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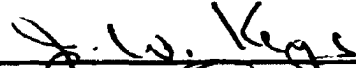


THE EFFECT OF RATE OF OFFSET OF QUANTAL SIGNAL ENVELOPES
ON THE DIFFERENTIAL SENSITIVITY FOR INTENSITY
OF ACOUSTIC INCREMENTS AND DECREMENTS

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
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Oklahoma City, Oklahoma
1969

THE EFFECT OF RATE OF OFFSET OF QUANTAL SIGNAL ENVELOPES
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APPROVED BY

DISSERTATION COMMITTEE

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CHAPTER I

INTRODUCTION

For well over a century the difference limen for intensity has been studied in various ways. As a result, numerous indexes of differential sensitivity to intensity have emerged. That is, for this particular aspect of sensory discrimination, there are as many difference limens as there are studies that have measured them. These indexes were obtained by measuring the relative difference limen for intensity (DLI), which is the relative magnitude in dB of intensity change that a person is just able to perceive as a change in loudness. Of the factors known to influence the size of the DLI, only a few have been explored in depth. This investigation has studied one such factor, that of the effect of rapid onset and offset and the effect of rapid onset and gradual offset on the DLI for increments and decrements.

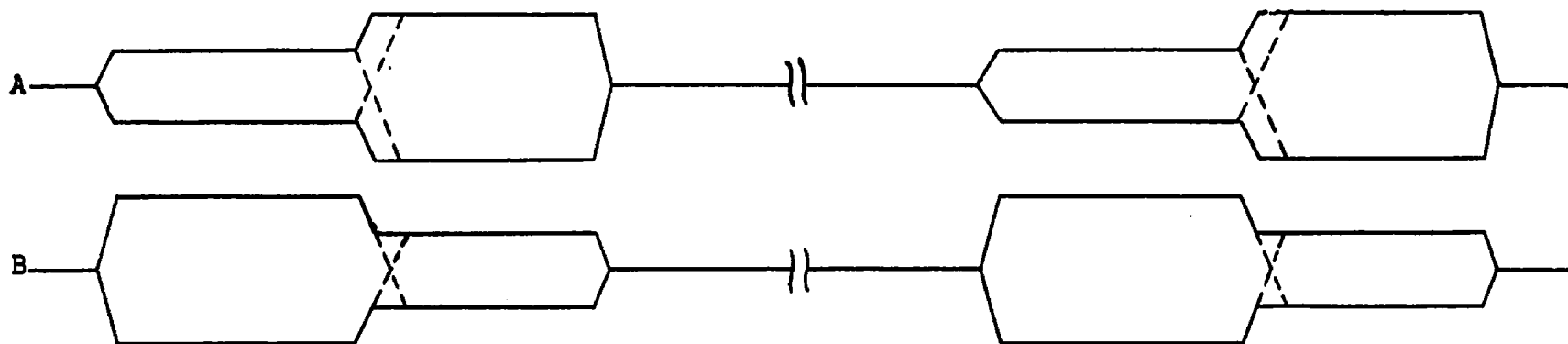
Only three of all the studies reporting measurements of differential sensitivity for intensity, directly report the relationship between the size of the DLI for increments (DLI_{inc}) and the size of the DLI for decrements (DLI_{dec}). In one of these studies, by Harris (7), in which

the Loudness-Memory Method was used, it was found that the DLI_{inc} was smaller than the DLI_{dec} . In the other two studies in which the Quantal Method was used, Anderson (1) and Churcher, King and Davies (3), it was also found that the size of the DLI_{inc} was smaller than the DLI_{dec} . However, Anderson reports that after about ten days of practice the difference between the size of the DLI_{inc} and the DLI_{dec} tended to disappear.

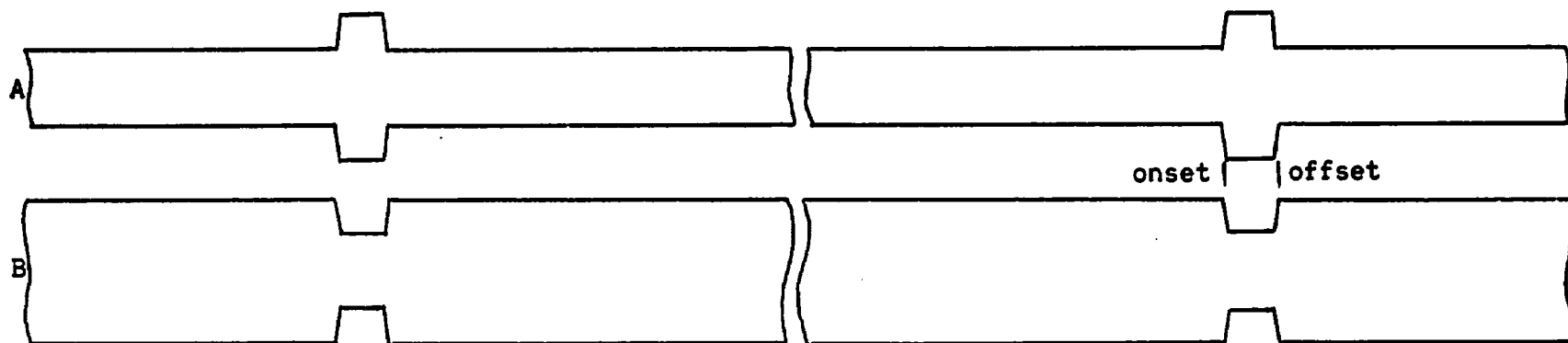
A basic difference exists between the signal envelopes and the two methods of signal presentation used in these studies. The signal envelopes are represented diagrammatically in Figure 1. The method of signal presentation in the first study, by Harris, consisted of standard and variable signals with no intervening interval. The intensity of the variable signal was either abruptly increased or decreased relative to the standard signal. Upon termination of the two signals, the subject judged whether the variable signal was louder or softer than the standard signal. This study revealed that normal hearing listeners were more sensitive to increases in intensity (DLI_{inc} -variable signal increased) than decreases (DLI_{dec} -variable signal decreased), i.e., the DLI for increments was smaller than the DLI for decrements. In the study by Anderson, the signals consisted of either a short duration increment or decrement of noise superimposed on a steady background of noise. The signal envelopes of the increment or decrement consisted of an abrupt onset succeeded by an abrupt offset. Her study also revealed that normal hearing listeners were more sensitive to increment than decrement changes but when the listeners were sufficiently trained they nearly became equally sensitive to both. The basic difference between the two signal envelopes lies in the fact that, in the Loudness-Memory Method, the subject received an

Figure 1. Signal envelopes for the Loudness Memory Method used by Harris (6) and the Quantal Method used by Anderson (1). Envelopes A are increment conditions and envelopes B are decrement conditions. Solid and dotted lines in Loudness Memory signals, used by Harris, indicate that signal transistion was accomplished in either of two ways not reported by Harris.

LOUDNESS MEMORY METHOD
(no interstimulus interval)



QUANTAL METHOD



intensity change with either onset or offset information for his louder or softer judgement, respectively. Whereas in the Quantal Method, the subject received an intensity change with both onset and offset information in both the increment and the decrement. It is possible that the reason Anderson found a disappearance of the difference between DLI_{inc} and DLI_{dec} is that, with training, her subjects learned to detect the offset intensity change of the decrement, which is actually an increase in intensity. The aggregate of prior DLI results and this explanation for Anderson's findings support the contention that the differential sensitivity of the normal auditory system is more sensitive to an increase in intensity than to a decrease in intensity. It is further hypothesized that, if the differential sensitivity were measured by the Quantal Method, a larger DLI would emerge for a decrement having an abrupt onset and a very gradual offset as compared to an increment or a decrement with both an abrupt onset and an abrupt offset.

The impetus for the present study was created by the scarcity of available information about the normal auditory mechanism concerning differential sensitivity for incremental and decremental changes in intensity and the author's belief that differential sensitivity for increments and decrements that contain a rapid increase in intensity will be greater than the differential sensitivity for decrements without such a rapid increase in intensity.

The following chapter is devoted to a review of the literature pertinent to factors influencing the relationship between the size of the DLI for increments and decrements as well as other studies which pertain to the requirements of designing an experiment to test the preceding hypothesis.

CHAPTER II

REVIEW OF LITERATURE

Introduction

When the intensity level of a pure-tone or a complex noise is varied sufficiently for an observer to detect a change the resultant effect is primarily a change in loudness. It would seem, therefore, a simple matter for an experimenter to measure the ability of the human ear to detect these changes of loudness by presenting various sized changes in intensity to a group of observers and then calculating their difference limen for intensity from their response to these changes. However, a study of previous investigations of differential sensitivity to intensity indicates that the relative DLI values obtained lack considerable agreement and appear to depend, to a large extent, on many experimental variables. Harris (8) points out that one of the most significant experimental variables that affects the size of the DLI, and one most relevant to the present study, is the shape of the signal envelope used with different methods of signal presentation.

Methods of Measuring Differential Sensitivity to Intensity

In a 1963 monograph, Harris (8) recognizes three primary auditory abilities in loudness discrimination that are measured with differ-

ent methods of presentation, each possessing a differently shaped signal envelope. These methods are: Loudness-Modulation, Loudness-Memory, and Loudness/Masking.

Loudness-Modulation is a pattern which ". . . is clearly concerned exclusively with amplitude modulation . . ." (8) (i.e., a signal whose amplitude is continuously changed about two or three times per second).

Loudness-Memory, on the other hand, is concerned with a loudness judgement of two closely separated signals. Harris states, "The critical features are a combination of memory plus a pure-tone stimulus" (8).

Loudness/Masking includes signals ". . . of noise-in-noise as well as of pure tones in a variety of noise backgrounds; . . . an increment in a steady-state tone . . . being the purest example of the Loudness/Masking Factor" (8).

While recognizing that numerous investigators, studying loudness discrimination, have sampled at least these three primary auditory abilities, Harris summarizes their findings in three general statements. First, normal hearers show (in some investigations very slightly) a decrease in the size of the DLI as the overall stimulus level increases. Second, the size of the DLI varies with the frequency of the stimulus (only slightly affected by tasks involving Loudness-Memory). Third, the magnitude of the DLI is affected by a multitude of factors, such as: experimental conditions, including psychophysical method, auditory pathologies, and again of utmost concern to this investigation the configurational details of the signal envelope.

In reviewing the various methods of presentation in use for mea-

asuring differential sensitivity to intensity, the question arises as to whether or not these methods can be adapted to satisfy the requirements for this investigation. It is with this question in mind that the following resume of methodologies is presented.

Loudness-Modulation Method

Riesz (27) was one of the first to measure loudness discrimination with the use of sinusoidal loudness-modulation. In order to overcome objections to transients in previous work by Knudsen (13), Riesz arranged two signals separated in frequency by three Hz. At equal intensities the two signals produced a clear three Hz beat. To measure the difference limen, the experimenter simply fixed the level of one signal and varied the level of the other. The smallest beat which the subject could detect was recorded and a ratio calculation was made of the difference in intensity between the two signals (ΔI).

Using the sinusoidal beat technique, Riesz and Harris (8) found that the difference limen decreased from approximately 3 dB at 5-dB SL to .4 dB at 80-dB SL. However, the DLI was quite unaffected by frequency changes.

With this method, the intensity of the composite signal changes sinusoidally at a rate which is dependent upon the frequency difference between the two signals feeding the earphone. Because of the frequency difference between the two signals, their phase relations constantly change. When they are in phase with each other, an intensity increase results (increment). When they are out of phase with each other, an intensity decrease is produced (decrement). Due to this constantly changing phase relationship between the two signals, separate DLI measurements

for increments and decrements would be most difficult to obtain, since the times of occurrence of increments and decrements could not be controlled or easily specified. Therefore, a sinusoidal modulation method is not well suited for studying differential sensitivity for increments and decrements separately.

Similar difficulty would be encountered if one were to attempt to carefully control an increment or a decrement change, if the intensity change were modulated rather abruptly. Luscher and Zwislocki (17) used such a technique which is commonly referred to as trapezoidal modulation. They established norms of detectable modulation for intensity, expressed in percent, for normal listeners and patients with different types of auditory pathology. Other studies using variations of this pattern for similar purposes are those of Lund-Iverson (16) and Jerger (10).

