increasing reference duration. However, in the case of medium durations (between 11.6 and 163.8 msec) the DL was reduced in direct proportion to the square root of the increase in duration. In the case of longer durations (between 144 and 600 msec) the DL became constant and independent of duration.

The foregoing studies demonstrate that duration is an important variable in judgments of the pitch of short tones. Similar relationships have been studied relative to duration and loudness. When the ear is presented with a tone, loudness characteristically builds up over a short period of time (38). Attempts to state the relationship between duration and intensity in a general mathmatical formula, however, have been only partially successful. Bekesy (3) applied Nernst's formula relating duration and intensity ($L = Kt^{\frac{1}{2}}$) to his own data and found it quite reliable for low intensities but not for intensities above 40 db. In an attempt to establish the relationship between optimum reverberation time (duration) for music and the volume of a room, Lifshitz (39) found loudness related to duration in such a way that an increase in duration could cause an apparent increase in loudness even though intensity was not changed. He derived a formula expressing the dependence of loudness on duration; however, Turnbull (59), in applying this formula to his own data, was unable to demonstrate the same relationship.

Other experimenters have demonstrated that intensity and duration are related in a rather specific manner for sounds of short duration. Miller (44) has shown that intensity must be increased 8.8 db for each ten-fold decrease in duration if threshold is maintained. He found, as did Bekesy (3), that this relationship was not linear over an extensive range of intensities. He extended his study over several intensities and observed that the loudness of loud noises was less dependent on duration than was the loudness of faint noises.

Several other investigators have described similar relationships between loudness and duration. Pollack (49) has found that a 10-db increase in the intensity of a white noise stimulus was necessary to overcome a ten-fold decrease in duration. Recently, Goldstein and Kramer (21) have shown that threshold for a 1000-cps tone changes as a function of duration. Their results, obtained at several durations, show that a ten-fold decrease in duration requires a 10-db increase in the strength of the stimulus to reach threshold. These findings are similar to those of Fodor (19) who found that threshold of pure-tone pulses was lowered by 9 db for each ten-fold decrease in duration below 150 msec. Munson (46) has shown that loudness increases rapidly, in the case of pulsed tones, up to 200 msec and his graphic data suggest that this relationship between loudness and duration probably extends to the area of 250 msec. This contrasts rather sharply with Bekesy's (2) finding that when two tones were compared (as in loudness matching with a standard tone of 200 msec duration) maximal loudness was reached after 180 msec and then gradually declined as duration was increased. Green, Birdsall, and Tanner (22) found, however, that signal detectability continued to increase as the duration of the signal (a 1000-cps tone masked with white noise) was extended from 250 to 3000 msec.

In an attempt to determine the nature of the neural integrative process, Garner and Miller (20) studied differential sensitivity for intensity as a function of duration. Their average data, obtained from two subjects over two frequencies at two sensation levels (40 and 70 db at 500 cps and 40 db at 1000 cps) indicated that the ability to discriminate changes in intensity was improved as the duration of the tone was increased. This trend was present for each of the conditions employed. Turnbull (59) has also shown that the ease of detection of changes in intensity is dependent on the duration of the tone. He found the DL of a 1024-cps tone to be larger at the duration of 35 msec than at the duration of 100 msec at various sensation levels.

Several investigators have applied information theory concepts to the psychophysical problem of discrimination of duration. The results of their investigations, expressed in terms of a detectability index, relate the parameter of intensity to that of duration. Green, Birdsall, and Tanner (22) carried out three experiments, each concerned with a different aspect of the ease of detection of a signal under varying conditions of duration and intensity. The stimulus was a 1000-cps tone masked by white noise. In the first experiment, signal duration was held constant while intensity was increased in discrete steps. The results indicated that the signal was identified correctly a greater number of times as the intensity was increased. In the second experiment, a constant energy signal was presented to the observer while the signal duration was increased in discrete steps. The data indicated that the range of signal durations between 15 and 100 msec were more easily detected than those of shorter or longer durations. This was the only temporal region in which the ear integrated acoustic power linearly over time, according to the authors. This finding is contradictory to that of other experimenters. Garner and Miller (20) found that the ear integrates acoustic energy linearly up to 200 msec while Fodor (19) suggested that linear integration continues for at least 150 msec. However, Harris, Haines, and Myers(29) found that linear integration may extend from 100 to 300 msec depending on the experimental group.

Creelman (13) reported on duration-discrimination as a function of base time, size of tonal increment, and signal intensity expressed as signal voltage. The stimulus was a 1000-cps tone masked by white noise. The data were reported in terms of a detectability index. The effect of signal intensity on duration-discrimination indicated that detection of a duration difference can be expected to increase with an intensity increase only at low signal-to-noise ratios. As the signals were made "loud and clear" above the noise, the dependence of the signal on intensity became negligible. When duration of the increment was held constant and the reference duration varied, the ability to detect the signal was reduced as the reference duration became longer. When the increment duration was varied and reference duration held constant, the results indicated that detection of duration differences was a linear function of the size of the increment.

Differential Limen of Duration

In general, the experimental work reported above indicates that duration is an important variable in the judgment of pitch and loudness of short tones. These studies have also shown that detection of duration is related to the intensity of the signal, to the size of the standard, and to the size of the increment. More systematic studies of these factors, including the specification of the limits of sensitivity of the ear to duration now will be considered.

Past studies of temporal discrimination have employed two basic types of stimuli: silent intervals bounded by auditory clicks and intervals of continuous sound bounded by silence. Data on time perception have usually been obtained by one of four experimental methods: verbal estimation; production; reproduction; and, comparison. However, the last of these, the method of comparison which requires judgments of the relative duration of two silent intervals or of two continuous stimuli, is of primary interest here since its use allows the calculation of a differential threshold. Recently, Chistovich (8) utilized this method to obtain an estimate of discrimination ability in the case of silent intervals delineated by auditory clicks. The subject compared a standard interval (5.5 msec to 196 msec) with a variable interval. In 50 per cent of the cases the variable interval was equal in length to the standard interval and in 50 per cent of the cases the variable interval differed from the standard interval by the amount ΔT (.1 msec to 40 msec). The subject reported whether the variable interval was the same as the standard interval or differed from it. The quantity ΔT was gradually reduced from one test series to the next. The relative DLs, as interpolated from the curve-plotted data of Chistovich, are shown in Table 4.

Several aspects of Chistovich's data (8) are interesting. First, when viewed as a whole, the Weber ratios are generally small, with the range of values extending from .15 to .25. A second point of interest is the relationship between the sizes of the Weber ratios over reference duration. The ratios increase in size from .16 (at 5.5 msec) to the largest value of .25 (at 20-msec reference duration). At this point, the trend is reversed and the values decrease in size as the duration is increased, with the smallest DL (.15) being obtained at the longest duration, 196 msec.

TABLE 4

MEAN WEBER RATIOS AS A FUNCTION OF REFERENCE DURATION INTERPOLATED FROM DATA OF CHISTOVICH

Reference Duration (msec)	Weber Ratio
5.5	.16
10	.25
20	.25
50	.19
100	.17
196	.15

These data indicate that the DL of short durations (5.5-msec reference duration) is smaller than the DL of longer durations (10, 20, 50, and 100-msec reference durations). However, Green, Birdsall, and Tanner (22) have shown that signal durations between 15 and 100 msec were more easily detected than those of shorter or longer durations. Chistovich's findings (at reference durations of 15 msec and beyond) are at least partly in keeping with Creelman's (8) prediction that a signal is easier to detect as increment duration is made larger. The explanation of the small Weber ratios at short reference durations may lie in the procedural technique employed by Chistovich. The particular instrumentation which he used imposed an approximate 10-sec delay between the presentation of interval pairs. Such a delay may have adversely affected the differential thresholds. Several authors (1, 10, 36, 50, 52, 62, 64) have indicated that judgments of time are influenced by the physical characteristics of the stimuli. Postman and Miller (51) and Needham (47) show that the duration of the stimuli, as well as the length of the interval, will result in an anchor effect (predisposing effect of preceding stimuli) while Kinney (33) demonstrates that ease of discrimination is closely related to the type of auditory pattern utilized as the stimuli. A second possible source of inaccuracy of measurement also existed in Chistovich's study. He indicates that the differential thresholds in the region of the smallest reference duration (5.5 msec) were difficult to measure because the sounds became distinguishable by their pitch. This particular phenomenon was previously described by Doughty and Garner (18) and may account for the increase in the Weber ratio reported by Chistovich from 5.5-msec to 10-msec stimulus duration and a decrease in the ratio beyond the 20-msec stimulus duration.

Judgments of differences between silent interval durations were studied by Gridley (23). The subjects were asked to judge whether the second interval of a pair was longer or shorter than the first. One Weber ratio was available (at the 75 per cent correct point) from her data and it is included in Table 5.

TABLE 5

MEAN WEBER RATIO CALCULATED AT ONE REFERENCE DURATION FROM DATA OF GRIDLEY

Reference Duration (msec)	109
Weber Ratio	.09

The value, obtained at 109 msec, is only slightly smaller than that found by Chistovich (8) at the 196-msec reference duration. Comparative use of Gridley's data is restricted by the fact that her procedure permitted uncontrolled serial learning during the experiment. Comparison of values from two comparable parts of the study indicate that the data were also biased unintentionally by a practice effect.

A rather lengthy experiment was carried out by Stott (56) in an attempt to determine accurately the error due to time-order (the effect due to temporal order of presentation of the reference and the variable stimuli). He employed a variation of the method of constant stimuli to obtain responses to a complete stimulus presentation that consisted of standard and variable duration tones separated by a 1.5-sec silent interval. The stimulus frequency was 1000 cps. The stimulus-intensity was not stated. An electro-mechanical timing device was employed to obtain the reference durations (.2 sec to 30 sec) and the variable durations (from

0 per cent to 20 per cent longer than the reference duration).

The results of the study were presented in such a manner that it is possible to interpolate values and then calculate a Weber ratio for the 75 per cent correct point. The ratios thus obtained (reference durations of 200 through 4000 msec) are shown in Table 6. An interesting feature of the data is that the largest ratios were found at the extremes of reference durations. At the longest duration, 4000 msec, the ratio was .160. At the shortest reference duration, 200 msec, the ratio was .142. The ratios of the durations of 400, 600, 800, 1000, and 1500 msec are of the same general size, all values falling in a range from .115 to .126. The smallest ratio shown in Stott's study (56) was that of .103 at the reference duration of 2000 msec.

The data obtained by Chistovich (8) and Stott (56) may be compared at one duration. Although Chistovich obtained his data with silent intervals, the Weber ratio of .15 interpolated from his curve at the reference duration of 196 msec is relatively close in value to the ratio of .142 interpolated from Stott's data at the reference duration of 200 msec.

More pertinent to the present study, perhaps, than the work of Stott is that of Henry (30) who undertook the only systematic study of duration DL known to the present author. Henry investigated the duration DL for relatively short tones (32 to 480 msec) using a modified method of constant stimuli. His subjects were presented a series of tones and asked to state whether the stimuli consisted of alternations of different durations or of repetitions of the same duration.

TABLE 6

MEAN WEBER RATIOS AS A FUNCTION OF REFERENCE DURATION INTERPOLATED FROM DATA OF STOTT

Reference Duration (msec)	Weber Ratio
200	.142
400	.120
600	.115
800	.118
1000	.126
1500	.123
2000	.103
4000	.160

The study was divided into three parts. The purpose of the first experiment was to determine the constancy of the Weber ratio over duration. A 500-cps tone was presented to seven subjects, three female and four male college students, at an SL of 50 db. The Weber ratios obtained are shown in Table 7. These values decreased in size as the reference durations of the tonal stimuli increased from 32 msec

TABLE 7

MEAN WEBER RATIOS OF 500-CPS, 50-DB STIMULUS AS A FUNCTION OF REFERENCE DURATION AS SHOWN BY HENRY

Reference Duration (msec)	Weber Ratio
32	.281
47	.203
77	.208
110	.196
175	.188
277	.172
480	.143

to 480 msec. The rate of decrease is not linear across durations. The largest ratio, .281, was found at the shortest duration, 32 msec. The ratios reported for the mid-range of durations (47, 77, and 110 msec) differ from each other by very small amounts (.203, .208, and .196). The ratios at 277 and 480 msec are .172 and .143, respectively. Henry's values are slightly larger than the data obtained by Stott (56) at 200 and 400 msec. Stott's ratios at the reference durations of 200 msec and 400 msec were .142 and .120, while

Henry's were .188 and .143 at the reference durations of 175 and 480 msec. The differences between the two studies, as Henry points out, may be due to differences in experimental procedure and equipment. Henry stated that Stott employed a different rise-decay time and that the data reported in the two studies were, for that reason, not comparable.

In a second experiment, Henry (30) was concerned with the effect of sensation level on the magnitude of the relative DL of duration. Four different sensation levels of 20, 40, 60, and 80 db were employed. The stimulus frequency was kept constant at 500 cps and data were obtained at three different tonal durations (47, 77, and 277 msec). Data were gathered from five subjects at the 47-msec reference duration, four subjects at the 77-msec reference duration and five subjects at the 277-msec reference duration. Of these subjects, two who had participated in the first experiment, cited above, served in all three parts of the second experiment. Two others did both the 47-msec reference duration and the 277-msec reference duration tests and one did both the 47-msec and the 77-msec reference duration tests.

