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MONAURAL DIFFERENTIAL SENSITIVITY
FOR SHORT STIMULUS DURATION

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TABLE OF CONTENTS

TABLE OF CONTENTS, Continued

Page

Chapter

LIST OF TABLES

LIST OF TABLES, Continued

Table Page

LIST OF TABLES, <u>Continued</u>

Table Page

LIST OF ILLUSTRATIONS

Figure Page

LIST OF ILLUSTRATIONS, Continued

MONAURAL DIFFERENTIAL SENSITIVITY
FOR SHORT STIMULUS DURATION

CHAPTER I

INTRODUCTION

The study of hearing is directed toward efforts to define the tenets which govern human auditory behavior. This purpose is achieved through an understanding of acoustic stimuli and the nature of the responses that they evoke. The degree of confidence and the accuracy with which sensory acuity can be specified is due, in part, to a growing understanding of psychophysical phenomena which has made it possible to relate stimulus to response. Fundamental to this knowledge is the measurement of the minimum acoustic energy that just evokes a response to the sensation of hearing and the smallest change in a stimulus that an observer can detect.

Information concerning man's sensitivity to minimum acoustic energies is academically interesting and clinically indispensible. Equally important, however, is the capacity to differentiate one sound from another, a function that is basic to man's effective use of the acoustic events that occur in his environment. It also provides valuable insight into the human being's ability to function in day to day situations. Inasmuch as communication is accomplished by utilizing transient signals, discrimination of relatively small changes in auditory stimuli is of the utmost importance.

The normal listener is able to differentiate two sounds if they vary sufficiently in their physical properties. The smallest change in a stimulus dimension that an observer can just detect defines the differential threshold, or difference limen (DL), for that dimension. The dimensions in terms of which the human auditory system is able to distinguish and classify auditory sensations are frequency, intensity, phase, and duration.

Differentiations by human beings on the basis of phase differences are not as easily assessed as are those due to differences in the other three parameters. As summarized by Stevens and Davis (70), the attention in the literature that has been devoted to frequency and intensity in an effort to define human discriminatory capacity is extensive. In addition to expanding our knowledge regarding the basic functioning of the auditory system (65, 68, 77), these studies have proven of value as a basis for clinical procedures directed toward the differential diagnosis of pathological etiologies (3, 15, 45, 47, 55, 56).

By contrast, duration as a parameter has been neglected. In fact, a salient feature of the literature is the paucity of information concerning differential sensitivity for duration which demonstrates the need for its definitive study. It is true that signal duration, as it affects perceived pitch and loudness, has been extensively scrutinized (14, 17, 18, 23, 24, 25, 26, 28, 29, 30, 35, 41, 50, 62, 76, 81), as have the psychological aspects of the perception of time and the estimation of filled and unfilled intervals (2, 19, 20, 21, 22, 27, 31, 32, 34, 36, 37, 60, 64, 75, 80, 82, 83). Although such studies provide valuable information about auditory function and the parameters that affect the measurement of differential sensitivity for duration, a definitive, systematic exploration of the duration limen (DL), per se, remains to be done.

This study was designed to fill this need, at least in part. Specifically, the study measured duration difference limens obtained from normal-hearing human beings when very brief tones were presented under various combinations of stimulus frequency and intensity.

A discussion of pertinent studies of differential sensitivity for stimulus duration, in addition to those which are germaine to the procedural variables that affect differential sensitivity, is presented in the following review of the literature.

CHAPTER II

HISTORICAL REVIEW OF THE PROBLEM

Introduction

The present study was an investigation of human auditory sensitivity to small physical changes in stimulus duration. Such a purpose necessitates a review of the literature concerning differential sensitivity, not only for the parameter of stimulus duration, but for the other parameters of stimulus frequency and intensity as well. In this section particular attention will be given to those studies which pertain to factors that affect differential sensitivity to tonal stimuli, as well as the procedures employed in its assessment.

The resolving power of the auditory system, as measured in the determination of DLs, is of clinical as well as theoretical interest. Because certain types of hearing losses exhibit abnormal sensitivity to intensity changes near threshold, the DL measurement is used in the differential diagnosis of hearing disorders. Although method, rationale and procedure differ somewhat, Denes and Naunton (15), Luscher and Zwislocki (56), and Jerger (46) have all proposed clinical tests utilizing differential sensitivity for intensity as a diagnostic tool. Even though not a DL by definition, the mean width of the excursions of Bekesy threshold tracings are related to differential sensitivity for intensity and are diagnostically meaningful when considered as part of a test battery (3). Likewise, the short increment sensitivity index (SISI) (48) is dependent upon differential sensitivity for intensity. The ear's sensitivity to changes in frequency, however, has not had as much clinical application. It would seem that the parameter of stimulus duration may also prove to be of clinical significance.

The psychophysicist and the experimental psychologist are concerned with how the human observer detects auditory signals. By varying the signal parameters, information as to how this is accomplished is provided and auditory theory is thereby formulated. Human discriminatory behavior is incompletely understood as is evidenced by a preponderance of discrepancies among data and conclusions offered in the literature (4, 52, 70).

Such discrepancies are a direct reflection of imperfect knowledge regarding the relationships between the physical parameters of a pure-tone and a human being's response to them. Research on frequency-intensity effects is voluminous (8, 39, 42, 49, 63, 66, 68, 69, 73, 78). Although some aspects of duration, as related to frequency and intensity, have been explored, a critical review of the literature reveals that the crucial study defining human discriminatory capacity for auditory stimulus duration does not exist. That it has thus far eluded careful investigation is surprising indeed, in view of the fact that duration is one of the few basic parameters of an auditory stimulus (61).

Differential Sensitivity for Frequency and Intensity

The magnitude of the just noticeable change in a stimulus has been of interest ever since 1834 when E. H. Weber stated that the ratio of the just perceptible increment in a stimulus to the base intensity from which it is determined is constant for all sense modalities. He was mistaken. The Weber ratio, or the relative difference limen ($\Delta I/I$) does not maintain a constant value either with regard to intensity (65) or frequency (68). There is evidence that this is equally true for duration (33, 43, 74).

The historical development of differential sensitivity is reviewed by several writers (8, 49, 78). Boring (8) compares and critically evaluates the data on frequency DLs as determined by such early workers as Delezenne, Preyer, Luft, Meyer, Stucker, and more recently by Vance, and Shower and Biddulph. Shower and Biddulph (68) were the only ones using electronic equipment and their study has generally been considered to be the classical work. Curiously enough, the limens of the earlier researchers, using reeds and tuning forks, are smaller than those of Shower and Biddulph. These differences Boring (8) attributes to the presence of transients and overtones introduced by the crude instrumentation in the abrupt changes of the stimuli used by the early scientists. Shower and Biddulph (68) objected to these earlier works because, instead of making their judgments on the basis of differences in fundamental frequency, the subjects were influenced by the presence of overtones; hence, the smaller limens.

Using thermionic oscillators, Shower and Biddulph (68) varied the stimulus sinusoidally in order to avoid the confusing transients of an abrupt stimulus change. But this approach also can be criticized. As Boring (8) states, an abrupt stimulus change without transients or clicks is desired. The procedure of sinusoidal variation results in limens that he considers too large to represent the maximal sensitivity of the ear to frequency changes while the data of the early experiments are felt to be too small. Harris (39) has raised the question whether the frequency modulation technique is not rather an experiment in some form of beats or masking. He further challenges the work of Shower and Biddulph (68) as lacking in stimulus control and in "a feeling for the psychological concept of differential threshold".

Combining the latest in electronic instrumentation with careful consideration for the psychology of discrimination, Harris (39) investigated differential sensitivity for frequency and obtained results which were in sharp contrast with those of Shower and Biddulph (68). His data do not support the widely held view that the Weber ratio is approximately constant beyond 1000 cps, while at frequencies below 1000 cps the absolute DL is approximately constant. Rather, he concludes that frequency discrimination data above 5000 cps must be considered tenuous because of loudness cues which may be operating.

In evaluating procedures used in studies of frequency DL, Boring (8) cites factors which may affect the size of the difference limen. These are: (1) subject practice reduces limen size, (2) differences between subjects cause the limen to vary, (3) the psychophysical methods of limits and of right and wrong cases do not yield comparable results, (4) the limens of sinusoidal change are larger than those of abrupt change, (5) the method of limits yields smaller limens than does the method of right and wrong cases, (6) transients tend to reduce limen size for the frequency region below that of the ear's maximal sensitivity, (7) limens become larger as the stimuli decrease in intensity.

Harris (38) lists three requisites for pitch discrimination studies: (1) the stimulus must be concentrated within the desired frequency region, without transients, (2) the psychophysical method must be defensible and clearly described, (3) the subject's performance must not be unduly influenced by practice, uneven motivation, or other extraneous factors.

Rosenblith and Stevens (66) go somewhat further in stating that a careful description must be given of the "stimulus ensemble", "response repertory", and all experimental aspects which might shed light on the mechanism of judgment response. In view of the contradictory nature of the literature on the size of the frequency DL, they explored the extent of DL variation as a function of psychophysical method. They employed the method of constants (coded AX by the authors) and the so-called ABX technique (40, 58), whereby a subject judges whether stimulus A or stimulus B is more like stimulus X. They do not conclude that one method is superior to the other, but only say that the ABX method yields larger DLs than does the method of constants. In fact, they deem it "imprudent to postulate a 'true' DL, or to infer the behavior of the peripheral organ from the size of the DL measured under a given set of conditions".

In summary, the DL measurement for frequency is meaningless unless the conditions and procedures under which the values are obtained are rigorously defined. The simpler the stimulus conditions, the better is the subject's judgment performance which can be evaluated only in terms of the way in which the task has been specified. Rosenblith and Stevens (66) have shown that DL size can be manipulated by varying procedure and stimulus conditions.

Shortly after the initial work in frequency DLs had begun, interest was also generated in differential sensitivity to stimulus intensity. Knudsen (49) briefly reviews the historical development of intensity limens. He reports early experiments conducted by Fischer and Wundt in 1880 who specified intensity DL values by comparing the distance that two similar lead balls fell, making successive impacts on a metal plate. Various intensities were produced by balls of different weights and by varying their heighth of fall. They found the Weber ratio to be independent of stimulus intensity. That is, the Weber ratio remained constant over the range of intensities used.

The pioneer work in intensity DL measurement, however, is considered to have been that of Wien (1888) whose tone source was a telephone receiver used in conjunction with a Helmholtz resonator. Intensity was measured by visual projection and amplification of the motion of a diaphram positioned within the resonator. The sound stimulus was carried from the resonator to an observer's ear by means of a rubber tube. Wien found his values to be a function of stimulus frequency as the DL varied in an irregular manner with intensity.

Thirty-five years later (1923), Knudsen (49) attempted to determine the sensitivity of the ear to small differences of intensity and frequency. By present standards his procedure and instrumentation left something to be desired. He, himself, writes that "contact noises" were evidenced in the higher frequencies.

The classic experiment of differential sensitivity for intensity was reported by Riesz (65) in 1928. He obtained intensity DLs as a function of frequency and intensity over the entire range of human auditory sensitivity. To avoid the problem of transients he employed a method of beating tones. The results indicated that DL size was dependent on the rate of signal fluctuation and that the DL was smallest with a three-cycle difference between tones. The size of the DL approached a constant value for intensities above 50 decibels but increased rapidly as stimulus intensity was lowered to threshold. The relative DL was minimal at 2500 cps. Riesz' work can be questioned for much the same reason as that of Shower and Biddulph (68) on frequency DL (i.e., sinusoidal variation results in relatively large limens).

Since different psychophysical methods yield dissimilar results (16, 66), Pollack (63) focused his attention on intensity discrimination under several experimental procedures which differed primarily in terms of the presence or absence of an objective comparison signal and in terms of the stability of test conditions. The purpose was to examine the range among differential thresholds as a function of the psychophysical method. The differential threshold was found to be slightly lower when an objective reference standard was available than when it was not. Considered more important was the fact that a stable standard reference, as opposed to a roving standard, yielded lower thresholds. The frame of reference provided by a method based on an objective standard allows the observer to "anchor" his judgments (83) whereas, when the standard is varied from trial to trial, the judgmental framework is relatively unstable and discrimination deteriorates over a wide range of inter-stimulus intervals.

The "anchor effect" refers to the influence of contextual factors. It has been demonstrated that the size of the indifference interval varies with the range of stimuli used in such a way that the indifference interval lies in the middle of the particular stimulus series employed (82). Ostensibly, the subject is able to build a judgmental framework against which ensuing judgments are made.

Frequency and Intensity DL as a Function of Reference Duration

The size of the difference limen for either frequency or intensity depends on the duration of stimulation. A consideration of frequency and intensity as a function of stimulus duration involves questions concerning the length of time that a tone must be on in order to acquire tonal quality as well as the minimum stimulus duration beyond which additional lengthening of the tone does not change the pitch.

It has been demonstrated (17, 23) that a tone does not lose pitch abruptly with shortened duration, but passes through several stages. Whereas Doughty and Garner (17) report two kinds of pitch threshold, Ekdahl and Stevens (23) describe three thresholds. At two or three milliseconds (msec) duration, a tone of 1000 cps has no pitch character, but is heard merely as a click. From the threshold of click-pitch at 10 msec, pitch changes with increased duration and becomes subjectively lower and the tone becomes louder. In the final stage (the threshold of tone-pitch which is approximately 30 msec), pitch quality is not altered with further lengthening of the tone.

Concerned with this same problem, Bürch, Kotowski and Lichte (9) studied pitch perception at very short stimulus durations and indicated that the absolute time necessary from the onset of a tone to identify pitch is shortest (approximately 10 msec) in the mid-frequency range. According to their arbitrary criterion, there must be three to four sound waves to perceive a pitch quality for tones below 250 cps. At 1000 cps, twelve waves are necessary and at 10,000 cps two-hundred and fifty are required. Turnbull's (76) data for the low and middle frequencies agree with those of Bürck, Kotowski, and Lichte (9).

Kucharski (51), interested in the smallest number of vibrations which allowed a subject to discriminate between the pitches of a pair of tones, reported that his seven subjects could distinguish two tones (750 and 1000 cps) presented successively for only 0.0054 second (sec) (sufficient to transmit about one cycle of the 1000-cps wave and two-fifths of a cycle of the 750-cps wave). Neither Turnbull (76) nor Bürck, Kotowski, and Lichte (9) found pitch discrimination possible at such short durations.

The variation of pitch discrimination as a function of stimulus duration is reviewed by several authors (18, 70, 76). In 1914 Anderson (1), using tuning forks of unspecified frequency, decreased the length of two successive tones from 2 to 250 msec and observed a reduction in accuracy with which a difference of one cycle could be discriminated. Bekesy (5), concerned with the same problem, established the dependence of the relative difference limen for frequency upon stimulus duration using two subjects and a 40-db, 800-cps tone. His work also demonstrated that a diminution in pitch takes place as stimulus duration is decreased. Turnbull's (76) data are in agreement with Bekesy's except at stimulus durations below 50 msec where Turnbull's DLs are larger than Bekesy's. Ekdahl and Stevens (23) indicate that the perceived pitch of all tones from 250 to 8000 cps is lowered with shortened duration. Bürck, Kotowski, and Lichte (9), on the other hand, suggest that the pitch of high tones falls while that of low tones is raised by shortening the tonal duration.

In 1944 Turnbull (76) extended previous studies to show more fully the relationship between pitch discrimination and stimulus duration. The relative frequency DL was determined for a series of duration values from the maximum of 500 msec to the shortest period which permitted measurement of the limen. As stimulus duration decreased, accuracy of pitch discrimination also diminished. Based on work done by Turnbull, Wever (81) reported that pitch differences of 2.8 cps can be determined 75 per cent of the time for stimulus durations greater than 100 msec. At shorter durations pitch discrimination drops sharply.

Doughty and Garner (18) studied pitch as a function of stimulus duration over a wide range of frequencies and duration times in an effort to resolve contradictions in the literature. In the first of a series of experiments, using the method of constants, their six subjects were asked to judge the comparison tone as higher or lower in pitch than the standard. All observations were made binaurally under earphones. The results showed a tendency for the upper intensity curves to drop with shortened duration, indicating a loss of pitch. For the lower intensity curves, the pitch loss at short durations was not present. They concluded that if a large pitch change does occur as a function of shortened duration, it is not revealed completely by the method of constants.

It was, therefore, decided to employ the method of average error. Using the same six subjects, the data revealed that considerable pitch change took place near the shorter durations. There was a decided loss of pitch for all frequencies as duration was reduced from 12 msec. The percentage of pitch change under the method of average error was considerably larger (2 to 4 per cent) than that obtained with the method of constants (less than 1 per cent); however, the direction of pitch change was the same for both psychophysical methods. Tone pitch was not significantly affected down to 25 msec. Pitch loss for 250 and 1000 cps at very short durations was less at 70-db than at 90-db SPL whereas for 4000 cps there was a trend toward a gain in pitch as a function of shortened duration. The authors concluded that both frequency and intensity interact in determining the direction and amount of pitch change as a function of signal duration.