Loudness-Memory Method

The two techniques described thus far have in common a tone whose amplitude is continuously changing approximately three times per second. But, Hirsh and his colleagues (9) state, "According to most definitions of the DL for intensity, a listener should compare two tones that differ with respect to intensity and judge whether they have the same or different loudness." The Pure Tone Loudness-Memory Method where two stimuli are compared, one following the other, is the method of constant stimuli in its classical form.

Normal data for such judgements have been provided by Dimmick and Olson (5), by Garner and Miller (6), by Montgomery (22), by Denes and Naunton (4), by Harris (7), by Hirsh, Palva and Goodman (9), and by Harris (8). The size of the relative DLI of all these studies, except

Harris (8), demonstrate much larger intensity difference limens at equal sensation levels than the amplitude-modulation techniques. Harris (8), however, found that under optimal conditions (forcing a subject to make a choice of 'louder'-'softer') the size of the DL for paired comparisons is very closely the same as that for amplitude-modulation. "There is no effect of frequency . . . from 125-6000 Hz . . . and . . . there is little effect of overall loudness except at the very weakest SL (5 dB)."

Typically with the Loudness-Memory Method a reference tone is presented first, followed by a brief period of silence and then a comparison tone. As such, this method is also unsuited to the present study since both the reference and the comparison tone are turned on and off separately with a period of silence between them. Therefore, it would be difficult to study the effect of rapid onset and offset and of rapid onset and gradual offset on the size of the difference limen for increments and decrements with the Loudness-Memory Method.

The Loudness-Memory Method with no interstimulus interval between the reference and comparison tones (7) is similar to a Quantal signal envelope. The Quantal Method, which was the basic method used in the present study, will be discussed in the following sections.

Loudness/Masking Method

According to Harris (8) one of the purest ways of sampling the Loudness/Masking factor is through the use of pure-tone increments in a steady-state tone. In 1941, this technique was described by Stevens, Morgan and Volkman (28) as the Quantal Method. This method has two distinct features: first, each stimulus is a brief intensity change in a steady-state signal without an intervening interval. Second, instead of

a single variable stimulus, a number of increments or decrements are presented consecutively and the subject reports perceived loudness changes.

Suggested in the theory on which the Quantal Method is based, is the notion that the DLI depends upon the activation of discrete neural units. Stevens and colleagues presented evidence, derived from the shape of the psychometric function, to support the assumption that the basic neural processes mediating a discrimination are of an all or none character. Their argument is presented in the following way:

"we assume that the neural structures initially involved in the perception of a sensory continuum are divided into functionally distinct units. . . . The stimulus which excites a certain number of quanta will ordinarily do so with a little to spare -- it will excite these quanta and leave a small surplus insufficient to excite some additional quantum. This surplus stimulation will contribute, along with the increment, ΔI , to bring into activity the added quantum needed for discrimination. . . . If fluctuation (in sensitivity) is large compared to the size of the individual quantum, it is evident that over the course of time all values of the surplus stimulation will occur equally often. . . . From these considerations it follows that, if the increment is added instantaneously to the stimulus, it will be perceived a certain fraction of the time, and this fraction is directly proportional to the size of the increment itself."

Although this theory and method was developed almost thirty years ago, it has received little application until the last fifteen years. In experiments conducted by Jerger (11) and Harris (8) both investigators employed the Loudness/Masking, or Quantal Method to determine the intensity difference limen. Their stimulus pattern incorporated intensity increments, which occurred periodically in a sustained reference tone. A predetermined number of increments of the same size are presented in a single run. By varying the increment size in successive runs and recording the percentage of correct responses in each run, a psychometric function for intensity differential sensitivity was computed.

While exploring the effects of frequency, overall loudness and many other acoustic parameters, Harris (8) found that the size of the DLI with the Loudness/Masking Method agrees well with the other two Methods. He found a very slight effect for low frequencies and the fact that the DLI is "strongly affected by overall loudness." The other acoustic parameters that were studied by Harris will be discussed in sections to follow.

In the review of the three primary auditory abilities of loudness discrimination (Loudness-Modulation, Loudness-Memory and Loudness/Masking) the author has attempted to point out how each of these methods is highly dependent on different signal envelopes. Furthermore, it has been shown that the first two methods (Loudness-Modulation and Loudness-Memory) are not easily adaptable for use in the present study and that the Loudness/Masking Method (Quantal) is best suited for studying the effects of both onset and offset on the differential sensitivity for intensity, such as is required for use in the present study.

In the section to follow separate consideration is given to DLI studies using: (1) the Loudness-Memory Method (two-tone signal pattern) and (2) the Quantal Method. The former Method employs a signal envelope which produces only increase changes in intensity (increment) or only decrease changes in intensity (decrement). The latter Method's signal envelope consists of both an increase change in intensity succeeded shortly by a decrease change (increment) and a decrease change succeeded shortly by an increase change (decrement). See Figure 1.

Studies on the Relation of Magnitude of the
DLI_{inc} and the DLI_{dec}, Using a
Loudness-Memory Method

As cited earlier, many studies of differential sensitivity have been conducted using a two-tone comparison or the Loudness-Memory Method. Most of these studies have measured the DLI_{inc} and the DLI_{dec} but have averaged the results of the two and reported a single value-DLI_{inc-dec}. The few remaining studies have measured and reported separately the sensitivity of the normal auditory mechanism for intensity increases (DLI_{inc}) and decreases (DLI_{dec}). Only Harris (7), however, has directly reported the size, in dB, of the DLI for increments and decrements. Others have referred to the differences in sensitivity by the amount of judgemental bias of the second of two successive stimuli. This judgemental bias is referred to as the 'time-order-error' or the 'time-error.'

The 'time-error' has a long history in psychophysical research and is considered by Harris to be "the most pervasive of the constant errors involved in intensive discrimination . . ." When the second of two successive stimuli exactly equal in energy is underestimated, the time-error is said to be positive. When the second stimulus is overestimated the error is said to be negative.

The many studies on the time-error in intensity discrimination for pure tones have been reviewed by Needham (24). He states that the error varies with speed of stimulus presentation, inter-stimulus interval, interpolated material, practice and other conditions. Over the years there has been the suggestion that the problem of time-error has some bearing upon memory phenomena. Köhler (15) is one who takes exception to the memory theories. His explanation for the time-error is an effect

caused by a persistence of a physiological electrochemical "trace" at the cortical level left by the standard stimulus. In turn the standard stimulus influences the subject's judgement of the magnitude of the variable stimulus. Köhler went on to hypothesize that if a second stimulus is judged against a new higher level (produced by the 'trace' of the first stimulus) that the subject would underestimate the second stimulus (positive time-error) by a contrast effect to his steady cortical level. If Köhler's hypothesis were true a positive time-error should be most prominent with very short or zero intra-stimulus intervals. This relationship is not borne out clearly by data reported in more recent literature.

Even though the time-error has been studied with inter-stimulus intervals (ISI) varying from 0 to 12 sec, only the very short and zero intervals are of concern to this study since the intensity changes in this study are immediate (without interval) and discrete.

In a DL experiment conducted by Postman (26), the effect of inter-stimulus intervals (0 to 6 sec) on the size of the DL was studied, using a two-tone comparison technique. He measured the DL for pitch and loudness (500-Hz tone and broad band noise) at three sensation levels (35, 55, and 75 dB) and reported the percent of time-error for each of these conditions. Postman reported, "There is no significant time-error for pitch and there is an appreciable, statistically significant time-error in the judgements of loudness." Postman's data shows that the smallest amount of time-error (positive) was present at the zero ISI (mean of 1%) for the 500-Hz tone and noise at all three sensation levels. The time-error rose to a positive 5 percent at a 2-sec ISI and dropped to a negative 5 to 10 percent for ISI's of 4 to 6 sec, respectively.

As mentioned earlier, Postman does not report a separate DLI measurement for increments and decrements but an average DLI can be computed for the zero ISI. For a 500-Hz tone at 55-dB sensation level a DLI of .75 dB, was obtained.

As stated earlier, a time-error is present when the loudness of the second of two successive stimuli is overestimated or underestimated. Therefore, the time-error will produce a difference between the size of the DLI increment and the DLI decrement. A positive time-error produces a DLI increment larger than a DLI decrement. A negative time-error produces a DLI increment smaller than a DLI decrement. The latter relationship seems to be supported by the results of the following studies.

In an experiment conducted by Harris (7), the course of the time-error in DLI measurements at 55-dB SL was studied, by varying the ISI from 0 to 1 sec. He used pairs of noise bursts of 1-sec duration and a method of constant stimulus differences (Loudness-Memory) with only a 'louder' or 'softer' judgement permitted. Harris concluded there was a ". . . strong tendency for the zero interval to produce a negative time-error. At longer intervals, this bias was practically absent." The negative time-error for the zero interval resulted in a DLI increment (.183 dB) smaller than a DLI decrement (-.806 dB). That is, the average subject required a .183 dB increase in the variable signal (compared to the standard signal) to correctly identify a 'louder' change 75 percent of the time and a .806 dB decrease in the variable signal to correctly identify a 'softer' change 75 percent of the time.

A DLI increment of .183 dB and a DLI decrement of -.806 dB is a difference (disregarding sign) in sensitivity of the normal auditory

mechanism of .623 dB. Table 1 illustrates the effect of inter-stimulus interval on the DLI for increments and decrements.

TABLE 1
THE EFFECT OF INTER-STIMULUS INTERVAL ON THE
DLI FOR INCREMENTS AND DECREMENTS
(Data taken from Harris (7))

Mean DLI	Inter-Stimulus Interval					
	0	.1	.2	.35	.5	1.0 Sec
Increments	+ .183	+ .671	+ .518	+ .508	+ .476	+ .466 dB
Decrements	- .806	- .508	- .645	- .692	- .613	- .582 dB
Difference	.623	.063	.127	.184	.137	.116 dB

Note the symmetry or lack of a difference between the DLI for increments and decrements for ISI's of .1 to 1.0 seconds. This finding indicates that there is very little effect, if any, on the loudness judgment of the second of two successive signals when the two signals are separated by .1 sec or more. Also, when two signals are separated by less than .1 sec there is a very strong tendency for the listener to over estimate the second stimulus (negative-time-error).

In keeping with Köhler's 'trace' theory, Zwislocki (31) has more recently hypothesized that a certain time interval is necessary for the complete cessation of neural activity after a stimulus has terminated. He states that this time interval is on the order of .2 sec which is in the same time domain as considered for temporal summation at threshold (21) and for full loudness at supra-threshold levels (2, 23).

If, in fact, some neural activity persists after the termination of a stimulus, it appears from the literature just cited that it rather acts to summate with a closely following stimulus. A summation effect seems to produce an over-estimation of loudness of the second stimulus and/or a diminution in the size of the DLI increment and an enlargement of the DLI decrement. This summation idea is quite opposite to the line of reasoning by Köhler (underestimation by a contrast effect) who predicted a positive time-error for short or zero ISI. As mentioned, the data published by Harris (7) does not support Köhler's contention.

Further support to the idea of residual neural activity present after the termination of a signal is borne out in a study conducted by Pollack (25). He used a method of limits and obtained a DLI for decrements at 85-dB SPL. The DLI's were obtained by varying the intensity of repeated bursts of noise as a function of the duration of the interval between the successive bursts. The listeners heard 5 seconds of steady noise followed by 5 seconds of interrupted noise whereupon they were to detect a just noticeable difference in the two portions of noise. Pollack found that the just detectable decrement is "constant and independent" of intervals of successive noise bursts greater than 55 msec and proportionally increased as the interval decreases below 55 msec. That is, as the separation between the individual noise bursts was increased from 3 msec to approximately 55 msec the DLI decrement became smaller (1.7 dB to .5 dB) and further increases in the separation of noise bursts had no apparent effect on the size of the DLI decrement. Pollack stated that:

". . . if the persistence of auditory sensation to a previous burst has not completely subsided, then the direct effects of stimulation will be confused with the persistence of auditory experience from previous stimulation. Under these circumstances

a larger differential in intensity will be necessary to insure detection of a decrement in intensity. The magnitude of differential, in turn is directly proportional to the level of persistence. However, if the persistence of auditory experience has completely subsided, we assume . . . there will be little effect on bursts of the same level . . ."