The results, shown in Table 8 reveal three general trends. First, an effect over intensity is noted for each duration. While this effect is relatively small and is not linear, the Weber ratio at each reference duration is larger at 20-db SL than at the SL of 80 db. Second, an effect across reference duration can be seen. In each case the

TABLE 8

MEAN WEBER RATIOS OF A 500-CPS TONE AS A FUNCTION OF STIMULUS INTENSITY AT THREE REFERENCE DURATIONS AS SHOWN BY HENRY

Sensation Level (db)	Reference Duration (msec)			
	47	77	277	Average
20	.204	.198	.149	.184
40	.153	.184	.137	.158
60	.166	.179	.147	.164
80	.157	.184	.139	.160
Average	.170	.186	.143	.166

relative difference in size of the Weber ratio, between the SLs of 20 and 80 db, becomes smaller as reference duration is increased. Third, with the exception of the 20-db SL, the Weber ratios obtained at the 77-msec reference duration are larger for each sensation level than are the values at the 47-msec reference duration. The influence of variability within the study can be seen when the results of the first experiment are compared to the results of the second. The stimulus for these two experiments was the same, a 500-cps tone presented at 50-db SL in the first experiment and at four sensation levels in the second experiment. Only the ratios obtained at the 20-db SL for the reference durations of 47 msec and 77 msec (.204 and .198) in the second experiment are approximately the same as those (.203 and .208) shown for the same respective durations in the first experiment. The rest of the ratios in the second experiment are consistently smaller at each reference duration than the DLs obtained in the first experiment. The existence of such differences between the values shown in the two experiments under comparable conditions indicate the presence of an effect due to some factor other than reference duration or sensation level. The subject sample utilized in the second experiment suggests that at least part of the variation between experiments is due to practice effect as a result of some of the subjects having previously served in the first experiment.

In a third experiment, Henry (30) sought to determine the effect of frequency on the duration DL. The reference duration was maintained at 77 msec and the sensation level was constant at 50 db. The stimulus frequency was varied in octave steps from 125 through 2000 cps. Weber ratios were obtained from three subjects. These data are displayed in Table 9.

The ratios, averaged over subjects for each frequency, decreased as the stimulus frequency increased. The DLs at 500, 1000, and 2000 cps agree relatively well, ranging in size from .156 to .161. The values at the lowest frequencies differ from each other by a relatively large amount and both are somewhat larger than the DLs obtained at the higher frequencies. The ratio found at 250 cps was .208 and that at 125 cps was .295.

TABLE 9

INDIVIDUAL WEBER RATIOS OF THREE SUBJECTS FOR 77-MSEC REFERENCE DURATION, 50-DB SL TONE AS A FUNCTION OF STIMULUS FREQUENCY AS SHOWN BY HENRY

Subject	Stimulus Frequency (cps)				
	125	250	500	1000	2000
S	.280	.208	.143	.130	.158
L	.260	.195	.169	.156	.117
F	.335	.221	.169	.182	.208
Average	.295	.208	.160	.156	.161

The result obtained at 500 cps (.160) in the third experiment agrees more closely with the value obtained at 60-db SL in the second experiment (.179) than with that found in the first experiment (.208). It is quite possible that the variability shown by these differences would have been reduced had a larger number of subjects been utilized in the third experiment.

Henry's study (30) is unique in its intended purpose of determining difference limens for duration. Unfortunately, the results show such inconsistencies that both the validity and reliability of the data must be questioned. The presence of a high degree of variability can be noted among comparable conditions of the three experiments. This variability is probably due, at least in part, to a practice effect. Several authors (5, 11, 26, 27, 31, 63, 64, 65) have reported that practice will have an effect on the results obtained by psychophysical methods. Variation due to practice can be reduced substantially by providing adequate practice in the experimental task prior to the point at which data is collected. Doughty and Garner (17) have shown that the use of experienced listeners as subjects serves to reduce inconsistencies as compared to the use of non-experienced listeners. Equally important in reducing variability in a subject's performance between comparable parts of a study is the feedback of information relative to the subject's performance during the experiment. Lukasweski and Elliot (41) have presented evidence that providing subjects with immediate knowledge of results is instrumental in reducing variability within a subject's range of scores.

As a consequence of the intra-study variations, the usefulness of Henry's data (30) as a normative instrument is open to question. The study does serve to point up the need to reduce variability within the experiment and between subjects through the selection of experienced listeners and by providing extensive practice in the experimental task.

Summary

The review of literature of differential sensitivity of the ear serves to point up the comparatively small amount of research concerned with determining the discriminatory capacity of the hearing mechanism to acoustic duration. Of these few studies, only one, that of Henry (30), was specifically addressed to the measurement of the difference limen of duration. Unfortunately, his data cannot be regarded as being an accurate representation of the limits of sensitivity of the ear to acoustic duration owing to intra-study inconsistencies.

The need for further research is exemplified by the lack of an adequate measurement of the DL of duration as well as by the inconsistencies existing within and between previous studies of acoustic duration. This experiment has been designed to provide an accurate and systematic measurement of the DL of duration under several combinations of reference duration, sensation level, and stimulus frequency. This study will serve to supplement the literature of differential sensitivity relative to the discriminatory capacity of the human ear to signal duration. A description of the instrumentation and experimental procedure utilized to obtain these measurements is presented in the following chapter.

CHAPTER III

SUBJECTS, APPARATUS, AND PROCEDURES

Introduction

This experiment was designed to study the ability of normal-hearing subjects to discriminate monaurally presented pure-tone auditory stimuli which differed only in duration. The DL of duration was measured under eighteen combinations of frequency, sensation level, and reference duration.

Variability among subjects was reduced by employing young, normal-hearing listeners who were practiced in the experimental task. Subject fatigue was minimized by limiting the length of each test period and by providing frequent periods of rest. As an aid in repeatedly focusing the subject's attention on the immediate task each trial was preceded by a warning signal. Performance of the task was enhanced by providing the subject with immediate knowledge of results following each judgment.

Differential threshold was estimated for each condition using a modified method of limits. Initially the stimuli were widely separated in duration. As testing continued for each experimental set, this difference was reduced by discrete steps until the limen was established.

A detailed description of the subjects, experimental apparatus, and procedures is presented in the subsequent sections.

Subjects

The experimental group used in this study consisted of ten normal-hearing young adults (five men and five women) whose age range was from 22 to 35 years (APPENDIX A). All subjects, with the exception of two, were college graduates. Of these two, one was an undergraduate and the other a high-school graduate. Prior to being selected for the experimental group, each subject was given a pure-tone audiometric test to determine the presence of normal hearing (re. USPHS norms) in each ear at octave frequencies from 125 through 8000 cps. Each subject selected for the experiment had a negative history of ear pathology. Only one ear of each subject was used in the collection of the experimental data. The right and left ear each served an equal number of times as the test ear in the experiment. The test ear was determined by drawing a card for each subject from a group of ten well-mixed cards, one-half of which were labeled "right" and one-half of which were labeled "left".

Apparatus

All procedures were conducted in a sound-isolated test-suite at the Speech and Hearing Clinic, University of Oklahoma Medical Center. The test-suite consisted of two adjacent rooms, a test chamber, and a control room. Entrance into the test chamber was provided by a pair of acoustically-treated doors. Visual communication was available through a five-pane, acoustically-damped window. The ambient-noise level within the test chamber was below 30 db as measured on the "C" scale of a sound level meter (General Radio, 759-B).

Hearing Testing Apparatus

Either of two pure-tone audiometers (Beltone, Model 10 AW or Allison, 15 B) with two air-conduction earphones (Telephonics, 39-10 ohm) were used in obtaining pure-tone thresholds. The earphones were mounted in MX-41/AR cushions and held in place over the subject's ears with a standard headband. The acoustic output of the earphones was determined at frequent intervals with an audiometric calibration unit (Western Electric 640 AA Condenser Microphone and Condenser Microphone Complement, Type 100D/E).

Experimental Test Apparatus

A block diagram of the experimental apparatus is shown in Figure 1. The stimulus frequency was produced by an audio-oscillator (Hewlett-Packard, 200 ABR) and fed to each of three electronic switches (Grason-Stadler, 829) through a dividing network.

The duration of the stimuli was controlled by interval timers, each consisting of a waveform generator (Tektronix, 162) and two pulse generators (Tektronix, 161), which trig-

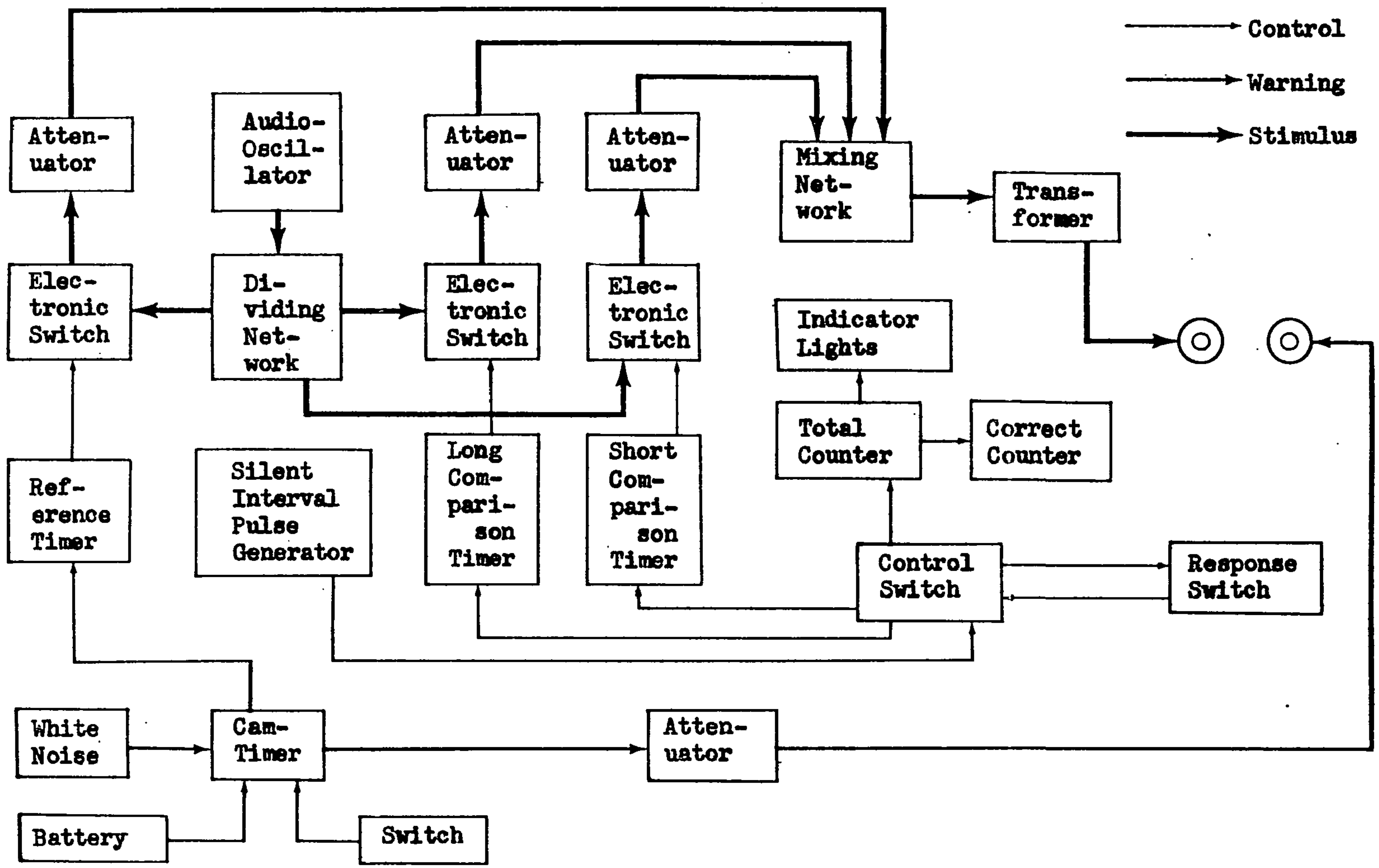

Fig. 1 - Block diagram of the experimental apparatus employed to obtain monaural DLs of duration of pure-tone auditory stimuli.

gered the electronic switches. The "reference" electronic switch and its companion timer supplied the reference tone, and the "long" and the "short" electronic switches, with their timers, provided the comparison tones. The output of the electronic switches was transmitted to the listener's earphone (Sharpe, Type B, Model HA-10) through separate attenuators (Hewlett-Packard, 350 AR), a mixing network, and an impedance-matching transformer (United Transformer, LS-33).

A cathode-ray oscilloscope (Tektronix, 532) was used as an aid in adjusting and maintaining the rise-decay times of the output of the electronic switches at 16 msec. An electronic counter (Berkeley, 5370) was utilized in adjusting the waveform generators and pulse generators to produce the specific durations (re. the 6-db down points). The output of the audio-oscillator was checked frequently with the oscilloscope, the electronic counter, and a vacuum-tube voltmeter (Hewlett-Packard, 400 DR).

