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THE EFFECT OF A COCHLEAR PATHOLOGY ON THE DIFFERENCE LIMEN FOR DURATION

CHAPTER I

INTRODUCTION

The study of differential sensitivity in the normal ear has bee of importance to those interested in psychoacoustics for many years. Boring (1) reports that the differential threshold for pitch was first determined in 1700 by Saveur, for intensity in 1856 by Renz and Wolf, ar for duration prior to 1865 by Mach.

In the intervening years a large number of investigators have labored to extend the work of these early pioneers. These workers have been from several academic and professional disciplines and have been known by many titles, but all have in common an interest in human auditory behavior. They have employed a great variety of apparatus from the vibrating strings, tuning forks, whistles, watches, falling pendulums ar lead balls, hammers and anvils, and metronomes of the pre-vacuum tube er to the electronic oscillators, switches, timers, microphones, earphones, and voltmeters of the modern psychoacoustic laboratory. Due to the efforts of these workers it may now be said that a great deal is known about the ability of the normal ear to detect small changes in the inter sity, frequency, and duration of pure tone stimuli.

It has been in comparatively recent times, however, that the di ferential sensitivity of the pathologic ear has been systematically investigated. The event which precipitated study of these abilities of the pathologic ear was the publication in 1928 of an article by Fowler concerning a phenomenon which he called "recruitment of loudness".

Fowler (14) described the results of an experiment conducted with a patient with one normal ear, the other exhibiting a 40 dB loss sharply localized at 4096 cps. He required the patient to equate the loudness of a tone heard alternately in each ear and noted that at high sensation levels the 40 dB difference between ears at 4096 cps disappeared. That is, when the tones were quite loud, tones of equal intensity were equally loud despite a discrepancy in threshold levels for the two ear. Fowler defined recruitment as ". . . an abnormal acceleration in the sensation of loudness with a relatively small increase in intensity."

It was noted that the recruitment phenomenon existed only in hearing loss of sensorineural origin. Thus, Fowler's test, or Alternate Binaural Loudness Balance (ABLB), was added to the otologist's armamentarium as an additional means of differentiating conductive and sensorineural losses.

The application of the ABLB is limited to those patients in whom a substantial difference between ears exists. Reger (48) proposed a technique which allows the monaural assessment of recruitment in cases in which either the thresholds are too similar or the loss in one ear is too severe to permit the use of the ABLB. The subject is required to determine the intensity level at which a tone of one frequency is equal in loudness to a tone of another frequency, both of which are presented alternately to the same ear. The technique requires that there be a substantial difference in threshold at the two frequencies. This test is often referred to as the Alternate Monaural Bifrequency Loudness Balance (AMBLB).

Employing the ABLB, Dix, Hallpike, and Hood (9), in 1948, demonstrated that patients known to have tumors affecting the VIIIth nerve displayed either an absence of recruitment or incomplete recruitment (less intensity in the unaffected ear at equal loudness) while patients with Meniere's disease manifested either complete or over recruitment. Complete recruitment means that equal intensity is present in the two ears at equal loudness while over recruitment means that more intensity is required by the unaffected ear to attain equal loudness. Since Meniere's disease is known to be a disease of the cochlea, the implication was that recruitment is a cochlear phenomenon. Hallpike and Hood (15), in a subsequent investigation, attempted to account for the presence of incomplete recruitment in the VIIIth nerve cases by pointing out that the cochlear blood supply may have been interrupted with resultant damage to the hair cells and other cochlear structures. The clinical detection of those patients with recruitment thus took on additional significance.

It has been found by some workers that the techniques of loudness balance, binaural or monaural, are not applicable to many clinical patients, either because the hearing lossess are such that the techniques are not feasible, or because the judgment of equal loudness is too difficult for the patient to make. As a result, other techniques have been proposed to measure indirectly the recruitment phenomenon[1]. The most widely applied technique has been the measurement of the difference limen for intensity.

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[1]One of the most extensive reviews of these techniques is Harris, J. D., "An Historical and Critical Review of Loudness Recruitment". MRL No. 200, XI, No. 17, 1952.

Shortly following, and partially because of, the publication of reports of the determination of the difference limen for intensity (DLI) in pathological subjects, interest in the difference limen for frequency (DLF) was aroused, although, as we shall see in a subsequent section, the report of the DLF for abnormal subjects preceded that of the DLI by many years. A search of the literature indicated that an investigation of the difference limen of duration (DLD) in impaired subjects has not been reported. The present study measured the DLD in subjects with one type of hearing impairment.

The next chapter contains a review of the literature concerning the sensitivity of the normal subject to differences between the durations of successive tones and the differential sensitivity of pathological subjects to changes in intensity and frequency. The investigations concerning the effects of duration on the loudness and pitch of pure tones in normal and pathological subjects are also reviewed. The literature indicates that the subject with cochlear pathology behaves in a characteristically abnormal manner to tests of differential sensitivity of intensity and frequency. Furthermore, an altered relationship between duration and the psychological attribute of intensity, loudness, is manifested by the subject with cochlear pathology. The purpose of the present investigation was to determine if the DLD in subjects with cochlear pathology is also abnormal.

In general, the present study determined the DLD at two frequencies and two sensation levels under several durations of the reference tone. The subjects employed all had hearing losses due to a cochlear pathology. The specification of the parameters of the experimental tones and description of the subjects, apparatus, and procedures, are presented in a later chapter.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

In the previous chapter, mention was made of the fact that patients with acoustic trauma and Meniere's disease, both of which result in pathology to the cochlea, manifest loudness recruitment when tested by either the binaural or monaural loudness balance test.

In the following sections, studies will be reviewed which indicate that patients with cochlear pathology are more sensitive to small intensity changes and less sensitive to small frequency changes than subjects with normal hearing. An altered relationship between the duration and the perceived loudness of pure tones has also been identified and will be discussed. In addition, the literature concerning the sensitivity of the normal ear to small differences in the duration of successive tones will be reviewed.

There have been nearly as many techniques for measuring the difference limen (DL) as there have been investigators. Generally, the techniques fall into one of two classifications: continuous or discontinuous methods of stimulus presentation. In the former, a tone is introduced and remains on for an indefinite length of time. While the tone is on, it is modulated in either intensity or frequency, depending on the parameter which is being investigated. These modulations vary, either continuously or abruptly, between two extremes with the standard intensity or frequency in the center. The subject recognizes the modulated stimulus as a "warble tone". The subject is required to signal when he is able to hear the "warble". The minimum amount of modulation the subject can detect consistently (usually fifty per cent of the time) is defined as the difference limen. In the discontinuous method a reference tone is presented for a predetermined period of time. The tone is followed by a silent interval of a specified duration. The examiner then presents a comparison tone which is identical to the reference tone in all respects except the parameter under investigation. The sequence of reference tone, silent interval, and comparison tone is repeated with changes in the difference between tones until the minimum parameter change that is perceptible is obtained.

Hirsh, Palva, and Goodman (25) point out that, in reality, there are many techniques for measuring the DL. Not only do the psychophysical procedures differ, but the patterns of modulation in the continuous method and the time relations between tones in the discontinuous methods differ from study to study. These differences in technique, plus differences in the sensation level at which the DL was measured, make direct comparison of results among studies difficult, if not impossible.

The factors mentioned above which hinder comparisons among studies are compounded by the problem of subject selection. Although the primary purpose of the DL studies of the pathological ear was to develop additional techniques for determining the presence of recruitment in order to differentiate cochlear from other sensorineural lesions, few of the studies present data obtained by either of the balance techniques. In the final analysis, Alternate Binaural or Monaural balance tests are the only methods which actually measure recruitment. The presence of recruitment in the subjects of these studies was not demonstrated but was inferred from the presumed etiology of the hearing loss. In addition, some of the studies employed as a criterion for subject selection demonstrable sensorineural hearing loss with no provision for separating the subjects into groups according to the site of lesion. Thus, the experimental groups in these studies contained subjects who may or may not be expected to display recruitment (9, 15).

The results of studies of the DLs for intensity and frequency will be reviewed in the following sections. Major emphasis will be devoted to those studies which are pertinent to the present investigation, i.e., studies in which a discontinuous technique was employed to measure the DL in subjects known to have a hearing loss due to a cochlear lesion. The review will include the studies in which the DLI and DLF were obtained from pathological subjects. In order to make optimal use of the DLs obtained from pathological subjects, most investigators found it necessary to evaluate their technique on normal subjects. The review which follows will cite the results obtained from normal subjects when appropriate. The classic studies of the DLI and DLF in normal subjects will not be discussed in detail.

Difference Limen for Intensity

Normal Subjects

Knudsen (30) reviewed the studies concerning the DL for intensity prior to the development of electroacoustic equipment. Among the ingenious techniques reported was that of Fisher and Wundt, in which lead balls of different weights, dropped from various heights, were employed to produce various intensities of sound.

The first studies of the difference limen for intensity and the difference limen for frequency which employed electroacoustic equipment were performed by Knudsen (30). The continuous, or modulation, technique was used for both measurements. The data obtained by Reisz (49) using amplitude modulation are usually considered to be definitive of the DLI. Churcher, King, and Davies (5) also used a continuous technique while Dimmick and Olson (8) employed a discontinuous technique. Stevens, Morgan, and Volkman (56) used the "Quantal" method. Montgomery (43) investigated the influence of experimental technique on the DLI. Harris (20) has reviewed and re-examined experimentally each of the techniques.

In general the above studies have indicated that:

1. The DLI is largest near threshold, decreasing as the intensity is raised, at least to a level of 50 dB above threshold.

2. The DLI is largest for tones at the lower end of the frequency scale, and is smallest at those frequencies at which acuity is greatest.

Pathological Subjects

Brinitzer (2) and de Mare (36) are generally cited as having been among the first to attempt to associate the recruitment phenomenon with abnormalities of the DLI in patients with hearing loss (20, 27, 31). However, Luscher and Zwislocki (34) were the first to succeed in measuring the DLI in pathological ears. They employed the continuous technique of amplitude modulation in which the changes in intensity set in abruptly and recurred at a rate of approximately two per second. A subject was asked to respond when he was able to detect the presence of the modulation. Initially, a degree of modulation which was easily perceptible was presented and then gradually decreased until the subject ceased to respond. The least value of modulation to which the subject responded consistently was taken as the difference limen. The DLI was expressed as per cent of modulation of the reference intensity.

The DLI values for normal hearing subjects are interpreted as confirming Reisz' (49) conclusions that the DLI is dependent upon the intensity, and to a lesser extent, the frequency of the tone. Luscher and Zwislocki's DLIs range from twelve per cent to eighteen per cent at 20 dB to three to four per cent at 80 dB above threshold for unpracticed subjects. At the lower intensities the values are approximately constant in the frequencies below 1000 or 2000 cps and increase at the higher frequencies. This frequency dependency disappears above the 40 dB sensation level. The authors suggest that the DLI in pathological cases should be assessed at the 40 dB sensation level in order to remove the influence of frequency.

In general, the results of the studies of patients with known pathologies by Luscher (31, 32) and Luscher and Zwislocki (34, 35) indicate that patients with conductive and retrocochlear lesions display normal DLIs and patients with lesions of the cochlea have abnormally small DLIs. They report that in a hearing loss of more than 30 dB, a DLI of eight per cent or less, obtained with a 40-dB sensation level stimulus, is indicative of a cochlear lesion.

At Luscher's suggestion, Neuberger (46) employed the same technique with a group composed mainly of acoustic trauma cases. He compared the DLI with the results of the Alternate Binaural Loudness

Balance test. At those frequencies at which recruitment could be demonstrated by the ABLB the DLI was two to six per cent. It thus became evident that an amplitude modulation DLI technique could reliably establish the cochlea as the site of lesion.

Denes and Naunton (6,7) employed a discontinuous technique in which the second of two tones was compared to the first and judged to be either the same or different. The two tones were each 1700 msec in duration and were separated by a 330-msec silent interval. Initially, the second tone was enough louder or softer than the reference tone for the subject to experience no difficulty in judging them to be different. A method of limits procedure in which the second tone was made more like the first tone in discreet steps was employed. The point of subjective equality was approached in both an ascending and descending manner and the DLI was defined as the difference in dB between the ascending and descending loudness balance points. Thus, the DLI reported by these authors is in reality a "double DLI". They report the results obtained at 4, 24, and 44 dB above threshold for twenty-three subjects with recruitment and for twenty subjects without recruitment, as determined by the ABLB. The frequency at which the determinations were made is not reported. Following are the mean DLIs in dB reported for the two groups:

Intensity (dB SL)	4	24	44
With recruitment	3	3-1/2	4
Without recruitment	4	4	2-1/2

It may be observed that the absolute size of the DLI at these levels with the technique described does not differentiate between recruiting and non-recruiting ears. However, Denes and Naunton recommend that the relationship between the DLIs at the 4 dB and 44 dB sensation levels does allow this decision. In this manner, each ear is compared with itself and not with the results obtained in a normative study. Thus, they conclude that if the DLI at 4 dB is greater than 44 dB, ". . . then it is assumed that recruitment is absent. If the latter is greater than or equal to the former, then recruitment is present." When this criterion is applied to the data from the forty-three individuals reported, the DLI and balance test are in agreement in forty of the cases. It is reported that, in two of the three cases in which the tests disagree, the discrepancy is the result of the participation of the contra-lateral ear in the test.

Jerger (26) employed a continuous technique patterned after Luscher and Zwislocki's. The DLI was assessed at 15 dB SL rather than 40 dB and the modulation was increased instead of decreased until noted by the subject. A wide range of etiological types was studied and the results confirmed the data from Luscher's clinic.

A year later Jerger (27) changed his procedure to the extent that he utilized the concept of each ear acting as its own control as advocated by Denes and Naunton (6, 7). However, he continued to use his modification of the Luscher-Zwislocki technique to assess the DLI at 10 dB and 40 dB sensation levels. His data show that in cases of cochlear loss of more than 30 dB the difference in the value of the DLI at the two levels is slight (about .10 dB) and in patients without cochlear loss the difference is close to 1 dB.

Hirsh, Palva, and Goodman (25), in 1954, examined the literature concerning the relationship between the DLI and recruitment until that time. They were critical of the amplitude modulation technique and employed a discontinuous technique in their experiment. The first, or reference, tone was 1910 msec in duration followed immediately by a comparison tone of 1750 msec duration. Each pair of tones was separated by a silent interval of about 230 msec. As in Denes and Naunton's (6) technique, the point of subjective equality was approached in discreet steps in both an ascending and a descending manner. The subjects were to judge whether the tones were "different" or "the same". The difference limen was defined as the difference in dB between the last magnitude judged as "different" and physical equality. The DLIs are reported as an "ascending DL", a "descending DL", and the sum of the "ascending" and "descending" DLs divided by two.

The DLI was measured at 5, 25, and 40 dB sensation levels at frequencies at which recruitment might be present. The presence or absence of recruitment was determined by the loudness balance tests. Data for three groups are reported. One group had normal hearing. The second exhibited hearing impairment with recruitment, while the third had hearing impairment without recruitment. The "ascending" and "descending" DLs divided by two at the three sensation levels for the three groups are reported below:

Intensity (dB SL)	5	25	40
Normal hearing group	2.49	1.91	1.42
Hearing impaired with recruitment	2.33	2.26	1.80
Hearing impaired without recruitment	2.29	1.97	1.58

The conclusion drawn from the preceding data is that normal subjects and patients with impaired hearing, with or without recruitment, cannot be differentiated on the basis of the size of the DLI determined by this procedure. Harris (20) suggests that had they used the principle of each ear acting as its own control employed by Denes and Naunton (6, 7) the differentiation may have been accomplished.

In 1955, Jerger (28) reported the results of a study in which the Quantal method of Stevens, Morgan, and Volkman (56) was used to measure the DLI at 1000 and 4000 cps at the 10 dB and 40 dB sensation levels. In this procedure, the subject was asked to listen to a continuous reference tone to which short intensity increments were periodically added. Psychometric functions, relating per cent of increments heard to increment intensity, were plotted and the DLI defined as the intensity increment at which fifty per cent were heard. Two groups of subjects were employed. The first had normal hearing at both test frequencies, while the second had been diagnosed as having acoustic trauma. The latter group had normal hearing at 1000 cps and a moderate sensorineural loss at 4000 cps. Results of monaural loudness matches between the two test frequencies indicated recruitment was present in each of the subjects of the group with impaired hearing.

Summarized below are the mean DLIs for the two groups at two frequencies and two sensation levels:

Frequency (cps)	1000	4000
10 dB SL		
Normal	2.28	1.81
Impaired	2.24	0.99
40 dB SL		
Normal	1.21	1.05
Impaired	1.16	0.46

It may be readily observed that at 1000 cps, where both groups have normal hearing, the DLIs are of quite similar magnitude. At 4000 cps, however, the group with cochlear hearing loss demonstrates much greater sensitivity to intensity change.

Four years later, Jerger, Shedd, and Harford (29) reported the results of a clinical adaptation of the procedure employed above. In the clinical modification, the intensity of the continuous reference tone was 20 dB above threshold. An increment of 200 msec duration with a rise-decay time of 50 msec occurred every five seconds. The magnitude of the increment was exactly 1 dB. Twenty such increments were presented at a given frequency, and the subject was required to respond to the presence of an increment. The results are reported as per cent of increments heard and are usually referred to as the SISI (Short Increment Sensitive Index). Subjects with normal hearing, conductive loss, or retrocochlear lesions may be expected to hear zero to fifteen per cent of the increments while patients with cochlear lesions typically have SISI scores of seventy to one-hundred per cent. Patients with hearing loss due exclusively to advancing age may have SISIs anywhere from zero to one-hundred per cent. The SISI test is used routinely in many Otological and Audiological Centers at the present time.

In summary, it is apparent that the DLs obtained by the method of amplitude modulation and the Quantal method successfully identify the patient with a hearing loss due to a lesion of the cochlea. There is still some controversy as to whether this differentiation may be accomplished employing a discontinuous technique. From the results of the successful studies, the following observations may be drawn:

1. DLIs in conductive loss cases are essentially the same as in

normal subjects.

2. DLIs obtained from subjects whose hearing loss is presumed to be of cochlear origin, are smaller than normal (modulation and Quantal techniques) or the DLI fails to improve with an increase in intensity (discontinuous techniques).

3. DLIs obtained from subjects whose hearing loss is presumed to be due exclusively to advancing age may or may not be more sensitive to small intensity changes than normal subjects.

4. DLIs obtained from subjects who exhibit sensorineural loss due to lesions of the VIIIth nerve are essentially the same as those yielded by normal subjects.