In a third experiment using a single subject Doughty and Garner concentrated on intensity and frequency effects. Five intensities were selected (30 to 100-db SPL) and six frequencies (250 through 8000 cps). A standard tone of 500 msec was used, whereas the comparison tone was held constant at 12 msec. As intensity decreased, the change in pitch for all frequencies tended to become successively less negative (or more positive), level off, and then at very low intensities become more negative (or less positive). There was no tendency toward negative pitch values at low intensities. Doughty and Garner (18) find it worth noting that, for 8000 cps, the direction of pitch change at all intensities was positive.

Similar to procedures followed by Pollack (63) on intensity discrimination, König (50) studied the effect of time on pitch discrimination under several psychophysical procedures, and compared pitch and intensity DLs. Attention is called to the accuracy of discrimination in the absence of an objective comparison signal and to the relatively large DLs associated with the instability of the testing conditions. König (50) further says:

> ...the single comparison standard procedure is undoubtedly the method which gives the smallest values for the difference limen, whereas the roving standard procedure yields the largest DLs. The difference limen for intensity discrimination usually seems to depend more on the method used than in the case of the difference limens for pitch discrimination.

No attempt was made to control or assess subject motivation and level of cooperation or practice effect, although these factors were recognized. Rather than explain the judgment processes that differentiate the psychophysical procedures, the discussion is confined to an examination of individual subject behavior. The conclusion is reached that differential sensitivity. for the most part, depends on undefined "higher order" individual factors, as well as the psychophysical procedure and the auditory end-organ.

In discussing the decline of pitch discrimination with time, Harris (41) charges that experiments concerned with the effect of elapsed time between the standard and comparison stimuli on pitch discrimination suffer from one of two faults. Either there has been insufficient information to allow a DL to be calculated, or the psychophysical method that was employed allowed the subject to anchor his judgments and thereby maintain discrimination over a long inter-stimulus interval.

Harris (41) showed that, with a fixed standard stimulus, no decline in pitch discrimination occurs up to a duration of 3.5 sec. After 15 sec an 0.8-cps pitch decrement is observed and, following 25 sec, there is a decline in observed pitch of 3.0 cps.

Several experimenters (5, 30, 35, 53, 62) have proposed to describe the relationship of intensity to duration. In 1929 Bekesy (5), using an 800-cps tone at less than 0.1 sec found that loudness was held constant when

$$I = k \log t C.$$

I is the intensity in db, k and C are constants, and t is time in seconds. k is negative so that, as stimulus duration decreased, intensity must increase to keep loudness constant.

With somewhat more extensive data, Lifshitz (53) stated thay any decrease in signal duration must be accompanied by a proportionate increase in intensity in order to maintain constant loudness. This relationship is expressed in the expression

$$It = K$$

where I is signal intensity in db, t is time in seconds, and K is a constant. His experimental data were obtained at frequencies from 50 to 4000 cps for durations of 0.012 to 0.69 sec and for intensities of 34 to 84-db loudness level. Turnbull (76) tested Lifshitz's formula. As an extension of his study on pitch discrimination as a function of stimulus duration, he reasoned that if a reciprocal relationship exists between duration and intensity as suggested by Lifshitz, then DLs obtained by a reduction of stimulus duration could likewise be obtained by a decrease in intensity. Turnbull (76) compared DL values resulting from each of these two procedures and observed wide differences. He concluded that his experiment did not support Lifshitz's formula expressing the relationship between time and intensity in audition.

Garner and Miller (30) studied the masked threshold of pure tones as a function of duration. They found that every ten-fold decrease in stimulus duration below 200 msec resulted in a 10-db threshold rise. For longer durations, threshold was not affected. Fodor (24) considered this same phenomenon, but reports that 150 msec rather than 200 msec is the point beyond which threshold undergoes no further change with respect to intensity. Also, Fodor's (24) results show a 9-db rise in threshold with each decimating decrease in duration instead of the 10-db reported by Garner and Miller (30). Green, Birdsall, and Tanner (35) differ with Garner and Miller (30) and with Fodor (24) in reporting that, as stimulus duration is extended from 250 to 3000 msec, signal detectibility continues to increase.

Inasmuch as the present investigation utilized short tonal stimuli, the studies reviewed in this section serve to point out those factors which affect the perception of very brief tones.

Differential Sensitivity for Stimulus Duration

Differential sensitivity for duration is another aspect of stimulus duration. It is one phase of the more encompassing problem of how time is perceived, appreciated, and experienced. Boring (7) reports that interest in the time sense began with Mach and Vierordt in the 1860's. Mach sought to test the applicability of Weber's law to time perception and Vierordt was the first to state that long time intervals are typically underestimated while short intervals are overestimated. Among the first to study the discrimination of continuous tonal lengths was Thorkelsen in 1885. The initial comprehensive review of the psychology of time was that of Nichols (60) in 1891. Since then there have been a number of reviews (2, 19, 20, 21, 22, 32) with Boring (7), Woodrow (83), and Wallace and Rabin (80) among the most recent.

Temporal intervals may be either filled or unfilled. That is, they may be tones bounded by silence or empty intervals bounded by sensory stimuli. Time sense behavior with respect to such stimuli may be investigated using any one of four major methods (80) (i.e., verbal estimation, production, reproduction, or comparison). Most experiments on the estimation of time have generally employed either the reproduction or comparison method. The method of reproduction requires that an observer merely reproduce a stimulus duration by giving him control of the stimulus. A long interval will be underestimated and a short interval will be overestimated (73). In the method of comparison, a comparison stimulus is judged as equal to, longer, or shorter in length than a standard stimulus interval. Given a series of comparison stimuli presented for differential judgment, the second stimulus of a pair must be somewhat longer than the first in order to be judged as subjectively equal (positive error), whereas for longer durations, the second must be shorter than the first in order that the two stimulus durations be judged as equal (negative error) (59, 64).

The intermediate point where the error in judgment is zero is the point of indifference, or the indifference interval. At this point the judgment of temporal intervals is unaffected by the order of stimulus presentations (74). From such data it is possible to interpolate a difference limen expressing the accuracy with which time intervals can be differentiated.

The literature reveals only a few studies from which a Weber ratio for stimulus duration can be calculated. Several investigations (6, 37, 11) comparing unfilled time are reported. In 1932 Gridley (37) asked her thirty subjects to compare the relative length of two unfilled intervals bounded by tactile stimuli and compared these judgments with estimates of silent intervals bounded by auditory stimuli. Using a standard interval of 1 second, twenty trials were given for each of five comparison intervals (0.02, 0.05, 0.09, 0.14, and 0.20 second plus the standard). Subjects were instructed to judge the comparison interval as longer or shorter than the standard. One Weber ratio can be calculated from her data. She obtained a Weber ratio of .09 for a reference duration stimulus of 109 msec.

Data were obtained in two sittings. A comparison of the percentage of correct judgments of the second sitting with that of the first, reveals an increase of 5.32 per cent correct judgments. This undoubtedly is the result of an acknowledged practice effect. In addition, there was a memory factor as evidenced by the fact that some subjects in the second sitting remembered the order of stimulus occurance from the first sitting. Randomization of stimulus presentations would be expected to have minimized the practice and memory factors.

Blakely (6) obtained just noticeable differences between unfilled intervals set off by auditory clicks. He attempted to eliminate the time-order errors by using the psychophysical method of constants where the standard was presented second as often as first. The interval lengths studied ranged from 0.2 to 30 sec. Discrimination was found to be most accurate at a standard duration of 0.6 second when the just noticeable difference was approximately 7 or 8 per cent of the standard. Discrimination decreased with increased interval length.

Most recently (1959), Chistovitch (11) reports on the discrimination of silent intervals bounded by short acoustic pulses. In one of a series of experiments, measurements of the differential threshold as a function of interval magnitude were made on four subjects. Each subject compared the standard stimulus (a silent interval of 1 msec bounded by a pair of pulses) with a variable stimulus which equalled the standard in 50 per cent of the cases and in the remainder of the cases equalled the standard plus the increment. The subject was required to report if the variable signal coincided with the standard or differed from it. Increment length was successively reduced from one test series to the next and the increment duration at which 75 per cent correct judgments were obtained was adopted as the differential threshold.

Chistovitch (11) plots the mean differential threshold for all subjects (Figure 2, p.494). From his data the relative DLs in msec are calculated in Table 1.

TABLE 1

ABSOLUTE AND RELATIVE DL VALUES APPROXIMATED
FROM DATA OF CHISTOVITCH

T	ΔT	ΔT/T
.85 msec	5.5 msec	.1545
	9.6	.2200
4.00	15.0	.2666
9.20	55.0	.1672
16.20	105.0	.1543
26.00	196.0	.1326

Unfortunately, during the interval between the presentation of the standard and the comparison stimuli as much as 10 sec was spent in adjusting equipment. It is likely that this rather lengthy time lapse affected the values of the obtained DLs (71, 72).

Undoubtedly one of the most extensive studies was that of Stott (74) who attempted to determine the time-order errors which are made in judging the comparative lengths of a pair of tones.

Individual and group data were collected in a series of four experiments using 524 subjects from whom 99,480 judgments were obtained. Initial experiments of this study showed that under certain conditions a time-order indifference point for tonal duration lies somewhere between 1.5 and 2.0 sec. An effort was, therefore, made to define the indifference point more precisely.

In the first pair of experiments twelve standard durations were used (.2, .4, .6, .8, 1.0, 1.5, 2.0, 4.0, 6.0, 10, 20, and 30 sec). For each standard five variable durations were employed (0, 5, 10, 15, and 20 per cent longer than the standard in each case). No mention is made of the intensity of the experimental tone. Using the psychophysical method of constants, a complete stimulus presentation consisted of a standard and comparison duration separated by a silent interval of 1.5 sec. Each pair was introduced by a warning signal (light flash) 1.5 sec prior to the onset of the first tone. The standard preceded the comparison tone half the time and followed it the other half. An experimental series consisted of twenty presentations of each variable in random order. Each subject was requested to respond by indicating whether the second tone was longer, shorter, or equal in duration to the first.

The apparatus used in these experiments consisted of an oscillator, a time control device, and a mechanism for measuring stimulus duration. An electromagnetically controlled gate was used to control the passage of a continuous auditory signal through a glass tube. Stimulus length was set by a time operated shutter.

The first portion of experiment I was composed of two parts. In the first, each of five subjects was to judge the second of the pair of tones as being longer or shorter than the first. Each experimental run began with the shortest variable duration and, at each successive sitting, the next longer one was used until the maximum duration was reached (ascending series). The order was then reversed and stimuli were presented in a descending series. In the last part of experiment I two groups of four and six subjects, respectively, were used. Data were collected only for the eight shorter standard durations. The group of six subjects judged the descending series followed by the ascending series, while the group of four subjects followed the same procedure as did individual subjects in the first half of this experiment.

The percentage of "variable longer" judgments was calculated for each combination of presentation order and standard duration presented to all fifteen subjects. The percentage difference (V-S minus S-V) between the presentation orders was taken as representative of the time-order errors.

The results were interpreted to indicate that the general outcome was a relative underestimation of the second member of a pair for all durations from 0.2 to 1.5 sec and a relative overestimation of the second tone for the longer durations (0.2 to 36.0 sec). Stott concluded that the indifference point under these conditions lay somewhere between 1.5 and 2.0 sec and estimated its probable length to be about 1.67 sec.

Experiment II was executed to further explore the indifference region. Four standards (1.0, 1.4, 1.8, and 2.2 sec) were used with the aforementioned five variables which were distributed equally as to length on either side of each standard and covered twice the range of the relative length. Twenty-seven subjects, twelve men and fifteen women, were used.

As in experiment I, both positive and negative errors appeared with each of the four standards. The shorter variables showed positive constant errors (C.E.s) while the longer ones showed negative C.E.s. In this case four indifference points were found, ranging from 0.95 to 1.8 sec. Stott (74) attributes this to differences in apparatus, procedure, and subjects between experiments I and II. Stott retabulated the judgments obtained from the twenty-seven subjects in the first sitting of experiment II at the 1.0 sec standard which suggested that a practice effect was very likely operating.

In an effort to minimize the factor of experience, an entirely different group of subjects was used for each standard duration in experiment III. The standards used were: 0.625, 0.8, 1.0, and 1.6 sec. The number of subjects for each standard was 100, 100, 74 (plus the results of 26 subjects in experiment II), and 86, respectively. The range of variable durations from 20 per cent shorter to 20 per cent longer than the standard were used in each instance.

The effect of experience in performing the experimental task is demonstrated by 45 of the 86 subjects who were given the 150 presentations. When the first thirty judgments (three for each standard-variable combination) from the 86 subjects are computed, the C.E.s are all negative, but when the 150 are computed the C.E.s are both positive and negative as was the case in experiment II. Stott (74) indicates that this is largely due to repeatedly judging the same standard-variable combination.

The results of experiment I (an indifference point of 1.67 sec) and experiment III (an indifference point of 0.92 sec) are at variance. Stott (74) attributes this variation to the number of subjects used in experiment III, the range and distribution of variables in relation to the standard, the number of judgments per sitting, and the number of standards with which the subject had experience.

Stott (74) concludes that the discrepancy between the results of experiments I and III is due to a practice effect of the first experiment. Furthermore, he says that differences in experience, in length of sittings, and in the range and order of standards used are probably important factors contributing to the great amount of disagreement among investigators of the past with respect to the time-order indifference point for stimulus duration.

The Weber ratio for the standard durations employed by Stott (74) were extrapolated from data showing the percentages of "variable longer" judgments. These calculated values are reported in Table 2.

TABLE 2

WEBER RATIO VALUES APPROXIMATED FROM DATA OF STOTT

T (msec)	$\Delta T/T$
200	.142
400	.120
600	.115
800	.118
1000	.126
1500	.123
2000	.103
4000	.160

In reviewing investigations which have proposed to specify an indifference interval, Woodrow (83) says:

> ...seldom have two investigators found the same value. Perhaps indifference intervals of 0.5 to 0.7 seconds have been reported more frequently than others, but the range extends from under 0.36 to 5.0 seconds (Woodrow, 1934). Sometimes no indifference interval has been found; sometimes several. Early investigators, contrary to Vierordt's law, have reported negative time-order errors (underestimation) for intervals shorter than the indifference interval and positive time-order errors (overestimation) for longer intervals. One study, made with relatively large groups of subjects found considerable percentage of subjects making positive time-order errors (by the method of reproduction) for all lengths of stimulus intervals from 0.3 to 4.0 seconds (Woodrow, 1934). It follows that, even under fixed experimental conditions, there is no single indifference interval valid for all subjects. A few investigations have been extensive enough to afford an estimate of the average indifference interval for a group of subjects. One study (method of reproduction of empty intervals bounded by short sounds) indicated a mean indifference interval of approximately 0.6 second (Woodrow, 1934); another (method of constant stimuli with empty intervals) indicated a mean indifference interval of approximately 0.7 (Blakely, 1933); and a third (method of constant stimuli with continuous tonal durations) showed an indifference interval of approximately 0.9 second (Stott, 1935).

The single study in the literature which was specifically designed to investigate the nature of the difference limen for stimulus duration is reported as a series of three experiments by Henry (43). He employed tones shorter than those used by Stott (74). The range of durations was from 32 to 480 msec in length. The first of three experiments investigated the constancy of the Weber ratio. Differential thresholds were obtained from seven subjects using a 500-cps tone presented at a 50-db sensation level (Table 3).

TABLE 3

MEAN WEBER RATIOS ($\Delta T/T$) FOR SEVEN SUBJECTS TESTED AT SEVEN REFERENCE DURATIONS AS SHOWN BY HENRY

Duration in msec	32	47	77	110	175	277	480
Weber Ratio	.281	.203	.208	.196	.188	.172	.173

It is possible to compare interpolated data of Henry's (43) results with those of Stott (74) at two points (Table 4).

TABLE 4

MEAN WEBER RATIOS ($\Delta T/T$) INTERPOLATED FROM THE DATA OF HENRY AND STOTT

Reference Duration in msec	Henry	Stott
200	.184	.142
400	.154	.120

At a reference stimulus duration of 200 msec, DLs of 0.184 and 0.142 were obtained by Henry (43) and Stott (74) respectively. At a 400-msec reference Henry (43) shows a Weber ratio of 0.154 in comparison with Stott's (74) 0.120. Henry (43) points out that this represents poor agreement and attributes this to differences in apparatus, calibration errors and experimental method; furthermore, Stott (74) used higher frequencies of unspecified intensity.