A control panel containing a re-cycling cam-timer (Industrial Timer Corporation), a three-position multi-pole lever-switch, and a single-pole push-button switch served to initiate: (1) the warning signal, (2) the reference tone and either the "longer" or the "shorter" comparison tone, (3) an appropriate light signal informing the subject of the correctness of his response. Two electronically-operated counters (Production Instruments, PIC-600) were also mounted on the panel. One counter recorded the total number of responses of a subject while the other recorded only the number of correct responses. Two lamps, one blue and one red, were also mounted in the control panel. These lights operated in parallel with the counters and indicated to the experimenter whether a given response was correct or incorrect.

A warning signal was produced by a white-noise generator (Grason-Stadler, F5539A) and transmitted to the non-test earphone (Sharpe, Type B, Model HA-10) through an attenuator (Hewlett-Packard, 350A). The duration of the warning signal (0.5 sec) was controlled by a microswitch on the cam-timer. A silent period of 0.8 sec, following the termination of the warning signal and preceding the reference tone, was also controlled by the cam-timer. At the end of the silent period, a second microswitch on the cam-timer closed and transmitted a 45-volt initiating pulse to the waveform generator in the reference tone circuit.

A pulse generator (Tektronix, 161), in conjunction with the waveform generator in the reference tone circuit, provided a 500-msec silent interval between the reference tone and the comparison tone. The duration of this interval was adjusted with the aid of the electronic counter just prior to an experimental run.

The subject's response box contained a self-return multi-pole lever-switch used as a response switch Also mounted on the box were two signal lights: a blue one which indicated a correct response and a red one which indicated an incorrect response. Movement of the response switch appropriately triggered one of the lights, as well as closed a circuit to the cam-timer which initiated the next test-cycle two seconds after the subject's response. Thus, during an experimental run, although the temporal relationship between comparison stimuli remained constant, the rate of presentation of stimulus pairs depended on the rate of a subject's response, permitting a subject the time he required to make a judgment.

Procedures

Initially, a schedule of testing was discussed with the subject. Ideally, such a schedule would call for testing to be done at the same hour on succeeding days until the testing was completed. The total length of time required for the subject to complete this experiment made it difficult to achieve such a rigid schedule owing to holidays, illness, and conflicting appointments. Thus, each subject was seen for testing as often as his own personal schedule would allow with the restriction that no test period be more than two hours in length.

Subsequent to an audiometric test, used to establish a subject's normal hearing acuity, each subject was given extensive practice in the experimental task. The procedures employed in the practice sessions were the same as those followed in succeeding experimental sessions. The two differed only in the number of conditions presented. The stimulus conditions employed in the practice sessions consisted of eight combinations of frequency (250 and 4000 cps), sensation level (10 and 50 db), and reference duration (300 and 1000 msec) and required between six and nine hours to complete. The experimental sessions consisted of eighteen combinations of frequency (250, 1000, and 4000 cps), sensation level (10 and 50 db), and reference duration (300, 500, and 1000 msec).

The practice and experimental runs were each divided into a number of test periods, the length of which were governed by the individual subject's personal time-schedule. An important consideration in this study was that the data remain free of the effects of subject fatigue. In this interest, subjects were instructed to inform the investigator if, at any time during a test period, he could no longer fully attend the task. In such a case, testing for that subject was discontinued and he was re-scheduled for another testing period. This occurred in only three instances during the course of the investigation.

The test periods were further divided into experimental sets, each of which provided an adequate number of trials to obtain a DL for a particular condition of reference duration, stimulus frequency, and sensation level. Generally, each test period consisted of several experimental sets. However, the number which were completed in any one period depended on the length of the test period, as well as on the speed with which the subject responded to the stimuli. In the event that an experimental set could not be completed in a given test period, the data were not used in the computation of the DL, and that experimental set was started again in the following test session.

The experimental apparatus was turned on from one and one-half to two hours preceding the scheduled test period in order to allow it to reach stable operating temperature. Just prior to the initiation of testing, the equipment was set to produce the frequency and the durations as predetermined by a randomized schedule. At this time the voltage output across the earphone was measured and each of the electronic switches were adjusted to produce equal voltage readings. The rise and the decay time as well as the waveform of the stimuli were checked and adjusted if necessary. The waveform and frequency output of the audio-oscillator were verified with the oscilloscope and the electronic counter. Duration of the stimuli and the silent interval were established with the electronic counter and by adjustment of the waveform generators. Frequent and periodic checks during the testing procedure were used to determine that the durations remained within ($\pm$) 0.5 msec of the required duration.

Each subject was instructed just prior to the first test period of the practice session. When questions arose, the subject was instructed on the procedure again. The subject was seated comfortably in the test room and given the response box. He was instructed as follows:

> You are participating in a research project that is basic to the understanding of human auditory behavior and of some significance in the field of audiology. Upon completion of the entire experiment you will be informed of the final results. This will be a grueling and lengthy procedure. Your sustained attention and alertness are essential and, therefore, the manner in which you perform the tasks to be assigned to you is of particular importance. This test session will take approximately two hours. There will be frequent rest periods during which you may relax; therefore, do not interrupt a test sequence that is in progress. If, for any reason, you find it necessary to stop the procedure, you need only to say so. You can be heard in the control room at all times.
>
> You are to perform two tasks. Each requires a set of instructions. Listen very carefully.
>
> In the first instance, you are going to hear a tone in your (test ear) ear. The first time you hear the tone it will be loud enough for you to hear it clearly. Indicate that you hear the tone by raising your index finger. The next tone you hear will be very soft. Each time, just the moment you are sure that you hear the tone, no matter how soft it is, raise your finger; then, immediately put it down. Make your response definite. Listen very carefully.
>
> In the second task you will hear sets of three sounds. The first will be a burst of noise in your (non-test) ear. This burst of noise is a warning signal indicating that you are to prepare for the two sounds to follow. These sounds are a pair of tones which you will hear in your (test ear) ear. The first tone will always be the same length within a test sequence. The second tone is always either longer or shorter than the first tone by a given amount. Your task is to judge whether the second tone is longer or shorter than the first tone. If you judge the second tone to be longer than the first, push the response

switch up to the position marked "longer". If, on the other hand, the second tone is shorter than the first, pull the response switch down to the position marked "shorter". Whenever you are correct, the blue lamp will light; whenever you are incorrect, the red lamp will light, regardless of the switch position you have selected. Do not reverse your judgment once a response has been made. Your first impression usually is the better one. Approximately two seconds following each response, you will be presented with another burst of noise followed by a set of tones. Once again, indicate with the lever whether the second tone is longer or shorter than the first. A number of these tone sets will be presented. Take as much time as you need before making your response. Be sure not to change your judgment once you have made it. A given pair of tones cannot be repeated; therefore, a response must be made for each pair of tones presented.

The task you are about to perform is rather unsatisfying. In spite of this people are able to do quite well. Listen very carefully and do the best you can.

Are there any questions?

As soon as your hearing thresholds have been determined, you will be briefly reinstructed through the earphone. Once the earphones have been comfortably positioned, please do not move them.

If the subject asked whether there were restrictions on the method by which he discriminated duration, he was instructed not to use any movement as a timing guide.

Following the instructions, the earphones were placed in position and adjusted for a comfortable fit. The subject was instructed over the talkback system to respond to threshold measurements by raising his finger when the tone was audible. An ascending technique in 2-db steps was employed in establishing threshold with a tonal stimulus of 500-msec duration. Threshold was defined as that point at which a response was obtained three different times in at least three ascending runs. The attenuators were then set to the appropriate sensation level for the test condition. The subject was informed, by means of the talkback system, of the stimulus frequency, the sensation level, and the reference duration for that particular experimental set. He was also instructed that the first two trials, the first consisting of the reference tone followed by the long comparison and the second consisting of the reference tone followed by the short comparison tone, would be given for practice. The results of these practice trials were not recorded as data in determining the DL. Testing was begun when it was evident that the subject had no questions concerning the test procedure.

The stimuli were always presented in the same order, the reference tone followed by the comparison tone. These tones were separated by a silent interval of 500-msec duration. The comparison tones were equally separated from the reference tone in terms of duration but they differed in direction. One comparison tone was longer than the reference tone and the other was shorter than the reference tone. A random schedule, constructed on the basis of a table of random numbers (57), determined whether the "long" or the "short" comparison tone was presented after the reference tone in any given trial.

The duration of the reference tone remained the same during the course of an experimental set. The difference in duration between the reference tone and the comparison tone was reduced in discrete steps (ΔT) as testing progressed until a DL was established for that condition. Testing was begun with the largest duration difference between the reference tone and the comparison tones and, when the subject's performance indicated he was correct in 75 per cent of his judgments, the durations of the comparison tones were changed to the next lower predetermined duration difference and testing was continued.

Duration differences between the reference tone and the comparison tones were progressively reduced in discrete steps until the subject was unable to discriminate between them significantly better than chance. The differences in duration between the reference and comparison stimuli (ΔT) for the reference duration of 300 msec were 60, 30, 20, 15, 10, and 5 msec. For the 500-msec reference duration the differences between the reference and the comparison tones were 100, 30, 20, 15, 10, and 5 msec. When the difference in duration between the reference tone and the comparison tones became so small that the subject's discriminatory ability fell below the 50 per cent level of correct response, the difference in duration between the reference and the comparison tones was increased by 4 msec and testing was continued. Succeeding differences in duration between the reference tone and the comparison tones were then progressively decreased by

1-msec steps until the subject was again unable to discriminate at a level significantly better than chance. The smallest difference between the reference tone and the comparison tones that could be discriminated correctly 75 per cent of the time was defined as the DL of duration under a given combination of experimental conditions.

The discrete steps by which the difference in duration between the reference tone and the comparison tones was reduced in the case of the 1000-msec reference duration were 200, 100, 60, 50, 40, 30, 20, 10, and 5 msec. On reaching a difference so small that the subject's responses fell below the level of chance, the difference in duration between the reference tone and the comparison tones was increased by 5 msec and testing continued. Testing with the 5-msec difference between the reference tone and the comparison tones concluded that particular experimental set. The DL was again defined as the smallest difference in duration between the reference tone and comparison tone that was discriminated correctly 75 per cent of the time.

A table of sequential analysis (7, 24, 54, 61) was utilized as a means of reducing the number of observations required in order to infer that the subject could discriminate a difference in duration between the reference tone and the comparison tones 75 per cent of the time or could not discriminate the difference more often than 50 per cent of the time. With this table (APPENDIX B) the number of correct responses is inspected following each response to determine whether adequate data have been acquired to reach a decision or whether testing must be continued. The table was constructed so that the decision of "pass" was made at the .05 level of confidence and the decision of "fail" was made at the .01 level of confidence. The range of correct responses between 50 and 75 per cent was the zone of indecision and if, by the one-hundredth trial, the subject's responses were not more than 75 per cent correct, it was arbitrarily decided that the subject had failed. In this experiment only 0.6 of 1 per cent of the total number of trials remained within the zone of indecision until the one-hundredth trial.

The subject was given a short rest period, one to two minutes on the average, each time the difference in duration between the reference tone and the comparison tones was changed. He was asked to "relax" and the durations of the reference stimulus and the comparison stimuli as well as the duration of the silent interval were measured. In the event that any of these durations varied by more than ($\pm$) 0.5 msec from the prescribed durations, the data were discarded and the subject was tested on that experimental pair again. Following these measurements, the equipment was set to produce the stimuli for the next experimental condition and testing was continued. This same procedure was followed until a DL was established for that particular experimental combination.

On completion of the experimental set, the subject was again given a rest period. During this rest period, the stimulus durations were measured as before and the equipment was then set to produce the stimuli for the next scheduled condition. Testing was continued following the procedures outlined above until the test period ended. Following the test period, the voltage out-put across the earphones, the rise time and the decay time, and the envelope waveform of the test stimuli were again verified.

This same procedure was followed for each subject, experimental set, and test period during the eight practice and eighteen experimental conditions. Data were recorded and a relative DL for duration was determined for each of these conditions.

The data of the experimental conditions were treated as a randomized complete block 2 x 3 x 3 factorial design and were submitted to an analysis of variance. The findings resulting from the procedures described are reported and discussed in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This investigation had as its purpose the determination of differential sensitivity to duration in normal-hearing adults. The differential limen of duration was established under eighteen combinations of reference duration (300, 500, and 1000 msec), frequency (250, 1000, and 4000 cps), and sensation level (10 and 50 db). The ten normal-hearing adults who served as subjects were practiced prior to the experiment and were given immediate knowledge of results during the test as part of the experimental procedure.

The stimuli consisted of a pair of tones, a reference, and a comparison stimulus. The reference stimulus was always presented as the first of the pair. In each pair of stimuli, the comparison tone was either longer or shorter than the reference tone. The subject's task was to judge whether the longer or the shorter comparison stimulus was presented. The difference in duration between the paired stimuli (ΔT) was progressively reduced in discrete steps until it became so small that the subject was unable to judge correctly in 75 per cent of the trials. The smallest difference (ΔT) which the subject judged successfully was then defined as the difference limen of duration under each experimental condition.

The data obtained by these procedures were subsequently converted to relative DL values to facilitate comparisons with previous studies. The mean relative DLs ($\Delta T/T$) of each condition, averaged over subjects, are reported in Table 10 and discussed below. The discussion is concerned first with the magnitude of the DLs. Subsequent sections deal with the parameters of sensation level, stimulus frequency, and reference duration.