Difference Limen for Frequency

Normal Subjects

Vance (60), in 1914, published a comprehensive review of the literature concerning the DLF. Since electroacoustic equipment was not available prior to 1920, these early studies employed vibrating reeds, tuning forks, and Galton whistles. The mechanical equipment precluded the accurate control and measurement of intensity and the precise measurement of frequency increments.

Following the invention of the thermionic vacuum tube and the subsequent development of electroacoustic equipment, there was renewed interest in the study of the ability of the normal ear to resolve small differences in frequency. Among those who have made use of the technological improvements are Knudsen (30) and Shower and Biddulph (52) who employed the continuous method of frequency modulation. Harris (19) and Rosenblith and Stevens (50) used variations of the discontinuous method.

Stevens, Morgan, and Volkman (56) also report data on the DLF utilizing the Quantal method. Despite differences in technique and allowing for expected variations among studies, certain general conclusions may be drawn:

1. The values of the DLF are smallest for frequencies up to 500 cps and increase in size for higher frequencies. For the lower frequencies the value may be less than 5 cps and at 4000 cps it may be as large as 20 cps.

2. The values of the DLF are largest near threshold decreasing in size to about 40 dB. Above this intensity the value remains approximately constant despite further increase in intensity.

Pathological Subjects

Stucker (59) reported in 1908 that the DLF in elderly subjects is larger than in young subjects. This information represents the state of knowledge concerning the DLF in pathological subjects prior to 1950.

In that year Shutts (53) studied the DLF in subjects who demonstrated a sensorineural hearing loss. No attempt was made to subdivide this group into cochlear and retrocochlear lesions. Shutts compared the size of the DLF in this group to that of adults with normal hearing. The method of constant stimuli, a discontinuous method of testing, was employed. The subject was to judge whether the second of two tones was higher or lower in frequency than the first. A total of ten variable stimuli, five of higher and five of lower frequency than the reference frequency, was used. These stimuli were selected to include variations which ranged from indistinguishable to obviously different from the reference tone. The tones were 500 msec duration and members of a pair were separated by a 500 msec silent interval. Ten presentations of each of the ten reference-comparison pairs constituted a single test. The 100 pairs were presented in random order. The tests were conducted at 500, 1000, and 2000 cps at 10, 25, and 40 dB above threshold. The entire series was pre-recorded on magnetic tape. A total of forty subjects was employed, twenty in each of the normal and pathological groups. In the latter group, DLFs at the 40-dB sensation level could not be obtained on all subjects.

The following DLFs in cps were obtained for the two groups at 500, 1000, and 2000 cps at 10 and 40 dB sensation levels:

Frequency (cps)	500	1000	2000
10 dB SL			
Normal hearing	6.42	9.16	15.58
Sensorineural loss	8.51	14.47	22.13
40 dB SL			
Normal hearing	3.28	4.51	8.86
Sensorineural loss	7.19	9.89	16.77

Although Shutt's data for subjects with normal hearing are slightly larger than similar measurements by previous investigators, the results are in general agreement. It may be noted that the DLFs for the pathological group are approximately twice the size of the normal group's. Large variations in DLF size were noted in the hard-of-hearing subjects. As in normal subjects, the pathological subject improves in ability to discriminate differences in frequency with an increase in intensity. However, the intensity level at which this ability plateaus was reached at 25 dB above threshold in the abnormal group, while the normal group continued to improve up to the limit of the sensation levels explored (40 dB). Shutts notes ". . . these findings form the basis for believing that the functions for pitch discrimination are not the same in the two types of ear" (53, p. 127).

The following year, Hayes (23) conducted a follow-up of the Shutts (53) study. The primary purpose was to compare the size of the DLF with the ability to discriminate speech. The equipment, methods, and procedures were approximately the same as in Shutts' study. The primary differences were the elimination of a control group of normal subjects and the randomization of the presentation order of the reference and comparison tones. DLFs were obtained at the same frequencies and sensation levels as in Shutts' study. Hayes employed three experimental groups with sensorineural hearing loss: one of young adults with good speech discrimination, one of older (over fifty years of age) adults with good speech discrimination, and one of older adults with poor speech discrimination. The following DLF values were obtained at 10 dB and 40 dB above threshold at 500, 1000, and 2000 cps for the three groups:

Frequency (cps)	500	1000	2000
10 dB SL			
Young adults with good speech discrimination	12.50	13.80	18.10
Older adults with good speech discrimination	11.00	17.86	26.08
Older adults with poor speech discrimination	15.93	19.43	39.42
40 dB SL			
Young adults with good speech discrimination	9.32	11.61	17.90
Older adults with good speech discrimination	8.91	11.57	23.30
Older adults with poor speech discrimination	17.03	18.81	30.50

Hayes (23) concluded:

1. The mean DLFs were larger in each group than those for normal hearers reported by Shutts (53).

2. The mean DLFs in the young adult group were relatively close to those obtained by Shutts (53) for an equivalent experimental group.

3. The mean DLFs of the older adults with good speech discrimination were about the same as those of the younger group.

4. The mean DLFs of the older adults with poor speech discrimination were somewhat larger than either of the other groups, but most differences were not significant.

5. The DLFs of some individuals differed widely from the group to which they belonged.

Meurman (39), in 1954, employed a frequency modulated pure tone (continuous method) to determine the DLF at a level 20 dB above threshold at the octave intervals between 125 and 4000 cps. He utilized five groups of subjects: normal hearing, conductive loss (predominantly otosclerotics), sensorineural (Meniere's disease), young patients with sensorineural loss, and older patients with sensorineural loss. The latter two groups included patients with various etiologies other than Meniere's disease. Briefly, Meurman (39) found that the DLFs in normal and conductive loss subjects are equivalent and that subjects with cochlear pathology have larger DLFs than normal hearing subjects.

Pickler and Harris (47), as part of a larger study of pitch discrimination in normal subjects, performed Alternate Binaural Loudness Balance tests at 1000 cps on one subject who had a 35 dB discrepancy between ears at that frequency. DLF measurements were obtained for each ear employing the method of constant stimulus differences in which the subject judged the second of two tones to be higher or lower in pitch than the first tone. These measurements were made at intensity levels judged by the subject to be equally loud. The results are presented in the following table:

Equal Loudness Levels		DLF in cps at Equal Loudness	
Normal ear	Defective ear	Normal ear	Defective ear
0	35		
25	45	6.25	13.5
40	47	1.78	3.3
55	50	1.75	2.0

It is clearly demonstrated that equal loudness in ears with recruitment does not always result in equal DLFs. The authors also produced temporary sensorineural deafness by subjecting a normal ear to noise of 140 dB SPL. They report pitch discrimination ability to be greatly reduced, sometimes even more than is demonstrated above.

In 1956, Butler and Albrite (4) employed a discontinuous technique which provides the basis for the method to be used in the present study. Briefly, the second or comparison tone was higher or lower in frequency than the reference tone by a predetermined amount. Initially, the discrepancy between tones was large enough to be easily recognized. The subject was to report whether the second tone was higher or lower in frequency than the first. Immediate knowledge as to the accuracy of the judgment was provided. A sequential analysis of the responses was used to infer whether the subject could discriminate a given frequency difference at least seventy-five per cent of the time or no better than fifty per cent of the time. The procedures and rationale for this statistical technique will be discussed in a later section devoted to procedures. When it became apparent that a subject had discriminated a given frequency difference, the difference between reference and comparison tones was reduced until a difference was found which the subject could not discriminate. The least frequency difference which the subject was able to discriminate was considered the DLF. The test was conducted at 500, 1000, 2000, 3000, and 4000 cps at an intensity of 90 dB above normal threshold. The paired tones were each 1500 msec in duration and were separated by a 750 msec silent interval.

Pilot data revealed that the DLF for normal and conductive-loss subjects were equivalent. Consequently, the study compared patients who had a sensorineural loss with patients who had a conductive hearing loss. Butler and Albrite (4) give the following median values for their two groups:

Frequency (cps	500	1000	2000	3000	4000
Conductive loss	1.3	2.8	4.8	5	15
Perceptive loss	2.6	4.5	7.6	20	40

The results indicate that patients with sensorineural hearing loss demonstrate poorer ability to discriminate small differences in the frequency of successive tones than do patients with a conductive hearing loss. This difference in performance is especially pronounced at the higher frequencies.

During a second phase of the study, conducted with similar groups, an investigation was made of the effect of five hours of practice on the size of the DLF at 4000 cps. The median DLF diminished to 10 cps for the conductive group and to 20 cps for the sensorineural group. Variability within groups was also markedly reduced. However, the group who had a sensorineural loss continued to have significantly larger DLFs.

Filling (13) employed a continuous method in which a tone 20 dB above the subject's threshold was modulated sinusoidally twice per second. The amount of modulation was gradually increased until the subject detected the warble. DLFs were evaluated at octave intervals from 125 to 8000 cps. Her subjects were divided into the following categories, according to the results of audiometric tests: normal hearing, pure conductive loss, pure sensorineural loss, and mixed conductive and sensorineural loss.

It was observed that conductive loss cases showed DLF values which were essentially the same as those exhibited by normal subjects. Mixed-loss cases displayed increased DLFs at all frequencies tested, but Filling noted no special tendency toward an increase in DLF value with increased loss. In contrast, the DLF in patients with a sensorineural hearing loss was related to the severity of the loss. That is, the value was largest in those patients with the greatest loss. In addition, there was a marked increase in the DLF values at the higher frequencies in patients with a sensorineural loss.

In an effort to determine whether the DLF might be used as a test for recruitment, Filling (13) compared the results obtained in her study with the results of the loudness balance techniques and the DLI. Luscher and Zwislocki's (34) technique was employed at 20 dB above threshold to determine the DLI. In order to use the DLF to predict the presence of recruitment, Filling employed a technique similar to Denes and Naunton (6) and Jerger (27), i.e., the DLF was measured at two intensity levels, 5 dB and 20 dB above threshold, at each of several frequencies. A ratio, r, was calculated for each frequency employing the formula:

$$r = \frac{\text{DLF at 5 dB above threshold}}{\text{DLF at 20 dB above threshold}}$$

The r value was calculated for groups of normal hearing subjects and elderly (sixty to sixty-nine years) subjects with hearing loss due to advanced age. The values obtained for the two groups at the octave intervals between 125 and 8000 cps were quite similar. The smallest mean r was 1.26 and the largest mean r was 1.73, both of which were obtained from the normal group.

Comparison of the r values obtained from pathological subjects with the monaural and binaural balance tests revealed that r values of 1.80 or less are associated with an absence of recruitment. Patients with recruitment had r values of 2.00 or more, except in a few cases which yielded values between 1.80 and 1.99. When the DLI and r ratio were compared the tests confirmed each other in the majority of the cases and were greatly at variance in a few cases.

McCandless (37) employed a discontinuous method to evaluate the DLF in sensorineural loss subjects. The method of limits was modified to reduce the number of presentations of reference-comparison pairs necessary to obtain the DLF. Each member of the pair was 1000 msec in duration and they were separated by a 500 msec silent interval. The value of the DLF was measured at 500, 2000, and 4000 cps at 10, 45, and 80 dB above the subject's audiometric threshold. Three groups of subjects were employed: a normal hearing group, a group with a high frequency loss which did not extend below 3000 cps who had a history of noise exposure, and a group with a mild-to-moderate sensorineural hearing loss over most of the audiometric range, that was more severe in the higher than the lower frequencies. The mean threshold at 4000 cps for the two pathological groups differed by 20 dB, the latter group having the greater loss. Summarized in the following are the mean DLF values at 500, 2000, and

4000 cps at the 10 dB and 45 dB sensation levels for each of the three groups:

Frequency (cps)	500	2000	4000
10 dB SL			
Normal hearing	3.20	4.72	10.90
High frequency loss	3.79	7.84	40.27
Mild to moderate sensorineural loss	6.40	21.08	98.44
45 dB SL			
Normal hearing	2.31	4.44	9.58
High frequency loss	2.82	7.53	28.83
Mild to moderate sensorineural loss	3.94	26.40	109.86

As in the studies previously cited, patients with sensorineural hearing loss exhibited larger DLF values than did subjects with normal hearing. Furthermore, the effect is apparent even at frequencies at which the hearing threshold was normal. This effect is clearly demonstrated by the results displayed above for the normal and high-frequency loss groups, both of which showed normal thresholds at 2000 cps. Higher variability among pathological subjects than among normal subjects is again noted.

In summary, several observations may be made concerning the results of the DLF studies of pathological subjects reported above:

1. DLFs obtained from subjects with conductive losses are essentially the same as those in normal subjects.

2. DLFs yielded by subjects with sensorineural hearing loss are larger than normal at all frequencies which were impaired and at nearby frequencies which were not impaired.

3. DLFs obtained from subjects in whom the loss was presumed to

be due to cochlear lesion, either by balance tests or presumed etiology, are larger than normal.

4. DLFs yielded by elderly patients with hearing loss due to advanced age may or may not be larger than normal.

5. DLFs obtained from subjects with sensorineural hearing loss due to lesions of the VIIIth nerve have yet to be established.

Influence of Duration on Loudness and Pitch

The relationship existing between the duration and the loudness of a pure tone has been studied rather extensively in both normal and impaired subjects. Among the more intensive investigations are those of Miskolczy-Fodor (41, 42), Eisenberg (12), and Harris, Haines, and Myers (22). The effect of decreasing duration on the pitch of a tone has been well documented by Burck, Kotowski, and Lichte (3), Doughty and Garner (10, 11), and by Luscher and Zwislocki (33). Apparently only the latter have studied the pitch-duration relationship in pathological subjects.

Duration-Pitch Relationship

Normal Subjects. As the duration of a tone is increased from two or three msec, the pitch experience reported by the subject goes through three principle stages(55). First, an essentially toneless click is heard. Second, the click assumes a pitch characteristic, but the apparent pitch is different from the pitch that would be present at a longer duration. Finally, a duration is reached beyond which further increase in duration results in little or no change in pitch.

Doughty and Garner (10, 11) have designated the durations at which the second and final stages of pitch experience are attained as click-pitch and tone-pitch threshold respectively. These two thresholds were assessed by Doughty and Garner (10) at octave intervals between 125 and 8000 cps at an intensity of 110 dB Sound Pressure Level in two highly trained subjects. The click-pitch threshold ranged from 17.9 to 4.0 msec and the tone-pitch threshold from 24.2 to 9.6 msec as the frequency was increased from 125 to 8000 cps. As intensity was decreased from 110 dB to 30 dB SPL for a 1000 cps tone, the click-pitch and tone-pitch threshold increased from 4.4 to 10.4 msec and from 10.2 to 21.6 msec respectively.

Pathological Subjects. Luscher and Zwislocki (33) investigated the "minimum period of tonal quality" at frequencies between 200 and 10000 cps in both normal and pathological subjects. From their discussion, it appears that the minimum period corresponds to the click-pitch threshold described above. The minimum periods obtained from normal subjects agree closely with the click-pitch thresholds of Doughty and Garner (10). The intensity levels employed by Luscher and Zwislocki are not mentioned, but they report the minimum period to be somewhat independent of tonal intensity. Conductive hearing loss apparently does not affect the minimum period, but "in perceptive deafness the 'minimum period' is either partially shorter (presbyacusis) or throughout longer than normal".

Duration-Loudness Relationship

In general, the studies of normal subjects indicate that, as the duration of a tone is reduced below a critical time limit, the loudness decreases and the threshold of audibility is raised.

Normal Subjects. Miskolczy-Fodor (41) obtained intensity thresholds for tones of 300, 100, 30 10, and 3 msec durations. The amount of threshold change in decibels re the threshold for the 300-msec tone was established. These results are reported in the following table:

Duration of tone in msec	100	30	10	3
Mean threshold change in dB re 300 msec tone	1.55	5.87	10.44	14.82

From an analysis of the results, Miskolczy-Fodor reports that the critical time, below which threshold increases and loudness decreases, is 150 msec. It may be seen that a tenfold decrease in duration, from 100 to 10 msec or from 30 to 3 msec, results in approximately a nine dB increase in threshold.

Miskolczy-Fodor (41) also varied the duration of the tone while holding the intensity constant at several supra-threshold levels. The shortest duration at which a tone of a given supra-threshold intensity was perceived was defined as the time threshold. The time threshold for several such intensities are reported below:

Level above threshold (dB)	3	6	10
Time threshold (msec)	67.0	35.0	13.7

Thus, a tone 10 dB above the threshold for a 300 msec tone must be at least 13.7 msec in duration to be perceived by the normal subject.

Eisenberg (12) reports time threshold data obtained from both normal and clinical populations. The following table gives the time threshold obtained from normal subjects at several intensity levels above the threshold intensity for a 250 msec tone:

Supra-threshold level (dB)	5	6	7
Time threshold (msec) at 1000 cps	40.1	29.5	-
Time threshold (msec) at 4000 cps	39.1	32.7	25.4

These results agree well with those obtained by Miskolczy-Fodor (41).

Pathological Subjects. In subjects with recruitment, Miskolczy-Fodor (42) found that the threshold change associated with a decrease in duration is smaller than that observed in subjects with a normal cochlea.

Eisenberg's (12) clinical population was divided into several groups according to clinical audiometric results. The time threshold was assessed at 5 dB above threshold at several frequencies. Reported below are the time thresholds obtained at 1000 and 4000 cps from the group with a sensorineural loss:

Frequency (cps)	1000	4000
Time threshold (msec)	27.7	13.7

Comparison with the preceding table indicates that the sensorineural loss group yielded time thresholds which are considerably shorter than those obtained from normal subjects under comparable conditions. The time threshold for 1000 cps at 5 dB for the sensorineural loss cases is approximately equal to the time threshold at 6 dB in the normal group. As Eisenberg states, ". . . thus, the magnitude of auditory sensation is 1 dB greater than in normal ears" (12, p. 66). The time threshold for 4000 cps at 5 dB in the sensorineural loss group is considerably shorter than the time threshold at 7 dB in the normal group. Comparison of the obtained time threshold of 13.7 msec with Figure 12 of Eisenberg's Dissertation (12), which relates threshold shift in dB to log time, reveals that the time threshold at 5 dB above threshold in the pathological subject is approximately equal to the time threshold at 10 dB in normal subjects.

The studies cited above indicate that subjects with cochlear pathology have different loudness and pitch experiences at short durations than do subjects with normal cochleas. Evidently, at equal intensity levels above threshold, tones of different durations result in different loudness experiences.

Difference Limen for Duration

Since the advent of electroacoustic equipment there have been but four studies of the differential sensitivity of the ear to tonal durations. The earliest two, by Stott (57) and Henry (24), although employing electronic tone sources, still relied on mechanical control of duration. The two remaining experiments, by Mencke (38) and Milburn (40), employed electronic equipment exclusively, to produce, control, and measure all tones and durations.