Henry's (43) second experiment in this series explored DLs for duration as a function of stimulus intensity. Three different durations of a 500-cps tone were presented to five subjects, two of whom had served in the previous experiment. Two others judged the 47 and 277-msec reference duration tests, while yet another observed for the 47 and 77-msec reference duration tests. The data are shown in Table 5.

TABLE 5

MEAN WEBER RATIOS (ΔT/T) AS A FUNCTION OF STIMULUS INTENSITY AT THREE REFERENCE DURATIONS AS SHOWN BY HENRY

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

These data reveal that, except for the 20-db intensity level, the DL for duration was altered little with a change in intensity. The author reports that the DL at 20 db increased "significantly" at the shortest duration (47 msec) over the DLs at the two longer durations.

In the final experiment, Henry (43) reports on the effect that signal frequency exercises on the duration difference limen. The length of a 50-db sensation level stimulus was held constant at 77 msec. Five octave frequencies in the range 125-2000 cps were used. The data from three subjects are tabulated in Table 6.

TABLE 6

INDIVIDUAL WEBER RATIOS (ΔT/T) FOR 77-MSEC TONES OF DIFFERENT FREQUENCY AS SHOWN BY HENRY

	Frequency in cps				
	125	250	500	1000	2000
Subject S	.290	.208	.143	.130	.158
Subject L	.260	.195	.169	.156	.117
Subject F	.335	.221	.169	.182	.208
Average	.295	.208	.160	.156	.161

Henry's (43) data show a tendency for the Weber ratio to be greatest at low frequencies, although he states that the data are too few to justify the calculation of critical ratios.

Henry (43) summarizes his study by stating that, for a 500-cps tone of 50-db sensation level, the average subject could discriminate a change in duration of approximately 14 per cent, whereas at the shortest durations discrimination was only half as good. Faint tones at low frequencies also resulted in poorer discrimination for a change in stimulus duration. Henry (43) fails, however, to explain discrepant data. In the initial experiment a Weber ratio of .208 was obtained for the 77-msec experimental stimuli, whereas in the third experiment an average value of .160 was obtained for the same stimulus. Although a 50-db stimulus was not employed in the second experiment, the values at 40 db (.184) and 60 db (.179) lie approximately midway between the Weber ratios of experiments one and three. Since some subjects were used in all three experiments, it is likely that this apparent increase in the ability to discriminate changes in stimulus duration in the later studies is largely due to a practice effect (13, 44).

Summary

It is apparent that, except for Henry (43), no investigator has been chiefly interested in determining difference limens for stimulus duration, although the calculation of DLs has been a by-product of studies in which indifference intervals were the primary concern (74). When reported by the various authors, DLs are in poor agreement at those points where comparison is possible. Moreover, interest and subject variability have been large. Henry's (43) experiment was extensive, but because of obvious intra-study inconsistencies, his data cannot be considered representative of human differential sensitivity to stimulus duration. Thus, with all due respect for the efforts of Stott (74) and of Henry (43) in particular, there has, as yet, been no reliable systematic delineation of the differential threshold for stimulus duration. Nevertheless, these investigators have made contributions from which further research can proceed.

This investigation was designed to specify DLs for short stimulus duration over a range of stimulus frequency and intensity. The experiment was programmed electronically and a two-alternative, forced-choice procedure was used throughout. Three features inherent in the procedure, sequential analysis (79), practiced subjects, and immediate knowledge of results, were used to minimize variance within and among subjects as well as to drive each subject to maximal performance. The use of practiced sophisticated subjects together with careful experimental control in the design of the study was expected to yield data that could be interpreted as representative of monaural differential sensitivity for short stimulus duration in the normal-hearing human being under near-optimal conditions. A description of the experimental conditions, as well as the apparatus and procedure by which experimental control was achieved and maintained, are outlined in detail in the following chapter.

CHAPTER III

PROCEDURE AND INSTRUMENTATION

Introduction

This experiment was designed to explore the capacity of the normal-hearing subject to discriminate minimal changes in stimulus duration as a function of short reference duration at several frequencies and intensities.

The apparatus utilized in this study consisted basically of three audio-oscillators, electronic switches and timers, mixing and splitting networks, attenuators, and specially designed switching and response equipment. The audio-oscillators were used to generate a pure-tone stimulus which fed through a splitting network to three electronic switches. The operation of the switches was triggered by three electronic timers controlling stimulus duration. The audio-signals from the electronic switches, selected for operation by the experimenter, were then fed through a mixer and transduced by the test earphone.

Differential sensitivity for stimulus duration, as a function of short reference duration, was studied at several frequencies and intensities using normal-hearing subjects. The experimental data was collected only after the subject had been given extensive practice in the experimental task.

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

Subjects

Data were collected from ten normal-hearing subjects, five men and five women, all between the ages of 21 and 35 having no known history of ear pathology. Each person's hearing acuity was assessed by an air-conduction threshold audiogram before acceptance as an experimental subject. Hearing thresholds of 10-db hearing level or better at octave frequencies from 125 through 8000 cps defined normal hearing.

Each subject was expected to be well rested prior to his participation in the study in order to insure mental and physical alertness for maximum performance in the experimental task. If, for any reason, the subject reported unrest and/or fatigue, the experiment for that subject was postponed.

One ear of each subject was used in the collection of data. The right ear was designated the test ear as often as the left ear. This designation was made on a random schedule.

Apparatus

All practice and experimental tests were conducted in a sound-isolated, two-room suite at the Speech and Hearing Center, University of Oklahoma Medical Center. The arrangement allowed visual communication between subject and experimenter. In addition, auditory communication was effected by an appropriate "talk-back" system.

Screening Apparatus

A commercially available pure-tone audiometer (Beltone, Model 10AW) feeding either of two earphones (Telephonic, Type 39-10Z) was used in the preliminary audiometric procedures administered to all subjects. The earphones were mounted in MX-41/AR cushions and held in a standard headband.

The acoustic output of the air-conduction system of this audiometer was calibrated by means of an audiometric calibration unit (Western Electric Condenser Microphone Complement, Type 100/DE used in conjunction with a Hewlett Packard Vacuum Tube Voltmeter, Model 400H).

Experimental Test Apparatus

Figure 1 shows a simplified block diagram of the experimental apparatus used in this experiment.

Three audio-oscillators (Hewlett-Packard, Model 200ABR) served as the signal sources for all reference and comparison stimuli. Stimulus duration was governed by three

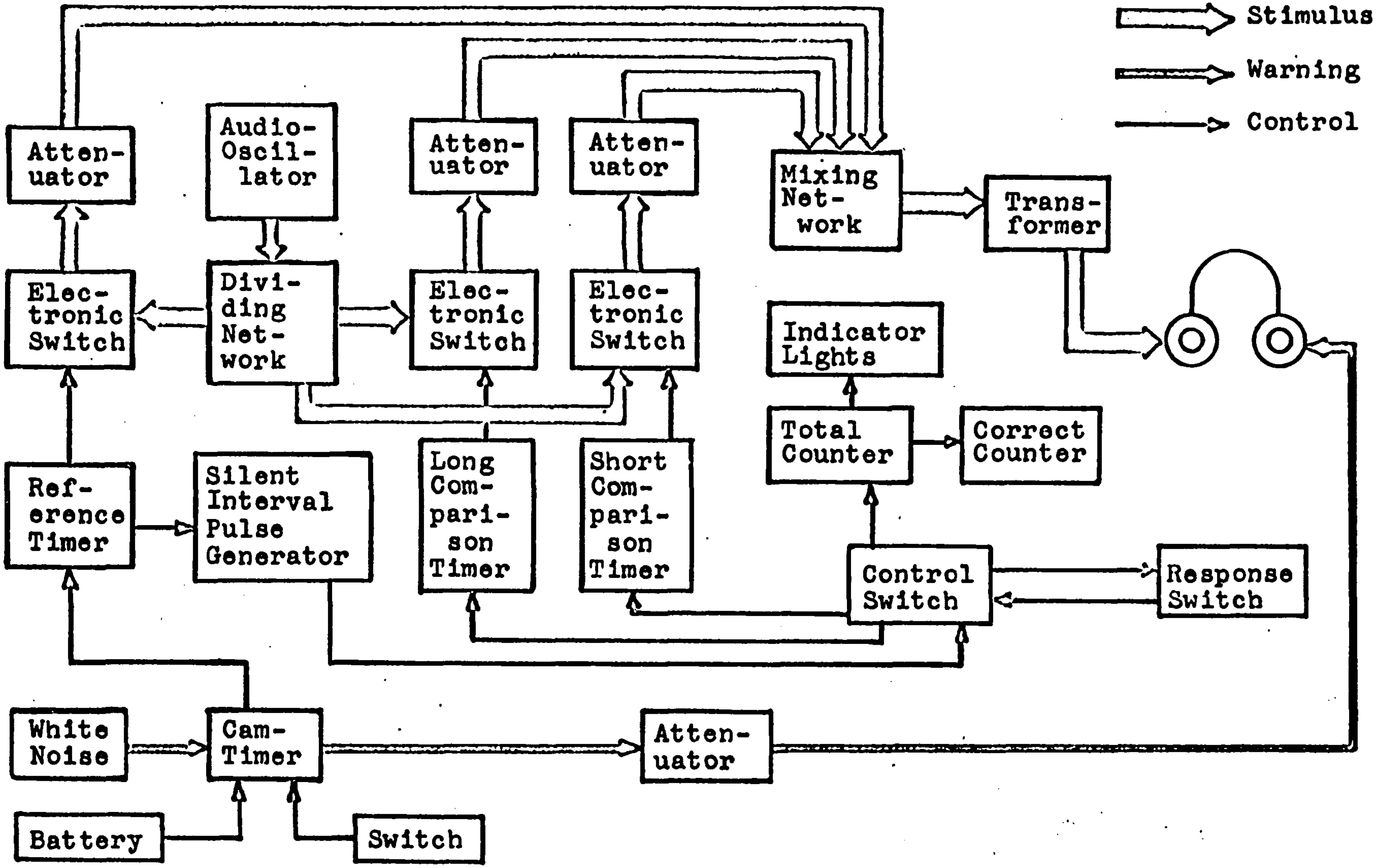

Fig. 1 - Simplified block diagram of the experimental apparatus.

sets of pulse generators (Tektronix, Type 161), each controlled by a waveform generator (Tektronix, Type 162). Stimulus sequence was regulated by three electronic switches (one Grason Stadler, Model 829C and two Grason Stadler, Model 829S112), which were triggered by the waveform generators.

Test stimuli were transduced and delivered to the subject's test ear via the test earphone (Sharpe, Type B, Model HA-10). A burst of white noise, used as an alerting signal, was fed to the non-test ear through a similar companion earphone. Both phones were mounted in dome-type ear-muffs with gelatin-filled composition cushions and held in position by an adjustable cushioned steel headband as supplied by the manufacturer.

Test stimulus intensity at the earphone was regulated by three 500-ohm attenuator sets (Hewlett Packard, Model 350AR). Impedence matching transformers (United Transformer Company, Model LS33) permitted maximum power transfer between the attenuator and the subject's earphone. White noise, delivered to the non-test ear as a warning signal, was obtained from a white noise generator (Grason Stadler, Model E5593A) whose output intensity at the earphone was fixed by an attenuator set (Hewlett Packard, Model 350A) at 50-db SPL.

The experimenter's switch was fabricated for rack mounting and consisted of an eight pole, three position, anti-capacity, lever action switch (Switchcraft, Model 60324L). It was designed to permit the experimenter to select for presentation either a longer or shorter comparison stimulus duration to be paired with a reference stimulus duration. A programmed sequence (a reference stimulus paired with a longer or shorter comparison stimulus) occurred automatically when manually triggered. A push button switch (Switchcraft, "Little Switch" 101), inserted in the circuit, activated a cam timer (Industrial Cam Timer Corporation) which began the initial programmed timing sequence. Thereafter, the circuit was so arranged that the subject response switch reactivated the cam timer each time a response was made. The warning signal of the ensuing pair of stimuli occurred 2 sec following each response. The cam timer consisted of three micro-switches. The first switch controlled its operation time. The second switch triggered and timed the warning signal while the third switch triggered the voltage of a dry-cell battery which, in turn, activated the electronic switches controlling the reference and comparison duration stimuli. The electronic components controlling the duration of each of the longer or shorter comparison stimuli were selected for operation at the experimenter's switch.

As opposed to the more traditional response tasks where the subject is not kept informed as to his performance, provision for immediate knowledge of results following each differential judgment illicits a significantly higher level of subject performance (13, 54, 67). In addition to its motivational aspect, knowledge of results has value in training subjects to make differential judgments (13). The means of providing the subjects in this study with immediate knowledge of results was achieved in the design of the subject response box.

The subject response box was constructed from a standard aluminum cabinet box (6" x 9" x 5") in which was mounted an eight pole, three position, lever action, spring loaded switch (Switchcraft, Model 60324L). When a subject judged the comparison tone to be longer than the reference tone, he was required to move the switch lever upward. When he judged the comparison tone to be shorter than the reference tone, he moved the lever downward. The switch positions, "longer" and "shorter", were so labeled on the face of the response box in order to assist the subject in identifying the appropriate response position.

A pair of lamps (1 inch in diameter, jewelled), mounted on the subject-response box, provided the subject with immediate knowledge of results. The circuit was so constructed that the blue lamp lighted with each correct response while the red lamp lighted with each incorrect response. A duplicate set of lights was provided on the experimenter's control panel. In addition, the operation of the counters in the experimenter's control room could be heard with each subject response. Thus, the experimenter had both a visual and an auditory cue that a response had been made.

Arranged in the circuit and positioned on the experimenter's control panel were two counters (PIC-600). One counter recorded a running total of the number of responses while the other recorded only the number of correct responses.

Experimental Control

The output voltage of the audio-oscillator was maintained at a constant level for each stimulus condition. Its output was monitored by a vacuum tube voltmeter (Hewlett Packard, Model 400DR) both before and after each experimental set to insure a stable voltage output during a given test set.

Signal frequency from the audio-oscillator was selected and monitored before and after each experimental set with the aid of an interval timer and counter (Berkeley Universal Eput and Timer, Model 7350). This instrument was also used to monitor the selection of all experimental stimulus durations. Stimulus duration values were checked prior to and following each experimental set. A rise and decay time of 16 msec for all experimental stimuli was accurately maintained by means of oscillascopic display of the stimulus envelope.

All experimental apparatus described above, except the earphoned and subject response box, were located in the control room of the two-room suite. The subject was seated in the test room adjacent to the control room. An auditory monitoring system permitted the experimenter to monitor all stimuli passed through the subject's earphones.

Procedure

This experiment was designed to specify the difference limen (DL) for pure-tone stimulus duration as a function of short reference duration. DLs were determined monaurally under twenty-four combinations of frequency, sensation level (SL) and reference duration. The frequencies employed were 250, 1000, and 4000 cps. The SLs were 10 and 50 db. Reference durations were quite short at 40, 60, 80, and 100 msec.

Using a forced choice technique, subjects were instructed to indicate in each case whether the comparison stimulus, always presented second, was longer or shorter than the standard which was always presented first. Each pair of stimuli presented for differential judgment was separated by a fixed silent interval of 500 msec. The time between pairs depended upon the speed with which a subject registered his judgment, and so varied slightly among pairs. A pair of stimuli were presented approximately 2 seconds after the subject responded to the previous pair.

Each experimental set consisted of presentations of a specific reference, paired with either of two comparisons, one longer and the other shorter than the reference. Reference durations were selected for every frequency-intensity combination. Each reference served as the standard for an entire test set. Random selection determined the reference tone to be assigned to any set. The increment and/or decrement duration values (ΔT) employed were selected on the basis of the results of a pilot study. It was felt that the ΔT of the initial test set for each experimental condition should be sufficiently large to enable a naive subject to pass the task with ease. The ΔTs as utilized for each of the reference durations are shown in Appendix B.

The order of the comparison tones (whether longer or shorter than the reference) to be paired with the reference of each test set was chosen on a random schedule. The values so selected and paired with the reference were presented to the subject for judgment, beginning with the largest increment/decrement values (ΔT) and becoming successively smaller, until the DL for that reference duration was established. Thus, within each test set, the reference duration stimulus was paired with every comparison stimulus duration value (reference stimulus duration plus or minus ΔT) that was necessary to bracket the differential threshold at that reference duration. The psychophysical method employed was a variation of the method of limits. For each test set the number of correct responses necessary to pass the task at a 5 per cent level of confidence or fail at a 1 per cent level of confidence was dictated by a table of sequential analysis (79). The use of sequential analysis eliminated the numerous judgments and lengthy procedure that is inherent in the classical psychophysical methods. At the same time, precision in statistical inference was not sacrificed.

The frequency and sensation level of both the reference and comparison stimuli were identical in any test set. The number of test sets comprising the entire experiment equalled the total number of reference stimuli or all frequency-intensity-duration conditions. An alerting signal (a 50-db SPL burst of white noise presented to the non-test ear) of 500-msec duration preceded the onset of each stimulus pair by 800 msec.