TABLE 10

MEAN RELATIVE DL OF DURATION ($\Delta T/T$) OF TEN NORMAL-HEARING SUBJECTS AT THREE STIMULUS FREQUENCIES, TWO SENSATION LEVELS, AND THREE REFERENCE DURATIONS

Stimulus Frequency (cps)	Sensation Level (db)	Reference Duration (msec)		
		300	500	1000
250	10	.0447	.0296	.0275
	50	.0320	.0186	.0260
1000	10	.0427	.0300	.0330
	50	.0240	.0274	.0275
4000	10	.0397	.0286	.0315
	50	.0263	.0270	.0250

Magnitude of the Relative DL

The results of this investigation do not agree with those reported by earlier investigators. Previous investigations have shown the magnitude of the difference limen for duration to be consistently larger than has the present study. The mean relative DLs found in this investigation ranged in size from .0186 to .0447 as shown in Figure 2 and Figure 3.

These results may be compared with those of Henry (30) at two reference durations (277 msec and 480 msec), even though his data were obtained at only one frequency (500 cps) and at different reference durations (32, 47, 77, 110, 175, 277, and 480 msec) than were employed in the present study. The comparison with Henry's study is shown in Table 11.

TABLE 11

DIFFERENTIAL LIMEN OF DURATION FROM PRESENT EXPERIMENT COMPARED WITH DATA FROM HENRY

Reference Duration (msec)	Present Study (50-db SL, 250 cps)	Henry 50-db SL, 500 cps)
277		.172
300	.0320	
480		.143
500	.0186	

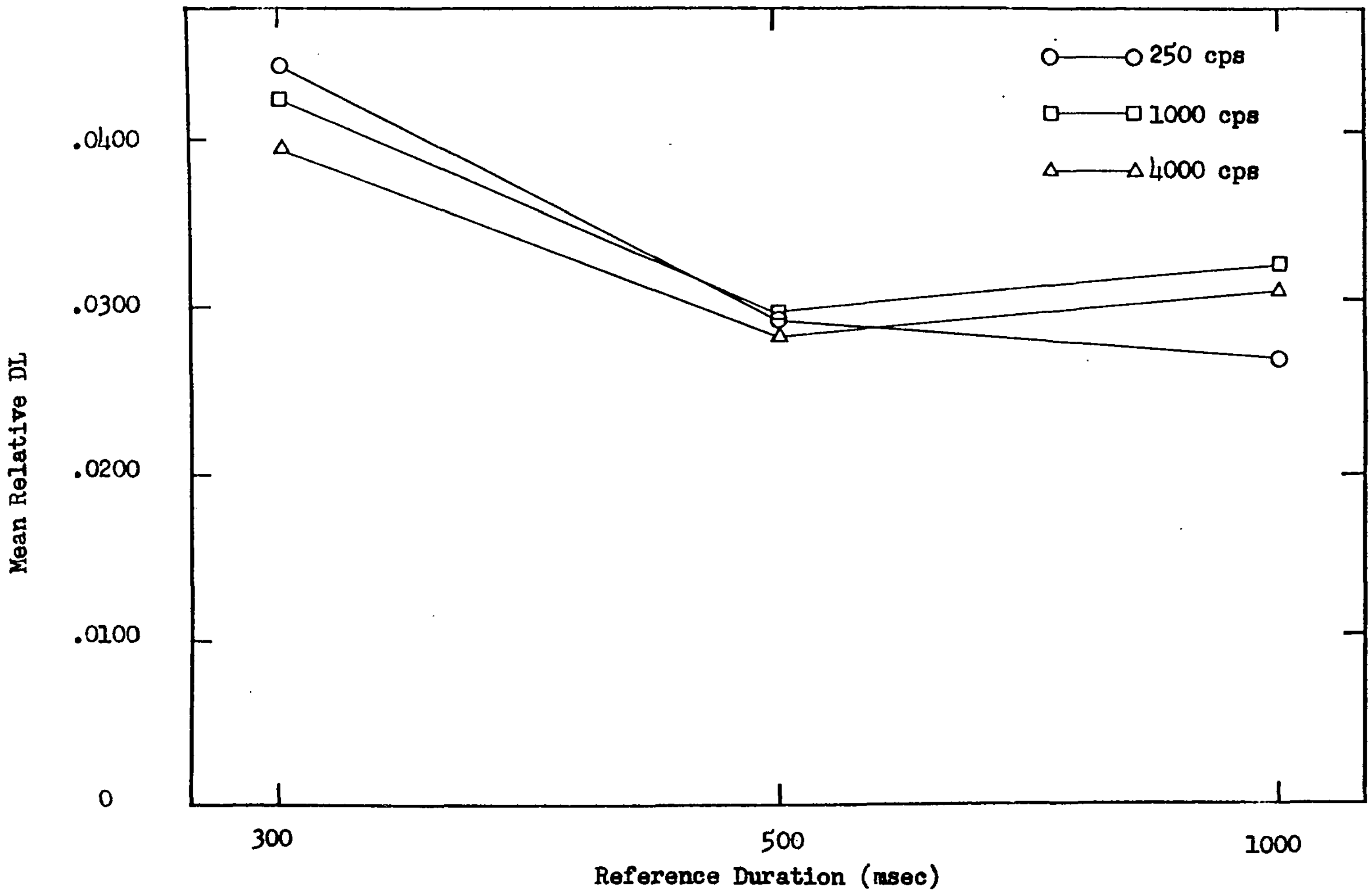

Fig. 2 - Mean relative DLs at a sensation level of 10 db plotted as a function of reference duration.

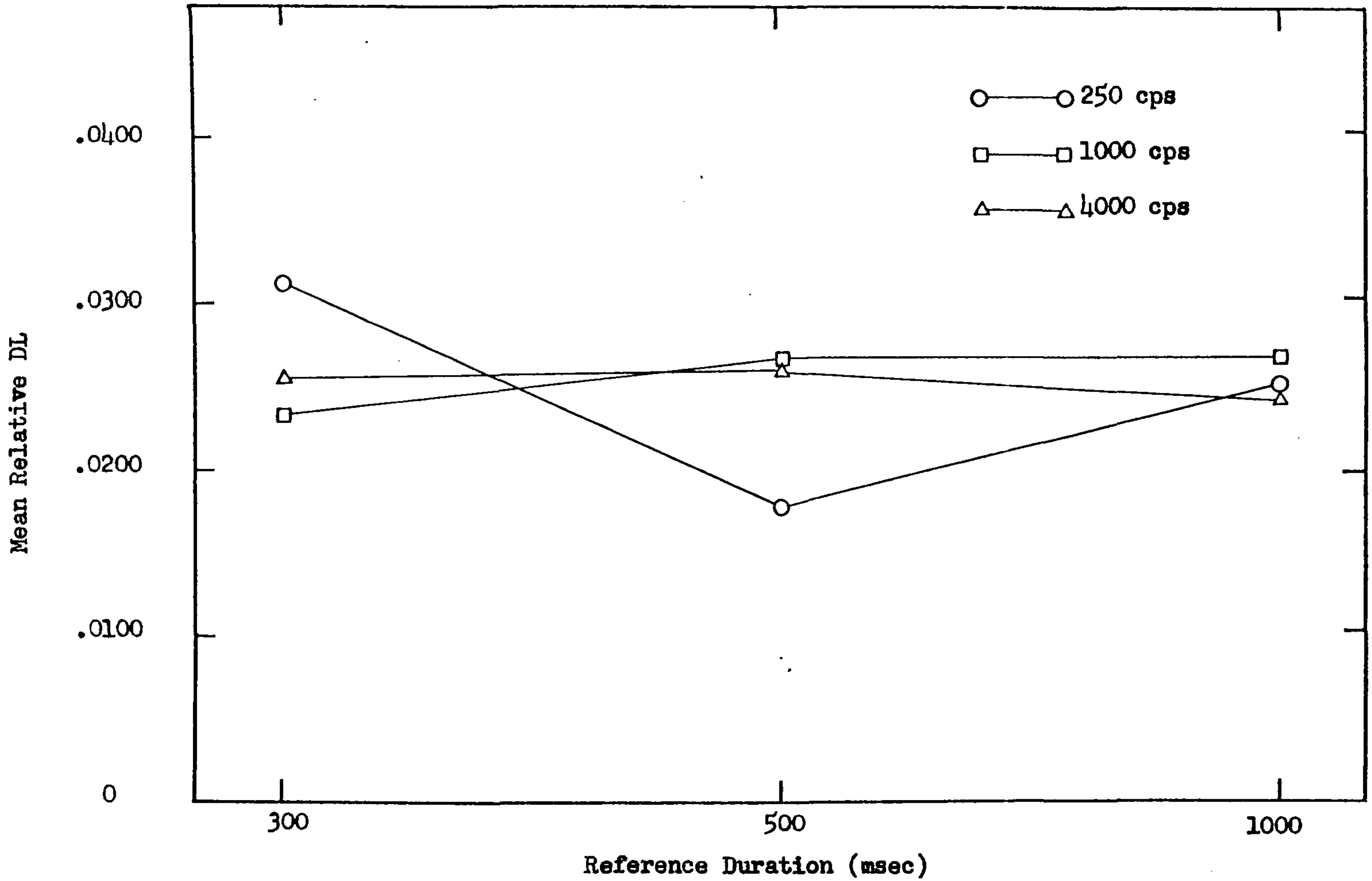

Fig. 3 - Mean relative DLs at a sensation level of 50 db plotted as a function of reference duration.

The largest DL (.0320 at the 250-cps, 300-msec, 50-db SL experimental condition) shown in Table 11 for this experiment is several times smaller than Henry's smallest DL (.143 at the 480-msec, 50-db SL experimental condition).

The data reported by Stott (56) are compared with the results of the present experiment in Table 12. Both studies obtained measurements at 1000 cps. The sensation level employed by Stott was not reported.

TABLE 12

DIFFERENTIAL LIMEN OF DURATION FROM PRESENT EXPERIMENT COMPARED WITH DATA FROM STOTT

Reference Duration (msec)	Present Experiment (10-db SL, 1000 cps)	Stott (SL not known, 1000 cps)
200		.142
300	.0427	
400		.120
500	.0300	
600		.115
800		.118
1000	.0330	.126

The smallest DL obtained by Stott (.115 at the reference duration of 600 msec) is approximately three times as large as the largest DL (.0447 at the 250-cps, 300-msec, 10-db SL experimental condition) found in the present experiment.

The variations in the size of the duration DL as reported by Henry (30) or Stott (56) and those of the present experiment may be explained in terms of several possible sources of variability. First, the experimental procedure of the present study was structured specifically to minimize experimental error due to subject fatigue. In addition, the subjects were well practiced prior to the experiment and were also provided with immediate knowledge of results during the experiment. Although experienced subjects obtain lower thresholds than non-experienced listeners (17), there is no evidence that Henry or Stott allowed their subjects to practice the experimental task, except as they participated in more than one experiment.

Secondly, the psychophysical methods employed in the three experiments were different. It has been shown that sophisticated, well-trained listeners will obtain lower thresholds when modifications of standard psychophysical methods are combined with refinements in apparatus (25, 28, 41, 48, 63). Inasmuch as the present experiment employed well-trained listeners who were provided immediate knowledge of results, as well as a psychophysical method of limits, modified to maximize a subject's discrimination performance, it might be expected that the DLs of the present study would be smaller than those reported by Stott (56) or Henry (30).

Stott employed the psychophysical method of constants in which the subject was asked to choose between three alternatives: longer, shorter, or equal. A modification of the method of constants in which the subject had two alternative choices, "yes" or "no", was utilized by Henry.

A third factor which may account for differences in the magnitude of the DL of duration as found by this experiment and those reported by Stott (56) and Henry (30) is that of stimulus duration control. The nature of the parameter demanded consistently accurate control of the duration of the stimulus, with reliable reproduction. The present study had the advantage of utilizing modern electronic equipment which was accurately calibrated to produce a relatively noise-free signal repeatedly over a long period of time. Furthermore, a selected duration was maintained within ($\pm$) 0.5 msec. The instrumentation utilized both by Stott and Henry was designed to produce a specific duration through an electro-mechanical arrangement. It is unlikely that these devices permitted the control or measurement of stimulus duration as accurately as was possible in the present study.

One means of viewing duration DLs is in terms of their magnitude across reference durations. Both Stott (56) and Henry (30) found that the DL increased in size at relatively short reference durations. This effect also was found in the present study but was not uniform across sensation levels and frequencies. The findings, graphed in Figure 2 and Figure 3, show that the presentation of 10-db SL stimuli uniformly resulted in higher limens at the 300-msec duration than at either the 500 or 1000-msec duration. The limen remains relatively stable between the two latter durations.