Miller (18) employed several independent direct methods and with Taylor (20) several independent indirect methods, to measure the duration of the persistence of auditory sensation for white noise. The various methods all point to an estimate of 50 to 65 msec for the duration of auditory persistence. Pollack concludes, therefore, his method is but another indirect method for measuring the same phenomenon.

The time-error in auditory sensation has been shown to affect the loudness judgement of the second of two successive stimuli. Its effect is most prominent when two successive stimuli are very close together (0 to .1 sec). The phenomenon of auditory persistence is but one explanation for the apparent negative time-error for two closely separated stimuli. It also appears that since the time-error is negative (over-estimation) the auditory persistence of a prior stimulus acts to summate with a second stimulus. Consequently, detection by a listener of increases in intensity are necessarily smaller. By contrast, for detection of decreases in intensity, the decreases must necessarily be made larger.

Studies on the Relation of Magnitude of the
DLI_{inc} and the DLI_{dec} Using
a Quantal Method

The same situation is true of studies measuring the DLI with the use of the Quantal Method as was true of those studies using the Loudness-Memory Method. That is, many investigators have obtained DLI measurements with the Quantal Method (1, 3, 8, 10, 28), but only two have reported sep-

arate measurements for increments and decrements. Following is a review of these two studies and their application to the present study.

In a study reported by Churcher, King and Davies (3), DLI measurements were made with two methods: first, a method of "discrete changes" (Loudness/Masking or Quantal Method) and second, a method with "cyclic changes" (Loudness-Modulation). Only the results obtained from the first method are of interest to the present study since difference limen measurements were taken for both incremental and decremental changes. The second method merely obtained measurements for what was termed "the total change of intensity which is just perceptible."

Churcher and colleagues accomplished a smooth transition, from one intensity level to another in 0.25 to 3 sec (i.e., the onset time for an increment or a decrement varied from 250 msec to 3000 msec). The subject had no indication of when to expect a change and was simply required to signal when an increment or decrement occurred. The intensity was changed back to its steady state over a period of 10 sec so that within an increment series, the subject was sensible only to loudness increases. Similarly, he was sensible to only loudness decreases within a decrement series.

In determining their DLI ("the just perceptible change"), the experimenter presented "roughly" 30 changes at one intensity level. Then in random order, the subject was usually presented five increment or decrement sizes with the ultimate aim of finding approximately the 80 percent response point. That is, four out of five correct responses "was sufficient as a minimum to record the change as recognized." With this measurement procedure they found that at equal sensation levels, "decre-

ments were about half again more difficult to detect than increments." (See Table 2.) Note there is a rather large effect of over-all loudness on the size of the DLI.

TABLE 2

DLI 80% (IN dB) FOR INCREMENTS AND DECREMENTS OF AN 800-Hz TONE
(Data taken from Churcher, King and Davies (3))

Sensation Level	Increments		Decrements	
	Mean	Mean Deviation	Mean	Mean Deviation
10	2.10	.62	2.47	.89
20	1.53	.34	2.12	.82
30	1.26	.25	1.87	.54
50	1.08	.18	1.30	.12
70	.60	.12	.82	.12
90	.38	.10	.75	.17

Anderson (1) studied the differential sensitivity for intensity in a rather unique way. Her signals were either increments or decrements of noise of 200-msec duration at approximately 70-dB SPL (".0032 V RMS"), in a continuous white-noise background. The listener's task was a two-alternative forced-choice task common in signal detection work. An increment or a decrement was presented in either of two judgemental intervals and the subject was to indicate in which of the two intervals an intensity change occurred. If the response was correct a green light flashed. The 75 percent response level was considered the DLI.

Anderson obtained the difference limen for intensity, monaurally,

on 5 subjects over a period of 10 days. There was a marked difference in the size of the DLI_{inc} and the DLI_{dec} at the beginning of the ten days of testing. On the first day, the DLI_{inc} was approximately .3 dB and the DLI_{dec} .8 dB. Over the ten days of testing there was a slight improvement in the sensitivity of increments but a much greater improvement in sensitivity for decrements. After the sixth day the difference in sensitivity between increments and decrements was reduced to about .15 dB, where the DLI_{inc} was .2 dB and the DLI_{dec} was .35 dB.

Since the sensitivity for decrements improved to a greater extent than the increments, Anderson suspected that her subjects were "missing out on the first part of the hole" (onset of decrement). She proceeded to test her hypothesis by presenting a simultaneous contralateral cue, with the idea that if the subjects knew when to listen they would be more attentive to the onset of the decrement. Anderson found that her subjects when provided with a contralateral cue initially attained greater sensitivity for decrements than did the monaural listeners (without contralateral cue). In other words, the degree of learning for decrements was largely eliminated by the presence of a contralateral cue. Although, with the contralateral cue the differential sensitivity for both increments and decrements improved slightly over ten days of testing, a slight increment superiority still remained.

Since Anderson was able to nearly eliminate the increment superiority after extensive training and by cueing her subjects, it became of interest to this writer to study the differential sensitivity of increments and decrements with both rapid onset and offset and increments and decrements with only a rapid onset and a gradual offset. It was felt

that under these conditions, subjects could be trained to be equally sensitive to increments and decrements with both rapid onset and offset as well as to increments with rapid onset only. Decrements with just a rapid onset, and a gradual offset would display decreased differential sensitivity. This hypotheses, formulated for the present study, was derived from the idea that subjects listening to decrements with both rapid onset and rapid offset would learn to detect the rapid offset (an increase in intensity). Thus, the differential sensitivity would be equal for increment and decrement conditions that presented the subjects with a rapid increase in intensity. Differential sensitivity would deteriorate for a decrement condition which did not possess a rapid increase in intensity.

The remainder of this review of the literature will be concerned with other factors that influence the magnitude of the DLI and their influence on the experimental design of this study.

Other Factors Influencing the Magnitude of the DLI
with a Quantal Signal Pattern and their Affect
on the Experimental Design of this Study

We have seen now that three separate auditory abilities exist in loudness discrimination; Loudness-Modulation, Loudness-Memory and Loudness/Masking. These three abilities are measured differently with respect to their method of presentation and signal envelope. We have also seen that with certain configurational patterns of the signal envelope, a difference exists in the sensitivity of the normal auditory mechanism for acoustic increments and decrements. However, we have not considered specifically some of the acoustic parameters of the Quantal-Type signal envelope that affect the magnitude of the DLI. Therefore, the

remainder of this chapter will be devoted to the magnitude of the relative DLI with respect to two acoustic parameters of the signal envelope; namely, duration and rise-fall time.

The most comprehensive study of the effects of duration and rise-fall time was conducted by Harris (8). He employed a 1000-Hz tone and a Quantal envelope (i.e., increments superimposed on a background of self-tone), but he had each of his listeners adjust the size of the increment to obtain his difference limen.

In studying the effects of duration on the over-all loudness, Harris used a constant 10-msec rise-fall time and showed a progressive improvement in the size of the DLI as the duration of the increment was increased from 20 to 300 msec. For increments longer than 300 msec (up to 2000 msec) the DLI remained constant. By performing these DL measurements at a variety of sensation levels (5 to 80 dB), Harris found that the duration effect, while observable, is less pronounced for 40-dB sensation level and above.

Garner and Miller (6) found the DLI for two subjects to be still improving slightly for durations between 300 and 400 msec for 1000-Hz tone at 40-dB SL. A higher sensation level for a 1000-Hz tone was not tested. For a 500-Hz tone at 70-dB SL, an asymptote was reached between 200 and 300 msec.

The information, available from Harris' data (i.e., asymptote in DLI_{inc} , for 60-dB SL, at 150-msec duration and remaining constant to 2000 msec) and data on duration of temporal integration at threshold (21) and for full loudness (2, 23), lead the author to obtain the DLI measurements in the present study at 60-dB SPL using a minimum signal envelope

duration of 200 msec.

In addition to the duration of the signal envelope, another parameter dimension arises, namely, the rise-fall time. Harris (8) explored the effect of rise-fall times of 5, 10, 20 and 50 msec on the DLI at sensation levels from 5 to 60 dB at 1000 Hz. He found that rise-fall times from 5 to 20 msec are essentially equivalent in their effect on the size of the DLI, irrespective of sensation level (except at 5-dB SL). Beyond 20 msec there is a noticeable deterioration in differential sensitivity clearly evident at 50 msec (approximately .2 dB). In consideration of the foregoing findings, a 10-msec rise-fall time seemed to be a reasonable choice for the rapid onset transition of the signal envelopes used in this study. Although a systematic study of the effects of rise-fall times has not been extended beyond 50 msec, Churcher and colleagues report a slightly smaller DLI (.2 dB) for rapid onsets (.25 sec) than slower onsets (3 sec). It was reasoned that if the DLI deteriorated approximately .2 dB from 20 to 50-msec rise-fall time and .2 dB more from .25 to 3 sec, a 1200-msec offset time would be imperceptible at or near the difference limen. Therefore, a 1200-msec offset time was used for the gradual offset transitions in the present study.

Conclusion

The preceding discussion reviews the methods of measuring differential sensitivity to intensity and the nature of loudness discrimination for increments and decrements using the Loudness-Memory Method and the Quantal Method. The purpose of this review was to select conditions for an experiment designed to measure the differential sensitivity to intensity for increments and decrements with the Quantal-Type signal en-

velope. The general procedure developed as a result of these considerations is outlined in the next chapter.

CHAPTER III

SUBJECTS, APPARATUS, AND PROCEDURE

Summary of Experimental Design

The purpose of the present study was to investigate the effect of the rate of signal offset on the differential sensitivity for acoustic increments and decrements. This goal was achieved by measuring monaural differential sensitivity for intensity to increments and decrements of a 1000-Hz tone presented at 60-dB SPL, and by subsequently plotting psychometric functions. Four signal envelopes were used in the DL measurements in each of two experiments. Two of the signal conditions (an incremental and a decremental) consisted of signal envelopes with a rapid onset and a rapid offset. The other two conditions (also an increment and a decrement) consisted of signal envelopes with a rapid onset and a gradual offset.

The subjects, apparatus and specific details pertaining to measurement procedures are discussed in the remainder of this chapter.

Subjects

Eight young adults (ages 22 to 32), with normal hearing sensitivity, served as subjects in the first experiment while four of the original eight were subjects in the second experiment. The subjects were considered to be sophisticated listeners since each was a graduate stu-

dent in Communications Disorders and each had previously served as a subject in experiments requiring fine auditory discrimination. Every subject was required to pass a pure-tone screening test at 500, 1000, 2000 and 3000 Hz presented at 5-dB hearing level (ISO 1964). All subjects were free of recent ear disease.

Apparatus

A single equipment assembly was constructed in order to administer all four signal conditions used in the two experiments. This assembly consisted of two separate circuits: (1) a circuit for producing and transducing the signals for the difference limen measurements and (2) a triggering circuit appropriately timed for the desired temporal characteristics of the signal envelopes. Figures 2 and 3 present block diagrams of these two circuits, respectively. This apparatus allowed the experimenter to present various sizes of intensity increments or decrements once every six seconds. The signal envelopes were superimposed on a sustained tone of the same frequency with either symmetrical rise and decay times or with the rise time differing from the decay time.

Equipment for Measuring Differential Intensity Sensitivity

The two experiments employed four different signal envelopes (two incremental and two decremental) which had the common feature of a periodic intensity change superimposed on a background tone of the same frequency (self-tone). The manner in which the increments and the decrements were turned on and off was not identical in all four conditions. Their distinguishing features are represented diagrammatically in Figure 4.

ments. Figure 2. Block diagram of apparatus for producing and transducing the increments and decrements.