Having allowed sufficient time for the apparatus to warm up, the equipment was adjusted and calibrated to provide the proper reference and comparison signals. The subject was seated comfortably and instructed carefully for threshold determination and the experimental task.

The following instructions were read to each subject prior to the initial test session:

> You are participating in a research project that is basic to the understanding of human auditory behavior and of considerable significance to the discipline of audiology. Upon completion of the entire experiment you will be informed of the results. This will be a gruelling and lengthy procedure. Your sustained attention and alertness is 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 one and a half to 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 good 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.

You are going to hear a tone in your (test ear) ear. 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.

Your second task is to listen to sets of three sounds. The first sound will be a burst of noise in your (non-test ear) ear. This burst of noise is a warning signal indicating that you are to prepare for the two sounds to follow. These sounds will be 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 fixed 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 tone, push the response switch up to the position marked "longer". If, on the other hand, the second tone is shorter than the first tone, pull the response switch down to the position marked "shorter". Whenever you are correct the blue lamp will light and 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 will be 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 sets will be presented. Take as much time as you need before making your response. Be sure not to change your response once you have made it. A given pair of tones cannot be repeated; therefore, a response must be made for each pair presented.
>
> Prior to the beginning of each experimental set you will be presented with four pairs of stimuli. The second tone of the first pair will always be longer. Push the lever up to the position marked "longer". The second tone of the second pair will always be shorter. Pull the lever to the position marked "shorter". The second tone of the third and fourth pair will, likewise, be respectively longer and shorter. Respond accordingly. These four pairs of stimuli are provided before each experimental set so that you will know exactly what you are to listen for. There will then be a short pause, whereupon the experimental run will begin.
>
> 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 do not touch or move them until you are asked to remove them.

Following the above-mentioned procedure the earphones were positioned and were not allowed to be moved throughout the test set. The response box was then placed in the subject's lap. Threshold in the test ear was obtained for the reference stimulus and each of the two comparison stimuli constituting that test set. Threshold was determined in 2-db steps using an ascending technique and was established each time any stimulus parameter was varied. Threshold was defined as the minimal stimulus intensity at which two responses to any three consecutive stimulus presentations were evoked.

Having established threshold for the reference stimulus and each of the two comparison stimuli, the attenuators were then set to the sensation level dictated by that particular experimental condition. Four pairs of stimuli (reference-long comparison, reference-short comparison, reference-long comparison, reference-short comparison) were then presented so that the subject would be familiar with the signals. The subject always knew the appropriate response to each of these four stimulus pairs.

According to a random schedule, the experimenter's switch was then set to select either a longer or shorter comparison stimulus to be paired with the reference. By means of a push-button switch, the experimenter activated the cam timer which initiated the timing sequence. The warning signal was delivered to the non-test ear. Following an 800-msec silent interval, the reference and the comparison stimuli, separated by a 500-msec silent interval, were presented to the test ear. The subject then judged whether the comparison tone was longer or shorter than the reference and actuated the response box accordingly. Immediate knowledge of results was provided by the system of lights on the subject response box. At the same time, the subject's response was registered in the control room by means of the system of lights and the counters. The cam timer was then reactivated and a second trial consisting of a warning signal and a pair of stimuli were presented for differential judgment. This procedure was repeated as often as necessary in order for the subject to pass or fail the task according to the table of sequential analysis.

On several occasions a subject passed a test in which the ΔT was as small as could be reliably measured. The instrumentation did not allow the measurement of stimulus duration values smaller than 1 msec. In each case, when the subject passed a test in which the ΔT was 1 msec, he was required to respond to a no-difference test. Here, the reference stimulus and both the "long" and "short" comparison stimuli were of identical stimulus duration. This was done on the premise that if the stimuli were presenting the subject with artifacts that were providing him a clue he should then pass the task. In such a case the subject would be suspected of making his judgments on a stimulus difference other than duration. If the subject failed the task, however, as was expected, there was every reason to believe that his judgments were being made strictly on the basis of differences in stimulus duration. This procedure served as an indispensable check on the reliability of stimulus control.

Another reference stimulus was then selected at random. While the equipment was being adjusted for the ensuing experimental condition the subject was allowed a short rest period. The afore-described procedure was followed for each test set with each subject.

The length of time required of each subject in order to complete the study was extensive. Each experimental condition consumed an average of forty minutes. An effort was made to gather the data for three experimental conditions at each subject appointment. A minimum of eight appointments was required of each subject to complete his participation in the study. Insofar as possible, test sessions were scheduled at a time when the subject could be expected to perform optimally.

In order to mitigate a differential practice effect across subjects (13, 44) and to bring all subjects to the same high level of discriminatory performances, each subject was practiced in the experimental task. In the format of the aforementioned experimental design and under experimental conditions, data from each subject were collected for reference stimuli at two frequencies (250 and 4000 cps), two intensities (10 and 50 db SL), and two durations (40 and 100 msec). Inasmuch as this procedure constituted a practice session, the data are not reported. The experiment itself was then executed and the data recorded.

Several features of this study were specifically designed to minimize experimental error, sampling error, and intersubject variability. These are: (1) appropriate calibration checks at regular intervals on all experimental stimulus parameters, (2) the silent time intervals that separated paired stimuli, (3) the use of young, alert, normal-hearing subjects who were highly practiced and sophisticated, (4) frequent rest periods to minimize fatigue, (5) the testing method which included sequential analysis and immediate knowledge of results.

The procedure employed was expected to yield a measure that is an estimate of a subject's best performance. It was anticipated that the results would reflect a significantly better human discriminatory capacity for auditory stimulus duration than had as yet been reported in the literature.

The raw data were submitted for statistical analysis. A 2 x 3 x 4 randomized complete block design was utilized in a statistical analysis of variance. There were ten blocks with a factorial design (2 x 3 x 4) in each block.

The statistical design was selected in collaboration with the Biostatistical Unit of the University of Oklahoma School of Medicine.

Summary

This study was designed to measure the difference limen for stimulus duration as a function of reference duration at several frequencies and intensities. Ten normal-hearing subjects were tested. DLs for short duration pure-tone stimuli were determined at the three stimulus frequencies of 250, 1000, and 4000 cps and at the two reference intensities of 10 and 50-db SL. The reference stimulus durations selected were 40, 60, 80, and 100 msec. Thus, DLs were obtained from each of the ten subjects for twenty-four different reference stimulus conditions.

A modified psychophysical method of limits together with sequential analysis, highly practiced subjects, and immediate knowledge of results were employed in gathering the data. Because of its motivational and training value the design was expected to yield measures that reflect a significantly more acute human capacity to discriminate changes in stimulus duration than has been reported previously.

This study was intended to fill a specific need that even a cursory acquaintance with the literature reveals to the serious student.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

Ten normal-hearing subjects were studied in this investigation of differential sensitivity for short duration pure-tone auditory stimuli. Difference limens were established at twenty-four combinations of reference duration (40, 60, 80, and 100 msec), frequency (250, 1000, and 4000 cps), and sensation level (10 and 50 db).

Paired pure-tone stimuli were presented to each subject monaurally. A modified psychophysical method of limits was employed using a two-alternative, forced-choice technique. The subject's task was to judge whether the comparison stimulus was longer or shorter than the reference stimulus which always preceded it. The duration (ΔT) by which the comparison stimulus differed from the reference stimulus was identical whether the comparison stimulus was longer or shorter than the reference stimulus. The magnitude of the difference in duration between the paired stimuli (ΔT) was reduced until the subject could no longer make a correct judgment. The smallest temporal difference between reference and comparison stimuli (ΔT) which the subject was able to identify was taken as the difference limen for stimulus duration under each experimental condition.

The results of these measurements are reported in tabular form in Table 7 and will be discussed in the subsequent sections in terms of their magnitude as well as functions of the parameters of sensation level, stimulus frequency and reference duration.

Magnitude of the Duration DL

The results of this investigation clearly demonstrated that the size of the difference limen for auditory stimulus duration is significantly smaller than has yet been reported. In this investigation the mean relative DLs for all subjects under all experimental conditions ranged in size from .026 to .085 (Figure 2). The relative DLs, obtained as raw data (Appendix A) ranged in size from .010 to .125. Absolute DLs as small as 1 msec were obtained from some subjects under certain of the experimental conditions.

It is possible to make some comparisons between Henry's (43) data and that obtained in this experiment, although Henry used a 500-cps stimulus as well as different reference duration values. Table 8 shows the mean Weber ratios for Henry's seven subjects in comparison with the ten subjects studied in this experiment. The smallest Weber ratio found by Henry (.196 at 110 msec reference duration) is approximately four-fold the size of even the largest Weber ratio (.057 at 40-msec reference duration) obtained in this

TABLE 7

MEAN WEBER RATIOS ($\Delta T/T$) AND STANDARD DEVIATIONS FOR PURE-TONE AUDITORY STIMULUS DURATION FOR TEN NORMAL-HEARING SUBJECTS AT THREE STIMULUS FREQUENCIES, TWO SENSATION LEVELS, AND FOUR REFERENCE DURATIONS

Stimulus Frequency (cps)	Sensation Level (db)	Reference Duration (msec)							
		40		60		80		100	
		M	SD	M	SD	M	SD	M	SD
250	10	.0675	.0237	.0566	.0333	.0700	.0400	.0480	.0225
	50	.0575	.0169	.0225	.0158	.0373	.0184	.0330	.0125
1000	10	.0700	.0197	.0666	.0208	.0525	.0142	.0470	.0183
	50	.0575	.0265	.0300	.0172	.0263	.0125	.0260	.0184
4000	10	.0850	.0293	.0733	.0238	.0613	.0149	.0490	.0137
	50	.0700	.0158	.0366	.0189	.0363	.0171	.0310	.0137

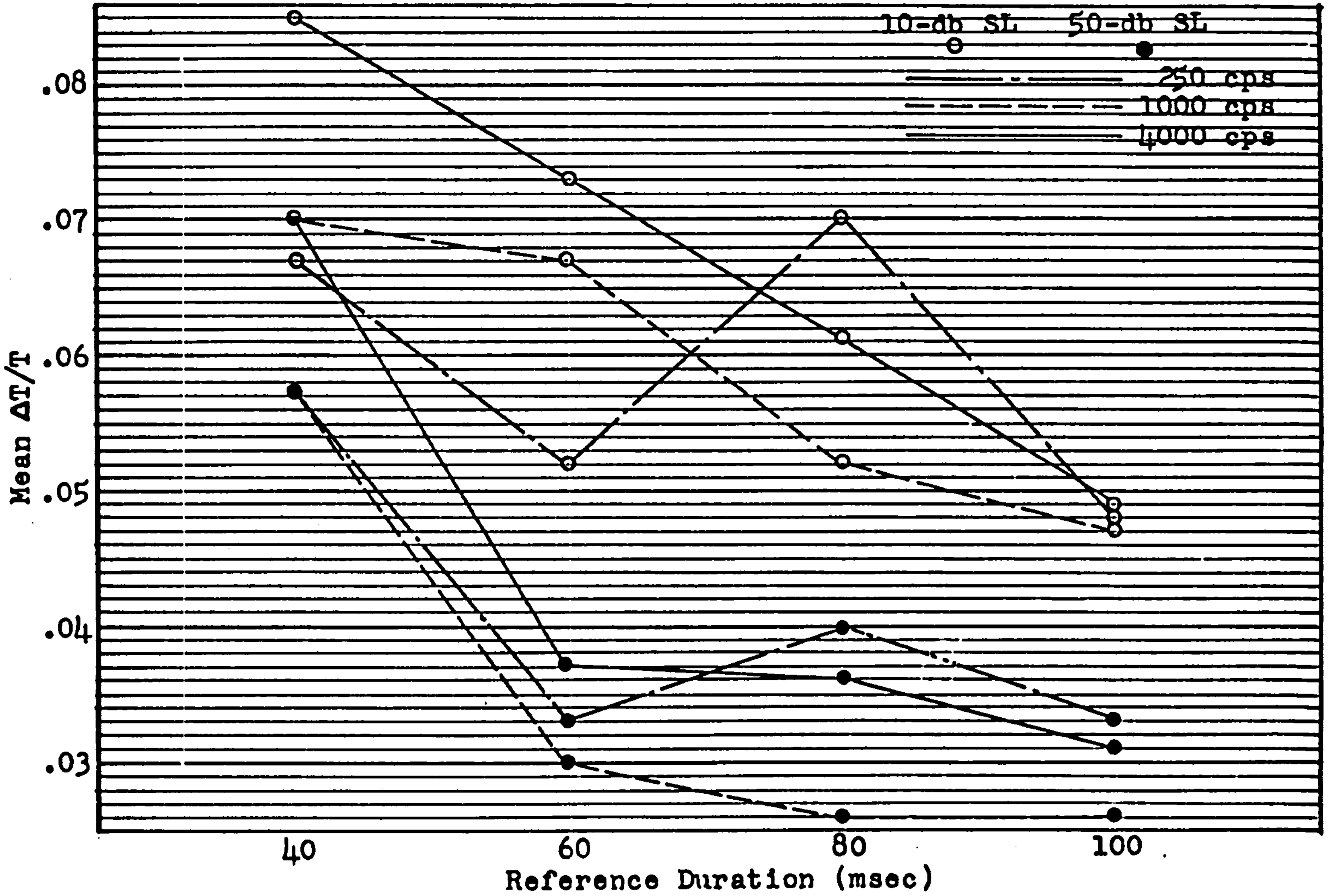

Fig. 2 - Mean relative DLs at three stimulus frequencies and two sensation Levels plotted as a function of reference duration.

TABLE 8

MEAN WEBER RATIOS ($\Delta T/T$) AT TWO FREQUENCIES FOR TEN SUBJECTS OF THIS EXPERIMENT COMPARED WITH THE DATA OF ONE FREQUENCY AS OBTAINED FROM HENRY'S SEVEN SUBJECTS (DATA ARE SHOWN AS A FUNCTION OF REFERENCE DURATION)

	Sensation Level	Stimulus Frequency	Reference Duration (msec)							
			32	40	47	60	77	80	100	110
Present Experiment	50 db	250		.057		.033		.040	.033	
Henry	50 db	500	.281		.203		.208			.196
Present Experiment	50 db	1000		.057		.029		.026	.026	

experiment. A direct comparison with Stott's (74) experiment cannot be made inasmuch as his shortest reference duration was 200 msec. The longest reference duration studied in this experiment was 100 msec. Neither does Stott specify the intensity of his 1000-cps stimulus. Even so, the interpolated Weber ratio of .145 for the 200-msec reference duration in Stott's experiment is still significantly larger than the largest DL (.125 for the 250-cps, 80-msec, 50-db SL experimental condition) measured on any of the ten subjects serving in this study.

Several factors would account for the rather large discrepancy in the size of the Weber ratio as reporded by Stott (74) or Henry (43) versus the results revealed in the experiment reported here. First, it is well known that different psychophysical methods yield dissimilar results (8, 17, 66). Both Stott (74) and Henry (43) used variations of the psychophysical method of constants whereas this study employed a variation of the method of limits. Furthermore, the present experiment was designed with the expressed purpose of minimizing the Weber ratio for stimulus duration by means of rigorous subject training, immediate knowledge of results, and stimulus control. A two alternative forced-choice procedure was employed. The two factors of feedback and forced-choice, when combined in a psychophysical procedure, have been shown by Lukaszewski and Elliott (54) to result in lower thresholds than when obtained by a no-forced-choice feedback, forced-choice-no-feedback, or no-forced-choice-no-feedback procedure.

Second, Stott (74) and Henry (43) were limited by the instrumentation of their day. A perusal of their instrumentation reveals the fact that they did not have at their disposal equipment which permitted the discrete control and precise measurement of test stimuli. On the other hand, the electronic equipment utilized in this experiment left little to be desired by current standards. The stimulus ensemble was meticulously calibrated to assure reliable measurement. An error no greater than plus or minus 0.5 msec was allowed in the measurement of stimulus duration. The parameters of intensity and frequency were equally well controlled.

The evidence from this experiment fails to support Weber's law. Inconsistency has characterized the results of efforts to determine whether Weber's law holds in the estimation of time (32). Zwirner (84) stated that DLs for auditory stimulus duration confirms Weber's law. Stott (74) and Henry (43), on the contrary, report data which refutes Weber's law. Similarly, the results of this experiment deny a constant Weber fraction. The magnitude of the Weber ratio across reference durations is compared in Figure 2. The trend for a smaller ratio at longer durations is confirmed. This effect is accentuated in the 10-db SL curve. Such a low intensity effect was also reported by Henry (43). The one notable exception can be observed at the reference duration of 80 msec.

