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THE EFFECT OF CONTRALATERAL NOISE ON INTENSIVE DIFFERENTIAL SENSITIVITY AS MEASURED BY TWO VARIANTS OF THE QUANTAL STIMULUS PATTERN EMPLOYING CONTINUOUS VERSUS DISCONTINUOUS BACKGROUND TONES

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CHAPTER I

INTRODUCTION

Man's environment is one of constant change. Stimuli existing in the world around him are continually varying in any one or more of several ways such as intensity, wavelength, spectral or molecular composition, and duration. The ability to recognize and respond to minute fluctuations in environmental stimuli is vitally important to the living organism since it constitutes a prime mechanism for self preservation. It is not surprising, therefore, that most living organisms are more responsive to changes in their environment than to steady-state conditions. This ability to sense small differences or changes in stimuli has been studied by behavioral scientists for over one hundred years and an extensive body of information has been developed on the subject of differential sensitivity.

In order to quantify an individual's sensitivity to small stimulus differences investigators have used as an index the smallest change in a stimulus or the least difference between stimuli that can be detected. This index of sensitivity is termed the difference limen or difference threshold. Because an organism's differential sensitivity appears to fluctuate as a function of time, it is generally agreed that the difference limen should be sampled over time and should represent the smallest change that is detectable in at least half the number of stimulus presentations.

In assessing the differential sensitivity of living organisms investigators have measured the difference limen for various parameters of many different stimuli. The present investigation is concerned with the measurement of the difference limen for change in the intensity of an acoustic stimulus. Many studies have been directed toward determining the variables that may influence the size of the difference limen for intensity (abbreviated DLI). The magnitude of the DLI has been found to be influenced by the details of the method used to measure differential sensitivity, by pathological or altered physiological states within the auditory system, and by a variety of other factors.

The measurement of differential sensitivity has been incorporated into the audiologist's armamentarium of clinical procedures because variations in DLI size appear to be associated with changes in the state of the auditory mechanism. The measurement of the DLI in patients exhibiting a variety of aural pathologies has resulted in the observation that the intensive difference limen appears to be smaller in those individuals with hearing loss of cochlear origin than in those with normal hearing sensitivity (11, 15, 28, 29, 37, 38, 39).

Two recent reports (3, 9) which suggest that noise presented to the opposite ear may significantly affect the magnitude of the monaural

DLI are of particular interest to those employing variations of DLI procedures for clinical purposes. This finding holds important implications for the audiometric applications of DLI testing, since clinically it is often necessary to introduce a masking noise to the non-test ear in order to prevent its participation in the measurement process.

While both of the studies alluded to above appeared to show a distinct influence of a contralaterally-presented thermal noise on the size of the DLI with respect to the values obtained in the absence of the noise, one experiment demonstrated an improvement in the DLI, but the other showed a trend toward deterioration of performance.

Both investigations involved the detection of brief-amplitude increments superimposed on a background tone of identical frequency. In one experiment, a series of 20 increments was mounted on a continuous background tone while a thermal noise was presented to the opposite ear. The result was a reduction in the magnitude of the DLI with respect to the values obtained in the absence of the noise at both 1000 and 4000 Hz, two of the three frequencies tested. In the other study, the background tone and contralateral noise were terminated immediately after the subject detected the presence of a single increment. The DLI observed under these conditions tended to be poorer than it was in quiet at 1000 Hz, the only frequency tested.

Thus, while the two experimental paradigms resembled one another in certain respects, they differed significantly in at least one important particular. Specifically, both studies employed variations of the quantal stimulus-pattern. The subject's task in either case was to detect the presence of increments superimposed on a background stimulus.

Furthermore, in both studies the initiation and termination of the contralateral noise were coincident with that of the background stimulus. The test frequency of 1000 Hz was also common to both studies. In one of the experiments, however, the background was presented continuously until a full complement of 20 increments had been introduced, while in the other experiment the background was interrupted after the detection of each increment.