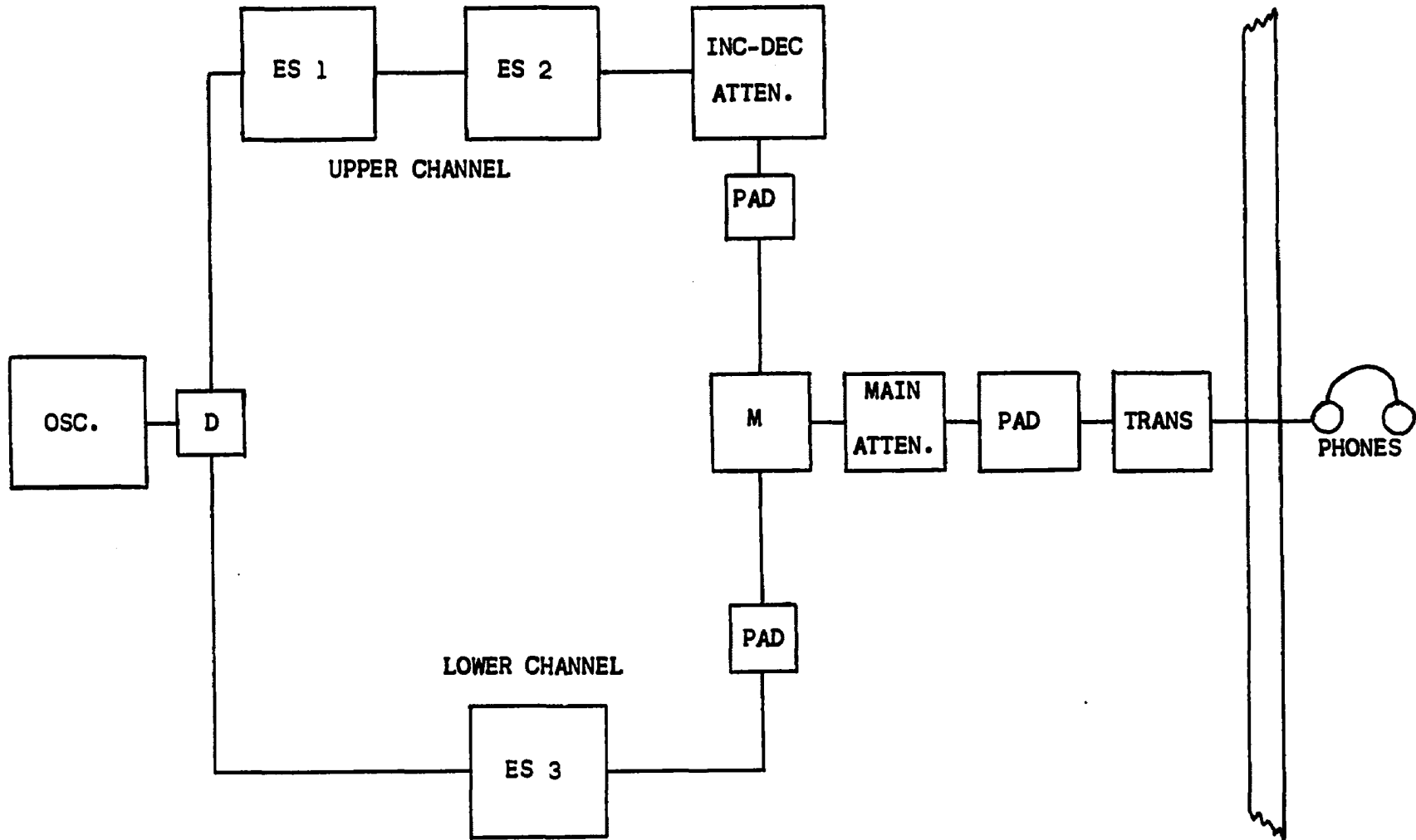


Figure 3. Block diagram of apparatus for triggering and switching the signal envelopes.

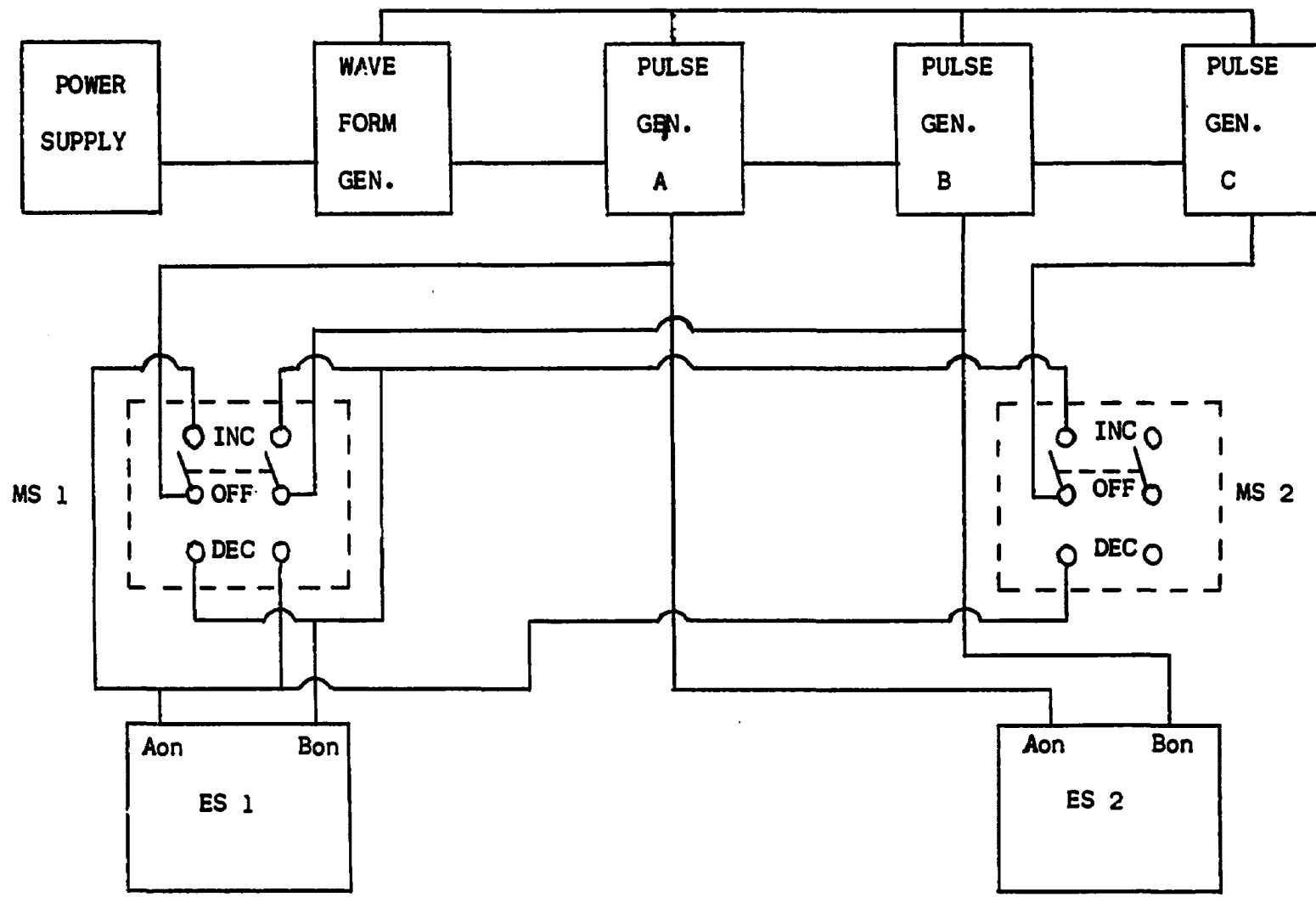
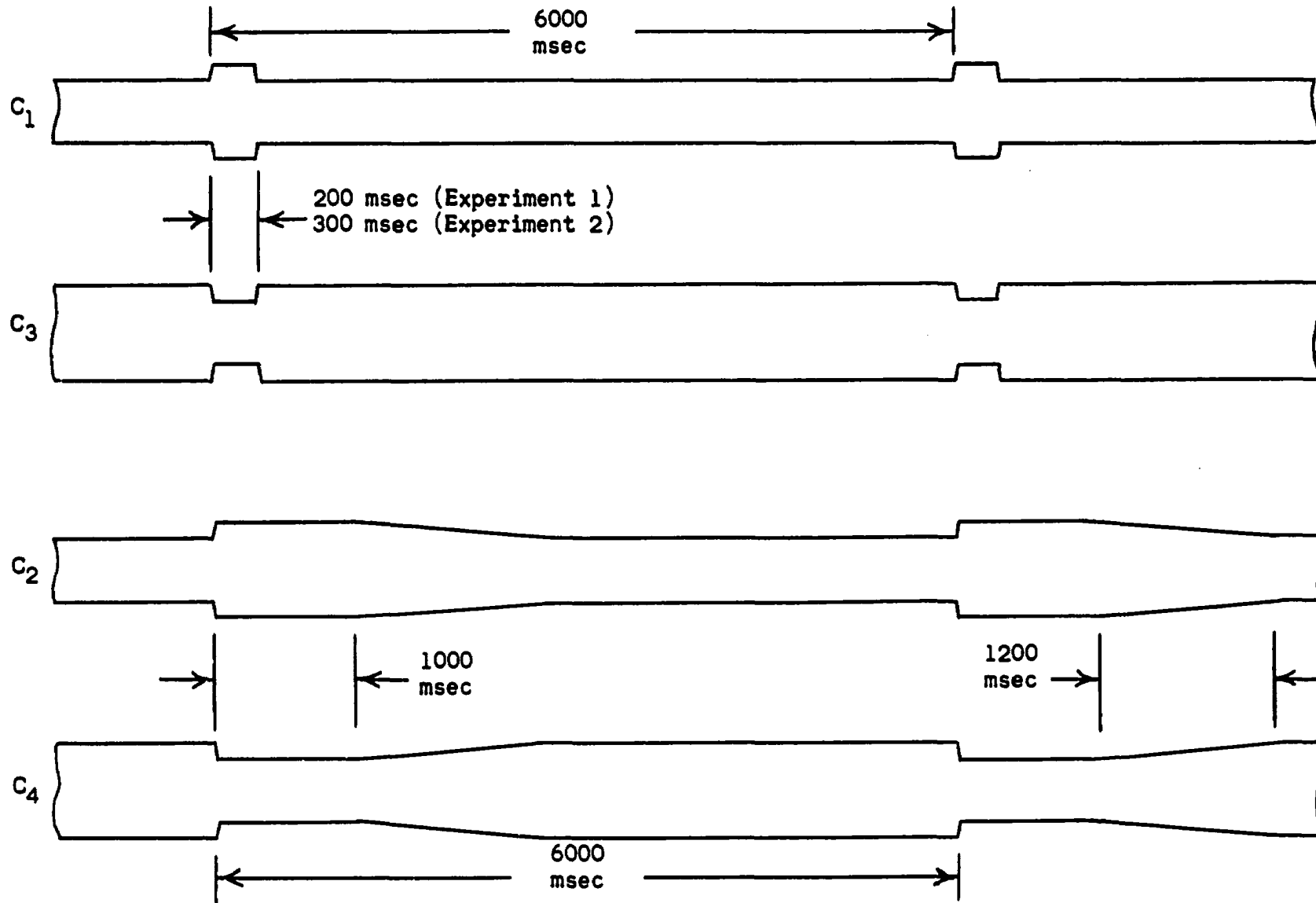


Figure 4. Signal envelopes in their temporal sequence used in the measurement of differential sensitivity.



A block diagram of the equipment used to produce these four signals is illustrated in Figure 2. The sustained self-tone was provided by dividing (D) the signal output from an audio-oscillator (Hewlett Packard Model 200 AB) labeled OSC. The signal was fed into Channel A of an electronic switch (Grason Stadler, Type 829C) labeled ES 3. A fixed 12-dB 'T' pad was inserted at the output of channel A. The signal was then fed into a mixer (M) which mixed the sustained tone with the increment or decrement of the upper channel. This electronic switch served to match impedance with the divider and mixing networks and acted as a unity gain amplifier.

The upper channel of this circuit controlled the shape and size of both the increments and decrements. This half of the divider network (D) fed the first of two electronic switches (Grason Stadler Type 829E) wired in series (i.e., the output of ES 1 fed into the input of ES 2) and thus provided independent control of rise and decay times.

The first electronic switch (ES 1) turned the increment or decrement on and thus controlled the abrupt onset (10 msec) of all four signal conditions. It also controlled the abrupt offset (10 msec) of two conditions. The second electronic switch (ES 2) fed by ES 1, provided gradual rise-decay times for the gradual offset of the remaining two conditions.