The functions plotted for the 50-db SL condition (Figure 3) do not follow the same trend as shown by the data at the 10-db sensation level. A pronounced difference is shown in the form of the data between the two sensation levels, when the magnitude of the DL is plotted as a function of reference duration at the stimulus frequencies 1000 and 4000 cps. The magnitude of the DL at the 50-db SL shows a negligible variation for each of these frequencies across reference duration (300, 500, and 1000 msec). The relatively flat characteristic of these two curves is in contrast with the irregular configuration of the function plotted for the 250-cps stimulus frequency. The DLs at this frequency vary in magnitude to produce a multi-form curve across reference duration. The largest variation in DL size at the 250-cps stimulus occurs between the two reference durations 300 and 500 msec. The maximal value (.0320) obtained at 300 msec decreases to the minimal value (.0186) at 500 msec.

In summary, the relative DL of duration decreases in magnitude as stimulus duration is increased from 300 to 500 msec. The exceptions to this trend, the stimulus frequencies of 1000 cps and 4000 cps at the 50-db SL, were previously noted. Relative DLs tend to remain stable between the reference durations of 500 and 1000 msec. The one exception in the present experiment is the DL at the 250-cps, 50-db SL condition. These data were submitted to an analysis of variance. The results of the statistical test (APPENDIX C) indicated that variation in the magnitude across reference duration was significant ($F = 8.023$; $P < .01$).

The function of frequency DLs and intensity DLs across reference values are similar to the duration DL function. Relative DLs of frequency decrease in size as stimulus frequency is increased in magnitude. The data of Knudsen (34), Shower and Biddulph (55), Harris (26), and Koester (36), included in Table 1, demonstrate this characteristic. Riesz (53), Montgomery (45), and Harris (29) have also shown that the magnitude of the intensity difference limen decreases as stimulus intensity is increased above threshold intensity. In general, these studies tend to indicate that the relative DL decreases in size as the stimulus magnitude is increased to the mid-range of stimulus magnitudes. The DL tends to remain more nearly constant in the mid-range of stimulus magnitude than at either extreme.

Sensation Level Effect

The relative DL of duration was obtained at two sensation levels, 10 and 50 db, for three stimulus frequencies at each of three reference durations. The mean relative DL of each stimulus condition is plotted in Figure 2 and Figure 3 as a function of reference duration. These figures indicate that sensation level has a consistent effect on the size of the difference limen. To demonstrate this effect clearly, the data have been plotted as the difference between the mean relative DL at 10-db and at 50-db SL, as a function of reference duration. These differences, shown in Figure 4, are the amount by which magnitudes of the DLs obtained at the 10-db SL exceeded those found at the sensation level of 50 db. The effect of sensation level was found to be statistically significant ($F = 22.078$; $P < .01$) when subjected to the analysis of various test (APPENDIX C).

Inspection of Figure 4 reveals that the relative DLs of duration were smaller at the higher sensation level (50 db) at each reference duration (300, 500, and 1000 msec). The effect of stimulus sensation level is less at the reference duration of 500 msec in the case of stimulus frequencies 1000 cps and 4000 cps and at the reference duration 1000 msec in the case of the 250-cps stimulus frequency. The largest effect of stimulus sensation level is shown at the 300-msec reference duration for the 1000-cps stimulus frequency. The effect of stimulus sensation level is relatively constant at the reference durations of 300 msec and 500 msec in the case of the 250-cps stimulus frequency. Beyond the 500-msec reference duration, the 250-cps stimulus frequency curve slopes downward to a small value at the 1000-msec reference duration. Graphically, this interaction is shown as a change in the magnitude of the difference values across reference dura-

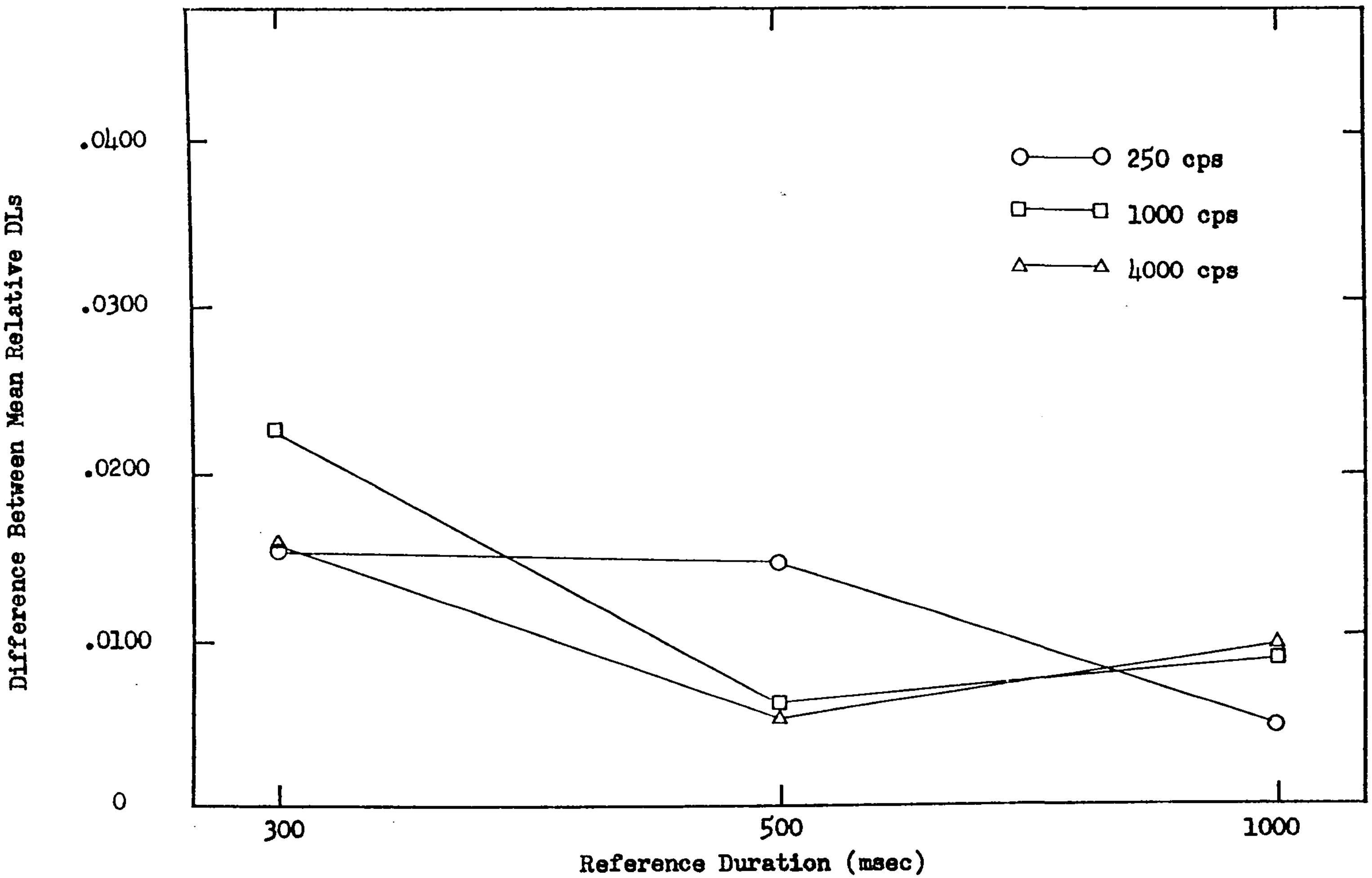

Fig. 4 - Difference between mean relative DLs at sensation levels 10 db and 50 db plotted as a function of reference duration.

tion. An analysis of variance did not show this interaction to be highly significant ($F = 3.775$; $.05 > P > .01$).

Henry (30), in his investigation of duration DLs as a function of stimulus intensity, concluded that the magnitude of the DL across reference duration was unaffected by sensation level. The findings of the present study do not support this conclusion, but, rather, that an increase in sensation level results in a decrease in DL regardless of stimulus frequency or stimulus duration. Inasmuch as the present study did not investigate sensation levels greater than 50 db, it cannot be stated that further changes in the DL would not result as sensation levels were increased beyond this point.

Frequency Effect

The mean relative DL was obtained at each of three stimulus frequencies 250, 1000, and 4000 cps. The results found at each reference duration (300, 500, and 1000 msec) at each sensation level (10 and 50 db) are plotted in Figure 5 and Figure 6 as a function of stimulus frequency.

Two prominent features of these data are immediately apparent. First, the functions plotted at the 10-db SL (Figure 5) for each of the reference durations (300, 500, and 1000 msec) show relatively little change in the mean relative DL values across stimulus frequency. The largest variation in mean DLs across stimulus frequency is shown for the 10-db SL, 300-msec reference duration. The DL decreases from .0447 at the stimulus frequency of 250 cps to .0397 at the stimulus

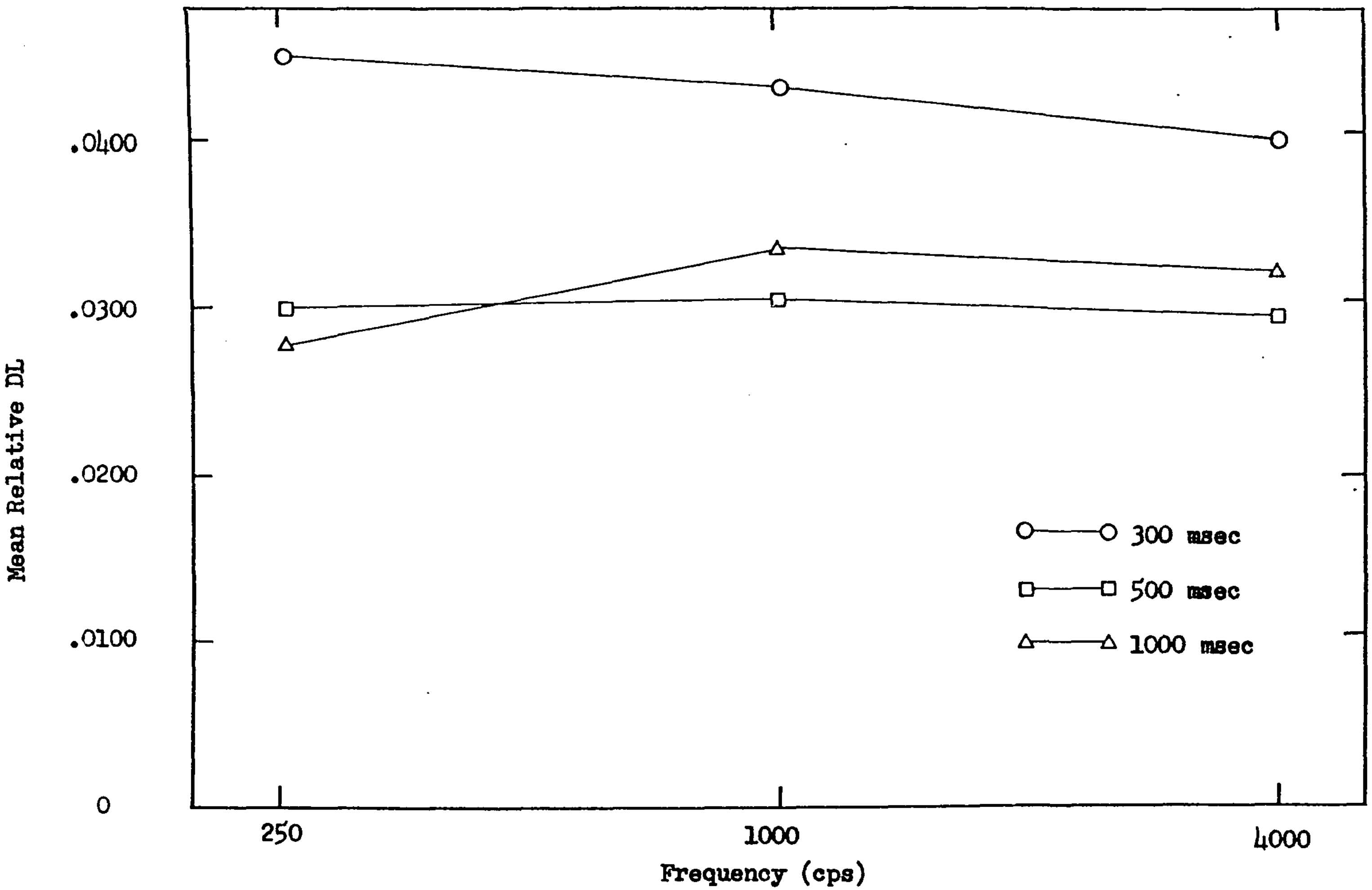

Fig. 5 - Mean relative DLs at a sensation level of 10 db plotted as a function of stimulus frequency.