When considered together, the two studies seem to suggest the possibility that a contralaterally-presented thermal noise may produce different effects on the magnitude of the DLI obtained with variations of the quantal pattern depending upon whether the background stimulus is continuous or discontinuous in character. The present study was undertaken to explore this possibility. The following chapter presents a review of the literature pertinent to the investigation.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The term "intensive differential sensitivity" is used to describe an organism's ability to appreciate a barely perceptible change or difference in the intensity of a stimulus. The smallest difference or change in intensity that can be recognized is designated as the difference limen or difference threshold and may be expressed either as an absolute or as a relative value. The absolute difference limen (ΔI) is represented by the amount of change in stimulus magnitude required to elicit a judgment of just noticeably different. The relative difference limen ($\frac{\Delta I}{I}$) represents a ratio between the amount of change in stimulus magnitude required to elicit a judgment of just noticeably different and the level of the reference stimulus at which the judgment is obtained. The relative difference limen expressed in dB is given by the formula $10 \log (1 + \frac{\Delta I}{I})$ (52, p. 138).

Assessments of differential sensitivity for intensity change provide a means by which the resolving power of the auditory system can be evaluated. In addition, measurements of the intensive difference limen have been used clinically to determine the probable site of lesion in various auditory disorders. Unfortunately, the difference limen for intensity or DLI does not remain invariant under different experimental or clinical conditions and investigators have isolated several different factors which influence the magnitude of the DLI. Recently, for example, two studies were performed which indicated that noise stimulation of one ear affects the magnitude of the DLI obtained for the opposite ear.

One of the studies suggested that the size of the DLI increased in the presence of contralateral stimulation, but the other investigation showed that the DLI became smaller. The results of these two studies hint at the possibility that the influence which contralateral stimulation exerts on the DLI may be partly dependent on the temporal characteristics of the measurement stimulus.

The present study was undertaken to investigate the effect of contralateral noise stimulation on the difference limen for intensity obtained with two temporally different stimulus patterns. The following sections of this chapter review the early investigations of intensive discrimination in normal listeners, discuss the clinical applications of DLI measurements and the factors which affect differential sensitivity for intensity, and present a rationale for the present investigation.

Early Studies of Differential Sensitivity in Normal Listeners

Many of the earlier studies of differential sensitivity for intensity in normal listeners were concerned with observing the change in the size of the DLI across frequency as a function of presentation level. The first investigation employing exclusively electroacoustic apparatus was performed by Knudsen in 1923 (34). Knudsen measured the DLI monaurally by the method of limits using an amplitude-modulation technique.

He found that the relative DLI decreased as the presentation level increased to a "moderate intensity" and thereafter it remained relatively constant for higher presentation levels. Using a 40-dB sensation level (SL) and various test tones, Knudsen found the DLI to be approximately constant across the frequency range studied (800 to 1600 Hz).

The investigation which produced the most widely accepted values for intensive differential sensitivity and which is credited as defining the relationship between the size of the DLI and its variation with presentation level and across frequency is that of Riesz (48). Riesz used a method of amplitude modulation which produced a sinusoidally-varying intensity increment. His results show that the relative DLI decreases as intensity increases to approximately 60-dB SL but that above this level the DLI remains almost constant in size. Greater variation in the size of the DLI across frequency at levels below 40-dB sensation level was found by Riesz than by Knudsen.

Dimmick and Olsen (12) used a paired-tone comparison with a method of constant stimuli in obtaining their measurements of the DLI. Their results were obtained in a sound field under conditions of binaural listening. Their subjects were instructed to report both incremental and decremental differences between the two tones and, when in doubt or when equality of sensation was judged, they were instructed to report "equal." At all presentation levels reported, Dimmick and Olsen's DLI values were larger than those of Knudsen (34) or of Riesz (48).

In a later investigation, Stevens, Morgan and Volkmann (53) introduced the quantal psychophysical method. In the quantal procedure the variable stimulus, which consists of a series of amplitude increments, is superimposed on a continuously-presented reference stimulus or background. The subject reports only his detection of the presence of an increment and not a judgment of greater or less as is common to other psychophysical procedures.

Stevens, Morgan and Volkmann used a "random" selection of incremental values for successive blocks of twenty-five increments and the first increment value selected for the start of a session was one that could be detected 100 percent of the time. They demonstrated the same dependence of DLI size on presentation level as had Knudsen, and Riesz, but the size of the DLI determined with the quantal method was considerably smaller than the values reported by the earlier investigators.

All of the above investigations showed that the size of the DLI varies with the sensation level at which differential sensitivity is measured. An interaction between frequency and presentation level was noted by Knudsen, and by Riesz. In general, the size of the DLI varies across frequency when presentation level is low but tends to remain approximately constant for presentation levels above 40-dB to 60-dB SL. The differences in DLI size observed at equivalent frequencies and presentation levels from investigation to investigation may be attributable to different experimental populations and procedures.