Stott (57) conducted a study which included the determination of the Difference Limen for Duration across reference durations that ranged from 200 to 4000 msec. His apparatus for controlling the stimulus duration was essentially mechanical and inaccuracies of up to 3.8 msec at the shortest durations were measured. Larger inaccuracies were present at longer durations. A 1000 cps tone was used for all measurements of DLD. The intensity of the tone was not specified.

The method of constant stimuli was employed. A complete stimulus presentation included a reference and comparison tone separated by an interval of 1500 msec. In half of the presentations the reference tone preceded the comparison tone and in half of the presentations it followed the comparison tone. The comparison tone was 0, 5, 10, 15, or 20 per cent longer than the reference tone. The subject was to decide whether the second tone was longer, shorter, or equal to the first tone. Psychometric functions relating the percentages of "variable longer" judgments to comparison tone duration were plotted and the DLD defined as the duration where the function crossed the seventy-five per cent correct response level. The DLDs obtained in this manner ranged from 28.36 to 642.96 msec for the 200 and 4000 msec reference durations, respectively.

Henry (24) reported a study of the DLD for several normal hearing subjects. Stimulus durations were controlled by a cam timer which closed microswitches. The duration of closure of the microswitches was controlled by micrometers. The resulting tones were calibrated for duration with an oscillograph. Henry's apparatus presumably permitted better control and measurement of the durations than did Stott's (57).

A series of tones was presented to the subject who was instructed to report whether the series consisted of repetitions of the same duration or of alternating duration. The size of the increments are not reported.

The results obtained with this method are reported by Henry as relative DLs (increment perceived seventy-five per cent of the time/reference duration) and have been converted into absolute DLs (the increment perceived seventy-five per cent of the time) for this discussion. The effects of reference duration and intensity upon the DLD were studied employing a 500-cps tone presented at 50 dB above the threshold obtained with a tone of 500 msec duration. As the reference duration increased from 32 to 480 msec the DLD increased from 8.99 to 68.64 msec. As intensity increased from 20 dB to 80 dB SL, the DLD decreased. The effect of stimulus frequency was assessed at the 77 msec reference duration at an intensity of 50 dB SL. DLDs decreased from 22.72 to 12.01 when frequency was raised from 125 to 1000 cps. The values obtained at 500, 1000, and

2000 cps were essentially equivalent.

Mencke (38) and Milburn (40) employed identical procedures and instrumentation to measure the DLD in normal subjects. The procedure was similar to that employed by Butler and Albrite (4) to assess the DLF in pathological subjects. Inasmuch as the present study used the same procedure, and similar instrumentation, a complete discussion of the technique will be presented in a later chapter. Briefly, a pair of tones, identical in frequency and intensity and separated from each other by a 500 msec silent interval, was presented to the subject. The duration of the second, or comparison, tone differed from the first, or reference, tone by a predetermined amount. The subject was to report whether the comparison tone was longer or shorter than the reference tone. He was immediately informed as to the accuracy of his judgment. A sequential analysis of the responses was used to infer whether the subject could discriminate a given duration difference at least seventy-five per cent of the time or no better than fifty per cent of the time. Initially, the difference between the reference and comparison tones was easily recognized. When it had been determined that the subject had discriminated successfully a duration difference, the difference was reduced in serial steps until a duration difference could not be discriminated. The least difference in duration which a subject could discriminate was considered to be the DLD.

The instrumentation employed by Mencke (38) and Milburn (40) allowed relatively accurate control and measurement of intensity, frequency, and duration. All durations were within .5 msec of the intended value.

Both investigators measured the DLD at 250, 1000, and 4000 cps at 10 dB and 50 dB sensation levels. Mencke (38) studied reference durations of 40, 60, 80, and 100 msec and Milburn (40) investigated reference durations of 300, 500, and 1000 msec.

The DLDs obtained by Mencke (38) were uniformly much smaller than those obtained by Henry (24). The values ranged from 1.8 to 5.6 msec when reference tones were used under conditions of 1000 cps, 50 dB SL, 60 msec and 250 cps, 10 dB SL, 80 msec. Several subjects were able to discriminate a one msec difference in duration under some of the experimental conditions. In general, Mencke (38) found that the magnitude of the DLD: (a) increased when reference duration was increased from 40 msec to 100 msec, (b) decreased when intensity was increased from 10 dB to 50 dB SL, (c) changed as a function of frequency, depending on the reference duration at which it was measured.

The DLD, in msec, obtained by Milburn (40) at reference durations of 300, 500, and 1000 msec for 250, 1000, and 4000 cps at 10 dB and 50 dB above threshold are displayed in Table 1.

The magnitude of the DLDs measured by Milburn (40) are smaller than those obtained in the same reference duration range by previous investigators (24, 57). Inspection of Table 1 indicates that the DLD increases with an increase in the reference duration and decreases with an increase in intensity. Frequency did not have a significant effect on the size of the DLD in this range of durations.

The DLDs obtained by Mencke (38) and Milburn (40) are much smaller than those obtained by Stott (57) and Henry (24). The discrepancy is probably due to several factors, among which are: the apparatus, which permitted the later investigators more accurate control of the duration of the tones; and the experimental technique of Mencke (38) and Milburn (40), which provided for a two-alternative, forced-choice, and immediate knowledge of the accuracy of the judgment. The present study was designed to

TABLE 1

MEAN DIFFERENCE LIMEN FOR DURATION AND STANDARD DEVIATIONS CALCULATED FROM DATA OBTAINED AT THREE REFERENCE DURATIONS, TWO SENSATION LEVELS, AND THREE FREQUENCIES, FROM SUBJECTS WITH NORMAL HEARING

Reference Duration (msec)	Sensation Level (dB)	Frequency (cps) 250 Mean DLD	250 S.D.	1000 Mean DLD	1000 S.D.	4000 Mean DLD	4000 S.D.
300	10	13.4	3.06	12.8	4.24	11.9	3.78
	50	9.6	6.90	7.2	3.71	7.9	3.21
500	10	14.8	4.96	15.0	6.80	14.3	4.57
	50	9.3	4.52	13.7	4.42	13.5	5.82
1000	10	27.5	9.79	33.0	12.74	31.5	11.56
	50	26.00	11.50	27.5	12.30	25.0	12.47

extend the information gained by Mencke (38) and Milburn (40) to a group of subjects with cochlear pathology. This investigation utilized their technique and a simplified version of their apparatus.

CHAPTER III

DESIGN OF THE INVESTIGATION

Introduction

It is apparent from the preceding review of the literature that subjects with cochlear pathology behave differently than normal subjects when required to differentiate small differences in intensity and frequency. The pathological subject can detect a smaller intensity change than a normal subject, but is poorer at discriminating a small frequency change. A search of the literature failed to reveal any information relative to the ability of the pathological subject to discriminate small differences in the duration of successive tones.

The studies of Mencke (38) and Milburn (40), which were cited previously, provide data concerning the DLD obtained from normal subjects over a wide range of reference duration (40 msec to 1000 msec), frequency (250 cps to 4000 cps), and intensity (10 dB to 50 dB SL). The present study was designed to investigate the differential sensitivity of the subject with cochlear pathology to small differences in duration between successive tones.

Miskolczy-Fodor (41, 42), Eisenberg (12), and Harris, Haynes, and Myers (22) have demonstrated that the normal relationship existing between duration and loudness is altered by a cochlear pathology. In order to insure that the DLDs measured in the present study were truly

DLD and were not contaminated by a loudness-duration interaction, reference durations above 150 msec were studied. It will be recalled that 150 msec is the critical time limit above which, according to Miskolczy-Fodor (41), an increase in duration will not result in an increase in loudness.

As has been mentioned, the subjects selected to participate in the present study were presumed to have hearing loss due to cochlear pathology. Among the several causes of a cochlear lesion, one in particular, acoustic trauma, recommends itself to this study. First, it is found in a sizable proportion of the adult male population. Second, it results in a characteristic hearing loss which is easily recognized by its audiometric configuration. The person with acoustic trauma may be expected to demonstrate normal hearing in the low and mid-frequency ranges and a sharply falling hearing loss that is most severe around 4000 cps. Third, this configuration is not only easy to recognize, but, more important for this study, it can provide both a normal frequency and a pathological frequency in the same ear. Thus, the DLD assessed at the pathological frequency and the DLD measured at the normal frequency may be compared with the results obtained under comparable experimental conditions from a normal group in order to ascertain the effect of the pathology on the ability to discriminate small differences in the duration of successive tones. Ample precedence for this procedure has been demonstrated in the preceding review of the literature concerning the DLs for intensity and frequency.

The present study measured the DLD in ten subjects with acoustic trauma at three reference durations (300, 500, and 1000 msec), two frequencies (1000 cps and 4000 cps) and two sensation levels (10 dB and

50 dB). The results obtained under these experimental conditions were compared with the results obtained by Milburn (40) under comparable conditions.

The details of subjects, instrumentation, and procedures will be discussed in subsequent sections of this chapter.

Subjects

The experimental group employed in the present experiment consisted of nine men and one woman between the ages of twenty-one and thirty-six years (Appendix A). Each subject had a history of exposure to noise and had normal hearing at 1000 cps, but a bilateral hearing loss at 4000 cps. Figure 1 displays the mean thresholds for the test ear.

Each prospective subject underwent a thorough screening procedure to determine whether he was to be included in the experimental group. The screening procedure included a pure-tone air-conduction and bone-conduction audiometric evaluation and a Short Increment Sensitivity Index (SISI) test. In order to be included in the experimental group, the test ear of each subject met the following criteria:

1. The audiometric thresholds at 125, 250, 500, 1000, and 2000 cps did not exceed 10 dB re USPHS norms.

2. The air-conduction and bone-conduction thresholds at 4000 cps were at least 20 dB but did not exceed 50 dB. Figure 1 displays the mean thresholds at each frequency for the ten subjects.

3. The SISI at 4000 cps equalled or exceeded seventy per cent.

The last criterion was selected to maximize the probability that the cochlea is the site of lesion. Jerger, Shedd, and Harford (29) have shown that SISI scores of seventy per cent or more are associated with

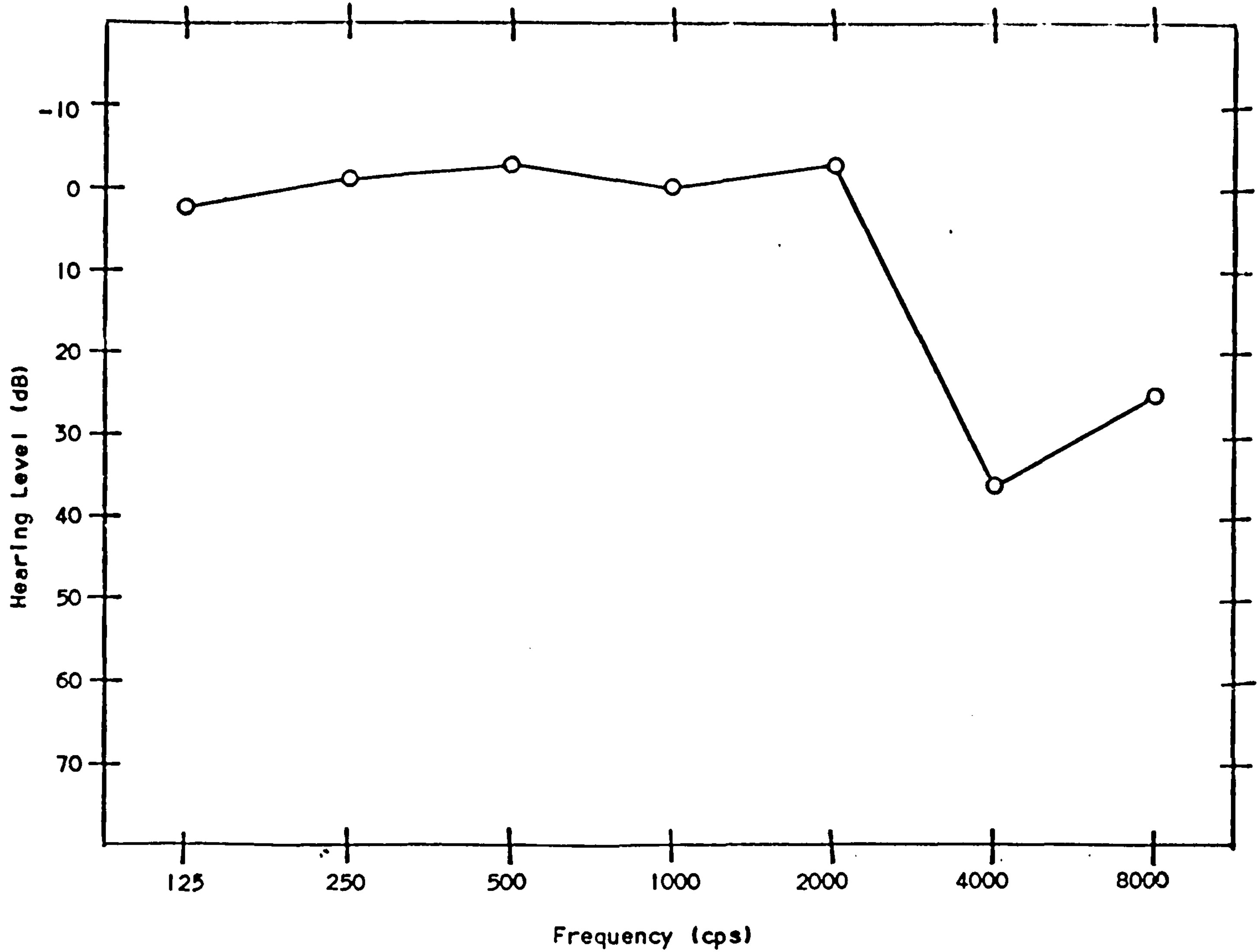

Figure I. Mean hearing level in dB re USPHS norm for the 10 subjects of the experimental group.

hearing losses that are diagnosed as being of cochlear origin. All subjects had a SISI score of eighty-five per cent or more at 4000 cps in the test ear. The mean SISI score for the ten subjects was 96.5 per cent.

The choice of experimental ear was governed by the above criteria. If both ears of a given subject met the criteria, the ear displaying greater acuity at 4000 cps was selected in order to eliminate the possibility of the participation of the non-test ear.

Apparatus

All tests, screening and experimental, were conducted in specially-constructed sound-isolated two-room testing suites at the Speech and Hearing Center, University of Oklahoma Medical Center.

Screening Apparatus

A commercially available pure tone audiometer (Allison, Model 21B) feeding either of two earphones (Telephonic, Type 39-10Z) or a low impedance hearing-aid type bone-conduction oscillator (Radioear B-70A) was used in the screening tests administered to all prospective subjects. The earphones were mounted in MX 41-AR cushions and held in a standard headband. The bone-conduction oscillator was held in a standard spring-steel oscillator headband.

The acoustic output of the air-conduction system was calibrated by means of an audiometer calibration unit (Western Electric Condensor Microphone Complement, Type 100/DE used in conjunction with a Western Electric microphone, Model 640 AA and a Hewlett Packard Vacuum Tube Voltmeter, Model 400H).

The output of the bone-conduction system was evaluated periodically with the aid of an Artificial Mastoid (Beltone, Model 5A).

The SISI test procedure has been described in a previous section. Briefly, a steady-state pure tone was presented at a sensation level of 20 dB monaurally to the prospective subject. An amplitude increment of one dB was added to the steady tone automatically once every five seconds. The subject was requested to respond to each increment heard. Twenty such increments were presented and the number of responses recorded. It was necessary to measure the SISI only at 4000 cps since normal hearing at other frequencies was required. A score of seventy per cent was necessary for inclusion in the experimental group. The SISI apparatus is an integral component of the audiometer employed for the screening procedures.

The audiometer was located in the equipment room and the earphones and bone-conduction oscillator were in the subject's room of the test suite. Visual contact between the control room and the subject's room was maintained through an acoustically-isolated window. Appropriate auditory contact was provided by a talk-back system incorporated in the audiometer.

Experimental Test Apparatus

Figure 2 represents a flow diagram of the experimental instrumentation.

Pure-tone stimuli were provided by one of two audio-oscillators (Hewlett-Packard, Model 200 ABR). The rise-decay time (16 msec) was controlled by an electronic switch (Grason Stadler, Model 829C). The output of the electronic switch was fed into the external input of a speech audiometer (Grason Stadler, Model 162) which provided the necessary control of the intensity and switching of the stimuli. The test

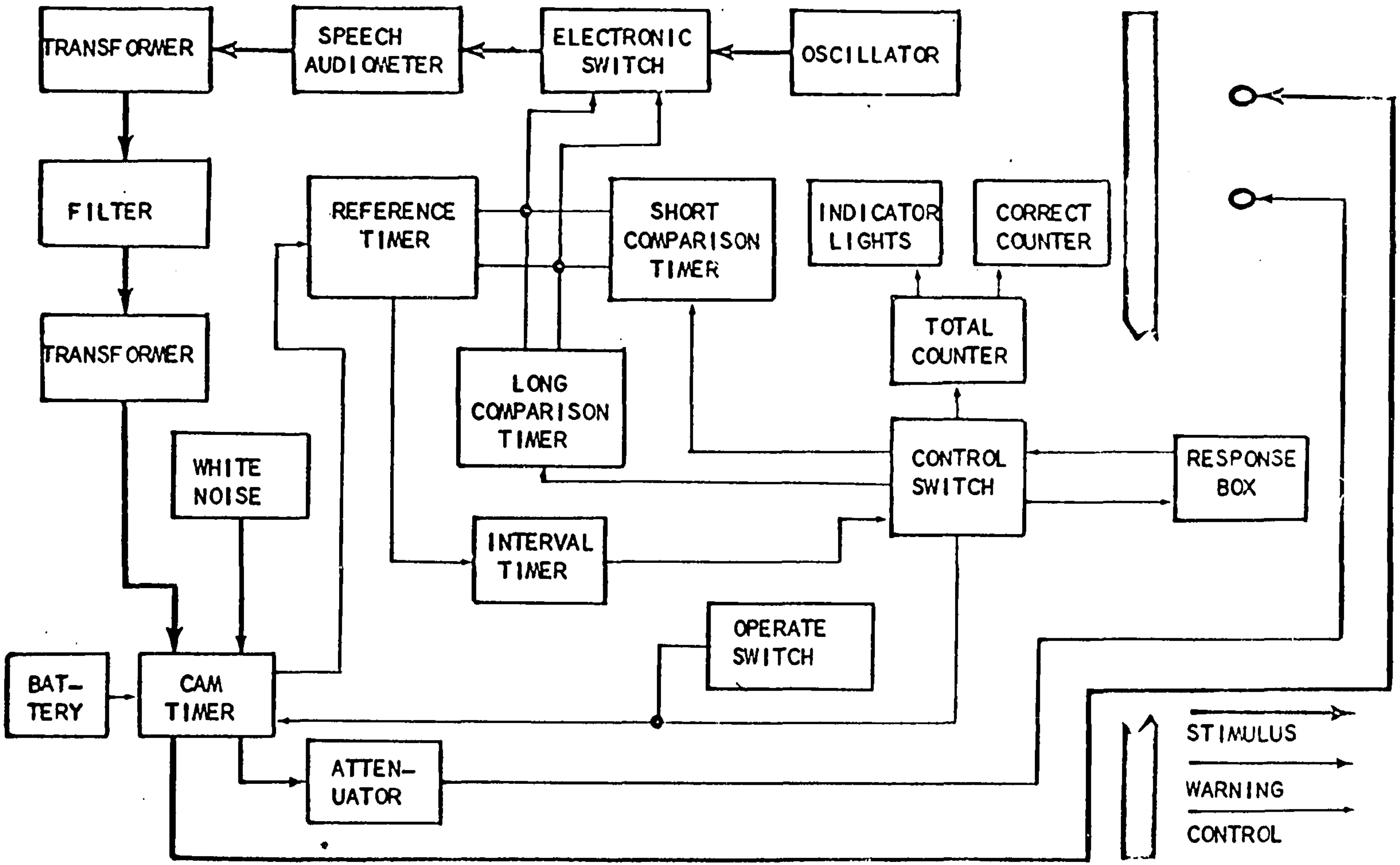

Figure 2. Flow diagram of the experimental apparatus.

signal then was delivered through one of two impedance matching transformers (United Transformer Company, Model LS 33) to a filter (Allison Labs, Model 2B) which was adjusted to pass only those frequencies above 600 cycles. The second transformer matched the impedance of the filter and the subject's earphone (Sharpe, Type B, Model H A-10). A warning signal, produced by a white-noise generator (Grason Stadler, Model E5593A), and controlled by an attenuator (Hewlett-Packard, Model 350A) fed a companion earphone. Both earphones were mounted in dome-type earmuffs with gelatin-filled cushions and were held in place by an adjustable headband provided by the manufacturer.