Only the curve of the 50-db, 1000-cps stimulus plotted in Figure 2 shows any constancy in the Weber ratio. The general trend of all the curves, plotting the DL as a function of reference duration, suggests that relative DL size might be expected to stabilize at some reference duration beyond 100 msec. Henry's (43) data also suggest this. His results, reported in Table 3, show negligible variance in DL size between the two reference durations of 277 and 480 msec (.172 versus .173). More recently, Milburn (57) has shown that duration DL size does, in fact, attain a fairly constant value at a reference duration of approximately 500 msec and that it then remains relatively constant over the range of durations studied (300-1000 msec).

The relative DL for duration, like DLs for frequency and intensity, enlarges at low stimulus magnitudes but maintains a nearly constant value for the middle range of stimulus durations. The relative DLs for frequency ($\Delta f/f$), according to Shower and Biddulph (68), are approximately constant at reference frequencies above 500 cps. Reisz (65) showed that the relative difference limen for intensity ($\Delta I/I$) at a given frequency approaches a constant value for intensities above 50-db SL, but increased rapidly as stimulus intensity is reduced toward threshold.

Discrimination of changes in frequency and intensity has been shown to be better under binaural stimulation than under monaural (12, 68, 77). Shower and Biddulph (68) demonstrated that monaural relative DLs for frequency are larger than binaural DLs. The work of Churcher, King, and Davies (12) and of Upton and Holway (77) supports the notion that binaural discrimination of intensity, also, is superior to monaural. A description of monaural DLs for stimulus duration resembles a description of DLs for stimulus frequency and intensity in that DL size increases at low stimulus magnitudes, but is relatively constant throughout the mid-range of stimulus magnitudes. Although the research is yet to be done, binaural stimulation might be expected to enhance the discrimination of stimulus duration as it does the discrimination of stimulus frequency and intensity.

Sensation Level Effect

Human discrimination of changes in auditory stimulus duration improves as the sensation level of the stimulus is increased from 10 to 50 db. DLs for stimulus duration were measured at the sensation levels of 10 db and 50 db. The mean Weber fraction ($\Delta T/T$) of each stimulus condition is plotted in Figure 2 as a function of reference duration. Inspection of these figures reveals that the sensation level at which the stimulus is presented has a decided effect upon the size of the difference limen. An analysis of variance applied to the data resulted in an F of 83.9 ($p < .01$), thus providing statistical corroboration of a differential effect on the size of the duration DL across sensation levels.

Figure 2 shows that subjects discriminated smaller changes in auditory stimulus duration at 50-db SL than at 10-db SL. The one exception is the presence of an interaction at the shortest reference duration (40 msec) between a 50-db SL signal at 4000 cps and a 10-db SL signal at 1000 cps. Inspection of Figure 2 also reveals somewhat greater variability across frequencies in the size of the duration DL at the 10-db sensation level than at the 50-db sensation level. The 10-db SL DLs at the longest reference duration (100 msec), however, are less variable across frequencies than their 50-db SL counterparts.

Henry (43) studied the Weber ratio as a function of stimulus intensity using sensation levels of 20, 40, 60, and 80 db. His stimulus was a 500-cps tone. He studied the effect of intensity at three reference durations. The results are shown in Table 5.

Data for all three reference durations suggest that stimulus intensity had little effect on DL size except at the lowest sensation level at the two reference durations of 47 and 77 msec where the Weber ratio is somewhat larger. Henry (43) reported that the data at 277 msec showed no intensity effect at all.

Although direct comparisons are not possible between Henry's data and that of this study, some interesting aspects do come to light. The data of the present experiment, shown as a function of SL, are compared with Henry's data in Table 9.

TABLE 9

MEAN WEBER RATIOS AS A FUNCTION OF STIMULUS INTENSITY COMPARING HENRY'S DATA WITH DATA OBTAINED FROM THE PRESENT EXPERIMENT

	Stimulus Frequency	Sensation Level	Reference Duration (msec)						
			40	47	60	77	80	100	277
Henry	500	20 db		.204		.198			.149
		40 db		.153		.184			.137
		60 db		.166		.179			.147
		80 db		.157		.184			.139
Present Experiment	250	10 db	.067		.057		.070	.048	
		50 db	.057		.033		.040	.033	
	1000	10 db	.070		.067		.052	.047	
		50 db	.057		.030		.026	.026	
	4000	10 db	.085		.073		.061	.049	
		50 db	.070		.037		.036	.031	

Whereas Henry (43) reported that variation of stimulus intensity appears to have little effect on DL size, the data of this experiment show that, in every case, regardless of reference duration or stimulus frequency, a change of stimulus intensity from 10 to 50-db SL does indeed have an effect on the Weber ratio. It may very well be that intensity changes in excess of 50-db SL no longer affect DL size as Henry's data suggest. All of Henry's data at sensation levels of 40 db and above for all three reference durations show very little variation across sensation levels. Further investigation of DL size as a function of sensation level is indicated.

Frequency Effect

The stimulus frequencies of 250, 1000, and 4000 cps were employed in this investigation. The mean Weber ratio corresponding to each reference duration at both sensation levels (10 and 50 db) is plotted in Figure 3 as a function of stimulus frequency. These mean relative DLs will be discussed independently in the succeeding paragraphs.

40 msec. When a 10-db SL, 40-msec reference duration stimulus is presented, the relative DL increases as the frequency of the stimulus is changed from 250 to 4000 cps. The function rises gradually from 250 to 1000 cps whereupon it increases moderately to 4000 cps. A reference stimulus of 40-msec duration presented at a 50-db SL yields a constant relative DL when frequency is changed from 250 to 1000 cps,

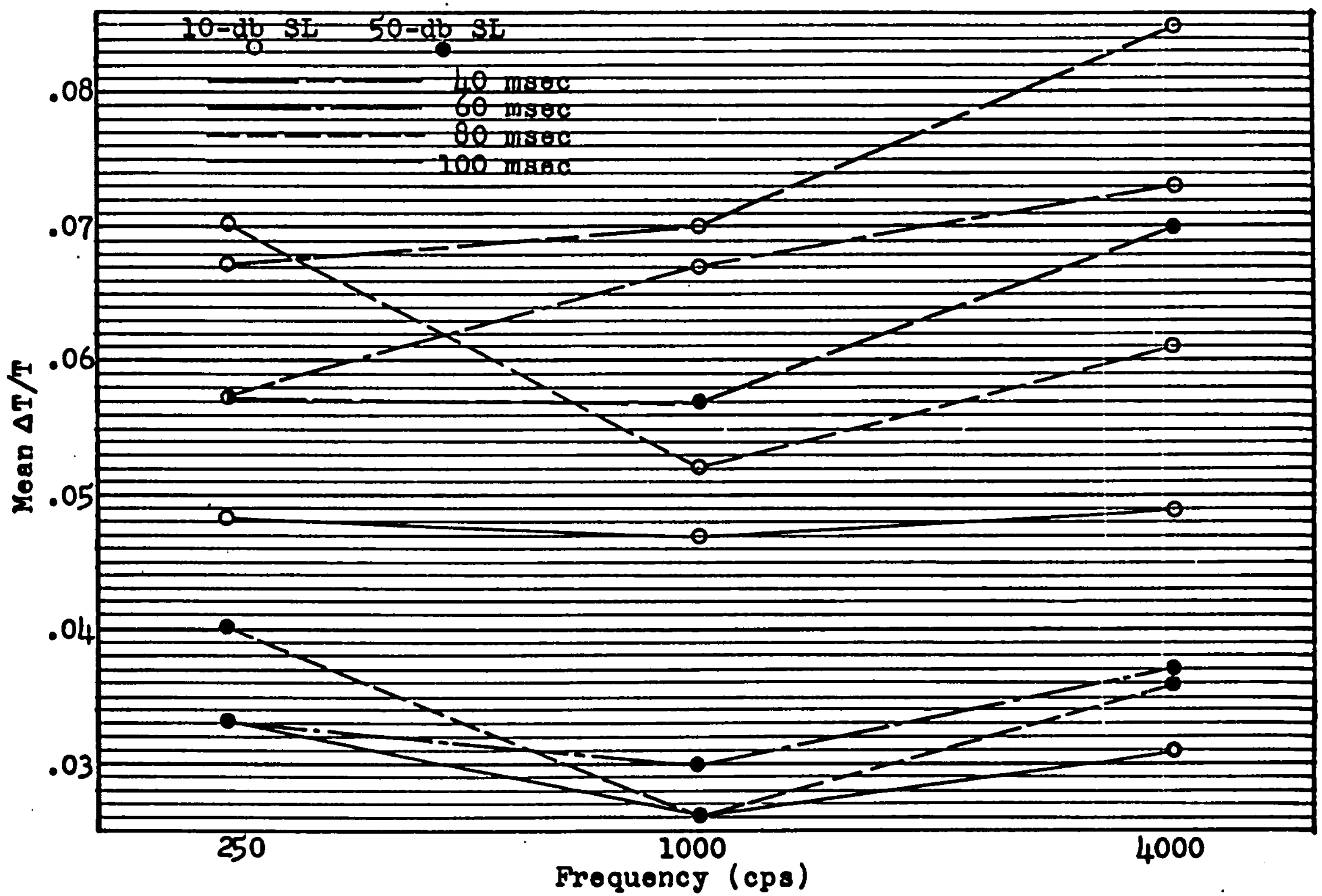

Fig. 3 - Mean relative DLs at four reference durations and two sensation levels plotted as a function of stimulus frequency.

but then produces a moderate increase from 1000 to 4000 cps.

The Weber ratios of the 40-msec reference durations as a function of frequency are plotted in Figure 4. The general configuration of the curves at both reference intensities (10 and 50-db SL) is quite similar. DL size as a function of frequency ranges from a minimum of .057 to a maximum of .085, disregarding stimulus intensity. DL size for the 50-db sensation level only ranges from a low of .067 to a high of .085. Identical Weber ratios (.057) were obtained for 250 and 1000 cps at the 50-db sensation level. The curve then rises to its sharpest function to attain a Weber ratio value of .070 at 4000 cps.

The smallest Weber ratio at the 10-db sensation level (.067) was obtained at the 250-cps stimulus. It is only slightly larger at 1000 cps (.070). From .070 at 1000 cps the Weber fraction increases to a maximum of .085 at 4000 cps. Like the 50-db SL curve, the sharpest function of the 10-db SL curve occurs between 1000 and 4000 cps. The greatest frequency effect for the 10-db SL, 40-msec reference duration is noted between 1000 and 4000 cps. There appears to be a slight frequency effect between 250 and 1000 cps where the relative DL at 10-db SL increases slightly.

60 msec. The smallest Weber ratio of the 10-db SL, 60-msec reference duration stimulus (.057) is recorded at

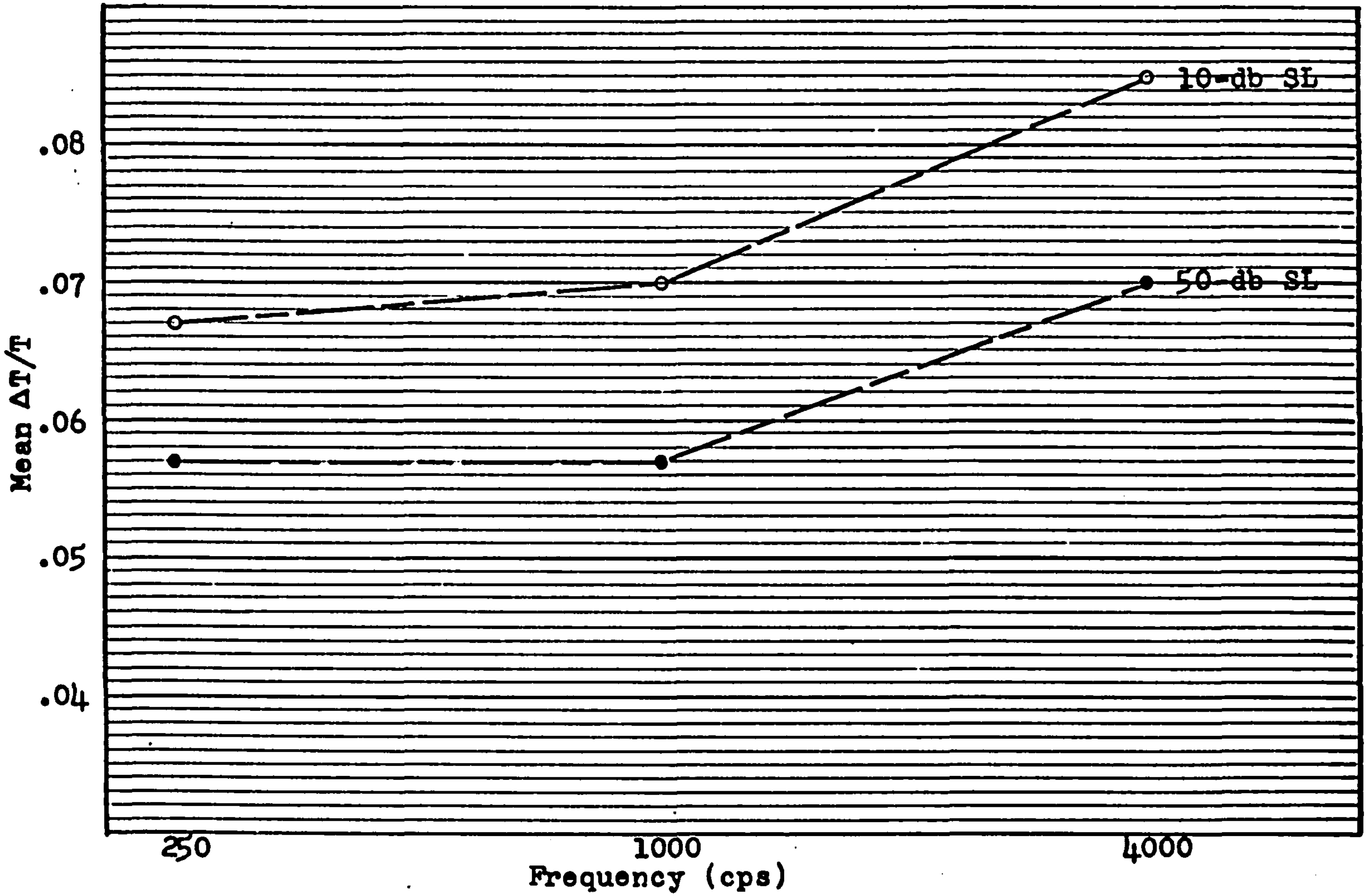

Fig. 4 - Mean relative DLs of a 40-msec reference duration stimulus plotted as a function of frequency at two sensation levels.

250 cps. Thereafter, it becomes larger when frequency is increased (.067 at 1000 cps and .073 at 4000 cps). On the other hand, the smallest Weber ratio for the 50-db SL, 60-msec reference duration stimulus (.030) occurs at 1000 cps. The relative DL then becomes larger when stimulus frequency is increased to 4000 cps (.037) and also as frequency is decreased to 250 cps (.033).

The Weber ratios of the 60-msec reference duration are plotted in Figure 5 as a function of stimulus frequency. DLs of the 50-db SL curve range from a minimum of .030 at 1000 cps to a maximum of .037 at 4000 cps. The Weber ratio of the 50-db SL, 60-msec reference duration stimulus decreases slightly in size (from .033 to .030) as stimulus frequency is increased from 250 to 1000 cps, becoming larger (.037) at 4000 cps.

The Weber fractions at the 10-db SL, 60-msec reference duration stimulus range in size from a minimum of .057 to a maximum of .073. A Weber ratio value of .057 was obtained at 250 cps. The DL value increases to .067 at 1000 cps and finally to .073 at 4000 cps. The relative DLs for this experimental condition become larger when stimulus frequency is increased from 250 to 4000 cps. The function appears to be only slightly steeper below 1000 cps than above.