Clinical Applications of DLI Measurements

The developers of clinically-oriented DLI procedures have used a variety of techniques to measure differential sensitivity. The purpose of almost all of the procedures, however, has been to demonstrate that the sensitivity to change in intensity of ears manifesting loudness recruitment is different from that of normal ears. The assumptions underlying the use of the DLI as an indicator of the presence of recruitment and the clinical procedures developed to assess DLI magnitude are reviewed in the following sections.

Assumptions Underlying Clinical Applications of DLI Measurements

Those who sought to use DLI measurements clinically anticipated that a heightened or increased sensitivity to intensity differences would be found in those patients with a cochlear hearing disorder manifesting recruitment, a phenomenon characterized by an abnormally rapid growth of loudness at suprathreshold levels. Furthermore, they assumed that if recruitment was associated with improved differential sensitivity for intensity, the recruiting ear should show a smaller DLI than the normal ear at equivalent presentation levels. These expectations were predicated upon the two basic assumptions enumerated by Hirsh, Palva and Goodman (22):

> First, it is assumed that since the loudness change corresponding to a given intensity change is much greater in a recruiting patient, the sensitivity to changes in intensity must be better, i.e., the DL must be smaller.
>
> Second, since the classic data on differential sensitivity show that the size of the DL in normal persons decreases as the intensity at which it is measured is increased, it is assumed that the DL at a given intensity will be smaller for a recruiting patient than for a non-recruiting patient, because the loudness associated with that intensity by the recruiting patient is greater.

Hirsh, Palva and Goodman (22) objected to the use of DLI measures as a clinical indicator of the presence of recruitment for several reasons, Their main objections concerned the assumptions underlying the use of DLI measurement for this purpose. The theoretical objection that they raised to the first assumption was as follows:

> This assumption would predict that a tone which is 40 DL's or just noticeable differences above the absolute threshold should sound twice as loud as a tone 20 DL's above absolute threshold, because there are twice as many discriminable steps in the former as in the latter. Newman made such comparison directly and showed that twice loudness is not equal to twice as many DL's. . . . in normal hearing the loudness for low tones increases more rapidly than does the loudness for middle-frequency tones; but the DL for low tones is larger, not smaller, than it is for middle-frequency tones! Furthermore, the function that relates loudness to intensity goes up rapidly at low intensities and then less rapidly at high intensities. If the above-stated assumption were true, then the DL should be small at low intensities and large at high intensities, but as a matter of experimental fact it is just the opposite.

Lüscher responded to the criticisms of Hirsh, Palva and Goodman by pointing out that since neither recruitment nor differential sensitivity had been "clarified theoretically, a rejection (of a relationship between the two) . . . for theoretical reasons, is not convincing . . . " (38). Lüscher stated that the fact that loudness grows rapidly in the lower frequencies with a concomitantly larger DLI than the middle or higher frequencies and the fact that the DLI is largest near threshold even though the growth of loudness is more rapid in this region does not necessarily refute the concept of using difference limen measurement as an indicator of the presence of recruitment. He reasoned that the actual number of decibels or fraction thereof involved in a DLI represents as different an amount of loudness growth as the decibel steps at a low intensity and at a high intensity represent a different amount of absolute increase in the physical signal. In other words, it appears that if the DLI is expressed in decibels it decreases with increasing intensity, but if the DLI is expressed as an absolute quantity it increases with increasing intensity. In this respect, the DLI conforms to what would be predicted from the loudness-growth function.

Apart from the theoretical considerations discussed by Hirsh, Palva and Goodman (22), and Lüscher (38) the most important reason for the lack of more widespread use of DLI procedures clinically appears to be inter- and intra-subject variability. Reference data for all categories of hearing capacity have not been established and in several studies (35, 36) a clear differentiation of DLI sizes from category to category has not been found. In addition, different DLI measurement procedures seem to yield different DLI magnitudes (12, 48, 53). Harris (20) has suggested that different DLI procedures measure different areas of the intensive differential sensitivity domain, accounting for the differences in DLI magnitude. This concept will be discussed in more detail in a later section.