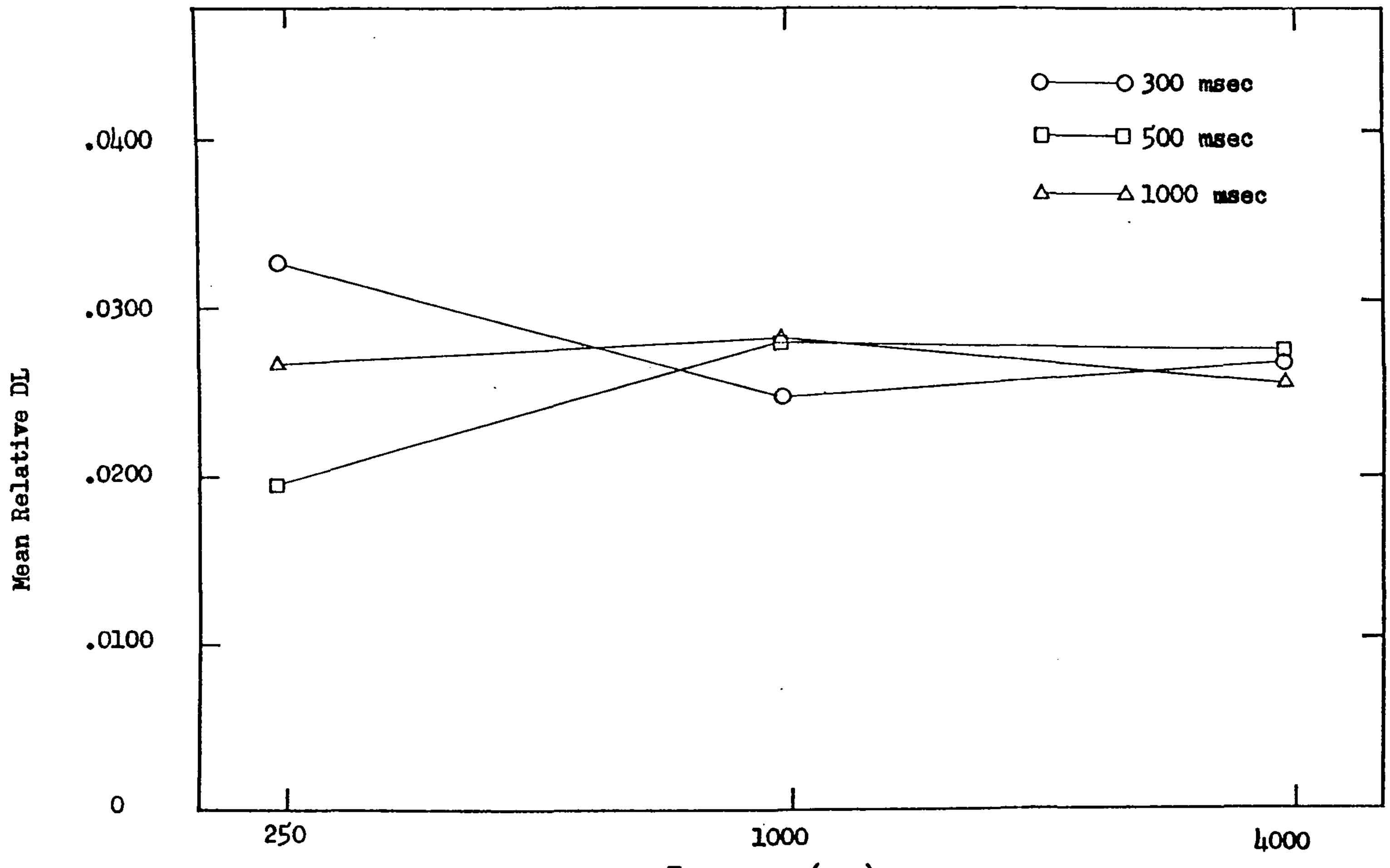

Fig. 6 - Mean relative DLs at a sensation level of 50 db plotted as a function of stimulus frequency.

frequency 1000 cps. The largest variation between two adjacent stimulus frequencies is shown in the case of the 1000-msec reference duration. The mean relative DL (10-db SL, 1000-msec reference duration) increases in size from .0275 at the stimulus frequency of 250 cps to the value .0330 at the stimulus frequency of 1000 cps.

Secondly, the configurations of the curves plotted from the mean relative DLs obtained at the 50-db SL (Figure 6) are very flat at the stimulus frequencies of 1000 cps and 4000 cps in the case of each of the reference durations (300, 500, and 1000 msec). The mean relative DLs obtained with the 1000-msec reference duration are consistently linear across all stimulus frequencies (250, 1000, and 4000 cps). A slight variation in DL size is noted for both the reference duration of 300 msec and of 500 msec as stimulus frequency is increased from 250 cps to 500 cps. In the case of the 50-db SL, 300-msec reference duration the DL decreases from .0320 at the stimulus frequency of 250 cps to .0240 at the stimulus frequency of 500 cps. The function of the 50-db SL, 500-msec reference duration increases from a DL of .0186 at the stimulus frequency of 250 cps to a DL of .0274 at the stimulus frequency of 500 cps.

The data of the present experiment cannot be compared directly with those reported by Henry (30). He obtained Weber ratios from three subjects using a 77-msec reference duration tone at five different frequencies (125, 250, 500, 1000, and 2000 cps). Although he states the data are too few to justify the calculation of ratios, his results suggest larger DLs for the lower frequencies.

An analysis of variance applied to the data of the present experiment indicated that stimulus frequency is not a statistically significant source of variation in the magnitude of the DL ($F = 0.165$; $P > .01$). It is concluded that the size of the difference limen is independent of stimulus frequency within the limitations imposed by this experiment.

The present experiment was limited to a consideration of only three stimulus frequencies (250, 1000, and 4000 cps). Further experimental research is needed to determine the effect of stimulus frequency on the size of the difference limen. The data plotted in Figures 5 and 6 suggest that stimulus frequencies lower than 125 cps and higher than 4000 cps might be profitably studied relative to the determination of the effect of stimulus frequency on the magnitude of the difference limen of duration.

Reference Duration Effect

The reference durations of 300, 500, and 1000 msec were employed in this experiment. The mean relative DLs obtained at each frequency are plotted as a function of reference duration in Figures 2 and 3. These data are discussed in the following sections.

250 cps. Mean DLs obtained with a 250 cps stimulus frequency are plotted as a function of reference duration in

Figure 7. Inspection of this figure reveals that the largest DLs were obtained at the shortest reference duration, 300 msec. The two curves decrease with almost identical slopes between the durations of 300 and 500 msec. With an increase in duration to 1000 msec, the 10-db SL curve becomes almost flat. The 50-db SL curve, however, rises rather sharply between the reference durations of 500 msec and 1000 msec.

The configurations of these curves suggest that the mean relative DL of low frequency stimuli might continue to increase in magnitude as reference durations are reduced to values below 300 msec. Mencke (43) has recently substantiated this trend. He found that relative DLs, obtained at the stimulus frequency 250 cps, were larger at the reference durations of 40, 60, 80, and 100 msec than those reported in the present experiment at 300 msec. Further experimental research is indicated to determine whether relative DLs obtained with low frequency stimuli remain stable at reference durations longer than 1000 msec.

1000 cps. The mean relative DLs of the 1000-cps stimulus are plotted as a function of reference duration in Figure 8. The 10-db SL curve shows a rather sharp decrease in the magnitude of the DL between the reference durations of 300 and 500 msec. The DL increases very slightly as the stimulus duration is increased to 1000 msec. The largest DL of the 1000-cps, 10-db SL stimulus was found at the shortest reference duration (300 msec). The 50-db SL curve is in

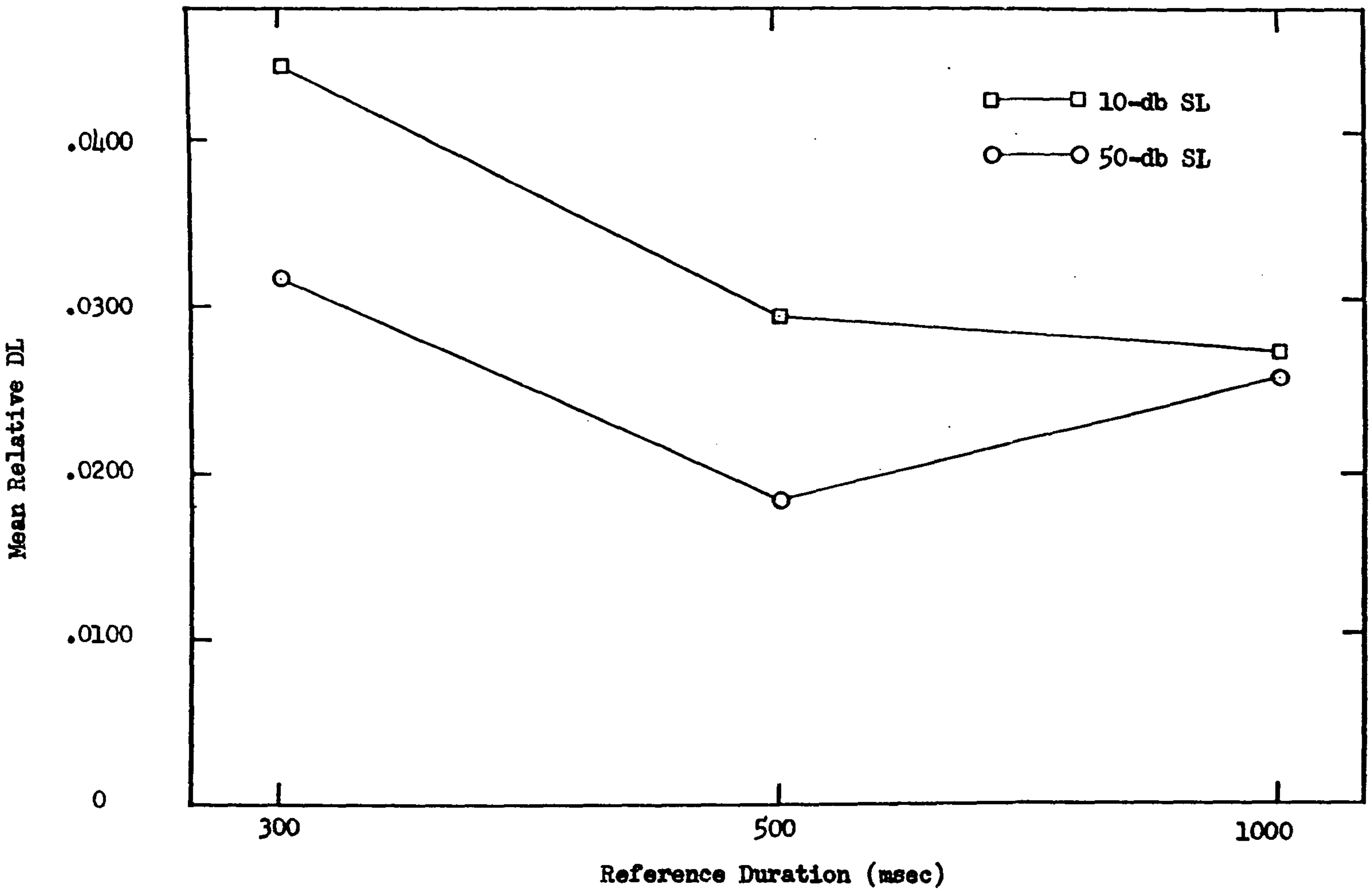

Fig. 7 - Mean relative DLs of a 250-cps stimulus plotted at two sensation levels, 10 and 50 db, as a function of reference duration.

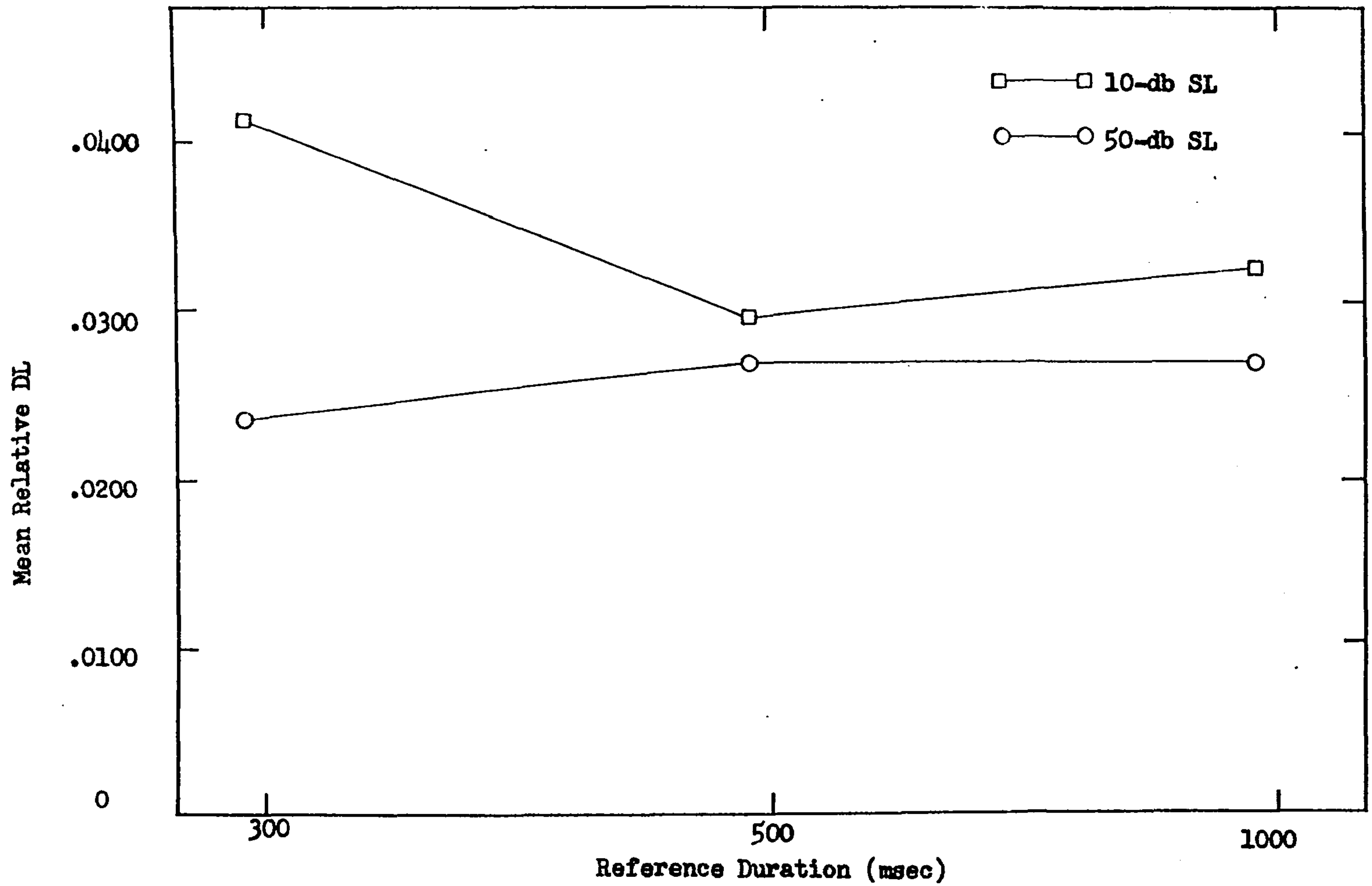

Fig. 8 - Mean relative DLs of a 1000-cps stimulus plotted at two sensation levels, 10 and 50 db, as a function of reference duration.