80 msec. The relative DL of the 80-msec reference duration stimulus at both the 10-db and 50-db sensation levels becomes smaller when stimulus frequency is decreased

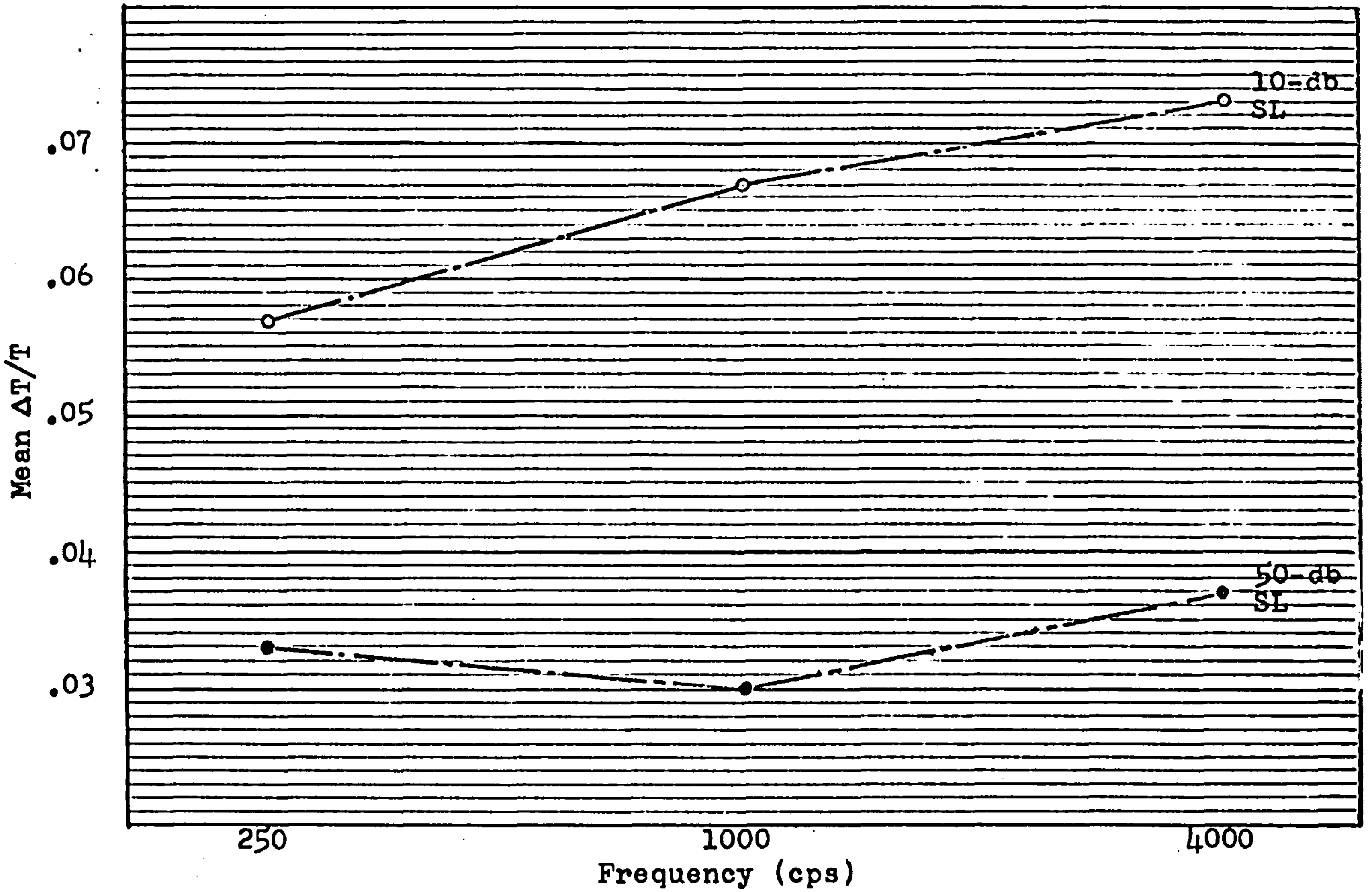

Fig. 5 - Mean relative DLs of a 60-msec reference duration stimulus plotted as a function of frequency at two sensation levels.

from 250 to 1000 cps, whereas it increases when frequency is increased from 1000 to 4000 cps.

The relative DLs of the 80-msec reference duration stimulus are plotted in Figure 6 as a function of stimulus frequency. Relative DL values of the 10-db SL curve range from a minimal .052 to a maximal .070, whereas the range for the 50-db SL curve is from .026 to .040.

The functions of the curves of the two sensation levels do not differ appreciably. In both instances the smallest DL is recorded at 1000 cps (.052 and .026 at the 10-db and 50-db SL curves respectively). In each case the DL becomes larger as stimulus frequency is increased from 1000 to 4000 cps (an increase from .052 to .061 in the 10-db SL curve and an increase from .026 to .036 in the 50-db SL curve). The function at both sensation levels is slightly steeper in the frequency range from 250 to 1000 cps than is the 50-db SL curve for the same frequency range. Just the reverse is true in the frequency range from 1000 to 4000 cps. Here, the 50-db SL curve is slightly steeper than the 10-db SL curve.

100 msec. The Weber ratios obtained using a 100-msec reference duration stimulus are plotted as a function of stimulus frequency in Figure 7. The functions of the two curves that represent the two sensation levels are quite similar except that the 10-db SL curve is somewhat flatter than the 50-db SL curve. Relative DL values of the 10-db SL

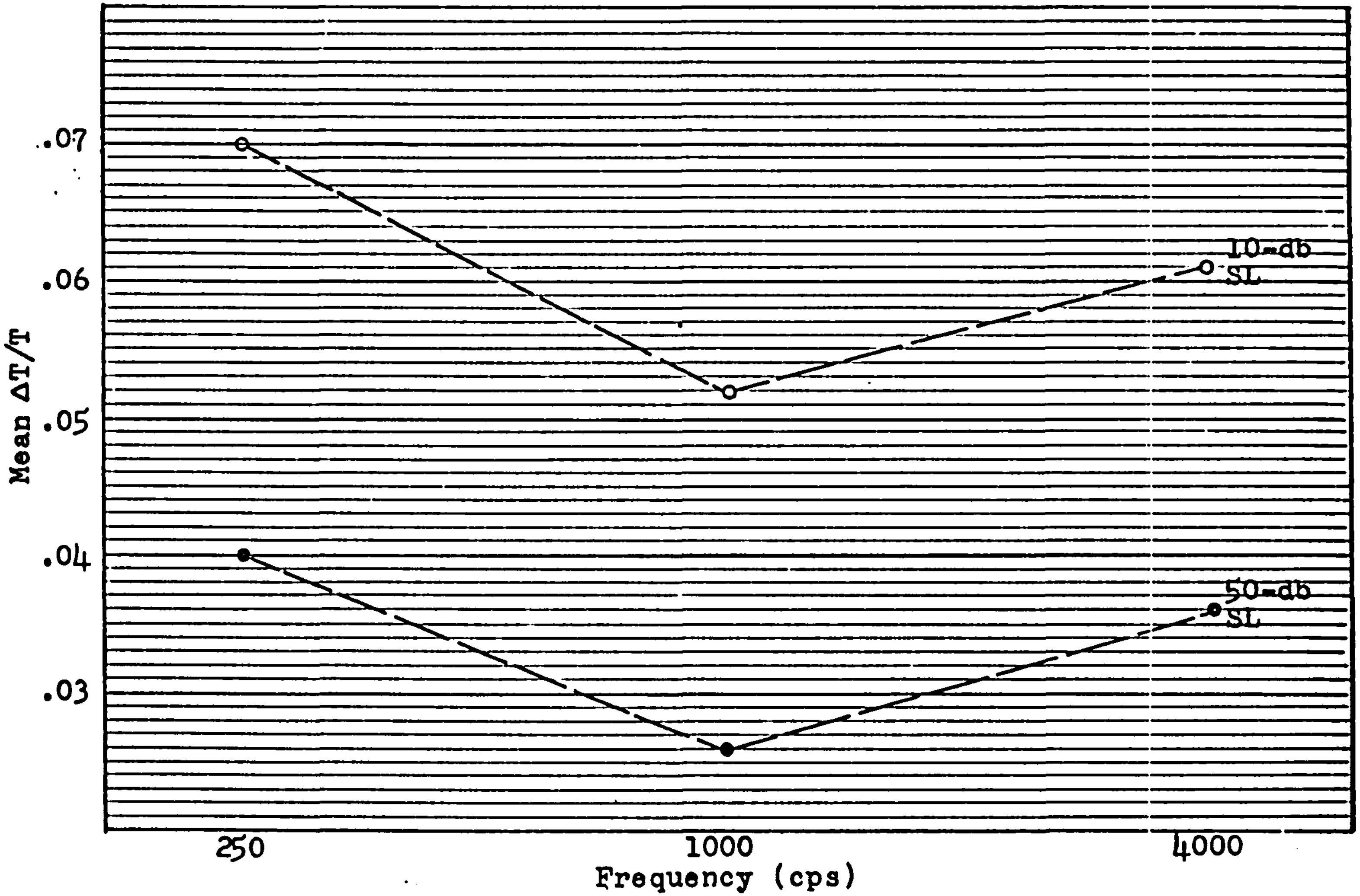

Fig. 6 - Mean relative DLs of an 80-msec reference duration stimulus plotted as a function of frequency at two sensation levels.

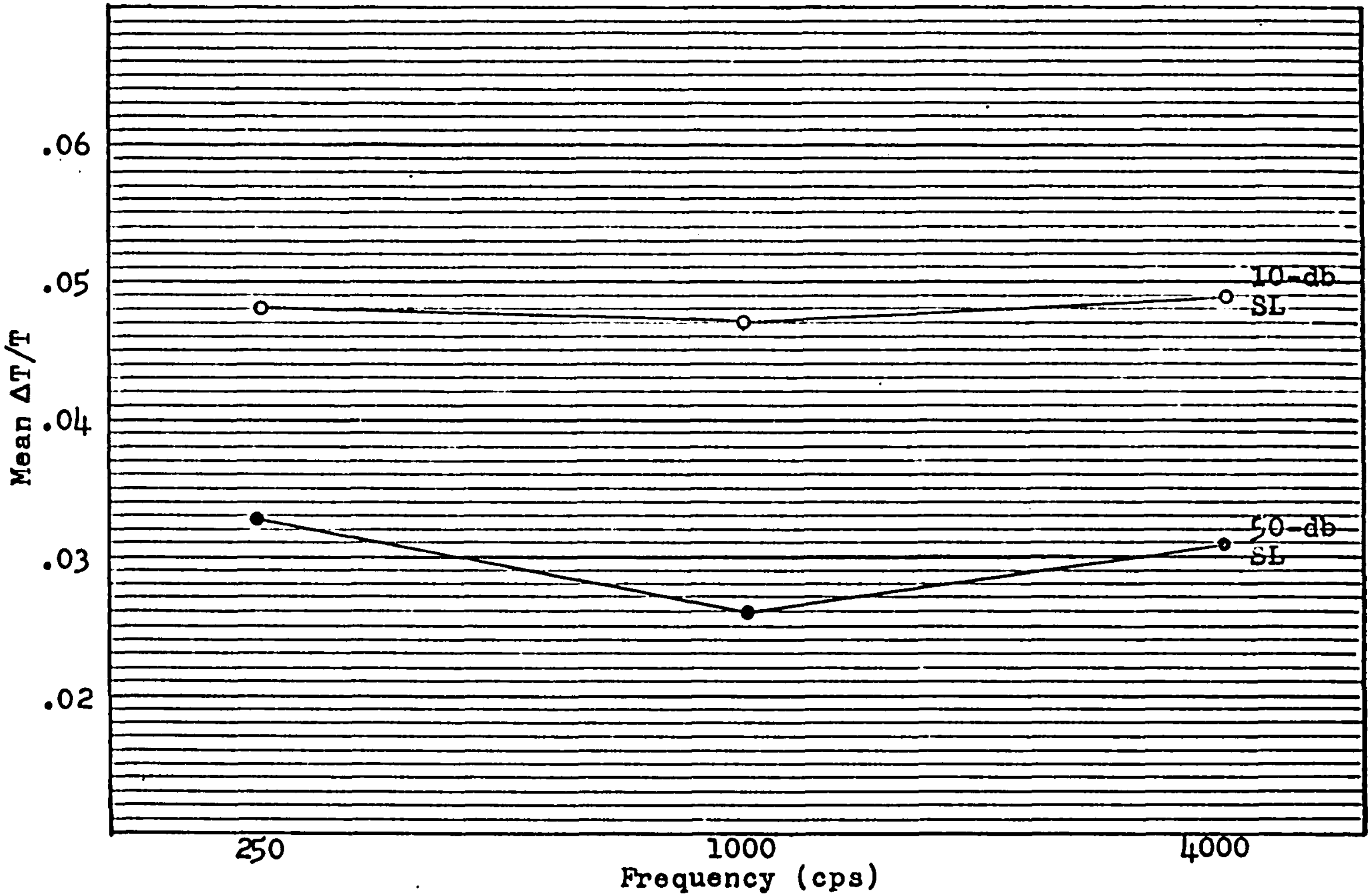

Fig. 7 - Mean relative DLs of a 100-msec reference duration stimulus plotted as a function of frequency at two sensation levels.

curve range from .047 to .049. This range indicates a surprisingly small amount of variation across frequencies from 250 to 4000 cps. The DL values of the 50-db SL curve range from .026 to .033, again indicating relatively small variation in DL size across frequencies, although the variation noted in the 10-db SL curve is less (.007 in the 50-db SL curve versus .002 in the 10-db SL curve). Both sensation level curves yield the smallest relative DLs at 1000 cps; however, the 50-db SL curve shows a greater tendency toward a smaller DL at 1000 cps relative to the other frequencies than does the 10-db SL curve.

Summary. All results in the form of mean relative difference limens are plotted as a function of stimulus frequency in Figure 3. Inspection of this figure reveals several trends. First, the size of the relative DL for duration as a function of stimulus frequency depends upon the reference duration from which the measurement is made. The smallest relative DLs as a function of stimulus frequency occur at 1000 cps. There are these exceptions: the smallest DLs at the 10-db SL, 40-msec and 60-msec reference durations occur at 250 cps; and the DLs at the 50-db SL, 40-msec reference duration are identical at both 250 and 1000 cps.

The relative DLs increase in size between 1000 and 4000 cps at both sensation levels. The lower frequency range reveals quite a different function. With the notable exception of the results for an 80-msec, 250-cps reference stimulus, a general pattern is apparent. At low reference durations (40 and 60 msec) and the low sensation level, the magnitude of the mean relative DL increases as stimulus frequency is changed from 250 to 1000 cps. There is a tendency at longer reference durations (80 and 100 msec) for the relative DL to diminish in size when stimulus frequency is increased from 250 to 1000 cps. Increasing the intensity of the stimulus has the effect of bringing about a reduction in DL size at shorter reference durations as stimulus frequency is changed from 250 to 1000 cps. As pointed out, DL size increases for both the 40 and 60-msec, 10-db SL, reference durations when frequency is changed from 250 to 1000 cps. At the 50-db sensation level, however, there is no tendency for DL size to become larger when frequency is changed from 250 to 1000 cps. Even at the shortest reference duration of 40 msec, DLs at 250 and 1000 cps are identical (.057).

The Weber ratio at 10-db SL is greatest at 4000 cps. The 80-msec reference duration is the one exception. Here, the largest DL occurs at a 250-cps stimulus. Increasing stimulus intensity has the effect of more nearly equalizing DL size, although this is not true for the 40-msec reference duration. With the exception of the 40-msec reference duration there is little difference in DL size between 250 and 4000 cps.

Henry (43) held the length of a 50-db SL stimulus constant at 77 msec and studied the effect of signal frequency on duration DL size. The data obtained from three subjects, at octave frequencies from 125 to 2000 cps, showed that DLs were largest at low frequencies. Henry's data are shown in Table 5. He did not investigate beyond 2000 cps and the present experiment did not employ a stimulus frequency below 250 cps. This fact may explain the contradiction between the results of these two studies.

The data of this experiment were submitted for a statistical analysis of variance of the effect of stimulus frequency. A significant F-ratio of 3.85 was obtained surpassing the .05 level of confidence. The conclusion is reached that the size of the Weber ratio depends on stimulus frequency.

Reference Duration Effect

Weber ratios were measured at four reference durations (40, 60, 80, and 100 msec). The mean Weber ratios of each stimulus frequency at each of the two sensation levels are plotted as a function of reference duration in Figure 2. These curves will be discussed separately.