The type 829E electronic switch makes available on the rear-chassis barrier strip, capacitor connections for external variation of rise-decay times. Two 10-MFD capacitors were connected in parallel to the external connections of ES 2 to permit gradual offset times (1200 msec). ES 1 and ES 2 were always set to trigger externally so that the

'on' and 'off' periods of these switches were controlled by a separate triggering circuit, described in the next section.

The output of the second electronic switch (ES 2) passed through a variable 'T' pad attenuator (Clarostat, Type CIT-500) labeled INC-DEC ATTEN. This attenuator was capable of 20 dB of attenuation in continuously variable steps. At the output of the variable attenuator a fixed 12-dB 'T' pad was inserted and then the signal was mixed (M) with the sustained tone of the lower channel. The composite signal then passed through the main attenuator (Hewlett Packard, Model 350 AR) labeled MAIN ATTEN. The output of the main attenuator was loaded with an isolation pad labeled PAD (Clarostat, Type CIT-500) through which the composite signal passed to a matching transformer (UTC, LS-33). The 10-ohm output of the matching transformer was connected to the experimental earphone (TDH-39) mounted in an ear cushion (MX-41/AR).

Triggering Equipment

The triggering circuit was used to provide external cycling of the two electronic switches (ES 1 and ES 2), which controlled the desired temporal characteristics of the signal envelopes. A block diagram of this circuit is represented in Figure 3. The power for the entire triggering circuit was furnished by a single power supply (Tektronix, Type 160A). A waveform generator (Tektronix, Type 162) produced a positive, negative going sawtooth waveform (6000-msec duration) which served to activate three pulse generators (Tektronix, Type 161). A counter-timer (Transister Specialities Incorporated, Model 361) was used to monitor the proper time intervals of the pulse generators (see Table 3).

The three pulse generators, when timed appropriately, and the

two manual switches, MS 1 and MS 2, controlled the 'on' and 'off' periods of the two electronic switches, ES 1 and ES 2. Manual switch MS 1, was inserted between pulse generators A and B and electronic switch ES 1. Manual switch, MS 2, was inserted between pulse generator C and electronic switch ES 1.

TABLE 3
THE TIMING SEQUENCE (IN msec) AMONG
THE FOUR PULSE GENERATORS

PG to PG		Time Interval Between Two Pulse Generators	
		Experiment 1	Experiment 2
A	B	2200 msec	2200 msec
B	A	3800 msec	3800 msec
A	C	210 msec	310 msec
C	A	5790 msec	5690 msec

With MS 1 in position INC, PG A was connected to the 'A on' terminal of ES 1. With MS 2 in position INC, PG C was connected to the 'B on' terminal of ES 1. Since PG C was set to trigger 210 msec (Experiment 1) or 310 msec (Experiment 2) after PG A, a short-duration (200 or 300 msec) increment was produced with fast onset and offset times (Condition 1). Switching MS 1 to position DEC, merely reversed PG A and B to 'B on' and 'A on' terminals, respectively, of ES 1. By also switching MS 2 to position DEC, which connected PG C to 'A on' of ES 1 (PG C set to trigger 210 msec or 310 msec after PG A) a short-duration (200 or 300 msec in Experiment 1 and Experiment 2, respectively) decrement was produced also

with fast onset and offset times (Condition 3).

In order to produce increments and decrements with fast onset and gradual offset times, pulse generator C was deactivated by switching MS 2 to the OFF position. This left all switching functions of ES 1 and ES 2 to pulse generators A and B. While MS 1 still served to route PG A and PG B to ES 1, PG A also was directly connected to the 'A on' terminal and PG B directly connected to the 'B on' terminal of ES 2. Since PG B was set to trigger 2200 msec after PG A, it was a simple matter to produce the signal patterns for Conditions 2 and 4 by either switching MS 1 to position INC (increment with fast onset and gradual offset times) or to position DEC (decrement with fast onset and gradual offset times), respectively. The duration at maximum amplitude change for Conditions 2 and 4 in Experiment 1 and 2 was 1000 msec with the remaining time (1200 msec) used for the gradual offset. For Conditions 1 and 3, the duration was lengthened from 200 msec in Experiment 1 to 300 msec in Experiment 2 (see Table 4).

General Location of Equipment

The subject's earphone was housed in a custom-built acoustically-treated room. This is a double-walled room with an ambient noise level of 14-dB SPL as measured with an octave-band noise analyser (General Radio, Type 1558-AP) with a center frequency band of 1000 Hz and wired in series with a sound level meter (General Radio, Type 1551-C). The remainder of the experimental equipment was located in a larger acoustically-treated room of single-wall construction. The experimenter could communicate with the subject by means of an intercommunication system.

TABLE 4

SUMMARY OF SWITCH POSITIONS AND SIGNAL ENVELOPES (ONSET AND OFFSET TIMES
AND ON AND OFF PERIODS AT MAXIMUM AMPLITUDE CHANGE) FOR EACH
TEST CONDITION IN EXPERIMENT 1 AND 2

Condition	Position of MS-1	Position of MS-2	Onset Time	Offset Time	On Period		Off Period	
					Experiment 1	Experiment 2	Experiment 1	Experiment 2
1	INC	INC	10 msec	10 msec	200 msec	300 msec	5780 msec	5680 msec
2	INC	OFF	10 msec	1200 msec	1000 msec	1000 msec	3800 msec	3800 msec
3	DEC	DEC	10 msec	10 msec	200 msec	300 msec	5780 msec	5680 msec
4	DEC	OFF	10 msec	1200 msec	1000 msec	1000 msec	3800 msec	3800 msec

Performance of the Apparatus

Measurements were made to determine and monitor the performance characteristics of the equipment. These measures included (1) determination of acoustic output, (2) measurement of linearity of the attenuators, (3) determination of increment sizes for different attenuator settings, (4) calibration of the rise-decay pattern, and (5) monitoring voltage across the earphones, monitoring subject response interval and the timing among the three pulse generators.

Acoustic output. The sound pressure level re. $0.0002 \text{ dynes/cm}^2$ was measured with an artificial ear that consisted of a Western Electro-acoustic Condenser Microphone Complement (Type 100D/E), and a Western Electric 640 AA microphone housed in an American Standards Association Type I, 6cc. coupler. The output of the condenser microphone complement was fed to a vacuum tube voltmeter (Ballantine Model 643). Weekly measurements were made of the output levels of the experimental earphone.

Measurement of linearity of attenuators. All of the measures on the linearity of the main attenuator were made with a vacuum tube voltmeter. The test signal was passed through the attenuators. The decibel value at the output of the attenuator was read directly from the dB scale of the voltmeter. Then a step of attenuation was introduced and the decibel value read again. This procedure was repeated throughout the range of attenuation of the main attenuator. The results of these measurements indicated that the main attenuator was essentially linear. The greatest cumulative error in any 10 dB or 1 dB steps of attenuation was .5 dB.

Determination of increment and decrement sizes for different at-

tenuator settings. The determination of the size, in dB (ΔI), of the increments and decrements, relative to the background tone, required use of the following equation:

$$\Delta I = 20 \log_{10} \frac{E_2}{E_1}$$

Where E_1 and E_2 are the voltages generated in the artificial ear assembly described above. The first voltage, E_1 , is that of the background signal alone while E_2 is the combined voltage of increment plus background.

It was necessary to calculate ΔI (with the above equation) for a sufficient combination of voltage settings (E_2) of the attenuator (INC-DEC ATTEN). This allowed the experimenter to choose any ample array of values of ΔI in .1-dB steps by adjusting the attenuator to the desired output voltage.

Calibration of the rise and decay pattern. The rise and decay times were determined by visual inspection of the waveform by means of a cathode ray storage oscilloscope (Tektronix, Type 564). This signal envelope was positioned on the oscilloscope screen so that the maximum amplitude of an increment or decrement covered forty millimeters. The 10 and 90 percent up points on the slope were respectively at 4 and 36 millimeters. So that with the fine (rise-decay) control, the length of the rise or decay time was adjusted to intersect the 10 and 90 percent amplitude points in the prescribed amount of time (i.e., 10 msec for the fast onset and offset times and 1200 msec for the gradual offset times).

Monitoring of voltage across the earphones, monitoring the subject response interval and the timing calibration among the three pulse generators. Throughout the experiment, the voltage across the terminals

of the earphone was monitored and always adjusted to the same voltage reading in order to obtain the proper acoustic output. This procedure minimized variations in signal intensity and allowed the experimenter to calculate ΔI from a constant base voltage (E_1).

The timing sequence of the waveform generator and the three pulse generators was calibrated before each test session. A counter timer was employed to count the number of increments or decrements presented to a given subject.

The subject was given one second to respond after the onset of the signal. A cathode ray oscilloscope (Tektronix, Type 321) was triggered on externally, by pulse generator A for increment conditions and pulse generator B for decrement conditions, and set for a sweep time of 1 sec (i.e., time base set at .1 sec/cm across a 10 centimeter screen). The oscilloscope screen was placed in front of an observation window in such a position that the experimenter could observe both the sweep of the oscilloscope and the subject response simultaneously. A correct response was recorded if the subject responded during the prescribed sweep time of 1 sec.

Procedure for Measuring Differential Intensity Sensitivity

It will be recalled that four signal envelopes in each of two experiments were utilized to measure intensity difference limens by means of the Quantal Method. Two signal envelopes were increments and two were decrements with the only distinguishing feature within an envelope pattern being the amount of time taken to turn the signal off. In all four conditions the signal onset time was 10 msec. For one incremental and

one decremental condition the offset time was 10 msec. For the remaining two conditions (an incremental and a decremental) the offset time was 1200 msec. Twenty increments or decrements of the same intensity change were presented at 60-dB SPL in a single series.

The listening task during the difference limen measurements was a simple one. Each subject was instructed to raise his finger every time he either heard an intensity increase or an intensity decrease. He was encouraged to respond to the slightest change in intensity but on the other hand to refrain from guessing.

The following instructions were read to each subject prior to an experimental test session:

You are going to hear a steady tone that will be on for about three minutes. Occasionally superimposed on this steady tone, you will hear a small rapid increase (or decrease) in the loudness of the steady tone. I would like you to raise your finger only when you are sure you hear either change in loudness, no matter how loud or faint it appears.

Before a test series was started, every subject was thoroughly trained in listening to successive minute changes in intensity. During the training period, the experimenter adjusted the level of intensity change of a given experimental condition to determine the range over which the subject responded between 0 and 100 percent of the presentations. After an estimate of this range had been made, several half series runs were conducted at levels where the subject responded to approximately 50% of the presentations. When no further improvement in performance was observed (i.e., two or more runs within ± 1 correct response), the subject was considered to be trained for that condition.

At such time, the first test series was begun as determined by a counter-balancing procedure described below. The test signals were

initiated six seconds after a subject reported being ready to begin. For this series, the experimenter chose an increment or a decrement size which he estimated would yield a score near the top of the subject's psychometric function (i.e., approximately 70 or 80 percent response). In the next series, an increment or a decrement was chosen that would locate a point near the bottom of the function (i.e., approximately 20 or 30 percent response). The choice of the size of intensity change for each succeeding run was based on the percent of response in preceding series and by a bracketing procedure which sought scores deviating above and below 50 percent by smaller and smaller amounts. When it was judged that a sufficient number of values (usually three or four values between 10 and 90 percent) had been obtained to allow a psychometric function to be computed, the testing for that particular condition was terminated. A second test condition was begun with identical criteria for obtaining values for computation of a psychometric function.

A single test session consisted of two training periods and two series of runs necessary to complete two test conditions. Two test sessions, of two hours each, were needed to complete an experimental series (four test conditions per experiment) for every subject.

Although the intensity increments or decrements were presented in series of 20 at regular 6-second intervals, the experimenter was able to modify the periodicity of this sequence to guard against false-positive responses. That is, if the listener responded to the first two signals, the third increment was presented 12 seconds after the second one. Similarly, if the listener detected the third, fourth and fifth signals, the sixth was not presented for 12 seconds and likewise in the case of the

ninth, twelfth, fifteenth, and eighteenth if the previous three signals were detected. Therefore, the normal 6-second interval between presentation of the signals was modified as many as six times in a single run of 20 signals, depending on the subject's performance. If a subject was found responding in a time-locked manner (i.e., by responding to the 'catch' items), the experimenter stopped the run and reinstructed the subject.