rather sharp contrast to the 10-db SL curve in that it is relatively flat across the range of reference durations used. In fact, the smallest DL measured was obtained under the 300 msec reference duration, the same point where the 10-db SL signal elicited the largest DL. The slope of these curves suggests that DLs obtained with a 10-db SL, 1000-cps stimulus would continue to increase in size if reference duration were decreased to values shorter than 300 msec. Recently, Mencke (43) has shown that the DLs of 1000-cps, 10-db SL stimuli of reference durations shorter than 300 msec (40, 60, 80, and 100 msec) do increase in size as reference duration is decreased. He found that DLs of 50-db SL, 1000-cps stimulus change only very slightly in magnitude as reference duration is decreased to 80 msec, supporting the trend seen in the present experiment's findings. The trend of the data plotted in Figure 8 suggests that DLs of 1000-cps stimulus frequency at both sensation levels (10 and 50 db) become relatively flat at 500-msec and may remain so for reference durations longer than 1000 msec. Further experimental work is required to determine the limitations of stability of the DL across durations longer than 1000 msec.

4000 cps. The mean relative DLs of the 4000-cps stimulus frequency are plotted as a function of reference duration in Figure 9. The patterns at both sensation levels are almost identical to those observed at the 1000-cps frequency. The 10-db SL curve decreases rather sharply with a decrease

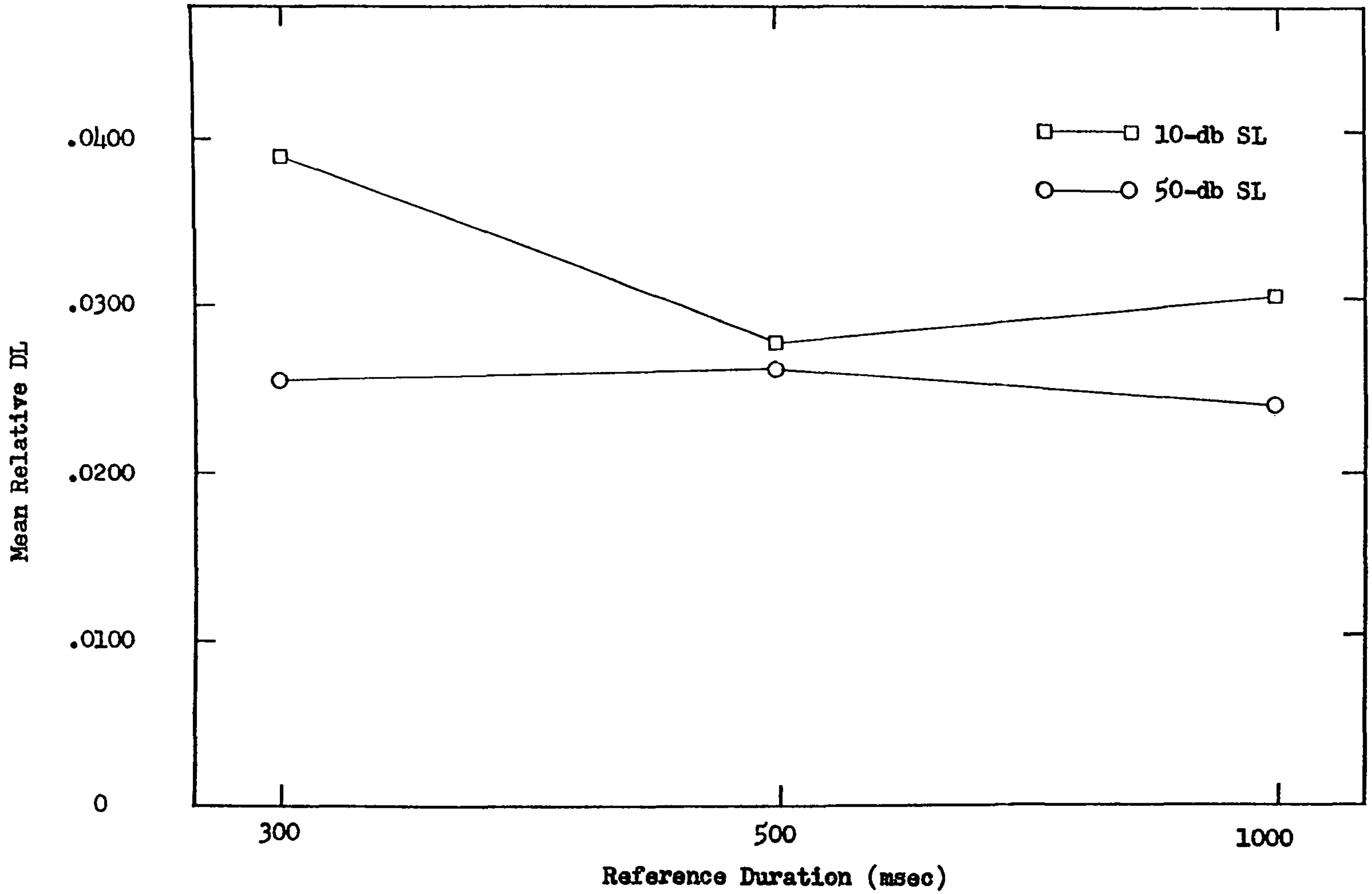

Fig. 9 - Mean relative DLs of a 4000-cps stimulus plotted at two sensation levels, 10 and 50 db, as a function of reference duration.

in reference duration from 250 cps to 500 cps, rising slightly with an increase in reference duration to 1000 cps. The 50-db SL curve, however, is relatively flat between the 300 msec and 500 msec reference durations and shows only a very slight drop as the reference duration is increased from 500 msec to 1000 msec. The 10-db SL curve suggests that DLs obtained for high frequency stimuli may continue to increase in size as the reference duration is decreased to values shorter than 300 msec. Mencke (43) has shown that DLs of 10-db SL, 4000-cps stimuli do, in fact, increase in size as reference stimuli of shorter duration are employed. The experimental data of the 50-db SL, 4000-cps stimuli also suggest that DLs obtained in the case of reference durations shorter than 300 msec might remain relatively stable. However, Mencke has found that DLs at the 50-db SL increase in size when reference durations shorter than 300 msec (40, 60, 80, and 100 msec) are employed. Additional experimental study is indicated relative to a determination of the stability of the DL at reference durations greater than 1000-msec.

Summary. The DLs at the 10-db SL at each stimulus frequency (250, 1000, and 4000 cps) decrease in size as reference duration is increased from 500 to 1000 msec. The DLs at the 50-db SL resulted in notably flat curves of both the stimulus frequencies 1000 and 4000 cps. Only the curve generated by the 250-cps stimulus frequency at this high sensation level showed a decrease from the reference duration of 300 msec to that of 500 msec. All frequency curves converged at the 1000-msec duration, essentially reaching the same DL value.

The greatest effect on the relative DL is observed in terms of the decrease between the reference durations of 300 msec and 500 msec. In the case of the stimulus frequencies of 1000 cps and 4000 cps, this effect is not present at the 50-db sensation level.

The data of this experiment were submitted to a statistical analysis of variance. The results of the analysis indicated that variation due to reference duration was statistically significant ($F = 8.023$; $P < .01$). The conclusion is reached that the size of the difference limen depends on reference duration, the principal effect occurring at reference durations shorter than 500 msec.

Subject Variability

The measurement of the relative DL for duration was obtained on ten sophisticated, normal-hearing adults, none of whom had a history of ear-pathology. Each subject was tested under the same conditions utilizing the same experimental techniques. The eighteen conditions of reference duration, sensation level, and stimulus frequency were presented to each subject in a random order. Special care was taken to maximize homogeneity of performance through exhaustive training in the experimental task, utilizing immediate knowledge of results. Consequently, the variation of the relative DL values among subjects is thought to be reasonably representative of variations in individual differential acuity among subjects of the type used.

The experimental data are presented in APPENDIX D. The means, standard deviations, and ranges of the absolute and relative difference limens are shown for each of the eighteen experimental conditions. The greatest inter-subject variability is shown at the 250-cps, 300-msec, 50-db SL experimental condition. The relative DL at that condition ranged from a minimum of .0133 to a maximum of .0866 with a mean of .0320 and a standard deviation of .0230. The smallest inter-subject variability is shown at the 1000-cps, 500-msec, 50-db SL experimental condition. The relative DL at that condition ranges from a minimum of .0180 to a maximum of .0420, with a mean of .0274 and a standard deviation of .0088.

Although the subjects utilized in this experiment were carefully chosen to represent a homogeneous group and each subject was specifically trained in the experimental task, the variability among subjects remained a significant factor. When submitted to an analysis of variance, the variability among subjects was tested with an error mean square that was obtained by pooling the subject by treatment sums of squares with the residual sum of squares. This procedure provided an improved estimate of the residual variance based on a greater number of degrees of freedom. The nature of the error term thus permitted an adequate estimate of variability among subjects.

The fact that subjects varied significantly in discriminative ability was shown by a significant "between-subjects" variance ($F = 3.334$; $P < .01$). As one might expect, even highly homogeneous individuals who have received intensive task-training, vary somewhat in their ability to discriminate on the basis of duration. Nevertheless, the variability among subjects was of a rather small magnitude as shown by the total range of DLs (.0050 to .0866) over all conditions of the experiment.

Summary

This experiment employed a modified psychophysical method of limits to investigate differential sensitivity to duration of pure-tone auditory stimuli. Difference limens were obtained from ten normal-hearing subjects at eighteen combinations of reference duration, stimulus frequency, and sensation level.

The mean relative DLs found in the present experiment range in size from .0186 to .0447. Relative DLs of this magnitude are consistently smaller than those reported by previous workers.

Data obtained in the present study are equivocal relative to a general statement of the constancy of the Weber ratio. The DLs at the 10-db SL tend to remain at a relatively constant size at two reference durations (500 msec and

1000 msec) but not at the third reference duration (300 msec). The DLs at the 10-db SL, 300-msec reference duration are larger, departing from the trend shown at the 500-msec and 1000-msec reference durations. The constancy of the Weber ratio is maintained well at each reference duration at the 50-db sensation level in the case of the stimulus frequencies 1000 cps and 4000 cps. The exception is the 250-cps stimulus frequency. Relative DLs obtained at 250-cps, 50-db SL vary from .0320 at the reference duration of 300 msec to .0186 at the reference duration of 500 msec.

The relative DLs obtained at the 10-db sensation level were larger than those found at the 50-db sensation level. This effect of sensation level was present at each reference duration (300, 500, and 1000 msec), although the extent of the difference was not linear across reference duration. When plotted as a function of reference duration, the differences between the mean relative DLs obtained at the 10-db SL and the 50-db SL were greater at the 300-msec reference duration than at the 500-msec reference duration. As reference duration was increased from 300-msec to 1000 msec the effect due to sensation level decreased.

The effect of stimulus frequency on the magnitude of the relative DL is minimal at both the 10-db and the 50-db sensation level in the case of each reference duration (300, 500, and 1000 msec). When the mean relative DLs obtained at the 10-db SL are plotted as a function of stimulus frequency, the resultant curve for each reference duration is relatively flat and shows only minimal variation across stimulus frequency (250, 1000, and 4000 cps). The data obtained at the 50-db SL are linear at the stimulus frequencies 1000 cps and 4000 cps. A very slight deviation from linearity is present at the frequency of 250 cps for the 300-msec and the 500-msec reference durations.

The greatest effect of reference duration on the size of the relative DL occurs as the reference duration is increased in value from 300 msec to 500 msec. An exception is shown at the 50-db SL at each of the two stimulus frequencies 1000 cps and 4000 cps. Minimal variation in the size of the DL at these two stimulus frequencies occurs as reference duration is increased from 300 msec to 1000 msec.