250 cps. The Weber ratios for the 250-cps stimulus are plotted as a function of reference duration in Figure 8. Both the 10-db SL and 50-db SL curves display the same general configuration. The 10-db SL curve drops moderately between the 40 and 60-msec reference durations, rising

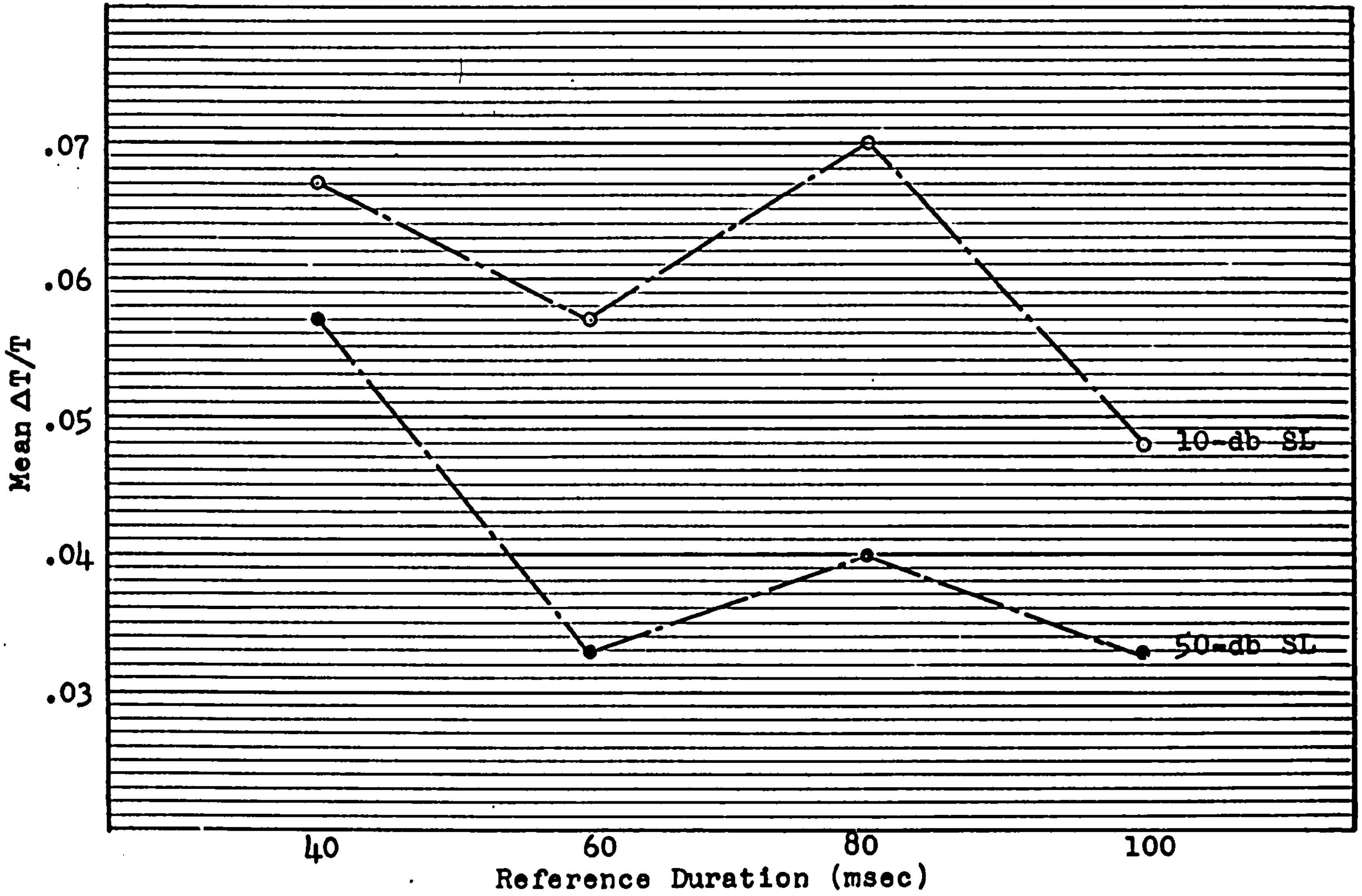

Fig. 8 - Mean relative DLs of a 250-cps stimulus plotted at two sensation levels as a function of reference duration.

rather sharply at 80 msec and then dropping precipitously at 100 msec. By contrast, the 50-db SL curve drops quite sharply from the 40 to the 60-msec reference duration, ascends gradually from 60 to 80 msec, and then diminishes just as gradually at 100 msec.

Of particular note in Figure 8 is the marked peak observed in both curves at 80 msec. The effect is somewhat more marked at the 10-db sensation level than at 50-db SL. This phenomenon, occurring at the 80-msec, 250-cps reference stimulus, also can be observed in Figures 2 and 3. The factors underlying this effect are not known and remain unexplained. The experimental control exercised in this study is felt to have minimized any artifact in instrumentation as a probably contributing factor. The Weber ratio obtained at the 80-msec, 250-cps stimulus, therefore, is thought to be an indicant of an auditory phenomenon which must await further study. Two reasons are offered in support of this contention. In addition to the rigorous control which was exercised in this experiment in order to preclude any artifact of instrumentation, concensual findings are available in the results of a previous study reported by Henry (43). Portions of Henry's finding are shown in Table 9. Although his experimental conditions are not identical with those of the present study, some are sufficiently close to warrant comparison between the findings obtained from the two studies.

The peaking, in the form of unexpectedly large DLs, observed in this study at the 80-msec, 250-cps condition also can be seen in Henry's data (Table 9). He used a 500-cps stimulus. His reference durations of 47 and 77 msec compare favorably with 40 and 80 msec as used in this study. Inspection of Table 9 shows that a larger DL was obtained at 77 msec than at either 47 or 277 msec. This phenomenon is reflected at all of Henry's sensation levels except 20 db which was the lowest SL he studied. By contrast, the present experiment demonstrated that the unexplained effect observed for an 80-msec, 250-cps stimulus is more pronounced at the lower sensation level of 10 db, a level even 10 db lower than the lowest SL used by Henry (43).

The factors producing the peaking effect at low stimulus frequency at an 80-msec reference duration may or may not be identical in both studies. The fact that the effect is present in Henry's data together with the knowledge that the experimental control exercised in the present study minimized procedural and instrumental artifacts lends credence to the actual presence of the observed effect. Further research is indicated to investigate the size of the difference limen for duration at low stimulus frequencies and at reference durations adjacent to 80 msec.

1000 cps. The Weber ratios of the 1000-cps stimulus are plotted as a function of reference duration in Figure 9. The 10-db SL curve shows a gradually sloping configuration

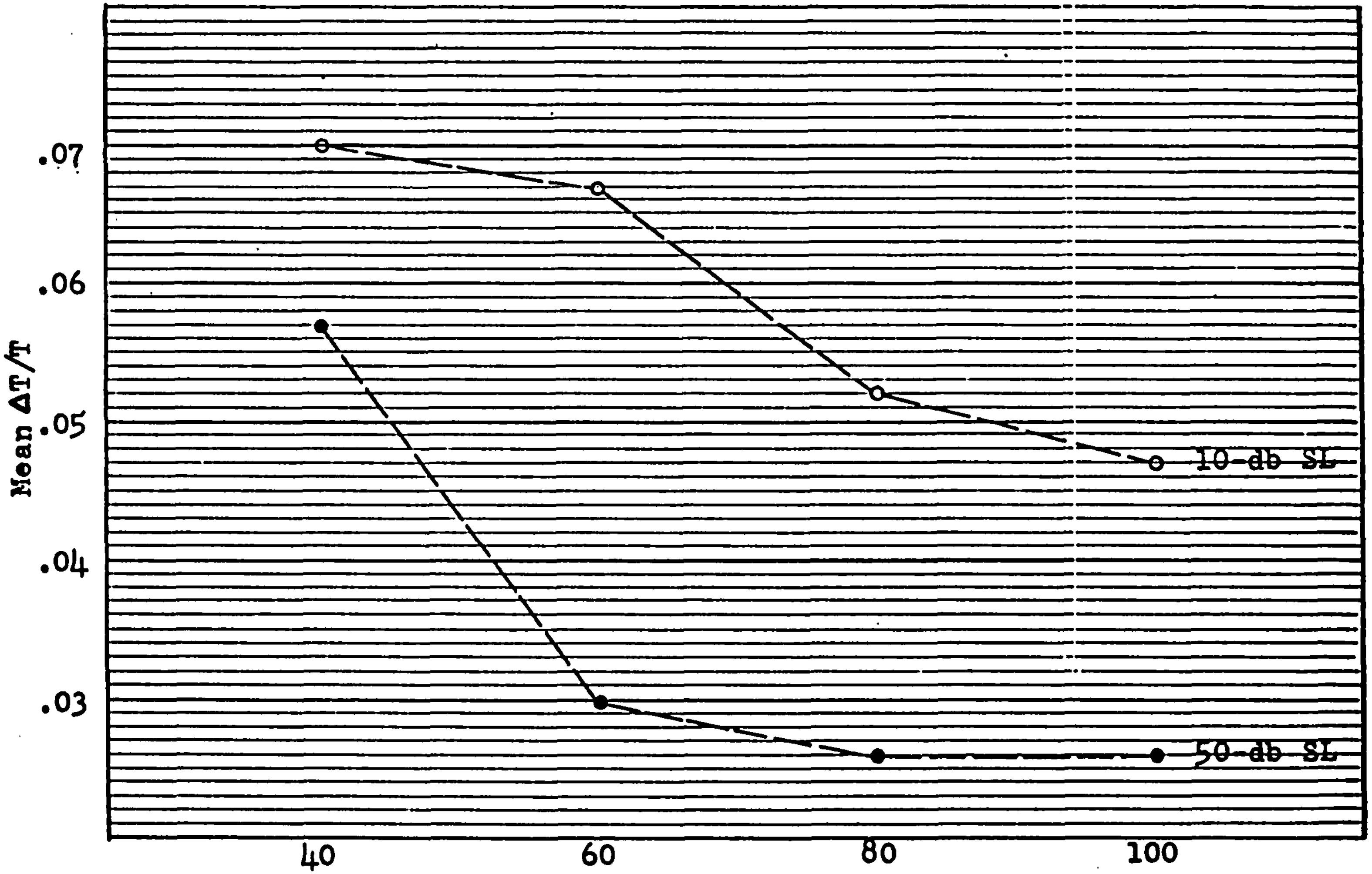

Fig. 9 - Mean relative DLs of a 1000-cps stimulus plotted at two sensation levels as a function of reference duration.

in the direction of diminishing relative DL size as reference duration increases from 40 to 100 msec. The most marked change in the slope of the curve takes place between 60 and 80 msec. The 50-db SL curve, on the other hand, drops sharply between 40 and 60 msec and begins to level off from 60 to 80 msec, from which point the curve is flat to 100 msec. In both sensation level curves the smallest relative DLs are noted at the longest reference durations and become larger as stimulus duration is decreased. The one exception is observed at the 100-msec, 50-db SL, condition where the Weber ratios are identical.

4000 cps. The Weber ratios of the 4000-cps stimulus are plotted as a function of reference duration in Figure 10. The 10-db SL curve is a descending straight line function in the direction of smaller Weber ratios with increased stimulus duration. The 50-db SL curve, on the contrary, gives evidence of an extremely sharp descending function between the 40 and 60-msec reference durations becoming relatively flat from 60 to 80 msec and then falling off slightly from 80 to 100 msec.

Summary. The mean Weber ratios are plotted as a function of reference duration in Figure 2 which shows the relationship between the relative DLs at the three stimulus frequencies of 250, 1000, and 4000 cps. Generally, relative DL size diminishes as stimulus duration is increased from 40 to 100 msec. The notable exception, as yet unexplained, can be

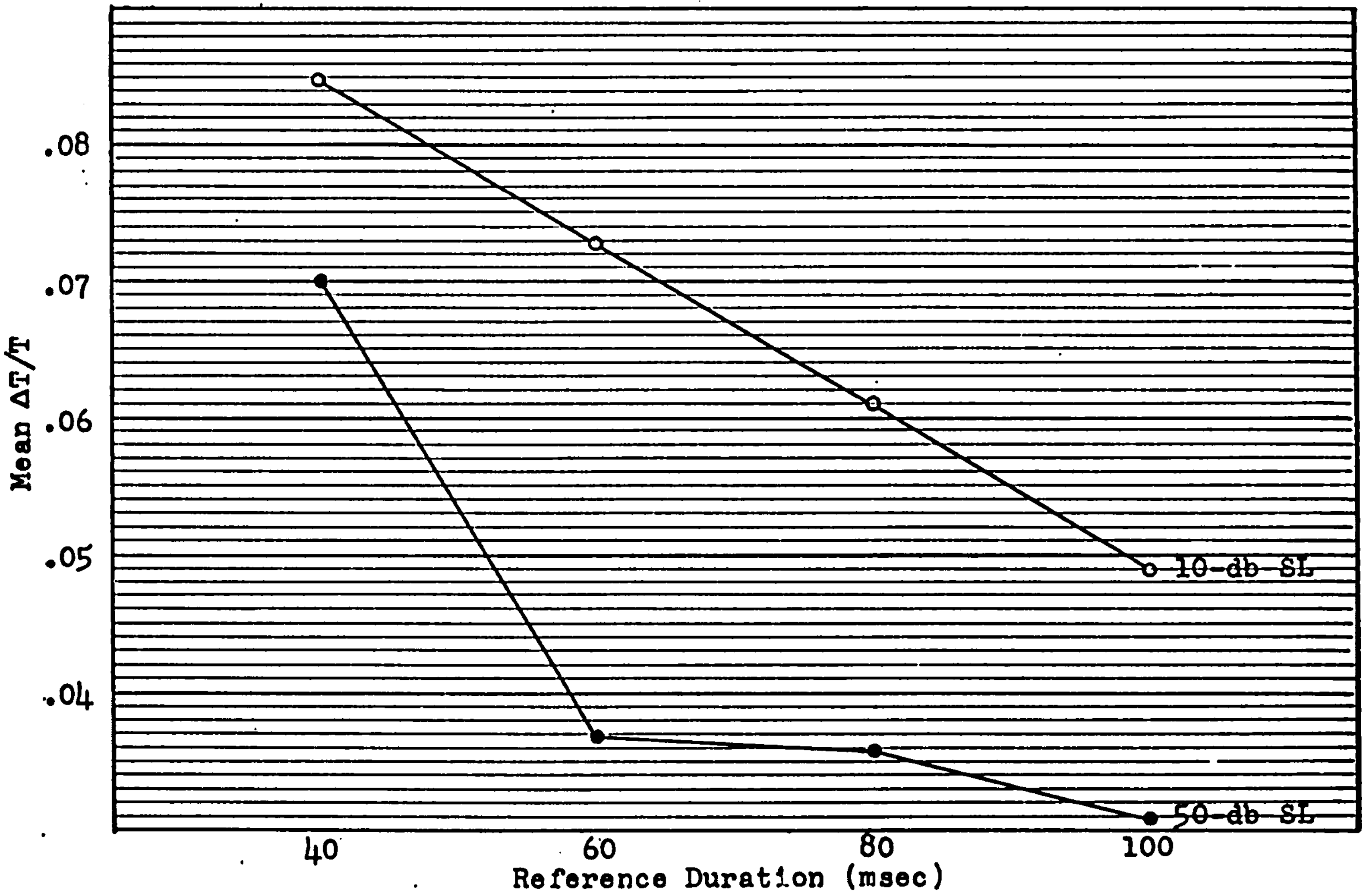

Fig. 10 - Mean relative DLs of a 4000-cps stimulus plotted at two sensation levels as a function of reference duration.

observed at the 80-msec, 250-cps condition. The magnitude of the relative DL for stimulus duration appears to depend upon the reference duration from which the measurement is made, and, for very short durations, is inversely related to it. This dependency is further corroborated in a statistical analysis of variance applied to the data across reference duration. The resulting F-ratio of 24.6 is significant at the .01 level of confidence.

The greatest effect on relative DL size is observed between the reference durations of 40 and 60 msec at the 50-db sensation level. Relative DL size across frequencies shows the least variability at the 100-msec reference duration, particularly at the 10-db sensation level. The reference durations of 60 and 100 msec at the 50-db sensation level show equal variability in relative DL size across frequencies.

Subject Variability

An attempt was made, in choosing subjects to serve in the experiment, to select only those individuals who were young, intelligent, and sophisticated in their orientation to the "listening" tasks that are characteristically required in the measurement of hearing. As might be expected, in spite of the precautions taken in the selection of subjects and their treatment, intersubject variability remained a significant factor.

The raw data are presented in Appendix A. The computed mean, standard deviation, and range of the absolute (ΔT) and relative DLs (ΔT/T) for each of the twenty-four experimental conditions is tabulated along with subject identification information. The 250-cps, 80-msec, 10-db SL experimental condition shows the greatest intersubject variability. The relative DL for that condition ranges from .0125 to .125, with a mean of .070 and a standard deviation of .037. The 1000-cps, 80-msec, 50-db SL experimental condition shows the least intersubject variability. The relative DL for that condition ranges from .0125 to .050, with a mean value of .026 and a standard deviation of .012.

Subject variability or the "subject effect" is a statistically significant variable of the study. Young normal sophisticated individuals differ in their ability to discriminate on the basis of auditory stimulus duration. The statistical analysis of variance yielded an F-ratio of 4.09 which surpassed the .01 level of confidence.

Summary

The size of the mean relative DLs for stimulus duration as measured in this study range from a minimal value of .026 to a maximal value of .085. The largest mean DL obtained in this experiment (.085 for the 4000-cps, 40-msec, 10-db SL experimental condition) is significantly smaller than the smallest mean DL reported by either Henry (43) (.137 for a 500-cps, 277-msec, 50-db SL experimental condition) or Stott (74) (.103 for a 1000-cps, 2000-msec experimental condition of unknown intensity).

The function of the relative DLs for stimulus duration plotted across reference duration is similar to the functions of the relative DLs for frequency and intensity. However, the relative DL values for stimulus duration, as established by the present experiment, are considerably smaller than Reisz's (65) relative DLs for intensity. Shower and Biddulph's (68) relative DL values are still much smaller than those for duration. These comparisons are shown in Table 10.