Counterbalancing Arrangement of Conditions to Reduce Effect of Systematic Biases

Prior to beginning the experiment, a counterbalancing plan was formulated to determine the sequence in which the conditions would be administered. Even though each subject was trained to the above criteria, so that probably no order effects would result, a counterbalance procedure was arranged to reduce the effect of systematic biases. Either two increment conditions (C_1 and C_2) or two decrement conditions (C_3 and C_4) were administered during a single session in order to simplify the listeners task. The counterbalance pattern, illustrated in Table 5, shows the eight possible sequences in which the four conditions in Experiment 1 may be arranged if increments or decrements are tested in one session. A similar pattern is illustrated in Table 6 for Experiment 2.

The experimental ear was the right ear for every subject. Then, one of the sequences was assigned to a subject according to a table of random numbers without replacement.

In order to compute the psychometric function, a method of least squares was employed. The increment or decrement values were obtained by substituting the desired percentage response point for y' in the least

TABLE 5
SCHEDULE FOR COUNTERBALANCING INCREMENTS AND
DECREMENTS IN EXPERIMENT 1

Sequence	Session I		Session II	
	Condition	Condition	Condition	Condition
1	1	2	3	4
2	2	1	3	4
3	1	2	4	3
4	2	1	4	3
5	3	4	1	2
6	3	4	2	1
7	4	3	1	2
8	4	3	2	1

TABLE 6
SCHEDULE FOR COUNTERBALANCING INCREMENTS AND
DECREMENTS IN EXPERIMENT 2

Sequence	Session I		Session II	
	Condition	Condition	Condition	Condition
1	1	2	3	4
2	2	1	4	3
3	3	4	1	2
4	4	3	2	1

squares equation where:

$$y' = a + bx$$

y' is the percentage of increments or decrements heard

x is the intensity of the increments or decrements

a is the y intercept

b is the slope of the function

The 50 percent data points derived from the psychometric function, were statistically analysed by a single factor design having repeated measures on the same subjects (31).

CHAPTER IV

RESULTS

Introduction

The present study was undertaken to investigate the effect of rate of offset of Quantal signal patterns on the differential sensitivity for intensity of acoustic increments and decrements. Monaural differential sensitivity to intensity (relative DLI) was measured for a 1000-Hz tone presented at 60-dB SPL. Four signal conditions were presented in each of two successive experiments. These conditions involved the presentation of Quantal signal envelopes as follows: (C_1) an increment with rapid onset followed by a rapid offset, (C_2) an increment with a rapid onset followed by a gradual offset, (C_3) a decrement with a rapid onset followed by a rapid offset and (C_4) a decrement with a rapid onset followed by a gradual offset.

The two experiments differed in the number of subjects tested and in the duration of the signal envelope of the increment and decrement condition with a rapid onset and offset (C_1 and C_3). In Experiment 1 ($N = 8$), Conditions 1 and 3 provided for signals of 200-msec duration, while in Experiment 2 ($N = 4$) the signals were 300-msec duration. Conditions 2 and 4 were identical in duration (1000 msec) in the two experiments.

The preceding chapter has described the apparatus and procedure by which these measurements were made. This chapter reports separately the results of Experiment 1 and Experiment 2 followed by a discussion of the findings, the ways in which they relate to earlier DLI studies and the theoretical implications of these results.

Results

Experiment 1

The mean 0, 50 and 100 percent points and the slope for the four conditions tested in the first experiment are reported in Table 7. Data obtained from individual subjects, including means and standard deviations, are reported in Appendix A. The mean psychometric functions for the four conditions of Experiment 1 are graphically represented in Figure 5.

TABLE 7

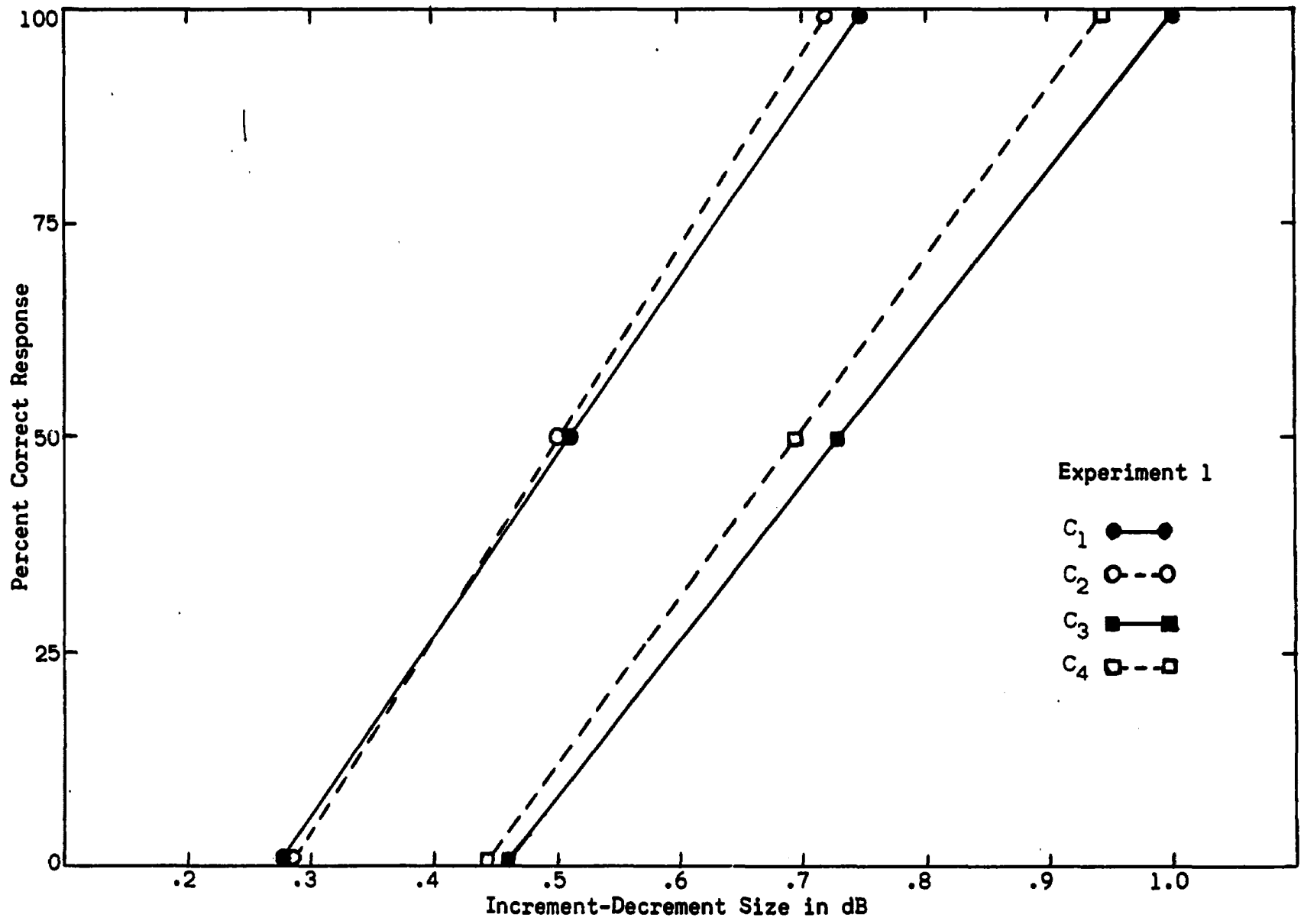
MEAN INCREMENT AND DECREMENT SIZES AND SLOPES OF PSYCHOMETRIC
FUNCTIONS FOR DIFFERENTIAL SENSITIVITY FOR 1000-Hz
TONE AT 60-dB SPL FOR EXPERIMENT 1

Measure ^a	Condition 1	Condition 2	Condition 3	Condition 4
0% point	.28	.28	.46	.44
50% point	.51	.50	.72 ^b	.69 ^b
100% point	.74	.72	1.03	.94
Slope	22.31	23.63	20.13	20.75

^a0%, 50% and 100% correct response points on the psychometric function expressed in dB. Slope expressed in percent per 0.1 dB.

^bSignificantly different than C₁ and C₂ at .01 level by DNMRT.

Figure 5. Mean least squares rectilinear psychometric functions for differential sensitivity to increments and decrements of a 1000-Hz tone at 60-dB SPL.



The mean DLI (50% point) for the four conditions was as follows: C_1 , .51 dB; C_2 , .50 dB; C_3 , .72 dB and C_4 , .69 dB. An analysis of variance (summary Table 8) on the DLI for the four conditions and eight subjects (computed as a randomized complete blocks design with subjects as blocks) reveals a significant difference (.01 probability level) for the DLI across the four conditions (treatments). The Duncans New Multiple Range Test (DNMRT) (30), indicated that the DLI for Conditions 3 and 4 are different (.01 probability level) from the DLI for Conditions 1 and 2, but not different from each other (i.e., $C_1 = C_2 \neq C_3 = C_4$). In other words, the two increment conditions (C_1 and C_2) produced significantly smaller DLI's than the two decrement conditions (C_3 and C_4). By a similar analysis no significant differences were found for the slopes of the psychometric functions across the four conditions (Table 8).

It was originally hypothesized that Conditions 1, 2 and 3 would yield smaller DLI's than Condition 4. This hypothesis was based on the idea that since Conditions 1, 2 and 3 each possessed a rapidly increasing change in intensity, this common feature would cause the DLI's to be essentially equal. However, the DLI for Condition 3 (decrement with rapid onset and rapid offset, 200 msec in duration) was of equal size to the DLI for Condition 4 (decrement with a rapid onset and a gradual offset). That is, Condition 3 did not yield a DLI as small as the two increment conditions (C_1 and C_2) even though it, too, possessed a rapid increase in intensity.

In seeking a reason for this unexpected result, it was suspected that the short duration decrement condition (C_3) was not sufficiently long to permit detection of the rapid offset (an increase in intensity).

TABLE 8
 SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE MEAN 50%
 POINT AND SLOPE OF EXPERIMENT 1
 N = 8

50% Point				
Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Subjects	7	.437		
Within Subjects	24	.386		
Treatments	3	.325	.108	38.64*
Treatments x Subjects	21	.061	.003	
Total	31	.823		

Slope				
Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Subjects	7	284.37		
Within Subjects	24	341.06		
Treatments	3	59.70	19.90	1.49
Treatments x Subjects	21	281.36	13.40	
Total	31	625.43		

*Significant at .01 level.

More specifically, it was thought that auditory persistence may have occupied some of the decrement duration. Therefore, Experiment 2 was conducted in which the duration of Conditions 1 and 3 were lengthened to 300 msec and Conditions 2 and 4 were left at 1000 msec, as they were in Experiment 1. Four subjects were tested in Experiment 2. They were selected, with the use of a table of random numbers, from the original eight subjects.

Experiment 2

The mean 0, 50 and 100 percent points and slope for the four conditions tested in the second experiment are reported in Table 9. The individual subject data, including means and standard deviations, are reported in Appendix B. The mean psychometric functions for the second experiment are graphically represented in Figure 6.