Stimulus durations were controlled by three pairs of pulse generators (Tektronix, Type 161), each pair triggered by a waveform generator (Tektronix, Type 162). The stimulus sequence and the duration of the silent interval were also controlled by waveform and pulse generators. The outputs of the pulse generators controlling stimulus durations triggered the electronic switch, thus turning the tone on and off.

A control panel, containing a cam-timer (Industrial Cam Timer Corporation) and several switches permitted initiation of the sequence of warning signal, reference duration, silent interval, and either of the comparison durations. A push-button switch on the face of the panel activated the cam-timer and began the sequence. A subject's response reactivated the cam-timer for each subsequent presentation of the stimulus sequence. The cam-timer assembly consisted of four microswitches. The first switch controlled the cam-timer's operating period. The second switch controlled the presentation of the warning signal. The signal was one-half second in duration and followed by two seconds the activation of the timer, whether by the experimenter or the subject's response. The third microswitch permitted the voltage from a dry-cell battery to trigger the waveform generator-pulse generator complex which controlled the reference and comparison durations. The fourth switch was inserted in the line to the test earphone. It was open during the period the cam-timer was in operation and closed only during the time the stimuli were being presented to the subject. The selector switch which controlled whether the longer or shorter comparison duration was paired with the reference duration was also mounted on the face of the control panel.

The subject was given an aluminum box which contained a three-position, spring-loaded, center-positioned, switch and a pair of lights, one red and one blue. The subject was instructed to judge whether the comparison tone was longer or shorter than the reference tone. The judgment was reported by the subject's moving the switch to an appropriately labeled position. A correct judgment lighted the blue lamp while the red lamp informed the subject of an incorrect judgment. In addition, the response activated the cam-timer and recycled the stimulus sequence.

A pair of lamps, identical to those which informed the subject of the correctness of his judgment, was mounted on the control panel to provide the experimenter with the same information. Two counters (PIC-600), mounted on the panel, kept an accurate count of the number of correct responses and the total number of responses. The counters and lamps also were activated by the subject's response switch.

Experimental Control Apparatus

The signal frequency was selected with the aid of an interval timer and counter (Berkeley, Universal Eput and Timer, Model 7350, or Transistor Specialties, Incorporated, Aptimeter, Model 261). Following a test set the frequency was rechecked. The interval timer also was used to measure and monitor samples of stimulus and interval durations prior to, during, and following each experimental set. All durations were maintained within .5 msec of nominal intended durations.

Prior to each test set the gain control of the speech audiometer was adjusted so that the signal peaked at "0" on the instrument's VU meter. Following the test set, the VU meter was again peaked to insure the output of the instrument had not changed.

A rise-decay time of 16 msec for the tonal stimuli was selected and maintained with the aid of an oscilloscope (Tektronix, Model 532).

In addition, an appropriate system to permit the experimenter to monitor all signals auditorially was provided.

The earphones and subject's response box were contained in the subject's room. The noise level in the room is below 30 dB as measured on the "C" scale of a sound level meter (General Radio, Model 759B). All other equipment described above was contained in the adjacent control room.

Procedure

The purpose of the study was to determine the DLD in the subject with a cochlear pathology. The maximum hearing impairment of the experimental group was at 4000 cps. The DLD for reference durations of 300, 500, and 1000 msec was determined at 1000 and 4000 cps at 10 dB and 50 dB sensation levels. Thus, the DLD was assessed at the frequency at which the cochlear pathology was manifested (4000 cps) and at a frequency at which hearing was normal (1000 cps). Comparisons of the DLD obtained at the two frequencies was possible as well as comparison with the DLDs obtained from a normal group by Milburn (40), employing an identical procedure and similar instrumentation.

Each reference duration was paired with a comparison duration. The comparison duration was either longer or shorter than the reference duration by a predetermined amount (ΔT).

Several values of ΔT were used with each reference duration. The ΔTs ranged in magnitude from values which were discriminated with ease by a naive, unpracticed subject to differences which were impossible to detect.

Each test set contained a specific reference duration paired with comparison durations which were either longer or shorter than the reference duration by a specific ΔT. For example, if the reference duration was 300 msec and the ΔT was 50 msec, the comparison duration of any pair was either 250 msec or 350 msec. A random schedule determined whether the comparison duration of any pair was longer or shorter than the reference. Thus, during a given set of trials, the subject was required to discriminate but one ΔT.

The largest value of ΔT was presented first. When it had been determined that the subject discriminated the difference between the reference and comparison durations at least seventy-five per cent of the time, the next smaller value of ΔT was presented. A short rest period was provided while the apparatus was adjusted. Successively smaller values of ΔT were presented until the smallest value which could be discriminated seventy-five per cent of the time had been determined. That value was defined as the DLD.

Specifically, the first duration differences the subjects were asked to discriminate were 60, 100, and 200 msec for the 300, 500, and

1000 msec reference durations respectively. Upon successful discrimination of these differences, the magnitude of the ΔT was reduced. When the 300 and 500 msec reference durations were employed, the following differences between reference and comparison tones were used successively: 30, 20, 15, 10, and 5 msec. When the subject was unable to differentiate between tones at the seventy-five per cent level, the duration difference was increased four msec and testing continued. When that ΔT was successfully discriminated, the ΔT was reduced in one msec steps until the smallest difference in duration that could be distinguished was determined.

After successful discrimination of the 200 msec difference between reference and comparison stimuli at the 1000 msec reference duration conditions, the following values of ΔT were employed: 100, 60, 50, 40, 30, 20, 10, and 5 msec. When the difference became so small it could not be discriminated, the difference in duration was increased five msec and testing continued. No further decrease in difference between tones was utilized. The DLD was defined as the smallest difference in duration between the reference and comparison tones that was discriminated seventy-five per cent of the time. This technique represents a modification of the method of limits.

For each set of ΔT, the number of correct responses needed to pass the task (seventy-five per cent correct response) at the .05 level of confidence or fail (fifty per cent correct response) at the .01 level of confidence was dictated by a table (Appendix B) of sequential analysis (61). The use of sequential analysis of the responses reduced the number of stimulus presentations necessary to permit a decision as to whether the task had been passed or failed, thus reducing the time required for the test. Sequential analysis permits the experimenter the additional advantage of specifying the confidence level at which the task is passed or failed.

The frequency as well as the sensation level of the signal that the subject received remained constant throughout a test set. The DLD (obtained from each of the ten subjects) was measured under twelve combinations of reference duration, frequency, and sensation level. Thus, twelve DLDs were obtained from each subject.

A two-alternative, forced-choice technique, in which each alternative had an equal likelihood of occurrence, was employed. Each subject was instructed (Appendix C) to compare the duration of the second of two tones to the first. He was to indicate whether the second tone was longer or shorter than the first by moving a switch to an appropriately labeled position. The response resulted in an indication to the subject of the accuracy of the judgment, a recording of the accuracy of the response on the experimenter's control panel, and the initiation of another pair of stimuli for comparison. The time between successive pairs of stimuli was thus partly determined by the speed with which a subject judged and responded to each pair. The sequence of events which followed each response was as follows:

1. A two second silent interval
2. A 500-msec white-noise warning signal to the non-test ear
3. An 800-msec silent interval
4. The reference stimulus
5. A 500-msec silent interval
6. The comparison stimulus

Following instructions to the subject relative to the experimental task, the test earphone was placed over the appropriate ear and the response box given to the subject. Threshold for a tone of appropriate frequency and duration was obtained in the test ear. An ascending technique employing two dB steps was utilized.

Once threshold had been established and the intensity of the stimuli adjusted to the proper sensation level, the subject was provided with four pairs of reference-comparison stimuli in order to familiarize him with the signals. The first two pairs combined the reference and longer comparison stimuli and the last two combined the reference and shorter comparison stimuli. The subject was informed of the order of presentation and required to respond appropriately.

The test sequence of warning signal and reference-comparison pair was initiated by the experimenter. The subject then judged whether the comparison stimulus was longer or shorter than the reference stimulus and responded by moving the switch accordingly. Immediate knowledge of the accuracy of the judgment was provided by the system of lights on the response box. The subject's response was also recorded on the experimenter's control panel by the system of lights and counters. In addition, the response activated the cam-timer. Another pair of stimuli were thus presented for judgment. The preceding sequence of events was repeated as often as necessary for the subject to pass or fail the task according to the table of sequential analysis.

Once the DLD for a given combination of reference duration, frequency, and intensity had been determined, a rest period was provided and another combination, pre-selected at random, was presented. The procedure described above was followed under each stimulus combination and with each subject.

As might be anticipated, the subjects differed as to prior experience with tasks which require careful listening. In order to reduce the effect of prior experience, each subject received extensive practice. Practice data were collected from a subject for eight combinations of reference duration, frequency, and sensation level under experimental conditions. Since these data represented practice, they are not reported. The experiment, itself, was conducted following the practice.

Several appointments were required to complete the screening evaluation, practice, and experimental determinations of the DLD. Subjects were paid for the time required.

The experimental design described above incorporates several features which served to minimize experimental error, sampling error, and intersubject variability. These are: (1) frequent calibration of the experimental parameters, (2) the warning signal, (3) the use of young subjects who were highly practiced and rewarded for their time, (4) frequent rest periods, (5) the technique employed, which provided the subject immediate knowledge of the accuracy of his judgments and sequential analysis of the responses.

The data obtained were analyzed statistically by means of an analysis of variance technique. A completely randomized block design was utilized. The analysis of variance performed by Milburn (40) included data obtained at 250 cps, as well as the frequencies of importance to this investigation. In addition, the analysis was performed on the relative DLD ($\Delta T/T$) rather than the absolute DLD (ΔT). For these reasons, his data for 1000 and 4000 cps were submitted to an analysis of variance identical to that performed on the data of the present study.

Summary

The purpose of the present study was to determine the effect of cochlear pathology on the ability of the subject to discriminate small differences in the duration of successive, pure-tone stimuli.

The study was designed to measure the difference limen for duration (DLD) at three reference durations, two frequencies, and two sensation levels in subjects with cochlear pathology. DLDs were obtained for reference durations of 300, 500, and 1000 msec. Pure tones of 1000 and 4000 cps presented at 10 dB and 50 dB sensation levels were employed. Twelve DLDs for each of ten subjects were determined.

The experimental procedure represents a modification of the method of limits. Highly practiced, well-motivated subjects were utilized. Immediate knowledge of results and sequential analysis of the responses were provided.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of the present investigation was to determine the effect of cochlear pathology on the ability to discriminate small differences in the duration of successive, pure-tone stimuli. The Difference Limen for Duration (DLD) was obtained from ten subjects with acoustic trauma at three reference durations (300, 500, and 1000 msec), two sensation levels (10 and 50 dB), and two frequencies (1000 and 4000 cps). The subjects selected met rigorous criteria as to the etiology and extent of the hearing loss. In addition, they were practiced extensively prior to the experiment, were given immediate knowledge as to the accuracy of their performance, and were financially rewarded for their participation.

By presenting 1000 and 4000-cps tones to subjects with acoustic trauma, measurements of the DLD were obtained at one frequency at which hearing was normal (1000 cps) and at one frequency where a loss due to a cochlear pathology existed (4000 cps). Thus, by comparing the DLD obtained at the two frequencies an indication of the effect of the cochlear pathology could be obtained.

Milburn (40) in a previous study employing an identical technique and essentially the same apparatus, obtained DLDs from normal subjects at the same combinations of reference, duration, sensation level, and frequency as were used in the present study. The DLDs obtained from the pathological subjects of the present investigation were compared with those obtained under identical conditions from the normal subjects of Milburn's study.

The stimuli consisted of a pair of tones identical in frequency and intensity but differing in duration. The reference tone always preceded the comparison tone by a fixed silent interval. The comparison tone was either longer or shorter than the reference tone by a predetermined duration (ΔT). The subject's task was to report whether a given pair of tones contained the longer or shorter comparison stimulus. The difference between the reference and comparison tones was diminished until the smallest difference in duration the subject could detect consistently was discovered. This difference was defined as the DLD for that subject for that combination of reference duration, sensation level, and frequency.

The DLD for each combination of reference duration, sensation level, and frequency was averaged over subjects. The data obtained by the procedures outlined above are listed in Table 2 and will be discussed in subsequent sections in terms of their magnitude, the effects of reference duration, frequency, sensation level, and subject variability. In addition, comparisons were made with the data obtained from normal subjects by Milburn, which may be found in Table 1.

Magnitude of the DLD

The mean Difference Limen for Duration obtained from the ten subjects of this study, averaged over all twelve experimental conditions, was 19.2 msec. The mean DLD obtained at each of the experimental conditions

TABLE 2

MEAN DIFFERENCE LIMEN FOR DURATION AND STANDARD DEVIATIONS CALCULATED FROM DATA OBTAINED AT THREE REFERENCE DURATIONS, TWO SENSATION LEVELS, AND TWO FREQUENCIES FROM SUBJECTS WITH ACOUSTIC TRAUMA

Reference Duration (msec)	Sensation Level (db)	Frequency (cps) 1000 Mean DLD	Frequency (cps) 1000 S.D.	Frequency (cps) 4000 Mean DLD	Frequency (cps) 4000 S.D.
300	10	14.4	5.66	15.2	5.69
	50	11.1	6.01	10.6	2.76
500	10	13.7	5.60	17.8	8.82
	50	12.5	6.06	13.1	6.64
1000	10	30.5	14.03	32.5	15.67
	50	32.0	15.13	26.5	12.92

has been plotted in Figure 3. It may be observed that the size of the DLD for the twelve conditions ranges from 10.6 msec for the 300-msec, 50-dB, 4000-cps stimulus to 32.5 msec for the 1000-msec, 10-dB, 4000-cps condition. The smallest DLD obtained as raw data (Appendix D) was three msec and the largest was fifty-five msec, a range of fifty-two msec.

Under experimental conditions which differed only with regard to subject selection, Milburn (40) obtained a mean DLD for all experimental conditions of 17.8 msec. Inspection of Table 1 reveals that the 300-msec, 50-dB, 1000-cps and the 1000-msec, 10-dB, 1000-cps mean DLDs of 7.2 and 33.0 msec respectively constituted the extreme mean values obtained for the twelve experimental conditions. The smallest and largest DLD obtained from any of the normal hearing subjects of his study are identical to those reported in the preceding paragraph for the subjects of the present study. An analysis of variance (Appendix E) applied to the data of the two studies resulted in an F of 0.44 which indicates that, within the limits of these studies, subjects with acoustic trauma do not differ at the .05 confidence level from normal subjects with regard to the ability to discriminate small differences in the duration of successive pure tone auditory stimuli.

Comparisons between Frequencies

Subjects with acoustic trauma were employed in the present investigation because they typically present a hearing loss which is specific as to site of lesion and as to the frequency range affected. Thus, the subjects of this study manifest normal hearing at 1000 cps and hearing loss due to a cochlear pathology at 4000 cps.