The data of Reisz (65) and of Shower and Biddulph (68) are supposedly not true DL measurements. Rather they are signal modulation thresholds by virtue of the method of sinusoidal variation that was employed. In an unpublished work, Ruhm (67) used the methodology described in the present experiment and obtained DLs for frequency similar in magnitude to those of Shower and Biddulph (68). It would seem that the method of sinusoidal variation, although criticized when applied to DL measurement, may not result in unrepresentative DL data.

There is considerable variability in the size of the relative DL among subjects. This is reflected both in the size of the standard deviations from the mean (see Appendix A) and in the statistical F-ratio of 4.09 which is significant at the .01 level of confidence. In spiteof this

TABLE 10

VALUES OF THE RELATIVE DIFFERENCE LIMEN FOR STIMULUS INTENSITY (ΔI/I), FREQUENCY (Δf/f), AND DURATION (ΔT/T)

Riesz (1000 cps)		Shower and Biddulph			Present Study (1000 cps)		
Reference Intensity	ΔI/I	Reference Frequency	Δf/f		Reference Duration	ΔT/T	
			10-db SL	50-db SL		10-db SL	50-db SL
10-db SL	.75	62 cps	.0678	.0351	40 msec	.070	.057
20-db SL	.40	125 cps	.0421	.0270	60 msec	.067	.030
30-db SL	.25	250 cps	.0212	.0099	80 msec	.052	.026
40-db SL	.23	500 cps	.0110	.0042	100 msec	.047	.026
50-db SL	.20	1000 cps	.0061	.0036			
60-db SL	.19	2000 cps	.0036	.0019			
70-db SL	.19	4000 cps	.0044	.0023			
80-db SL	.18	8000 cps	.0051	.0025			
90-db SL	.17						

variability the data are meaningful with significant F-ratios resulting for each of the main effects of sensation level, stimulus frequency, and reference duration.

When very short duration pure-tones are used as stimuli, the size of the difference limen for signal duration depends on the sensation level, the frequency, and the reference duration of the stimulus.

CHAPTER V

SUMMARY AND CONCLUSIONS

Satisfactory and efficient communication in the form of speech depends upon man's ability to discriminate changing auditory signals over time. This fact demonstrates the importance of a thorough investigation of the parameters affecting an auditory stimulus.

A rather impressive amount of literature is available regarding differential sensitivity to auditory stimuli. The ability of both the normal-hearing and impaired-hearing subject to discriminate changes in one or more of the parameters describing a tone has been investigated. By far the greater part of the literature is concerned with the parameters of frequency and intensity.

Still a third parameter describing a tone is signal duration. A cogent feature of the literature on differential sensitivity is the paucity of interest demonstrated in duration as an auditory stimulus parameter. Efforts to define the difference limen for stimulus duration in normal-hearing subjects have been limited to no more than two studies.

Both of these studies are in poor agreement where comparisons are possible. Furthermore, the reliability of each of the studies is poor. Therefore, in reviewing the literature on duration DLs, the student is presented a confusing picture of the human being's ability to discriminate auditory stimuli on the basis of signal duration. The present study was designed to obtain valid and reliable data on the function of the difference limen for stimulus duration.

Experimental Design

It was the purpose of this investigation to specify the monaural difference limen for stimulus duration as a function of relatively short reference duration. DLs for ten young normal-hearing subjects, five male and five female, were determined under twenty-four combinations of stimulus frequency, sensation level, and reference duration. The frequencies studied were 250, 1000, and 4000 cycles per second, while reference durations were 40, 60, 80, and 100 milliseconds. The sensation levels selected were 10 and 50 decibels.

Insofar as instrumentation and procedure would allow, it was specifically intended to obtain the smallest DL of which the young, normal human being is capable. To this end the experimental design incorporated three elements: (1) each subject was highly practiced prior to the gathering of experimental data so that any practice effect might be eliminated, (2) each subject was provided with immediate knowledge of results so that following each judgment the subject knew whether or not his response was correct, (3) finally, the

the number of correct judgments required of the subject in order to pass or fail the experimental task was determined by a table of sequential analysis. This eliminated the lengthy procedure associated with the other psychophysical methods without sacrificing precision of measurement.

Each subject was presented with paired pure-tone stimuli. The reference stimulus was always presented first. The comparison stimulus was then presented following a fixed silent interval. The subject's task was to judge whether the comparison stimulus was longer or shorter than the reference.

The psychophysical method employed is best described as a modified method of limits. Insofar as the author is aware, it was first used in audiological research by Butler and Albrite (10) and later by Ruhm (67). The duration of the reference stimulus, always the first stimulus of a pair, was held constant within each experimental condition and only the duration of the comparison stimulus was varied. The duration of the comparison stimulus selected for the initial test set of each experimental condition provided for an adequate difference (ΔT) between the paired stimuli so that all subjects could be expected to pass the task with ease. The difference in stimulus duration (ΔT) was then decreased in predetermined steps with each successive test set until the subject could no longer pass the task. The ΔT characterizing the last test set which the subject was able to pass defined the DL for that experimental condition.

Results and Conclusions

The magnitude of the difference limen for a short auditory stimulus duration depends on stimulus frequency and intensity and on the duration of the reference stimulus. Furthermore, it is shown to be significantly smaller than has yet been reported. Strikingly, some subjects were able to discriminate a 1-millisecond difference in stimulus duration under several of the experimental conditions. The mean relative DLs for all experimental conditions ranged in size from .026 to .085.

Weber's law does not hold true for stimulus duration. The function of the relative DL for short stimulus duration resembles the function of frequency and intensity DLs at low stimulus magnitudes. In general, the size of the relative DL for duration increases as the reference duration is shortened from 100 msec. This apparently does not hold true for a 250-cps stimulus, however. The magnitude of the duration DL also increases when the sensation level of the reference stimulus is decreased from 50 to 10 decibels. The size of the relative DL for duration as a function of stimulus frequency depends on the reference duration from which the measurements are made.

Suggested Further Research

A study is currently being completed by Milburn (57) who is investigating the duration DL using reference durations ranging from 300 to 1000 msec. His instrumentation and procedure are identical to that described here. A wealth of research projects concerning the DL for signal duration await study. The following are offered as suggested topics for further investigation:

1. Duration DLs as a function of long reference duration.
2. Duration DL as a function of reference durations adjacent to 80 msec and using stimuli of low frequency.
3. The function of the duration DL across the range of audible stimulus frequencies.
4. The function of the duration DL across a wide range of sensation levels.
5. The duration DL in various pathological cases.
6. The effect of binaural stimulation on the magnitude of the duration DL.
7. The effect of practice in judging differences in stimulus duration on the magnitude of the duration difference limen.
8. The duration DL as a function of psychophysical method.
9. The monaural duration DL in the presence of continuous contralateral stimuli.

Further research, in addition to extending our knowledge concerning the effects of signal duration on man's auditory experiences, may contribute to knowledge concerning the neurological mediation of auditory stimulus duration.

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Appendix A

Subject Identification and Individual Subject Data

TABLE 11

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 100-MSEC, 4000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps

REFERENCE DURATION - 100 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL DL IN MSEC	10-db SL ΔT/T	50-db SL DL IN MSEC	50-db SL ΔT/T
1	M	22	L	4	.040	3	.030
2	F	23	R	3	.030	4	.040
3	M	30	L	4	.040	1	.010
4	F	25	R	4	.040	5	.050
5	M	27	L	5	.050	2	.020
6	F	27	L	5	.050	5	.050
7	F	35	R	7	.070	2	.020
8	M	28	R	6	.060	2	.020
9	M	23	R	7	.070	3	.030
10	F	22	L	4	.040	4	.040
MEAN DL				4.9	.0490	3.1	.0310
STANDARD DEVIATION				1.370	.0137	1.370	.0137
RANGE		LOW		3	.030	1	.010
		HIGH		7	.070	5	.050

TABLE 12

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 80-MSEC, 4000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps

REFERENCE DURATION - 80 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL DL IN MSEC	10-db SL $\Delta T/T$	50-db SL DL IN MSEC	50-db SL $\Delta T/T$
1	M	22	L	3	.0375	3	.0375
2	F	23	R	7	.0875	3	.0375
3	M	30	L	5	.0625	1	.0125
4	F	25	R	4	.050	2	.0250
5	M	27	L	4	.050	4	.050
6	F	27	L	6	.0750	2	.0250
7	F	35	R	6	.0750	6	.0750
8	M	28	R	4	.050	2	.0250
9	M	23	R	5	.0625	3	.0375
10	F	22	L	5	.0625	3	.0375
MEAN DL				4.9	.0613	2.9	.0363
STANDARD DEVIATION				1.197	.0149	1.370	.0171
RANGE		LOW		3	.0375	1	.0125
		HIGH		7	.0875	6	.075

TABLE 13

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 60-MSEC, 4000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps

REFERENCE DURATION - 60 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	3	.050	2	.0333
2	F	23	R	5	.0833	4	.0666
3	M	30	L	6	.100	4	.0666
4	F	25	R	2	.0333	1	.0166
5	M	27	L	4	.0666	2	.0333
6	F	27	L	4	.0666	2	.0333
7	F	35	R	3	.050	2	.0333
8	M	28	R	6	.100	1	.0166
9	M	23	R	5	.0833	3	.050
10	F	22	L	6	.100	1	.0166
MEAN DL				4.4	.0730	2.2	.0366
STANDARD DEVIATION				1.430	.0238	1.135	.0189
RANGE		LOW		2	.0333	1	.0166
		HIGH		6	.100	4	.0666

TABLE 14

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-MSEC, 4000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps

REFERENCE DURATION - 40 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	4	.100	2	.050
2	F	23	R	5	.125	3	.075
3	M	30	L	5	.125	2	.050
4	F	25	R	2	.050	4	.100
5	M	29	L	3	.075	3	.075
6	F	27	L	4	.100	2	.050
7	F	35	R	2	.050	3	.075
8	M	28	R	3	.075	3	.075
9	M	23	R	2	.050	3	.075
10	F	22	L	4	.100	3	.075
MEAN DL				3.4	.0850	2.8	.070
STANDARD DEVIATION				1.174	.0293	.6325	.0158
RANGE	LOW			2	.050	2	.050
	HIGH			5	.125	4	.100

TABLE 15

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 100-MSEC, 1000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps

REFERENCE DURATION - 100 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	3	.030	2	.020
2	F	23	R	6	.060	1	.010
3	M	30	L	5	.050	1	.010
4	F	25	R	1	.010	2	.020
5	M	27	L	5	.050	1	.010
6	F	27	L	5	.050	4	.040
7	F	35	R	7	.070	7	.070
8	M	28	R	4	.040	3	.030
9	M	23	R	4	.040	3	.030
10	F	22	L	7	.070	2	.020
MEAN DL				4.7	.0470	2.6	.0260
STANDARD DEVIATION				1.828	.0183	1.838	.0184
RANGE	LOW			1	.010	1	.010
	HIGH			7	.070	7	.070

TABLE 16

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 80-MSEC, 1000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps

REFERENCE DURATION - 80 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	$\Delta T/T$	DL IN MSEC	$\Delta T/T$
1	M	22	L	3	.0375	3	.0375
2	F	23	R	5	.0625	1	.0125
3	M	30	L	3	.0375	1	.0125
4	F	25	R	6	.0750	2	.0250
5	M	27	L	4	.050	2	.0250
6	F	27	L	4	.050	2	.0250
7	F	35	R	4	.050	4	.050
8	M	28	R	6	.075	3	.0375
9	M	23	R	3	.0375	2	.0250
10	F	22	L	4	.050	1	.0125
MEAN DL				4.2	.0525	2.1	.0263
STANDARD DEVIATION				1.135	.0142	.994	.0125
RANGE	LOW			3	.0375	1	.0125
	HIGH			6	.075	4	.050

TABLE 17

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 60-MSEC, 1000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps

REFERENCE DURATION - 60 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	3	.050	2	.0333
2	F	23	R	5	.0833	1	.0166
3	M	30	L	5	.0833	3	.050
4	F	25	R	2	.0333	1	.0166
5	M	27	L	3	.050	1	.0166
6	F	27	L	4	.0666	1	.0166
7	F	35	R	5	.0833	2	.0333
8	M	28	R	3	.050	2	.0333
9	M	23	R	6	.100	1	.0166
10	F	22	L	4	.0666	4	.0666
MEAN DL				4.0	.0666	1.8	.0299
STANDARD DEVIATION				1.247	.0208	1.033	.0172
RANGE	LOW			2	.0333	1	.0166
	HIGH			6	.100	4	.0666

TABLE 18

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-MSEC, 1000-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps

REFERENCE DURATION - 40 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	3	.0750	2	.050
2	F	23	R	3	.0750	3	.0750
3	M	30	L	1	.0250	1	.0250
4	F	25	R	2	.050	2	.050
5	M	27	L	3	.0750	3	.0750
6	F	27	L	3	.0750	3	.0750
7	F	35	R	3	.0750	3	.0750
8	M	28	R	3	.0750	1	.0250
9	M	23	R	4	.100	4	.100
10	F	22	L	3	.0750	1	.0250
MEAN DL				2.8	.070	2.3	.0575
STANDARD DEVIATION				.7888	.0197	1.059	.0265
RANGE		LOW		1	.0250	1	.0250
		HIGH		4	.100	4	.100

TABLE 19

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 100-MSEC, 250-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps

REFERENCE DURATION - 100 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	5	.050	4	.040
2	F	23	R	6	.060	3	.030
3	M	30	L	1	.010	4	.040
4	F	25	R	1	.010	1	.010
5	M	27	L	4	.040	2	.020
6	F	27	L	7	.070	4	.040
7	F	35	R	7	.070	5	.050
8	M	28	R	5	.050	4	.040
9	M	23	R	7	.070	2	.020
10	F	22	L	5	.050	4	.040
MEAN DL				4.8	.0480	3.3	.033
STANDARD DEVIATION				2.251	.0225	1.252	.0125
RANGE		LOW		1	.010	1	.010
		HIGH		7	.070	5	.050

TABLE 20

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 80-MSEC, 250-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps

REFERENCE DURATION - 80 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	3	.0375	4	.050
2	F	23	R	9	.1125	4	.050
3	M	30	L	1	.0125	1	.0125
4	F	25	R	4	.050	2	.0250
5	M	27	L	5	.0625	4	.050
6	F	27	L	5	.0625	6	.0750
7	F	35	R	8	.100	2	.0250
8	M	28	R	10	.1250	2	.0250
9	M	23	R	8	.100	3	.0375
10	F	22	L	3	.0375	4	.050
MEAN DL				5.6	.070	3.2	.040
STANDARD DEVIATION				2.989	.0374	.6325	.0184
RANGE		LOW		1	.0125	1	.0125
		HIGH		10	.1250	6	.0750

TABLE 21

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 60-MSEC, 250-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps

REFERENCE DURATION - 60 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	1	.0166	2	.0333
2	F	23	R	4	.0666	3	.050
3	M	30	L	3	.050	1	.0166
4	F	25	R	6	.100	1	.0166
5	M	27	L	4	.0666	2	.0333
6	F	27	L	3	.050	3	.050
7	F	35	R	4	.0666	3	.050
8	M	28	R	2	.0333	1	.0166
9	M	23	R	4	.0666	3	.050
10	F	22	L	3	.050	1	.0166
MEAN DL				3.4	.0566	2.0	.0333
STANDARD DEVIATION				1.350	.0225	.9428	.0158
RANGE		LOW		1	.0166	1	.0166
		HIGH		6	.100	3	.050

TABLE 22

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-MSEC, 250-CPS EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 250 cps

REFERENCE DURATION - 40 msec

SUBJECT	SEX	AGE	TEST EAR	10-db SL		50-db SL	
				DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	M	22	L	2	.050	3	.0750
2	F	23	R	3	.0750	2	.050
3	M	30	L	1	.0250	2	.050
4	F	25	R	2	.050	1	.0250
5	M	27	L	2	.050	3	.0750
6	F	27	L	3	.0750	3	.0750
7	F	35	R	4	.100	2	.050
8	M	28	R	3	.0750	2	.050
9	M	23	R	3	.0750	2	.050
10	F	22	L	4	.100	3	.0750
MEAN DL				2.7	.0675	2.3	.0575
STANDARD DEVIATION				.9487	.0237	.6750	.0169
RANGE	LOW			1	.025	1	.025
	HIGH			4	.100	3	.075

Appendix B

Values of ΔT as Utilized With Each Reference Duration

TABLE 23

VALUES OF ΔT AS UTILIZED WITH EACH REFERENCE DURATION

Reference Duration	Values of ΔT						
40	10	7	5	3	1	0	
60	15	11	7	5	3	1	0
80	20	15	9	5	3	1	0
100	25	15	9	5	3	1	0