TABLE 9

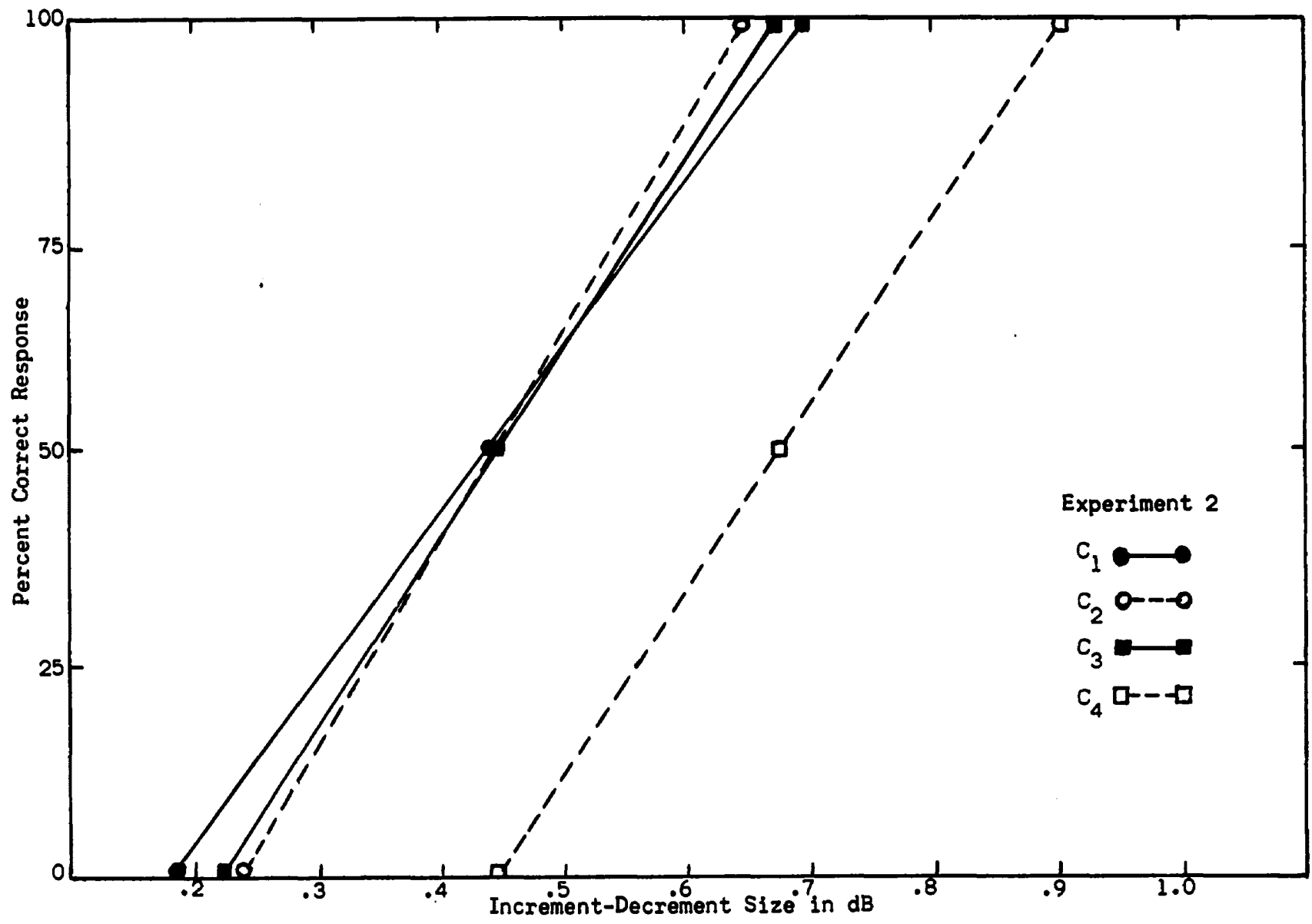
MEAN INCREMENT AND DECREMENT SIZES AND SLOPES OF PSYCHOMETRIC FUNCTIONS FOR DIFFERENTIAL SENSITIVITY FOR 1000-Hz TONE AT 60-dB SPL FOR EXPERIMENT 2

Measure ^a	Condition 1	Condition 2	Condition 3	Condition 4
0% point	.18	.24	.22	.44
50% point	.44	.44	.45	.67 ^b
100% point	.69	.65	.67	.91
Slope	20.00	26.25	22.13	21.63

^a0%, 50% and 100% correct response points on the psychometric function expressed in dB. Slope expressed in percent per 0.1 dB.

^bSignificantly different than C₁, C₂, and C₃ at .01 level by DNMRT.

Figure 6. Mean least squares rectilinear psychometric functions for differential sensitivity to increments and decrements of a 1000-Hz tone at 60-dB SPL.



The mean DLI (50% point) for the four conditions was as follows: C_1 , .44; C_2 , .44; C_3 , .45 and C_4 , .67. An analysis of variance (summary Table 10) on the DLI for the four conditions and four subjects in Experiment 2 also reveals a significant difference at the .01 probability level. The Duncan's New Multiple Range Test (30) indicated that Condition 4 differed from the other three conditions (i.e., $C_1 = C_2 = C_3 \neq C_4$). In other words, the original hypothesis was supported, since the DLI was equal in Conditions 1, 2 and 3, whereas, in Condition 4, the only condition without a rapid increase in intensity, the DLI was significantly larger (less sensitive). By a similar analysis, no significant differences were found for the slopes of the psychometric functions across the four conditions (Table 10).

Of additional note are the treatment-by-subjects mean squares in Table 8 and Table 10 for Experiments 1 and 2, respectively. These values are representative of how alike or unlike the subjects acted across the experimental conditions in the two experiments. The fact that the mean square values are extremely small, relative to the treatment mean values, and are identical (.003) for the two experiments indicates that subjects performed alike (e.g., DLI less for increments than decrements) across the four conditions and alike in the two experiments.

This study measured the differential sensitivity to intensity using four different Quantal signal envelopes in each of two successive experiments. Only the duration of one incremental and one decremental condition in the two experiments differed. In Experiment 1 their duration was 200 msec and in Experiment 2 it was 300 msec. It has been demonstrated by this study that the differential sensitivity for normal

TABLE 10
 SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE MEAN 50%
 POINT AND SLOPE OF EXPERIMENT 2
 N = 4

50% Point				
Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Subjects	3	.047		
Within Subjects	12	.186		
Treatments	3	.161	.054	19.89*
Treatments x Subjects	9	.025	.003	
Total	15	.233		

Slope				
Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Subjects	3	40.37		
Within Subjects	12	291.12		
Treatments	3	84.87	28.29	1.23
Treatments x Subjects	9	206.25	22.92	
Total	15	331.49		

*Significant at .01 level for two-tailed test.

hearing listeners for a decrement with a rapid onset and a gradual offset (1000-msec duration) is less than all increment conditions tested and less than a decrement with a rapid onset and a rapid offset (300-msec duration). Secondly, the differential sensitivity of a decrement of 300-msec duration is equal to increments of 300 and 1000-msec duration. Finally, a decrement of 300-msec duration appears to yield (although not statistically tested) greater differential sensitivity than a decrement of 200-msec duration.

Discussion

It has been pointed out earlier that no two DLI studies are alike and, therefore, no two studies will likely result in the same size DLI. However, there is general agreement between the results of this study and other studies using a similar method and signal envelope. The DLI_{inc} of .5 dB found in the present study falls in the range from .3 dB to 1.2 dB found by several other investigators (1, 3, 8, 11, 28). A more reasonable way of comparing these results with other studies is to compare differences in the size of the DL's for increments and decrements.

Churcher, King and Davies made DLI measurements for an 800-Hz tone at a variety of sensation levels (see Table 2). The method of signal presentation and the shape of the signal envelopes used in that study are similar to the shape of the rapid onset-gradual offset signal envelopes (C_2 and C_4) used in the present study. However, their onset and offset times are much slower (onset .25 to 3 sec, offset 10 sec) than those of the present study (onset 10 msec, offset 1200 msec). At 50-dB sensation level, they found a DLI of 1.08 dB for increments and 1.30 dB for decrements. This difference in dB of .22 dB in Churcher's study

agrees very well with the difference between increments and decrements of Conditions 2 and 4 of .19 dB and .23 dB in Experiment 1 and Experiment 2, respectively.

Churcher and his colleagues used an 80 percent criterion for their DLI in contrast with 50 percent in the present study. Furthermore, their onset times were considerably longer than those of the present study. These two factors alone are sufficient to cause the DL's found by these workers to be larger than those found in this study.

These investigators report mean deviations of their data as a measure of dispersion. This measure should be of the same order of magnitude as a standard deviation reported for the data in the present study. The mean deviations obtained by Churcher and his colleagues of .18 dB and .12 dB, for increments and decrements, respectively, agree well with the standard deviations obtained in the first experiment of this study of .13 dB for both increments and decrements (C_2 and C_4).

Anderson (1), likewise, compared the size of the DLI for increments and decrements but also used a different method (signal detection), a slightly higher measurement level (70-dB SPL) and a different signal (white noise). However, the shape of the signal envelopes and signal durations (200 msec) were very similar to those used in Conditions 1 and 3 of Experiment 1. After several days of training her subjects, Anderson obtained relatively stable DLI values of about .2 dB for increments and about .35 dB for decrements. This difference of .15 dB is also in very good agreement with the difference found between C_1 and C_2 of .21 dB in Experiment 1.

The reason that the results of Experiment 2 supported the orig-

inal hypothesis while those of Experiment 1 did not, rests on the fact that lengthening the duration of Conditions 1 and 3, from 200 msec (E1) to 300 msec (E2), improved the intensity discrimination for Condition 3 (a rapid onset-offset decrement). The increase in discriminatory ability was sufficient to produce DLI values equal in magnitude to the increment conditions (C_1 and C_2).

If we accept the theory of Zwislocki (32) and the findings of Pollack (25), Miller (18) and Miller and Taylor (20), that a certain time interval is necessary for the complete cessation of neural activity after a stimulus has terminated (auditory persistence) an explanation seems to be straightforward. The auditory persistence measured by these investigators (25, 18, 20) is 50 to 65 msec in duration and begins at the onset of the decrement (a rapid decrease in intensity). The auditory persistence, therefore, takes away 50 to 65 msec of 'off' time or steady off time level, from the decremental duration. Apparently, auditory persistence causes the deterioration of differential sensitivity for the increase in intensity that comprises the offset of a 200-msec decrement. So that, 50 to 65 msec of the duration of a 200-msec decrement is occupied by auditory persistence, leaving only 135 to 150 msec of unhampered 'off' time. This remaining time is seemingly not long enough for temporal integration and therefore, for normal differential sensitivity to an increase in intensity (offset of decrement).

On the other hand, a decrement of 300-msec duration is apparently off long enough despite the auditory persistence. Consequently, normal differential sensitivity prevails for the offset of such a decrement. As has been mentioned earlier, the normal auditory system apparently po-

sesses an integration time of approximately 200 msec at threshold (21) and at suprathreshold (2, 23) levels. This study points up still another acoustic parameter, the affect of duration on intensity discrimination of a decrement, which relates to the time domain of 200 msec. The contaminating factor of auditory persistence is such that the duration of the persistence effect is additive to the temporal integration time necessary for detection of the offset of a decrement.

CHAPTER V

SUMMARY

Introduction

Loudness discrimination of the normal auditory mechanism has received considerable attention for more than half a century. However, relatively little attention has been given to the difference in differential sensitivity to intensity for acoustic increments and decrements.

The limited information available in the literature which bears on this difference is somewhat contradictory. Harris (7) and Churcher, King and Davies (3) found a difference in increment and decrement sensitivity (increment sensitivity greater than decrement) of approximately .6 dB and .2 dB, respectively. Anderson (1) also found a difference in sensitivity (.15 dB) in the same direction, but reports that this difference tends to disappear over a 10-day period of testing. The method of presentation and the signal envelopes used in these three investigations were also very different.

As a consequence of the limited information available on increment and decrement sensitivity and the differences in the results and methodologies of previous studies, the present study was undertaken to measure the differential sensitivity to intensity for increments and decrements using the Quantal Method with two different types of signal enve-

velopes. One envelope consisted of a rapid onset and offset and the second envelope consisted of a rapid onset and gradual offset. Specifically, this study was designed to test the hypothesis that normal differential sensitivity (relative DLI) for increments and decrements that contain a rapid increase in intensity will be greater than the differential sensitivity for decrements without such a rapid increase in intensity.

Procedure

A group of eight normal hearing young adults served as subjects in the first experiment and four of the original eight served as subjects in the second experiment. The basic procedure was to establish monaural psychometric functions for differential sensitivity for a 1000-Hz tone at 60-dB SPL using the Quantal Method. Four different experimental conditions were tested, two incremental and two decremental, in each of two experiments. The signal envelope for one incremental (C_1) and one decremental (C_3) condition was of short duration with a rapid onset (10 msec) and a rapid offset (10 msec). The two remaining conditions (one incremental- C_2 and one decremental- C_4) consisted of a signal envelope with a long duration (1000 msec) having a rapid onset (10 msec) and a gradual offset (1200 msec). Only Conditions 1 and 3 differed in Experiment 1 and Experiment 2. In Experiment 1, Conditions 1 and 3 were 200-msec duration and in Experiment 2 they were 300-msec duration.