The relationship between the DLDs obtained at the two frequen-

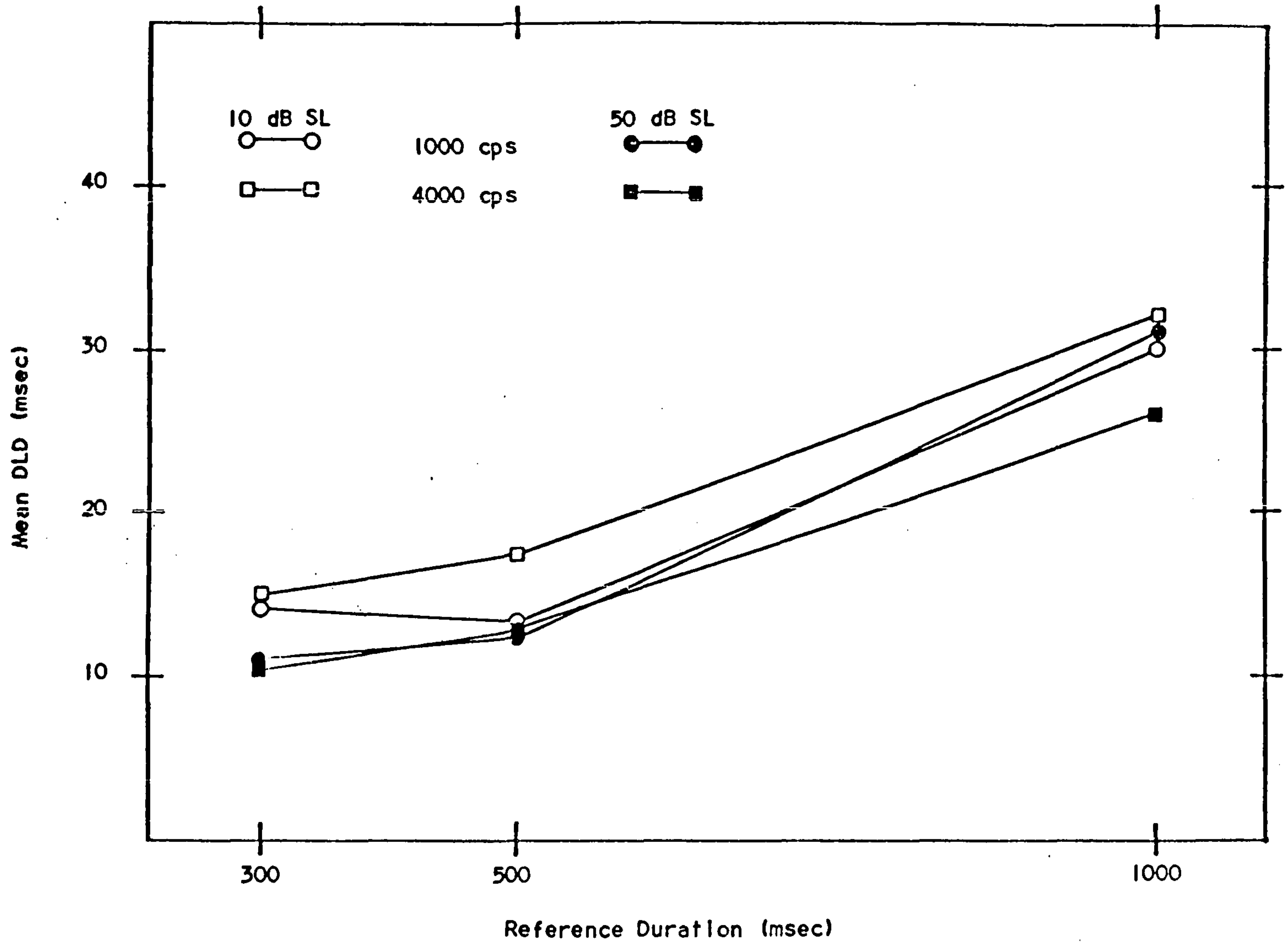

Figure 3. Mean DLDs at two frequencies and two sensation levels as a function of reference duration.

The mean DLD averaged over the three reference durations and the two sensation levels for 1000 and 4000 cps was 19.0 and 19.3 msec, respectively. An analysis of variance (Appendix E) indicated the observed difference between the two frequencies is not significant ($F = 0.013$ $P > .05$).

When a similar between-frequency comparison of Milburn's data is performed (Appendix E), the mean DLDs of 18.2 and 17.4 msec for 1000 and 4000 cps, respectively, are not found to be significant ($F = 0.370$ $P > .05$).

Comparisons of the mean DLDs obtained by Milburn (40) from normal subjects with those from the pathological subjects of the present study are displayed in Table 3 and Figures 7 through 12.

Between Studies

In Figure 7, the two studies are compared with regard to the mean DLD obtained for 1000 cps at the 10-dB sensation level as a function of reference duration. The normal subjects were slightly more sensitive than the pathological subjects at the 300-msec reference duration and less sensitive at the 500-msec and 1000-msec conditions. The largest difference between studies, 2.5 msec, is at the last condition.

The studies are compared at the 1000-cps, 50-dB sensation level condition in Figure 8. Milburn's normal subjects are more sensitive at the 300-msec and 1000-msec conditions and less sensitive at the 500-msec condition than the pathological subjects. The largest difference between groups, again under the 1000-msec condition, is 4.5 msec.

Figure 9 represents a comparison between the two studies at 1000 cps averaged across sensation levels as a function of reference duration. The largest difference between studies, 2.8 msec, occurs at the

TABLE 3

MEAN DIFFERENCE LIMENS FOR DURATION FOR TEN SUBJECTS WITH ACOUSTIC TRAUMA (PRESENT STUDY) COMPARED WITH DATA OBTAINED FROM NORMAL SUBJECTS BY MILBURN AT IDENTICAL CONDITIONS OF REFERENCE DURATION, SENSATION LEVEL, AND FREQUENCY

Reference Duration (msec)	Sensation Level (dB)	Frequency (cps) 1000		Frequency (cps) 4000	
		Milburn	Present Study	Milburn	Present Study
300	10	12.8	14.4	11.9	15.2
	50	7.2	11.1	7.9	10.6
500	10	15.0	13.7	14.3	17.8
	50	13.7	12.5	13.5	13.1
1000	10	33.0	30.5	31.5	32.5
	50	27.5	32.0	25.0	26.5

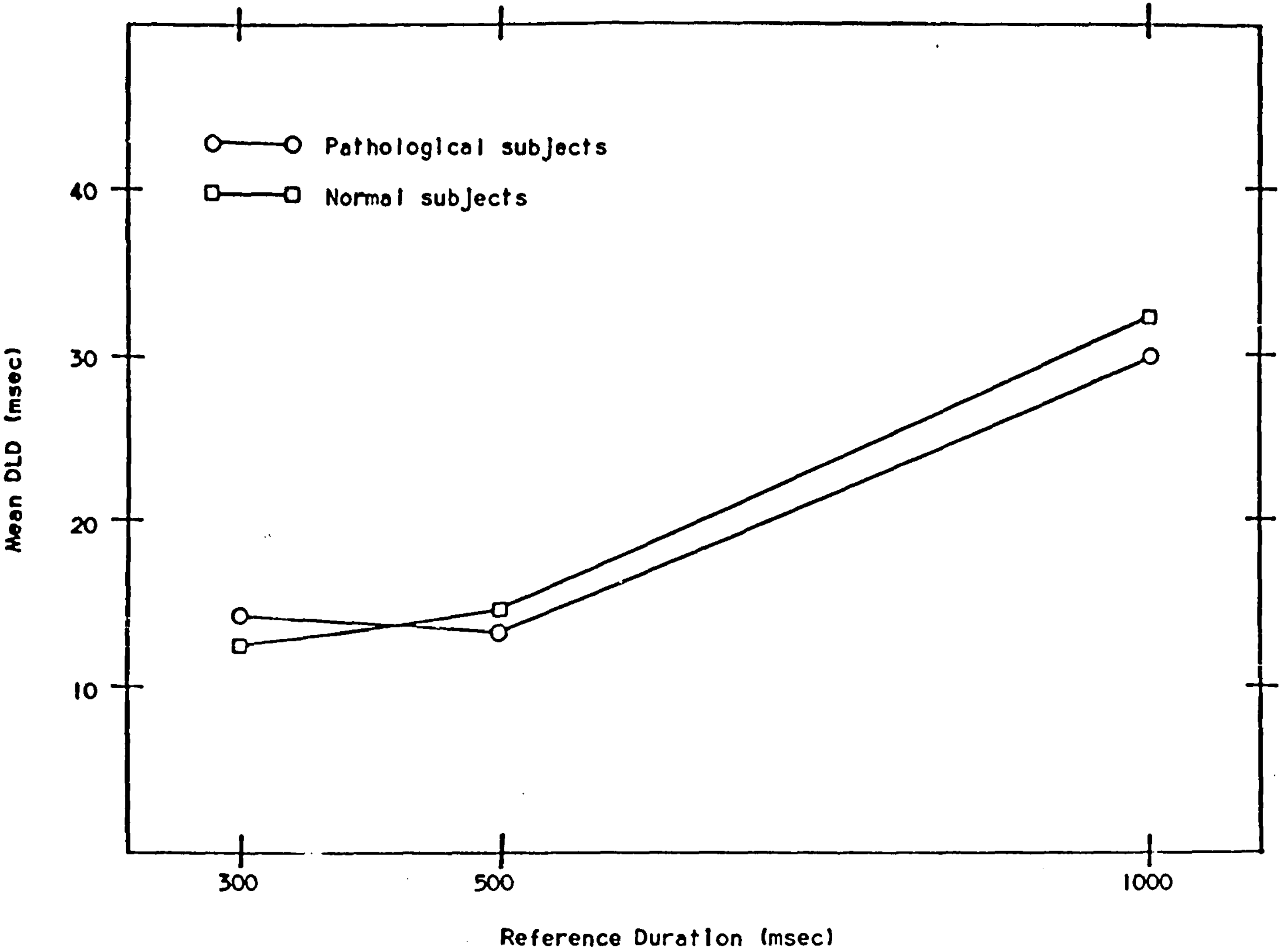

Figure 7. Mean DLDs at 1000 cps at 10 dB sensation level obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

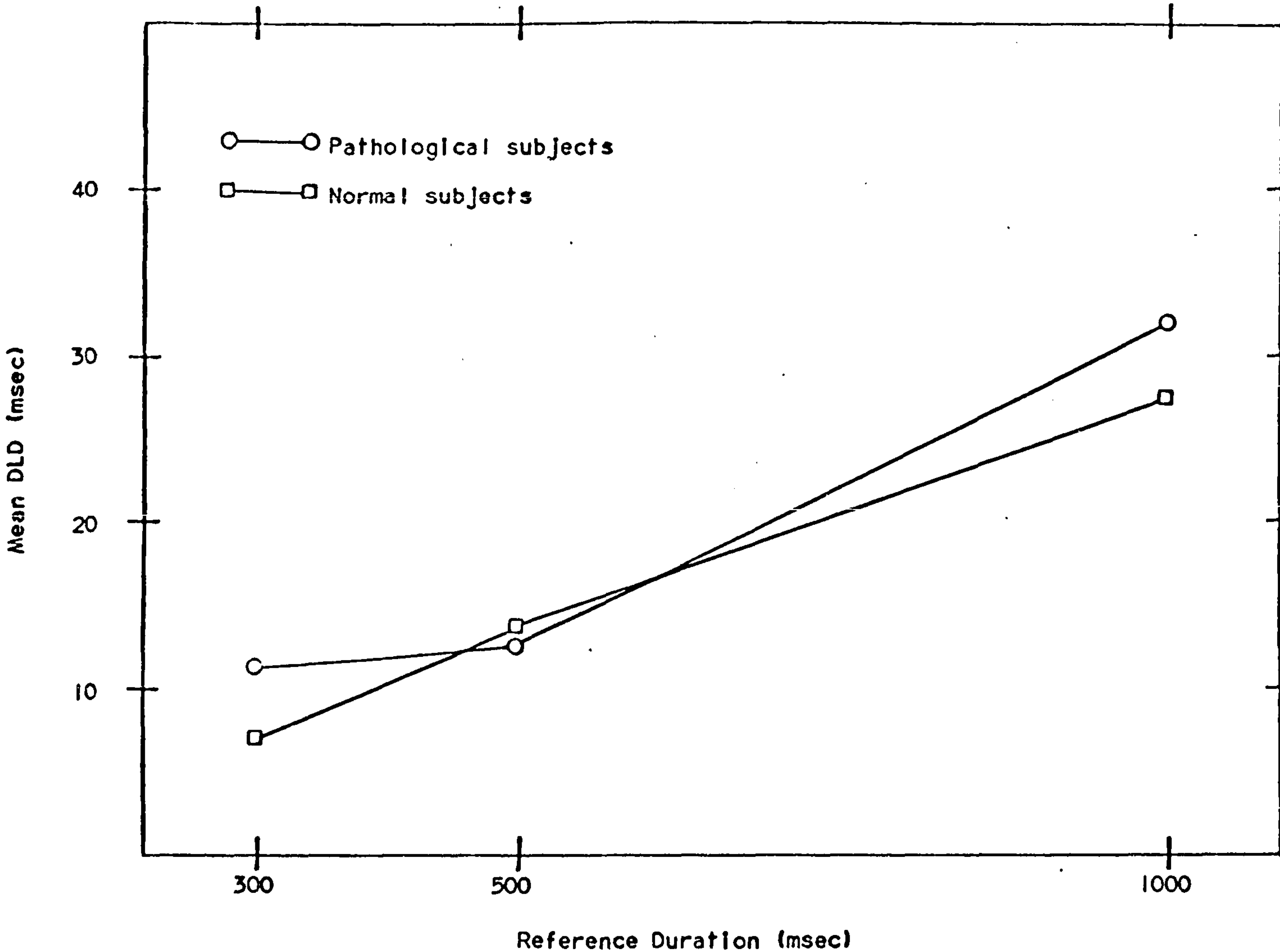

Figure 8. Mean DLD at 1000 cps at 50 dB sensation level obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

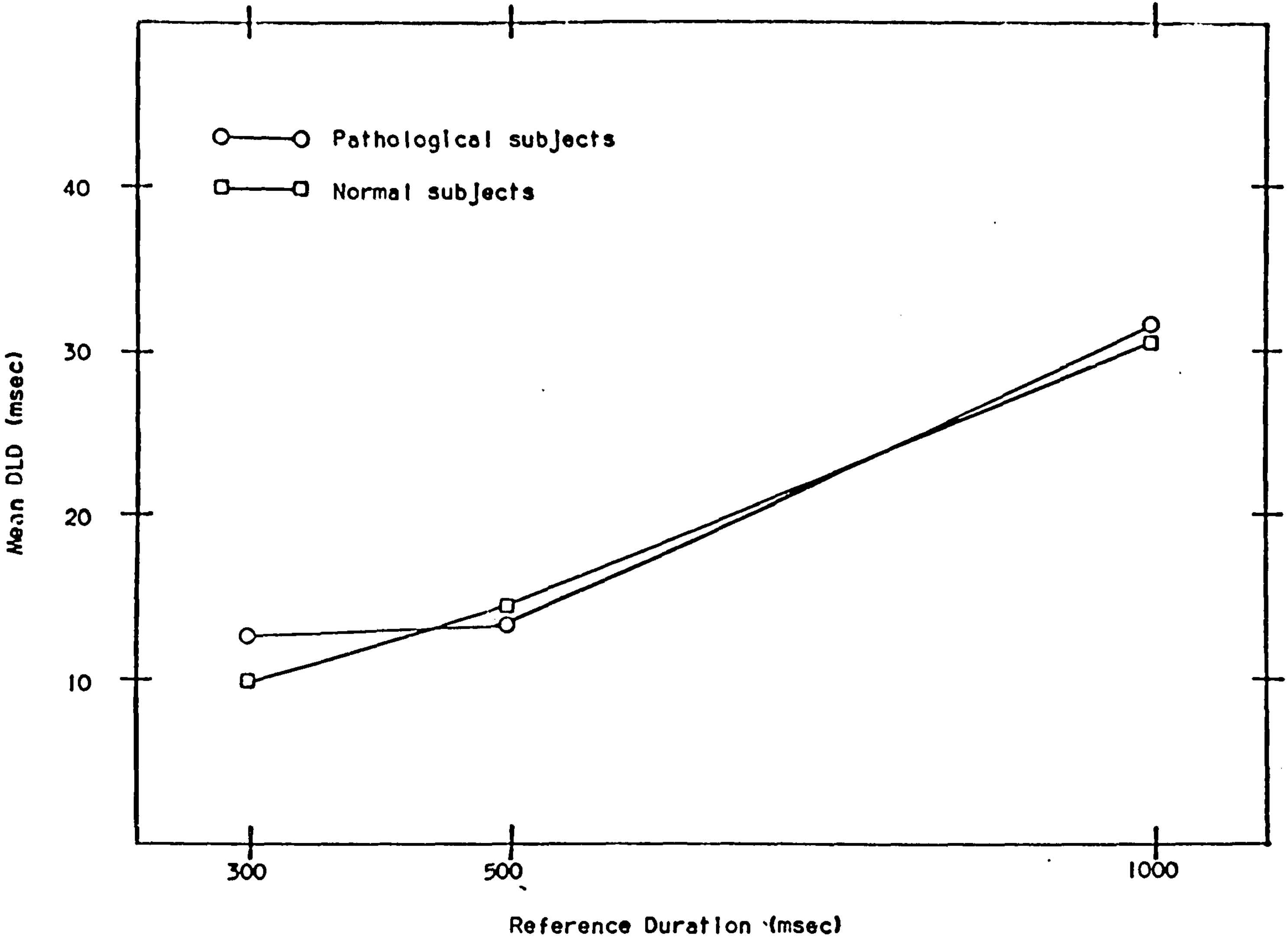

Figure 9. Mean DLD at 1000 cps averaged over sensation levels obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

300-msec reference duration while the difference of one msec at the 1000-msec reference duration is the smallest. At both of these durations, the normal hearing subjects yielded the smaller mean DLD while the smaller DLD at the remaining duration was obtained from the pathological subjects.

When the mean DLD at 1000 cps (the frequency at which both groups have normal hearing) is averaged across sensation levels and reference duration, a difference of 0.8 msec between groups is observed, with Milburn's group yielding the smaller DLD.

Figure 10 portrays the mean DLD for each group obtained for 4000 cps at 10-dB sensation level as a function of reference duration. It may be readily observed that the normal group is more sensitive at each reference duration. The differences between groups range from 1.0 to 3.5 msec at the 1000 and 500-msec reference durations, respectively.

Under the 50-dB sensation level, as displayed in Figure 11, the magnitude of differences between groups at 4000 cps ranges from 0.4 to 2.5 msec. The pathologic group is again less sensitive at two of the three reference durations.

The difference between studies at 4000 cps, averaged across sensation levels, is plotted as a function of reference duration in Figure 12. The normal subjects employed by Milburn yielded a smaller mean DLD at every reference duration than did the subjects with a cochlear pathology. The magnitude of difference ranged from 1.2 to 4.0 msec at the 1000 and 300-msec reference durations, respectively.