The diversity in the ability of subjects to perform alike under the experimental criterion of this study is manifested in the range of the relative DLs (APPENDIX D). Submitted to an analysis of variance, subject variability was shown to be statistically significant, albeit within a relatively narrow range of limen values.

The results of this study emphasize the variability of the relative DL of duration under various combinations of reference duration (300, 500, and 1000 msec), sensation level (10 and 50 db), and stimulus frequency (250, 1000, and 4000 cps). Based on the data of this experiment it may be concluded that the size of the relative DL of duration is significantly related to the variables of reference duration and sensation level. The magnitude of the DL was found not to be dependent on stimulus frequency.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Basic to an understanding of auditory function is an establishment of the limitations of the analytic ability of the hearing mechanism. Rather extensive research has been instrumental in providing an index of the discriminatory capacity of the ear relative to the parameters of frequency and intensity. A third parameter, duration, has not been explored as fully, although it is equally as important to a concept of total auditory function.

Sufficient evidence is presented in the literature of differential sensitivity of the ear to point up the need for additional experimental work relative to a rigid definition of the response capabilities of the hearing mechanism to acoustic duration. Previous investigatory work has been supplemented by the present experiment designed to obtain measurements of the DL of duration representative of the faculty of the normal-hearing subject to detect differences in acoustic duration.

In this experiment a complex of electronic equipment was utilized to produce paired stimuli which differed only in in duration. A modified psychophysical method of limits was employed using a two-alternative forced-choice technique to obtain responses from ten normal-hearing, well-trained subjects. This procedure yielded a measurement of the relative DL of duration under eighteen conditions of reference duration (300, 500, and 1000 msec), stimulus frequency (250, 1000, and 4000 cps), and sensation level (10 and 50 db). These data were treated as a randomized block 2 x 3 x 3 factorial design and submitted to an analysis of variance.

Conclusions

Based on the data of this experiment several conclusions may be drawn. First, the magnitude of the relative difference limen of pure-tone auditory stimuli of moderately long duration is significantly related to duration of the reference stimulus and to sensation level. Secondly, the magnitude of the relative DL of duration is not highly dependent on stimulus frequency. Finally, it may be concluded that, relative to duration judgments, Weber's law holds only in the case of higher stimulus frequencies and at a moderately high sensation level.

Suggested Further Research

The present study has provided data related to the ability of a normal-hearing subject to discriminate moderately long signal duration. Differential sensitivity of the normal-hearing subject to acoustic duration of short auditory stimuli (40-msec to 100-msec reference duration) has recently been investigated by Mencke (43). Cooper (12) is presently investigating the capacity of the subject with a loss of hearing to respond to small differences in acoustic signal duration. Several additional aspects relative to a study of differential sensitivity of the hearing mechanism to acoustic duration suggest themselves.

Specifically, there is a need for further information concerning the size of the relative DL at durations longer than those undertaken in the present experiment. Investigation of the effects of binaural stimulation as well as the effects of various stimulus frequencies and sensation levels are desirable. A more adequate understanding of the relationship between the magnitude of the relative DL and the psychophysical method employed may be reached following further experimentation in which various psychophysical methods are utilized.

Further research relative to the differential sensitivity of the hearing mechanism to acoustic duration is desirable not only on the basis of added information regarding specific measurements of the DL but also from the standpoint that such information may be worthwhile in helping establish the physiological and neurological limitations imposed by the human organism.

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APPENDIX A

Subject Identification

TABLE 13

SUBJECT IDENTIFICATION: SEX, AGE, AND TEST EAR

SUBJECT	SEX	AGE	TEST EAR
1	F	23	L
2	M	27	L
3	F	30	R
4	M	22	R
5	F	27	R
6	M	29	L
7	M	32	R
8	F	31	R
9	F	35	L
10	M	28	L

APPENDIX B

Table of Sequential Analysis

TABLE 14

TOTAL NUMBER OF STIMULI AND CORRESPONDING NUMBER OF CORRECT RESPONSES TO PASS AT .05 LEVEL OF CONFIDENCE OR FAIL AT .01 LEVEL OF CONFIDENCE

Number Pairs Presented	Limits Pairs Correct		Number Pairs Presented	Limits Pairs Correct	
	Fail	Pass		Fail	Pass
7	1	7	41	22	28
8	1	7	42	23	29
9	2	8	43	23	29
10	3	9	44	24	30
11	3	9	45	25	31
12	4	10	46	25	31
13	5	10	47	25	32
14	5	11	48	27	33
15	6	12	49	27	33
16	6	12	50	28	34
17	7	13	51	29	34
18	8	14	52	29	35
19	8	14	53	30	36
20	9	15	54	30	36
21	10	15	55	31	37
22	10	16	56	32	38
23	11	17	57	32	38
24	11	17	58	33	39
25	12	18	59	34	39
26	13	19	60	34	40
27	14	20	61	35	41
28	15	21	62	35	41
29	15	21	63	36	42
30	15	21	64	37	43
31	16	22	65	37	43
32	17	22	66	38	44
33	17	23	67	39	44
34	18	24	68	39	45
35	18	24	69	40	46
36	19	25	70	41	46
37	20	26	71	41	47
38	20	26	72	42	48
39	21	27	73	42	48
40	22	27	74	43	49

TABLE 14 Continued

Number Pairs Presented	Limits Pairs Correct		Number Pairs Presented	Limits Pairs Correct	
	Fail	Pass		Fail	Pass
75	44	50	88	52	58
76	44	50	89	53	58
77	45	51	90	53	59
78	45	51	91	54	60
79	46	52	92	54	60
80	47	53	93	55	61
81	47	53	94	56	62
82	48	54	95	57	62
83	49	55	96	57	63
84	49	55	97	58	63
85	50	56	98	58	64
86	51	57	99	59	65
87	51	57	100	59	65

Criterion

Pass: 75% of the judgments at a .05 level of confidence
Fail: 50% of the judgments at a .01 level of confidence

APPENDIX C

Summary of the Analysis of Variance

TABLE 15

SUMMARY OF THE ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Subjects	9	0.00406	0.00045	3.334 **
Frequency	2	0.00004	0.00002	0.165
Duration	2	0.00217	0.00108	8.023 **
Intensity	1	0.00299		22.078 **
F X D	4	0.00067	0.00017	1.243
F X I	2	0.00002	0.00001	0.092
D X I	2	0.00102	0.00051	3.775 *
F X D X I	4	0.00042	0.00011	0.777
Error	153	0.02071	0.00013	

** Significant at 1 per cent level of confidence

* Significant at 5 per cent level of confidence

APPENDIX D

Experimental Data

TABLE 16

SUBJECT DATA FROM THE 250-CPS, 300-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps				
REFERENCE DURATION - 300 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	13	.0433	5	.0166
2	10	.0330	10	.0333
3	16	.0533	26	.0866
4	15	.0500	4	.0133
5	10	.0333	9	.0300
6	9	.0300	16	.0533
7	12	.0400	5	.0166
8	18	.0600	11	.0366
9	16	.0533	5	.0166
10	15	.0500	5	.0166
MEAN DL	13.4	.0447	9.6	.0320
STANDARD DEVIATION	3.062	.0102	6.899	.0230
RANGE LOW	9	.0300	4	.0133
RANGE HIGH	18	.0600	26	.0866

TABLE 17

SUBJECT DATA FROM THE 250-CPS, 500-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps				
REFERENCE DURATION - 500 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	12	.0240	14	.0280
2	15	.0300	10	.0200
3	14	.0280	15	.0300
4	10	.0200	5	.0100
5	13	.0260	4	.0080
6	20	.0400	11	.0220
7	9	.0180	4	.0080
8	14	.0280	5	.0100
9	15	.0300	15	.0300
10	26	.0520	10	.0200
MEAN DL	14.8	.0296	9.3	.0186
STANDARD DEVIATION	4.962	.0099	4.523	.0090
RANGE LOW	9	.0180	4	.0080
RANGE HIGH	26	.0520	15	.0300

TABLE 18

SUBJECT DATA FROM THE 250-CPS, 1000-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps					
REFERENCE DURATION - 1000 msec					
SUBJECT		10-db SL		50-db SL	
		DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1		50	.0500	30	.0300
2		30	.0300	20	.0200
3		25	.0250	35	.0350
4		30	.0300	20	.0200
5		25	.0250	10	.0100
6		35	.0350	15	.0150
7		15	.0150	35	.0350
8		20	.0200	15	.0150
9		25	.0250	45	.0450
10		20	.0200	35	.0350
MEAN DL		27.5	.0275	26.0	.0260
STANDARD DEVIATION		9.789	.0098	11.498	.0115
RANGE	LOW	15	.0150	10	.0100
	HIGH	50	.0500	45	.0450

TABLE 19

SUBJECT DATA FROM THE 1000-CPS, 300-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps				
REFERENCE DURATION - 300 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	Δ T/T	DL IN MSEC	Δ T/T
1	14	.0466	3	.0100
2	13	.0433	3	.0100
3	5	.0166	10	.0333
4	9	.0300	9	.0300
5	11	.0366	10	.0333
6	20	.0666	9	.0300
7	16	.0533	5	.0166
8	16	.0533	4	.0133
9	10	.0333	14	.0466
10	14	.0466	5	.0166
MEAN DL	12.8	.0427	7.2	.0240
STANDARD DEVIATION	4.237	.0141	3.71	.0124
RANGE LOW	5	.0166	3	.0100
RANGE HIGH	20	.0666	14	.0466

TABLE 20

SUBJECT DATA FROM THE 1000-CPS, 500-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps

REFERENCE DURATION - 500 msec

SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	Δ T/T	DL IN MSEC	Δ T/T
1	10	.0200	10	.0200
2	3	.0060	16	.0320
3	19	.0380	15	.0300
4	15	.0300	9	.0180
5	14	.0280	9	.0180
6	25	.0500	18	.0360
7	12	.0240	11	.0220
8	22	.0440	21	.0420
9	21	.0420	10	.0200
10	9	.0180	18	.0360
MEAN DL	15.0	.0300	13.7	.0274
STANDARD DEVIATION	6.798	.0136	4.423	.0088
RANGE LOW	3	.0060	9	.0180
RANGE HIGH	25	.0500	21	.0420

TABLE 21

SUBJECT DATA FROM THE 1000-CPS, 1000-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps					
REFERENCE DURATION - 1000 msec					
SUBJECT		10-db SL		50-db SL	
		DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1		35	.0350	30	.0300
2		30	.0300	30	.0300
3		45	.0450	25	.0250
4		15	.0150	25	.0250
5		30	.0300	10	.0100
6		45	.0450	35	.0350
7		55	.0550	15	.0150
8		20	.0200	30	.0300
9		35	.0350	20	.0200
10		20	.0200	55	.0550
MEAN DL		33.0	.0330	27.5	.0275
STANDARD DEVIATION		12.736	.0127	12.304	.0123
RANGE	LOW	15	.0150	10	.0100
	HIGH	55	.0315	55	.0550

TABLE 22

SUBJECT DATA FROM THE 4000-CPS, 300-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps				
REFERENCE DURATION - 300 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	Δ T/T	DL IN MSEC	ΔT/T
1	14	.0466	5	.0166
2	10	.0333	4	.0133
3	15	.0500	10	.0333
4	13	.0433	10	.0333
5	9	.0300	7	.0233
6	18	.0600	14	.0466
7	10	.0333	5	.0166
8	15	.0500	10	.0333
9	5	.0166	9	.0300
10	10	.0333	5	.0166
MEAN DL	11.9	.0397	7.9	.0263
STANDARD DEVIATION	3.784	.0126	3.213	.0107
RANGE LOW	5	.0166	4	.0133
RANGE HIGH	18	.0600	14	.0466

TABLE 23

SUBJECT DATA FROM THE 4000-CPS, 500-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps				
REFERENCE DURATION - 500 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	15	.0300	16	.0320
2	16	.0320	3	.0060
3	15	.0300	15	.0300
4	15	.0300	15	.0300
5	13	.0260	11	.0220
6	14	.0280	20	.0400
7	24	.0480	21	.0420
8	6	.0120	13	.0260
9	10	.0200	16	.0320
10	15	.0300	5	.0100
MEAN DL	14.3	.0286	13.5	.0270
STANDARD DEVIATION	4.572	.0091	5.817	.0116
RANGE LOW	6	.0120	3	.0060
RANGE HIGH	24	.0480	21	.0420

TABLE 24

SUBJECT DATA FROM THE 4000-CPS, 1000-MSEC EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps				
REFERENCE DURATION - 1000 msec				
SUBJECT	10-db SL		50-db SL	
	DL IN MSEC	$\Delta T/T$	DL IN MSEC	$\Delta T/T$
1	30	.0300	20	.0200
2	30	.0300	35	.0350
3	40	.0400	25	.0250
4	30	.0300	30	.0300
5	10	.0100	10	.0100
6	55	.0550	35	.0350
7	35	.0350	15	.0150
8	35	.0350	30	.0300
9	25	.0250	5	.0050
10	25	.0250	45	.0450
MEAN DL	31.5	.0315	25.0	.0250
STANDARD DEVIATION	11.559	.0116	12.472	.0125
RANGE LOW	10	.0100	5	.0050
RANGE HIGH	55	.0550	45	.0450