A single equipment assembly was constructed in order to administer all four conditions used in this investigation. The output from a pure tone oscillator was split into two channels. The upper channel controlled the shape and size of the increments and decrements. An external triggering circuit controlled the desired temporal characteristics of the

signal envelopes of the upper channel. The lower channel provided the sustained background tone. The signals from the upper and lower channels were then mixed and sent through an attenuator network and matching transformer to the experimental earphone.

The signals used in the differential sensitivity measurements were a series of increments or decrements superimposed upon a background of the same pure-tone. Each test series incorporated either twenty increments or decrements of fixed value which occurred at regular 6-second intervals. The size of the increment or decrement was varied from series to series by a bracketing procedure. Three to four sizes of test signals were used to obtain a measurement of the percentage of signals heard, between 10 to 90 percent. These three or four measurements allowed the psychometric functions to be computed. Before the actual difference limen testing, a training session using 10 test signals was conducted with various sizes of increments and decrements. Throughout each training series and test series, the subject simply raised his finger whenever he noted either a rapid increase or decrease in intensity. Either two increment conditions (C_1 and C_2) or two decrement conditions (C_3 and C_4) were presented in a counterbalanced order in one of two 2-hour test sessions.

Results

The psychometric functions for the four test conditions in the two experiments were derived by fitting least squares rectilinear functions to the empirically obtained percentages of response. The relative difference limens (50 percent points) and the slope of the functions were statistically analyzed by an analysis of variance (computed as a random-

ized complete blocks design) to determine the levels of statistical significance. To separate the differences, the Duncan's New Multiple Range Test was employed. The major results, derived from these analyses are summarized below.

Experiment 1

(1) The size of the relative difference limen was found to be smaller for the two increment conditions ($C_1 = .51$ dB and $C_2 = .50$ dB) than the two decrement conditions ($C_3 = .72$ dB and $C_4 = .69$ dB). The difference of approximately .2 dB between increments and decrements, was found to be statistically significant at the .01 level (DNMRT).

(2) The slopes of the psychometric functions for the four test conditions were found not to be significantly different.

Since the DLI results of Experiment 1 did not support the original hypothesis, Experiment 2 was conducted in an attempt to investigate this failure. In Experiment 2 the short duration conditions (C_1 and C_3) were lengthened from 200-msec duration in Experiment 1 to 300-msec duration in Experiment 2. It was suspected that by lengthening the duration of this decrement the subject may be able to detect the offset (an actual increase in intensity) of the same magnitude as the increment onsets (C_1 and C_2). Following is a summary of the findings of Experiment 2.

Experiment 2

(1) The size of the relative difference limens for the first three conditions are essentially equivalent; that is, the DLI for Conditions 1, 2 and 3 were approximately .44 dB. The lengthened duration of Conditions 1 and 3 to 300 msec essentially improved the loudness discrimination for

Condition 3 (a decrement with rapid onset and offset) to equal that of the two increment conditions (C_1 and C_2). Only Condition 4 (DLI of .67 dB) was found to be significantly different at the .01 probability level (DNMRT).

(2) Again, the differences in the slopes of the psychometric functions for the four test conditions were found not to be statistically significant.

It was demonstrated by this study that the differential sensitivity for a decrement with a rapid onset and a gradual offset, 1000-msec duration, was equal to a decrement of 200-msec duration, less than increments of 200, 300 and 1000-msec duration and less than a decrement, 300-msec duration. The differential sensitivity for a decrement of 300-msec duration, was equal to increments of 300 and 1000-msec duration.

It appears from the findings of Experiment 1 compared to the findings of Experiment 2 that the difference in differential sensitivity between short duration increments and decrements, with rapid onset and rapid offset, is highly dependent on the duration of the decrements. Such that when the duration of increments and decrements is 200 msec, the differential sensitivity is greater for increments. However, when the duration of the increments and decrements is 300 msec, the differential sensitivity of the two signals is essentially equal. Differential sensitivity for increments does not appear to improve by lengthening duration, whereas decrement sensitivity does.

Since these findings indicate that normal hearing listeners possess essentially equal loudness discrimination ability for increments and decrements when the duration of these signals is 300 msec, it is suggest-

ed to this writer that a trained subject is able to detect the offset of the decrement with normal incremental differential sensitivity. A decrement of 200-msec duration, is apparently too short for normal detection of this offset. It is also suggested that the phenomenon of auditory persistence, beginning at the onset of a decrement and lasting from 50 to 65 msec, cuts that much time off the duration of the decrement. A decrement of 300-msec duration is left with 200 msec plus, which seemingly is long enough for temporal integration to be complete. A decrement of 200-msec duration, is left with only 100 msec plus, seemingly not long enough for temporal integration to be complete. It appears, therefore, that the persistence effect is additive to the duration of a decrement and that the duration must be long enough to equal or exceed the minimum integration time of 200 msec plus the duration of auditory persistence. A minimum duration of 200 msec for complete temporal integration time falls into the same time domain of other auditory abilities requiring a minimum of 200 msec.

BIBLIOGRAPHY

1. Anderson, S. R. Detection of increments and decrements in continuous white-noise background. Paper presented at the 73rd American Acoustical Society Convention, April, 1967.
2. Bekesy, G. V. Cited in Miller, G. A. The perception of short bursts of noise. J. Acoust. Soc. Am., 1948, 20: 160-170.
3. Churcher, B. G., King, A. J., and Davies, H. The minimum perceptual change of intensity of a pure tone. Phil. Mag., 1934, 18: 927-939.
4. Denes, P., and Naunton, F. R. The clinical detection of auditory recruitment. J. Laryng. Otol., 1950, 64: 375-398.
5. Dimmick, F. L., and Olson, R. M. The intensive difference limen in audition. J. Acoust. Soc. Am., 1941, 12: 517-525.
6. Garner, G. F., and Miller, G. A. Differential sensitivity to intensity as a function of the duration of the comparison tone. J. Exp. Psychol., 1949, 34: 450-463.
7. Harris, J. D. The effect of inter-stimulus interval on intensity discrimination for white noise. Am. J. Psychol., 1949, 62: 202-214.
8. Harris, J. D. Loudness discrimination. J. Speech Hear. Dis., 1963, Supp. 11: 1-63.
9. Hirsh, I. J., Palva, T., and Goodman, A. Difference limen and recruitment. Arch. Otolaryng., 1954, 60: 525-540.
10. Jerger, J. F. A difference limen recruitment test and its diagnostic significance. Laryngoscope, 1952, 62: 1316-1332.
11. Jerger, J. F. Loudness recruitment and the intensity difference limen. Ph.D. dissertation, Northwestern University, Evanston, Illinois, 1954.
12. Jerger, J. F., Shedd, J. L., and Harford, E. R. On the detection of extremely small changes in sound intensity. Arch. Otolaryng., 1959, 69: 200-211.

13. Knudsen, V. O. The sensibility of the ear to small differences in intensity and frequency. Physical Rev., 1923, 21: 84-103.
14. Koester, T. The time error and sensitivity in pitch and loudness discrimination as a function of time interval and stimulus level. Arch. Psychol., 1945, 297: 5-69.
15. Köhler, W. Cited by Needham, J. G. The time-error in comparison judgements. Psychol. Bull., 1934, 31: 229-243.
16. Lund-Iverson, L. An investigation on the difference limen determined by the method of Luscher and Zwislocki in normal hearing and in various forms of deafness. Acta Otolaryng., 1952, 42: 219-224.
17. Luscher, E., and Zwislocki, J. A simple method for indirect monaural determination of the recruitment phenomenon (difference limen in intensity in different types of deafness). Acta Otolaryng., 1948, 78: 156-168.
18. Miller, G. A. The perception of shortbursts of noise. J. Acoust. Soc. Am., 1948, 20: 160-170.
19. Miller, G. A. Sensitivity to changes in the intensity of white noise and its relation to masking and loudness. J. Acoust. Soc. Am., 1947, 19: 609-619.
20. Miller, G. A., and Taylor, W. The perception of repeated bursts of noise. J. Acoust. Soc. Am., 1948, 20: 171-182.
21. Miskolczy-Fodor, F. Relation between loudness and duration of tonal pulses. 1. Response of normal ears to pure-tones longer than click-pitch threshold. J. Acoust. Soc. Am., 1959, 31, 1128-1134.
22. Montgomery, H. C. Influence of experimental technique on the measurement of differential intensity sensitivity of the ear. J. Acoust. Soc. Am., 1935, 7: 39-43.
23. Munson, W. A. The growth of auditory sensation. J. Acoust. Soc. Am., 1947, 19: 584-591.
24. Needham, G. J. The time-error in comparison judgements. Psychol. Bull., 1934, 31: 229-243.
25. Pollack, I. Sensitivity to differences in intensity between repeated bursts of noise. J. Acoust. Soc. Am., 1948, 23: 650-653.
26. Postman, L. The time-error in auditory perception. Am. J. Psychol., 1946, 59: 193-219.

27. Riesz, R. R. Differential intensity sensitivity of the ear for pure-tones. Physical Rev., 1928, 31: 867-875.
28. Stevens, S. S., Morgan, C. T., and Volkman, J. Theory of the neural quantum in the discrimination of loudness and pitch. Am. J. Psychol., 1941, 54: 315-335.
29. Swets, J. A. Is there a sensory threshold? Science, 1961, 134: 168-177.
30. Steel, R. G. D., and Torrie, J. H. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York, 1960, Chapter 7.
31. Winer, B. J. Statistical Principles in Experimental Design. McGraw-Hill Book Co., New York, 1962, Chapter 4.
32. Zwislocki, J. Theory of temporal auditory summation. J. Acoust. Soc. Am., 1960, 32: 1046-1060.

APPENDIX A

SUMMARY OF INDIVIDUAL SUBJECT DATA IN EXPERIMENT 1

TABLE 11

SUMMARY OF INDIVIDUAL SUBJECT DATA FOR THE 50% POINTS AND SLOPES
FOR 1000-Hz TONE AT 60-dB SPL IN EXPERIMENT 1

Subject	Condition 1		Condition 2		Condition 3		Condition 4	
	50% Point	Slope	50% Point	Slope	50% Point	Slope	50% Point	Slope
1	.50	32.5	.44	27.5	.62	27.5	.62	18.5
2	.34	23.0	.30	30.0	.45	19.5	.46	22.5
3	.72	17.0	.69	20.0	.86	16.5	.90	15.0
4	.53	18.5	.61	19.5	.75	16.0	.74	16.5
5	.51	22.5	.52	19.5	.67	21.5	.66	18.5
6	.60	22.5	.59	25.0	.94	20.0	.74	27.5
7	.46	17.5	.43	20.0	.78	22.5	.80	27.5
8	.41	25.0	.42	27.5	.68	17.5	.63	20.0
Mean	.51	22.3	.50	23.6	.72	20.1	.69	20.7
SD	.12	5.0	.13	4.4	.15	3.8	.13	4.7

APPENDIX B

SUMMARY OF INDIVIDUAL SUBJECT DATA IN EXPERIMENT 2

TABLE 12

SUMMARY OF INDIVIDUAL SUBJECT DATA FOR THE 50% POINTS AND SLOPES
FOR 1000-Hz TONE AT 60-dB SPL IN EXPERIMENT 2

Subject	Condition 1		Condition 2		Condition 3		Condition 4	
	50% Point	Slope	50% Point	Slope	50% Point	Slope	50% Point	Slope
2	.41	19.0	.38	20.0	.37	22.5	.53	22.0
4	.48	17.5	.54	38.0	.52	22.5	.74	21.5
7	.41	20.0	.41	27.5	.45	22.0	.79	22.5
8	.44	23.5	.43	19.5	.44	21.5	.63	20.5
Mean	.44	20.0	.44	26.2	.45	22.1	.67	21.6
SD	.03	2.5	.07	8.6	.06	0.5	.12	0.8