A mean DLD at 4000 cps, averaged across sensation levels and reference durations, of 17.4 was obtained for the group of subjects who had normal hearing at that frequency. The subjects with cochlear pathol-

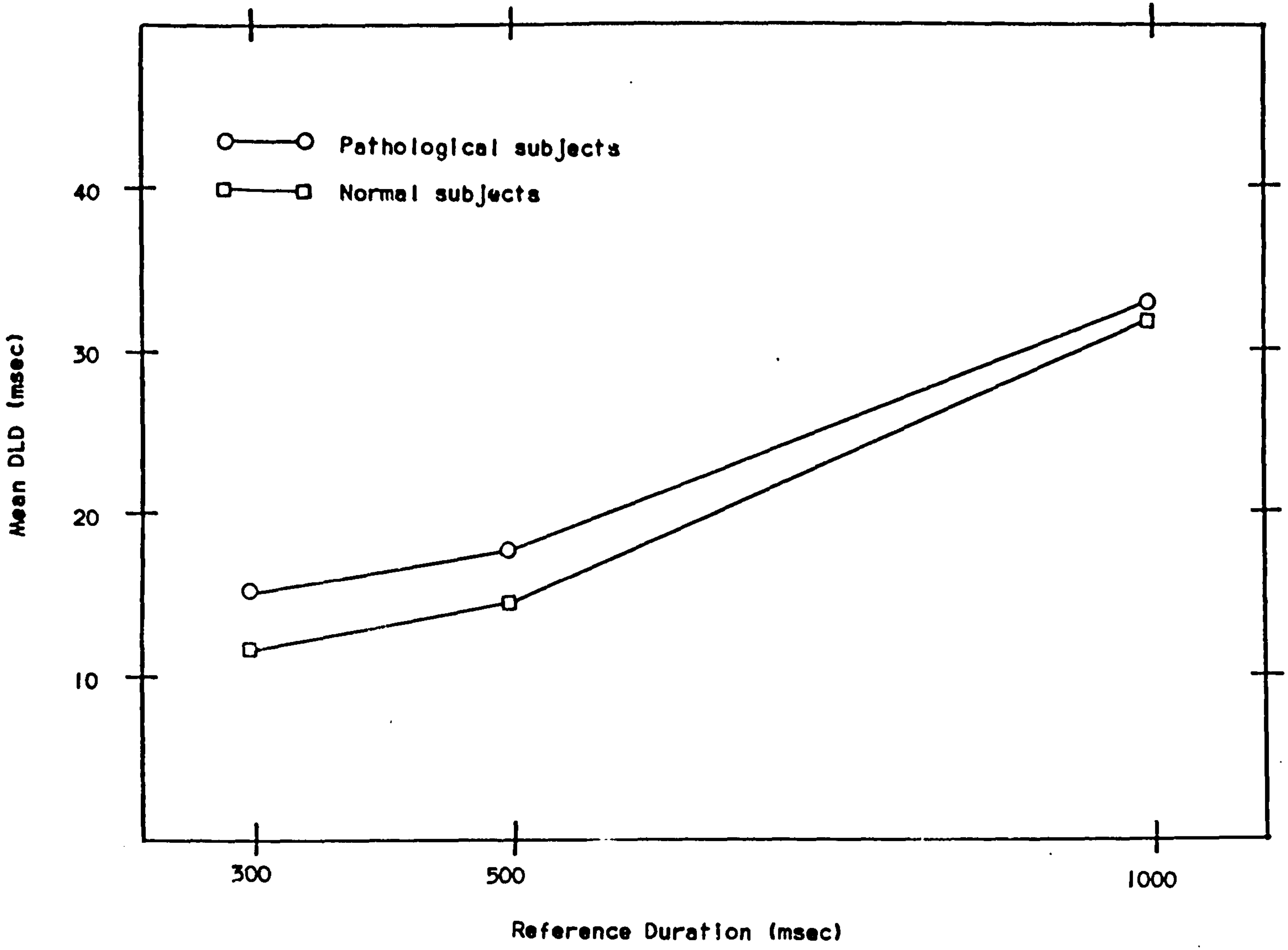

Figure 10. Mean DLD at 4000 cps at 10 dB sensation level obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

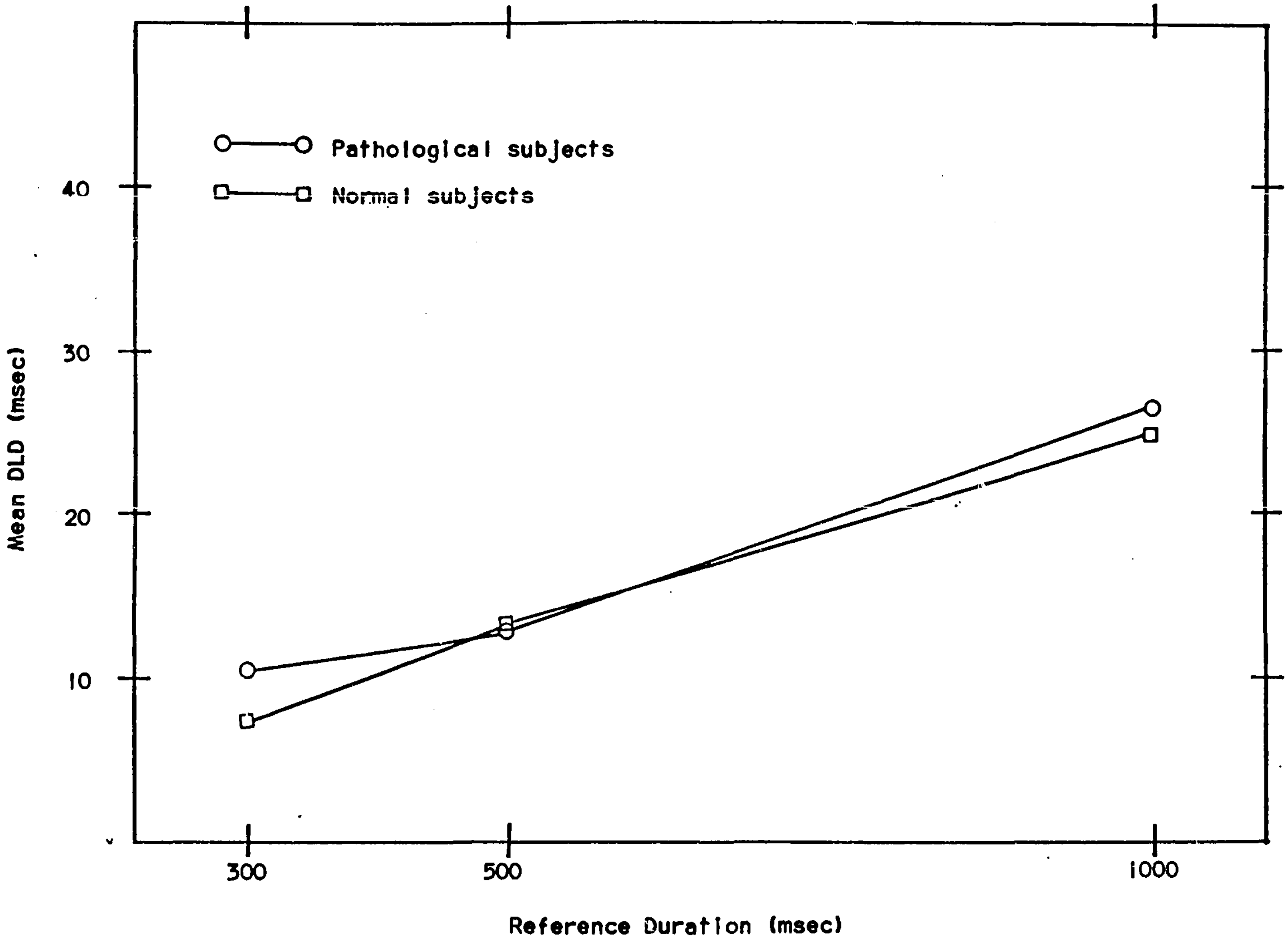

Figure 11. Mean DLD at 4000 cps at 50 dB sensation level obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

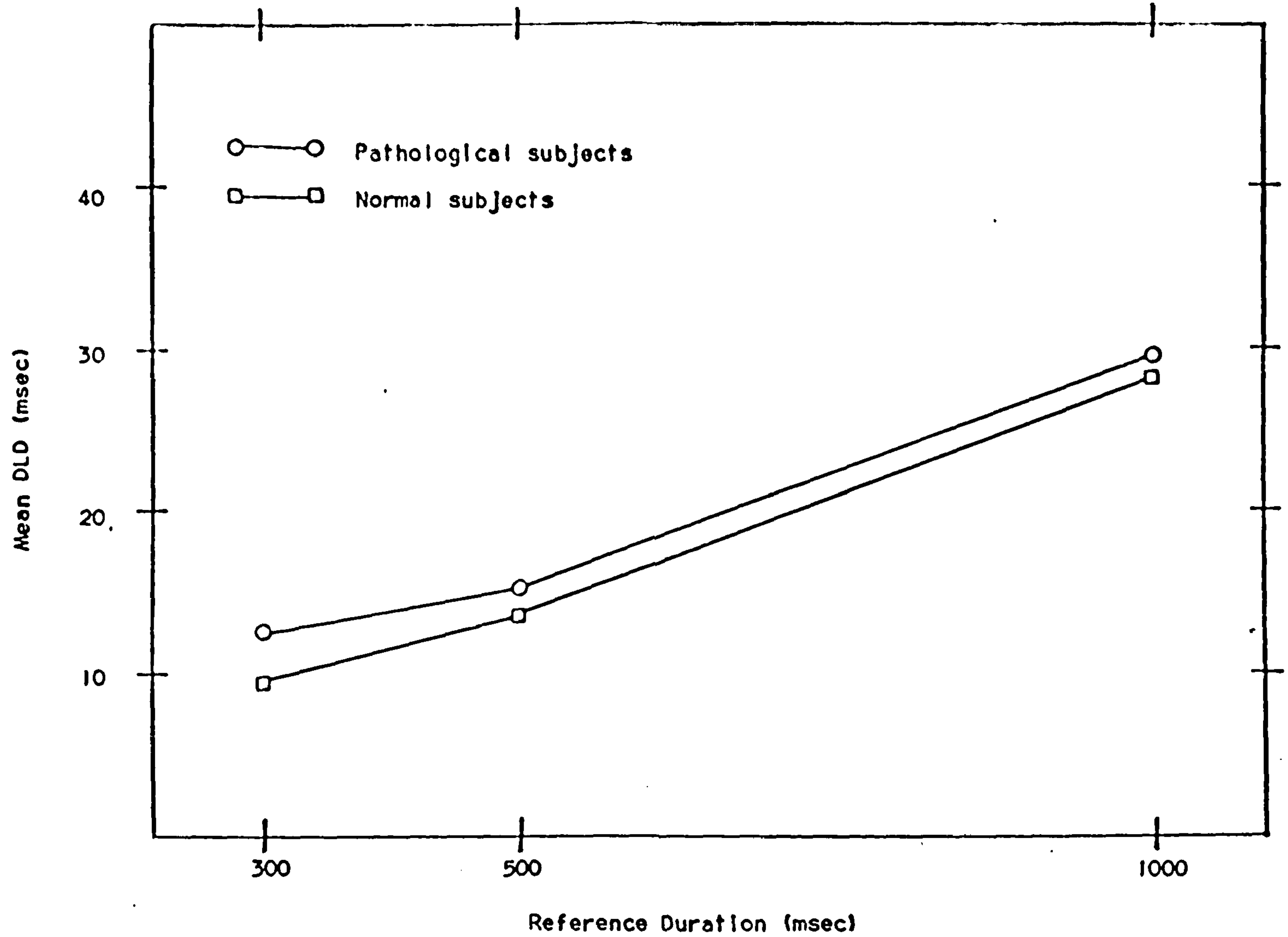

Figure 12. Mean DLD at 4000 cps averaged across sensation levels obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

ogy yielded a mean DLD of 19.3 at 4000 cps. The mean difference between groups at 1000 cps and 4000 cps, respectively, was 0.8 and 1.9 msec.

When the two studies are compared, experimental condition by experimental condition, as in Figures 7, 8, 10, and 11, the largest difference in mean DLD observed between groups is 4.5 msec, which was obtained under the 1000-cps, 1000-msec, 50-dB condition. This difference is considerably smaller than the least difference necessary to be significant (LSD .05 = 7.20). Thus, it may be said that the group with normal hearing and the group with a cochlear pathology do not differ significantly in their ability to discriminate small differences in duration under any of the experimental conditions of the present study.

Summary

The mean Difference Limen for Duration obtained for 1000 and 4000-cps tones at reference durations of 300, 500, and 1000 msec and at 10-dB and 50-dB sensation levels from ten subjects with acoustic trauma are compared in Figures 4, 5, and 6. The difference between frequencies at each experimental condition ranges from 0.5 to 5.5 msec at the 300-msec, 50-dB, and 1000-msec, 50-dB conditions, respectively. At those experimental conditions the DLD at 4000 cps is smaller than 1000 cps. At the other four conditions the converse is true. When the DLD for the two frequencies is averaged over sensation level and displayed as a function of reference duration (Figure 5), the difference between frequencies ranges from .1 msec at the 300-msec reference duration to 2.4 msec at the 1000-msec duration.

Averaging the DLD obtained at each combination of reference duration and sensation level for each frequency reveals a mean difference between frequencies of only .3 msec, a difference which is not significant at the .05 level of confidence.

The data obtained from the pathological subjects of the present study are compared with the data obtained by Milburn (40) from subjects with normal hearing in Table 3 and Figures 7 through 12. The difference between studies at the two frequencies averaged across sensation level and reference duration was .8 and 1.9 msec for the 1000 and 4000-cps tones, respectively. When the mean DLD obtained for each combination of frequency, reference duration, and sensation level are compared directly, the difference between studies ranges from .4 to 4.5 msec for the 4000-cps, 300-msec, 50-dB and 1000-cps, 1000-msec, 50-dB conditions, respectively. None of the observed differences are significant at the .05 level of confidence.

Comparisons among Reference Durations

The Difference Limen for Duration was measured at each of three reference durations (300, 500, and 1000 msec). The mean DLD at each stimulus frequency and at each sensation level is portrayed as a function of reference duration in Figure 3. These curves will be discussed separately.

1000 cps

The mean DLDs obtained at 1000 cps are displayed in Figure 13. The 10-dB sensation level function falls slightly between the 300 and 500-msec reference durations and then rises moderately between 500 and 1000 msec. The 50-dB function rises slightly from 300 to 500 msec and then more sharply between the 500 and 1000-msec reference durations. The difference between the two shorter durations is not more than 1.5 msec while

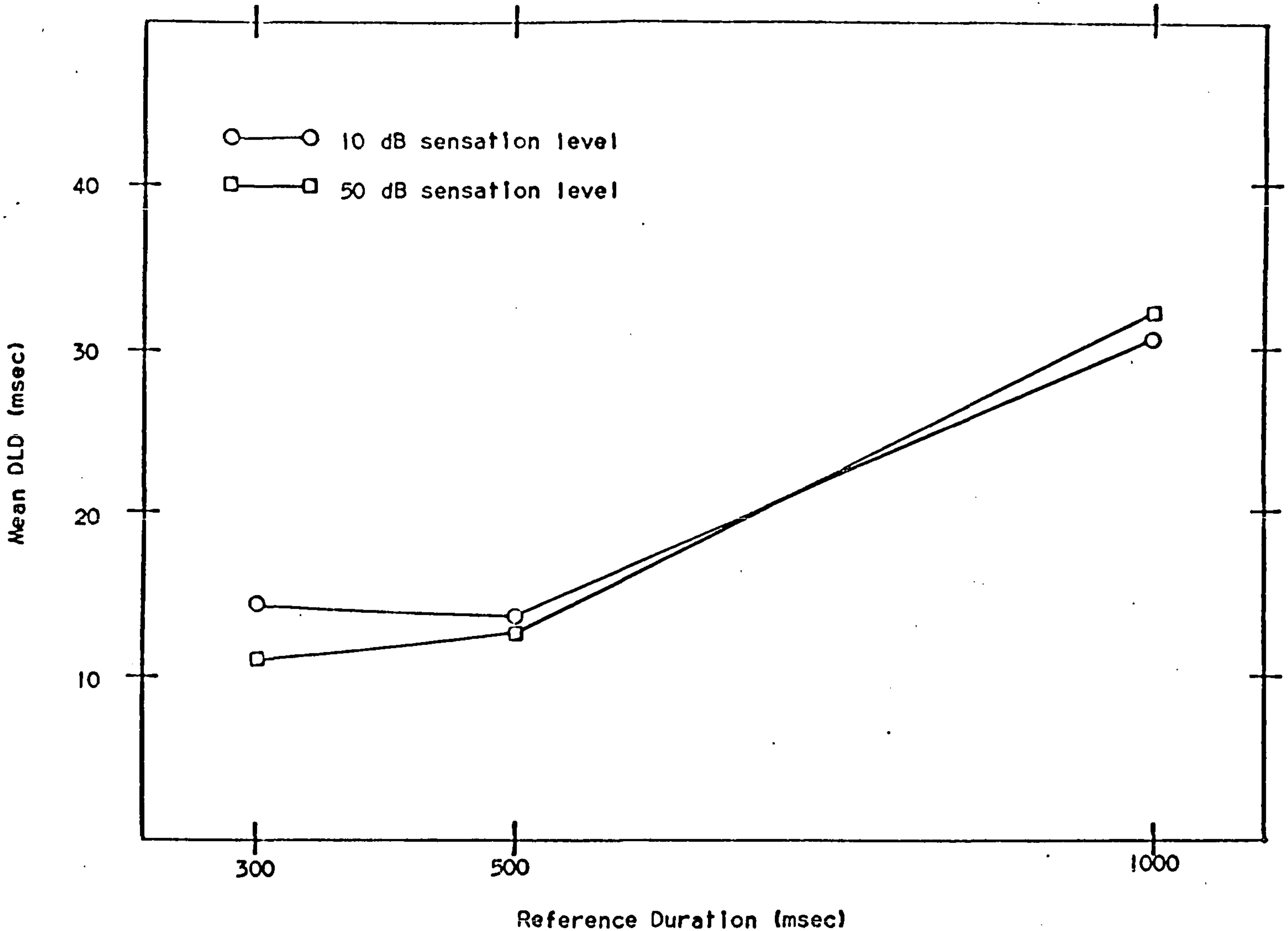

Figure 13. Mean DLD for 1000 cps at two sensation levels as a function of reference duration.

the DLD obtained at 1000-msec duration is more than twice the value of the 500-msec DLD at both sensation levels.

4000 cps

Figure 14 presents the mean DLD obtained at 4000 cps. At both the 10 and 50-dB sensation levels the function rises slightly between the 300 and 500-msec reference durations. Again the DLD at 1000 msec is approximately twice the magnitude of the 500-msec duration.

When the mean DLD is averaged across sensation levels and frequencies, as portrayed in Figure 15, the growth in magnitude of the DLD with an increase in reference duration is apparent. An analysis of variance indicated that the differences among the DLDs at the various reference durations are significant beyond the .01 confidence level.

For purposes of comparison, equivalent data from Milburn's (40) study are also plotted in Figure 15. It may be observed that the greatest difference between studies (2.8 msec) exists at the 300-msec reference duration. At the 1000 and 500-msec durations, the studies differ by 1.1 and 1.2 msec, respectively.

Mencke (38), who investigated the DLD at reference durations of 40, 60, 80, and 100 msec, and Milburn (40) confined their discussion of the DLD as a function of reference duration to the relative DLD ($\Delta T/T$) rather than to the absolute DLD (ΔT). That is, they were concerned with whether the relative DLD remained constant across reference duration. Mencke (38) concluded that the ratio was not constant, but increased as the reference duration shortened. Milburn (40) found that the size of the relative DLD was dependent on reference duration; the effect being most noticeable at durations shorter than 500 msec.

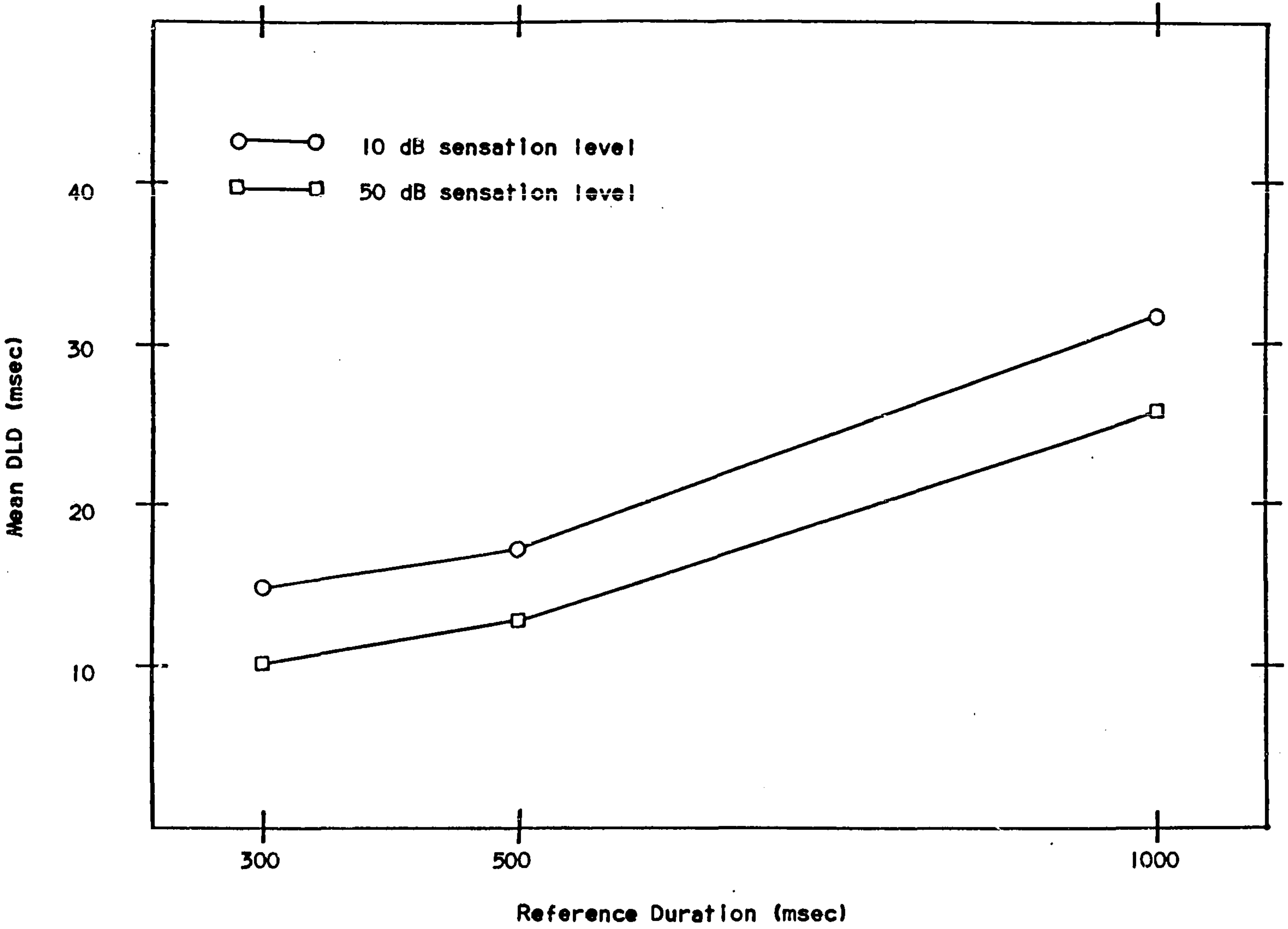

Figure 14. Mean DLD for 4000 cps at two sensation levels as a function of reference duration.

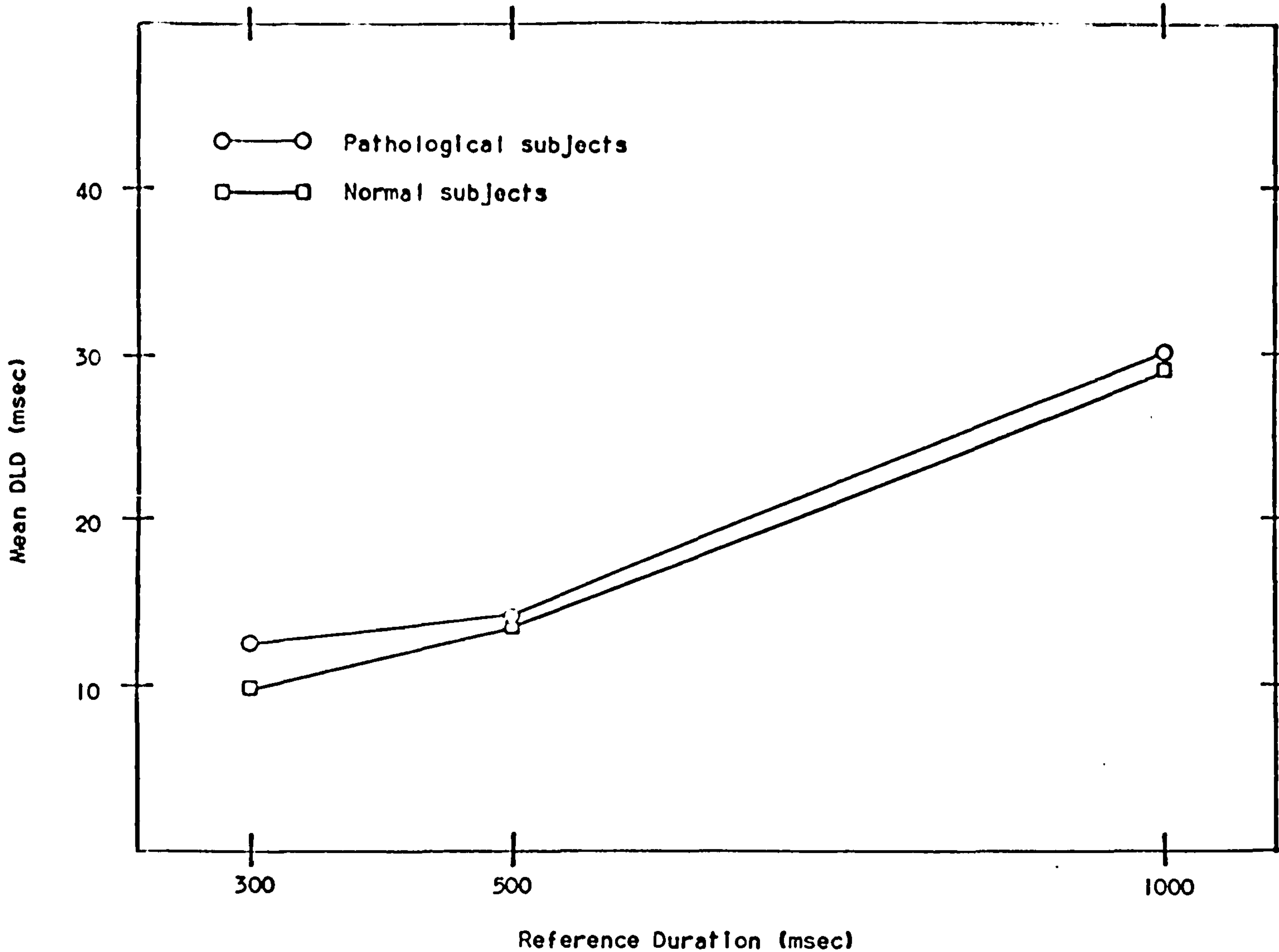

Figure 15. Mean DLD averaged across sensation levels and frequencies obtained from normal subjects by Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

Inspection of Figure 15 indicates that the relationship between the absolute DLD and reference duration may be linear. In order to investigate the possibility further, the mean absolute DLD obtained at 1000 and 4000 cps by Mencke (38) and Milburn (40) employing normal-hearing subjects has been averaged across frequencies and sensation levels and is plotted as a function of reference duration in Figure 16. The investigations employed identical apparatus and procedures to investigate the magnitude of the DLD within two ranges of reference durations. In Figure 16, the long line represents the regression of mean DLD on reference duration (54) and the points represent the observed mean DLD. The Sample Regression Coefficient (0.0276) indicates the mean DLD increases 2.76 msec for every 100-msec increase in reference duration. The data from the present study have been plotted in a similar fashion in Figure 16. A Sample Regression Coefficient of 0.0265 was obtained.

Summary

The mean DLDs are plotted as a function of reference duration in Figure 3. In general, it may be said that the DLD increases in magnitude linearly with an increase in reference duration. In the present study, the sole exception was for the 1000-cps, 10-dB sensation level curve in which a slight decrease (0.7 msec) in the mean DLD between the 300-msec and 500-msec reference durations was observed. In normal-hearing subjects, the mean DLD apparently increases in magnitude 2.76 msec for every 100-msec increase in reference duration between 40 and 1000 msec.

Comparison between Sensation Levels

Differential sensitivity to the duration of successive pure tone stimuli was measured at sensation levels of 10 and 50 dB. The mean DLDs

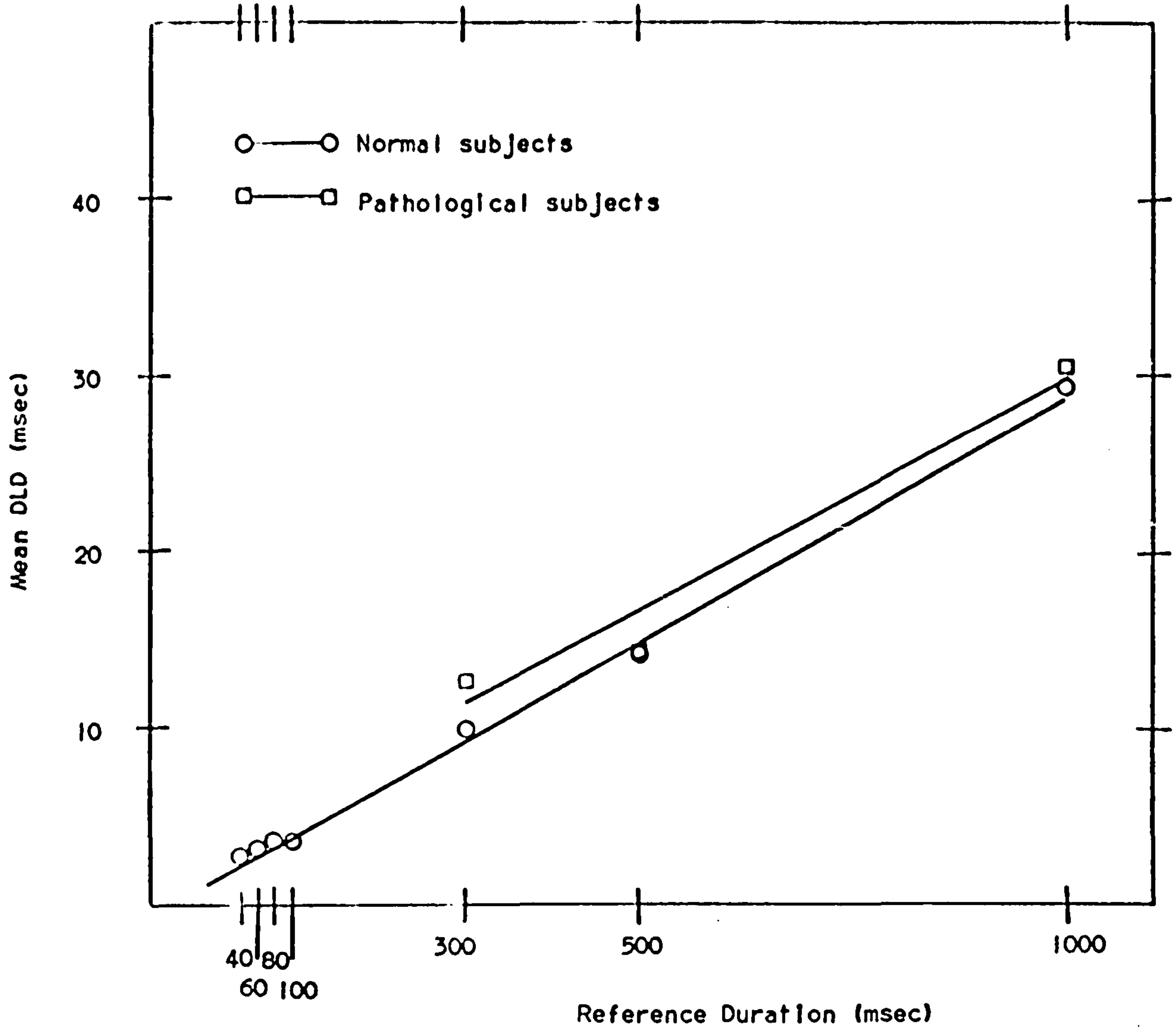

Figure 16. Mean DLD averaged over two frequencies (1000 and 4000 cps) and two sensation levels (10 and 50 dB) obtained from normal subjects by Mencke (38) and Milburn (40) and from the pathological subjects of the present study as a function of reference duration.

for a 1000-cps tone at the two intensities as a function of reference duration are displayed in Figure 13. The data for 4000 cps is plotted in similar fashion in Figure 14.

1000 cps

Inspection of Figure 13 indicates that the DLD at the 1000-msec reference duration for a 1000-cps stimulus is 1.5 msec larger at the 50-dB sensation level than at the 10-dB level. At the 300-msec and 500-msec reference durations the DLD is smaller by 3.3 and 1.2 msec, respectively, for the more intense stimuli.

4000 cps

The relationship between sensation levels is more consistent for the 4000-cps frequency. Figure 14 reveals that the DLDs obtained at 50 dB are from 4.6 to 6.0 msec smaller than those obtained at 10 dB.

When the mean DLD at each sensation level is averaged across frequencies and reference durations, a difference of 3.1 msec between the 10 and 50-dB conditions is observed. A difference of this magnitude approaches, but does not exceed, significance at the ninety-five per cent confidence level (calculated $F = 3.69$, $F_{.05} = 3.94$).

Inspection of Milburn's data (40), as reported in Table 1, reveals that, under each combination of frequency and reference duration, the mean DLD decreased as the intensity of the stimulus was increased from 10 dB to 50 dB above threshold. The magnitude of decrease ranged from 0.8 to 6.5 msec for the 4000-cps tones at 500 and 1000 msec, respectively. When the mean DLD is averaged across reference durations and frequencies, a mean difference of 4.0 msec between sensation levels is observed. An analysis of variance indicates that the observed difference is significant beyond the .01 level of confidence.

The mean DLDs obtained at the 10 dB and 50 dB sensation levels at each reference duration from the normal and pathological groups are reported in Table 4. The data have been averaged across frequencies. It may be observed that in both studies the mean DLD obtained at each reference duration decreases with an increase in intensity. In the normal group, the decrease ranges from 1.1 to 6.0 msec. The pathological group demonstrates less variability among reference durations as shown by decreases in mean DLD ranging from 2.2 to 3.9 msec as intensity is increased. The mean decrease averaged across reference durations is 4.0 and 3.1 msec for the normal and pathological groups, respectively. The observed difference of less than one msec leads to the conclusion that the two groups do not differ with regard to the effect of an increase in sensation level on the magnitude of the DLD.

Summary

The mean DLD is plotted for two frequencies and two sensation levels as a function of reference duration in Figure 3. This figure shows that subjects with a cochlear pathology discriminated slightly smaller changes in the duration of successive auditory stimuli at the 50-dB sensation level than at the 10-dB sensation level. The one exception was the 1000-cps, 1000-msec condition. The results of an analysis of variance indicate that the observed mean difference between sensation levels of 3.1 msec approaches but does not exceed significance at the .05 level of confidence. An analysis of Milburn's (40) data revealed that, for his groups of normal subjects, a mean difference of 4.0 between sensation levels was significant at the .01 level. Despite the fact that

TABLE 4

MEAN DLD AVERAGED ACROSS FREQUENCY AS A FUNCTION OF SENSATION LEVEL COMPARING MILBURN'S DATA FOR NORMAL SUBJECTS WITH THE DATA OBTAINED IN THE PRESENT STUDY EMPLOYING PATHOLOGICAL SUBJECTS

	Sensation Level	Reference Duration (msec)			Mean
		300	500	1000	
Normal Subjects	10 dB	12.4	14.7	32.3	19.8
	50 dB	7.6	13.6	26.3	15.8
Difference		4.8	1.1	6.0	4.0
Pathological Subjects	10 dB	14.8	15.8	31.5	20.7
	50 dB	10.9	12.8	29.3	17.6
Difference		3.9	3.0	2.2	3.1

the statistical tests indicate that sensation level is a significant variable in Milburn's (40) study, and is not a significant variable in the present study, one must conclude, on the basis of a difference between groups of only 0.9 msec. that the normal subjects and the subjects with a cochlear pathology react alike to an increase in the intensity of the stimuli from 10 dB to 50 dB sensation level.

Mencke (38) performed an investigation on normal-hearing subjects, employing similar instrumentation and an identical procedure to that used in the present study, with the exception that shorter reference durations were employed. Mencke found that an increase in sensation level resulted in a decrease in the magnitude of the relative DLD. Henry (24), in an earlier study, reported that with an increase in intensity from 20 dB to 80 dB SL, the magnitude of the relative DLD decreased. Further investigation of the DLD as a function of sensation level in normal, as well as pathological subjects, is indicated.

Subject Variability

Care was taken in the selection of subjects for the present study, to utilize only young, intelligent individuals with hearing loss of prescribed severity due to acoustic trauma. Each subject selected was practiced extensively prior to the collection of data. Arrangements were made to pay the subjects for their cooperation. The procedure, including immediate knowledge of the results, forced choice, and sequential analysis of the responses, was designed to reduce intersubject variability. Despite the precautions taken in selection and treatment of subjects, variability among subjects remained a significant factor.

The variability among subjects may be observed by inspection of the raw data (Appendix D). The absolute and relative DLD obtained from each subject is tabulated for each experimental condition. In addition, the mean absolute and relative DLDs along with the standard deviations and ranges are included. The 4000-cps, 1000-msec, 10-dB condition shows the greatest variability. The absolute DLD at that experimental condition includes a range of forty-five msec with a mean of 32.5 and a standard deviation of 15.67. The least variability is shown by the 4000-cps, 300-msec, 50-dB experimental condition with a range covering nine msec, a mean of 10.6 and a standard deviation of only 2.76.

The analysis of variance yielded an F of 4.05 which exceeded the .01 level of confidence. It must be concluded that the subjects of the present study differed in their ability to discriminate between successive pure tones on the basis of stimulus duration.

The variability among the pathological subjects of the present study was compared at each experimental condition with the variability among the normal-hearing subjects of Milburn's study. The normal-hearing subjects had smaller standard deviations at ten of the twelve experimental conditions. The exceptions were for the 1000-cps, 500-msec, 10-dB and the 4000-cps, 300-msec, 50-dB conditions. The largest difference in standard deviations between groups was 4.25, found at the 4000-cps, 500-msec, 10-dB condition. The least difference between groups, 0.45, was obtained at both the 4000-cps, 1000-msec, 50-dB and 4000-cps, 500-msec, 10-dB conditions. The variability among the normal subjects was also statistically significant at the .01 confidence level (F = 2.73). A test of homogeneity of variance produced an F of 1.33, which is not significant at the .05 level of confidence. Thus, it may be concluded that the two studies did not differ with regard to intersubject variability.

Implications of the Present Investigation

In Chapter II, studies were reviewed which demonstrated that subjects with a cochlear pathology behave differently than do normal subjects when they are required to differentiate small changes in intensity and frequency. The results of the present investigation indicate that sensitivity to changes in duration of auditory stimuli is unaffected by the presence of a cochlear pathology. Neff (45) provides a model of the neural mechanism of auditory discrimination which helps to explain the above findings.

Neff's model asserts that a change in the frequency of an auditory stimulus causes ". . . a shift in the place of maximum response in the cochlea and a shift in the place of excitation in neural units of the auditory system . . .". A cochlear pathology at the frequency at which differential sensitivity is being measured results in an increase in the magnitude of the difference limen for frequency. It follows that the amount of displacement of the maximal response must be greater to be recognized as a change in frequency by the subject with a cochlear pathology than the normal-hearing subject.

When the stimulus frequency is held constant and the intensity is increased ". . . there is more widespread activity in the cochlea and new neural units are caused to fire". The effect of a cochlear lesion is that of an increase in sensitivity to a change in intensity at the involved frequency. Thus, at the differential threshold, less spread of response on the basilar membrane is required by the subject with a cochlear pathology than by the normal-hearing subject.

In the present study of differential sensitivity to changes of duration, both the frequency and the intensity of the stimuli were held constant. Neither a shift in the place of maximal response nor an increase in the spread of activity took place. The result of the presentation of two tones differing only in duration was a change in the duration of activity of the cochlea and the affected neural units. The equivalency of the data obtained from normal subjects and from subjects with acoustic trauma leads to the conclusion that this aspect of cochlear function is unaffected, within the limits of the present study, by the presence of a cochlear pathology.

Summary

A modified psychophysical method of limits was utilized to investigate the magnitude of the Difference Limen for Duration of pure-tone auditory stimuli obtained from ten subjects with normal hearing at 1000 cps and a hearing loss due to a cochlear pathology at 4000 cps. Difference limens were obtained at the above-mentioned frequencies for six combinations of reference durations and intensity. Thus, twelve DLDs were obtained from each subject.

The mean absolute DLDs obtained in this investigation ranged from 10.6 to 32.5 msec under the 4000-cps, 300-msec, 50-dB SL and 4000-cps, 1000-msec, 10-dB SL conditions, respectively. These DLDs are of the same general magnitude as obtained by Milburn (40) from normal-hearing subjects.

The mean DLDs obtained at 4000 and 1000 cps were compared in order to determine whether the cochlear pathology had an effect upon the magnitude of the DLD. A mean difference between frequencies of 0.3 msec indicates that this parameter was not a significant variable. Comparison with Milburn's investigation revealed that subjects with normal hearing do not differ from subjects with acoustic trauma relative to the ability to discriminate differences in tonal duration.

The reference duration at which the DLD was assessed was shown to be a variable in the present study. The mean DLD increased in magnitude significantly as reference duration increased from 300 to 1000 msec. For normal-hearing subjects, the mean DLD increases 2.76 msec for every 100-msec increase in reference duration between 40 and 1000 msec. A similar function was noted for the subjects of the present study.

Milburn (40) found the mean DLD decreased significantly with an increase in stimulus intensity from 10-dB to 50-dB sensation level. Analysis of the present study found this variable to be non-significant, although the mean difference in the magnitude of the DLD at the two intensities (3.1 msec) was less than one msec smaller than obtained by Milburn. The reason for this discrepancy is not clear.

The magnitude of the DLD varied significantly among subjects. Under several experimental conditions the extreme values of the DLD from individual subjects enclosed a range of forty-five msec and, under one condition, a range of but nine msec. A test of homogeneity of variance comparing the variability of the DLD obtained from pathological subjects of the present study with Milburn's data indicates the two groups did not differ in this aspect of their performance.

Within the limits of the present study, the size of the difference limen for duration is dependent upon the reference duration, the individual subject, to some extent upon the intensity, and is independent of the frequency at which it is measured. The presence of a cochlear pathology does not exert an influence upon the magnitude of the DLD.

CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

In recent years, a great deal of information has been accumulated relative to the ability of the subject with a cochlear pathology to discriminate small changes in intensity and frequency. Many of the studies were performed with a practical goal in mind--the differential diagnosis between lesions of the cochlea and the VIIIth cranial nerve. It has been reliably established that patients with a cochlear pathology manifest increased ability to detect small intensity differences and decreased ability to detect small frequency differences. These investigations have resulted in several clinical tests which reliably differentiate cochlear lesions from other lesions of the auditory system.

While investigations of human ability to differentiate among pure tone stimuli solely on the basis of small differences in these two parameters have been numerous, studies of the third major parameter specifying a pure tone, duration, have been scarce. Until the past year, there were but two studies (24, 57) concerned with differential sensitivity of duration. Recently Mencke (38) and Milburn (40) have used modern electroacoustic instrumentation to examine this ability in normal subjects. They investigated the DLD as a function of frequency, intensity, and reference duration for two ranges of the latter parameter. Mencke

(38) studied the range between 40 and 100 msec and Milburn (40) between 300 and 1000 msec. Prior to the present study information regarding the DLD in subjects with a cochlear pathology was unavailable.

Experimental Design

The purpose of this experiment was to determine whether the difference limen for duration is altered by a cochlear pathology, as are the DLs of intensity and frequency. To this end, the DLD was obtained under twelve combinations of frequency (1000 and 4000 cps), intensity (10 and 50 dB sensation levels), and reference duration (300, 500, and 1000 msec) from ten subjects with acoustic trauma. Subjects with this particular pathology were selected because they typically exhibit normal hearing at one of the test frequencies (1000 cps) and diminished hearing, accompanied by abnormal sensitivity to changes in intensity, at the other test frequency (4000 cps). Thus, by comparing the magnitude of the DLDs obtained at the two frequencies, the effect of the cochlear pathology may be observed. The reference durations and sensation levels employed are identical with those utilized by Milburn (40) in his study of normal subjects. Comparison of the results of this experiment with Milburn's data provides another indication of the effect of the pathology.

The apparatus employed to measure the DLD permitted close control of the parameters of frequency, intensity, and duration. All durations were held within 0.5 msec of the intended value. The instrumentation was essentially the same, and the procedures were identical to those employed by Mencke (38) and Milburn (40).

The procedures utilized several features designed to minimize the effect of the differences among subjects relative to prior experience in listening tasks of this nature. All subjects were practiced extensively prior to the collection of data and were paid for their cooperation. A two-alternative, forced-choice technique was employed with provision for immediate knowledge of results. Sequential analysis of the responses reduced the amount of time required of each subject and, in addition, allowed specification of the confidence level at which a subject passed or failed each experimental condition.

Pairs of pure tones were presented to the subject. The second tone of a pair differed from the first only in duration. The subject's task was to determine whether the second tone was longer or shorter in duration than the first. Initially, the discrepancy between tones was easily discriminated. When it had been determined that at least seventy-five per cent of the time, the subject could correctly determine whether the second tone was longer or shorter than the first, the discrepancy was reduced by a predetermined amount. Eventually the subject was unable to discriminate at a better than chance level. The least difference which could be discriminated defined the DLD. This procedure represents a modification of the psychophysical method of limits.

Results and Conclusions

The results of this experiment indicate that a cochlear pathology does not influence the magnitude of the DLD. The difference between the DLDs obtained at the two frequencies employed in the present study was not significant. In addition, essentially no difference was observed between the DLDs yielded by the pathological subjects of the present study and the normal subjects of Milburn's study.

It has been determined that the DLD increases linearly as a function of reference duration. For every 100 msec increase in reference duration from 40 to 1000 msec, the DLD increases 2.76 msec.

The magnitude of the DLD decreases, although not significantly, when intensity is raised from 10 to 50 dB above threshold. Despite all precautions employed in the apparatus and procedures, the subjects differed significantly in their ability to detect small differences in duration.

Since the results of the present study indicate that, unlike the DLs of intensity and frequency, the difference limen of duration is unaffected by the presence of a cochlear pathology, it must be hypothesized that this aspect of auditory behavior must be mediated at a more central site. The research of Sharlock and Neff (51) indicates that, following destruction of the neural auditory pathways above the level of the medial geniculate body, the cat is able to discriminate changes in intensity and frequency. However, the animal's ability to discriminate a change in the duration of a tone is either severely impaired or lost completely. Whether or not this phenomenon occurs in man is, as yet, unknown. Its investigation, involving the difference limen for duration in clinical patients with confirmed lesions of the higher auditory pathways, is indicated.

Suggested Further Research

Suggestions for further research into the ability of normal human subjects to discriminate small deviations in tonal durations have been put forth by Mencke (38) and Milburn (40). Sharlock and Neff's research into differential sensitivity in cats (51) indicates that at least for that animal, the DLD is a function of the cortical auditory areas. It is apparent that the knowledge gained in this and previous studies should be extended to include subjects with various pathologies of the higher auditory pathways.

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Appendix A

Subject Identification

TABLE 5

SUBJECT IDENTIFICATION

SUBJECT	Sex	Age	Test Ear	Thresholds in dB re USPHS Norms 125	250	500	1000	2000	4000	8000	SISI %
1	M	33	R	0	-10	-5	5	0	30	0	100
2	M	32	L	5	0	-5	-5	-10	50	65	100
3	M	24	L	5	5	0	5	0	50	40	90
4	M	33	L	-5	-5	-5	-5	-10	25	45	100
5	M	21	L	0	-5	-5	-5	5	25	10	100
6	M	33	R	5	0	0	0	-5	40	10	100
7	M	27	L	10	10	5	0	0	35	5	90
8	F	22	L	0	0	-10	-5	-10	30	10	100
9	M	28	L	0	0	10	10	5	40	25	100
10	M	36	R	0	-5	-10	-5	-5	35	45	85
X		28.9		2.0	-1.0	-2.5	-.5	-3.0	36.0	25.5	96.5

Appendix B

Table of Sequential Analysis

TABLE 6

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

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

TABLE 6 (CONTINUED)

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

Criterion

Pass: Seventy-five per cent of the judgments at a .05 level of confidence

Fail: Fifty per cent of the judgments at a .01 level of confidence

Appendix C

Instructions to Subjects

Instructions to Subjects

You are participating in a research project that is basic to the understanding of human auditory behavior and of some significance in the field of audiology. Upon completion of the entire experiment you will be informed of the final results. This will be a grueling and lengthy procedure. Your sustained attention and alertness 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 two hours. There will be frequent rest periods during which you may relax; there, do not interrupt a test sequence that is in progress. If, for any reason, you find it necessary to stop the procedure, you need only to say so. You can be heard in the control room at all times.

You are to perform two tasks. Each requires a set of instructions. Listen very carefully.

In the first instance, you are going to hear a tone in your (test ear) ear. The first time you hear the tone it will be loud enough for you to hear it clearly. Indicate that you hear the tone by raising your index finger. The next tone you hear will be very soft. Each time, just the moment you are sure that you hear the tone, no matter how soft it is, raise your finger; then, immediately put it down. Make your response definite. Listen very carefully.

In the second task you will hear sets of three sounds. The first will be a burst of noise in your (non-test) ear. This burst of noise is a warning signal indicating that you are to prepare for the two sounds to follow. These sounds are a pair of tones which you will hear in your (test ear) ear. The first tone will always be the same length within a test sequence. The second tone is always either longer or shorter than the first tone by a given amount. Your task is to judge whether the second tone is longer or shorter than the first tone. If you judge the second tone to be longer than the first, push the response switch up to the position marked "longer". If, on the other hand, the second tone is shorter than the first, pull the response switch down to the position marked "shorter". Whenever you are correct the blue lamp will light 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 is the better one. Approximately two seconds following each response you will be presented with another burst of noise followed by a set of tones. Once again, indicate with the lever whether the second tone is longer or shorter than the first. A number of these tone sets will be presented. Take as much time as you need before making your response. Be sure not to change your judgment once you have made it. A given pair of tones cannot be repeated; therefore, a response must be made for each pair of tones presented.

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

Are there any questions?

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

Appendix D

Individual Subject Data

TABLE 7

SUBJECT DATA FROM THE 1000-cps
300-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps				
REFERENCE DURATION - 300 msec				
SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	15	.050	17	.057
2	14	.047	14	.047
3	8	.027	7	.023
4	23	.077	11	.037
5	11	.037	8	.027
6	19	.063	5	.017
7	21	.070	16	.053
8	5	.017	3	.010
9	12	.040	8	.027
10	16	.053	22	.073
MEAN DLD	14.4	.0481	11.1	.0371
STANDARD DEVIATION	5.66	.0188	6.01	.0199
RANGE	18	.060	19	.063

TABLE 8

SUBJECT DATA FROM THE 1000-cps
500-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps				
REFERENCE DURATION - 500 msec				
SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	11	.022	14	.028
2	10	.020	17	.034
3	14	.028	9	.018
4	15	.030	5	.010
5	23	.046	10	.020
6	4	.008	4	.008
7	15	.030	10	.020
8	15	.030	14	.028
9	21	.042	19	.038
10	9	.018	23	.046
MEAN DLD	13.7	.0274	12.5	.0250
STANDARD DEVIATION	5.60	.0112	6.06	.0121
RANGE	17	.038	17	.038

TABLE 9

SUBJECT DATA FROM THE 1000-cps
1000-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 1000 cps				
REFERENCE DURATION - 1000 msec				
SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	20	.020	25	.025
2	45	.045	55	.055
3	20	.020	25	.025
4	40	.040	20	.020
5	20	.020	25	.025
6	20	.020	45	.045
7	20	.020	25	.025
8	20	.020	10	.010
9	45	.045	35	.035
10	55	.055	55	.055
MEAN DLD	30.5	.0305	32.0	.0320
STANDARD DEVIATION	14.03	.0140	15.13	.0151
RANGE	35	.035	45	.045

TABLE 10

SUBJECT DATA FROM THE 4000-cps
300-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps

REFERENCE DURATION - 300 msec

SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	20	.067	7	.023
2	15	.050	10	.033
3	9	.030	9	.030
4	23	.077	9	.030
5	10	.033	8	.027
6	16	.053	11	.037
7	15	.050	12	.040
8	5	.017	10	.033
9	19	.063	14	.047
10	20	.067	16	.053
MEAN DLD	15.2	.0507	10.6	.0353
STANDARD DEVIATION	5.69	.0190	2.76	.0092
RANGE	18	.060	9	.030

TABLE 11

SUBJECT DATA FROM THE 4000-cps
500-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps				
REFERENCE DURATION - 500 msec				
SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	26	.052	10	.020
2	30	.060	15	.030
3	15	.030	11	.022
4	24	.048	24	.048
5	5	.010	9	.018
6	16	.032	5	.010
7	20	.040	25	.050
8	4	.008	10	.020
9	25	.050	8	.016
10	13	.026	14	.028
MEAN DLD	17.8	.0356	13.1	.0262
STANDARD DEVIATION	8.82	.0176	6.64	.0133
RANGE	26	.052	20	.040

TABLE 12

SUBJECT DATA FROM THE 4000-cps
1000-msec EXPERIMENTAL CONDITION

STIMULUS FREQUENCY - 4000 cps				
REFERENCE DURATION - 500 msec				
SUBJECTS	10-dB SL		50-dB SL	
	DL IN MSEC	ΔT/T	DL IN MSEC	ΔT/T
1	40	.040	30	.030
2	15	.015	20	.020
3	10	.010	15	.015
4	35	.035	55	.055
5	10	.010	35	.035
6	35	.035	25	.025
7	45	.045	20	.020
8	35	.035	10	.010
9	55	.055	20	.020
10	45	.045	35	.035
MEAN DLD	32.5	.0325	26.5	.0265
STANDARD DEVIATION	15.67	.0157	12.92	.0129
RANGE	45	.045	45	.045

Appendix E

Analysis of Variance

TABLE 13

SUMMARY OF THE ANALYSIS OF VARIANCE
(NORMAL SUBJECTS VS. PATHOLOGICAL SUBJECTS)
RANDOMIZED COMPLETE BLOCK DESIGN
WITH TEN PAIRS OF REPLICATIONS

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Replications	9	1798.48	199.831	0.76
Normal vs. Pathological	1	114.795	114.795	0.44
Error	9	2353.13	261.46	

TABLE 14

SUMMARY OF THE ANALYSIS OF VARIANCE
OF THE PRESENT STUDY
(PATHOLOGICAL SUBJECTS)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Subjects	9	2572	305.77	4.05 **
Frequency	1	1	1	0.01
Duration	2	7590	3795	50.20 **
Intensity	1	279	279	3.69
F X D	2	85	42.5	0.56
F X I	1	125	125	1.65
D X I	2	13	6.5	0.08
F X D X I	2	48	24	0.32
Error	99	7483	75.59	

** Significant at one per cent level of confidence

TABLE 15

SUMMARY OF THE ANALYSIS OF VARIANCE
OF MILBURN'S STUDY
(NORMAL SUBJECTS)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Subjects	9	1395	155	2.73 **
Frequency	1	21	21	0.37
Duration	2	8248	4124	72.57 **
Intensity	1	467	467	8.22 **
F X D	2	21	10.5	0.19
F X I	1	1	1	0.02
D X I	2	134	67	1.18
F X D X I	2	6	3	0.05
Error	99	5626	56.83	

** Significant at one per cent level of confidence