Clinical DLI Procedures

Brinitzer (4) is credited with being the first to use the DLI for the clinical assessment of hearing function. His attempt to show the diagnostic potential of DLI measurements, however, was not completely successful. Most developers of clinical DLI procedures since Brinitzer's time have tried to demonstrate that intensive discrimination in hearing impaired patients manifesting loudness recruitment is different than in those without recruitment.

Lüscher and Zwislocki (39) employed an amplitude-modulation procedure to assess intensive discrimination. Their apparatus produced trapezoidal modulations of a carrier tone at a rate of 2.5 per second. The patient's task was to report the point at which he could no longer distinguish the modulation. Lüscher and Zwislocki reasoned that the most advantageous intensity for determining the DLI was 40 dB above threshold since Riesz (48) had shown that at this level in the normal ear the size of the DLI was only slightly dependent on frequency differences. The rationale for Lüscher and Zwislocki's test rests on the assumption that the DLI at any level is smaller in an ear manifesting recruitment than in a non-recruiting ear.

Denes and Naunton (11), on the other hand, reasoned that the relationship between DLI magnitude and presentation level should be different for the ear showing recruitment than for the non-recruiting ear. Inasmuch as the normal ear yields a DLI which decreases in magnitude with increased presentation level, they concluded that the recruiting ear should not show this decrease since the loudness growth in a recruiting ear is rapid near threshold and then approaches the slope of the normal loudness function at higher sensation levels. Consequently, these investigators concluded that the DLI in a recruiting ear should be small near threshold and should increase in magnitude as intensity increased.

Denes and Naunton employed a paired-tone comparison procedure to measure the DLI at two sensation levels. The presence of recruitment was inferred if the DLI obtained at a level close to threshold was equal to or smaller than that measured at a higher sensation level. The absence of recruitment, on the other hand, was inferred if the DLI decreased in size as sensation level was increased.

The "Northwestern DL Test" developed by Jerger (28) represented a modification of the Lüscher-Zwislocki procedure. Jerger also used amplitude modulation to produce intensity fluctuations but he changed the presentation level to 15-dB SL, first, on the premise that recruitment is greatest just at and above threshold and, second, on Doerfler's findings that "the DL in perceptively deafened ears is abnormally decreased to the greatest degree in the range from 10 to 30-dB sensation level" (15). The presence of recruitment was inferred if the DLI obtained from a patient with decreased hearing sensitivity was smaller than that obtained from normal hearing individuals.

Jerger (29) took advantage of what he considered to be the best aspects of the procedures of both Lüscher and Zwislocki and Denes and Naunton in his "DL Difference Test." He used amplitude modulation to produce intensity variations and obtained a measurement of the DLI at two sensation levels (10- and 40-dB SL). The interpretation of the results of this test was essentially the same as that used in Denes and Naunton's procedure, i.e., when the difference between the size of the DL at 10-dB SL and at 40-dB SL was large, an absence of recruitment was inferred. The degree of recruitment was presumed to increase as this difference became smaller.

Although all the above investigators have reported that clinical DLI procedures possess diagnostic potential, others have failed to demonstrate a consistent difference between the performance of those individuals with normal hearing and those with hearing loss. Lidén and Nilssen (35), for example, reported that the variability in the size of the DLI obtained with the Lüscher-Zwislocki procedure was so large that it was not possible to distinguish between recruiting and non-recruiting ears. Similarly, Lund-Iverson (36) was not able to differentiate between his three experimental groups (normal, conductive hearing loss, and sensorineural hearing loss showing recruitment) on the basis of the size of the DLI obtained with the Lüscher-Zwislocki test.

The early clinical DLI procedures were assumed to be "indirect" indicators of the presence of recruitment (22). It now appears, however, that a reduced DLI and loudness recruitment are not invariably linked (35, 36) and that the presence of loudness recruitment is not necessarily associated with a cochlear site of lesion (5, 41).

Jerger (32) appears to have been first to advance the notion that it is far less important for a test to be a good predictor of recruitment than to be a good predictor of site of lesion within the auditory system. According to him, the Short Increment Sensitivity Index (SISI) is such a test. The SISI test (33) represents an extension of the clinical DLI procedures although it is not formally a DLI test nor was it intended to indicate the presence of recruitment. Jerger, in fact, has presented evidence which indicates that the SISI test is a poor predictor of recruitment but a fairly good predictor of site of lesion.

In the SISI procedure, twenty intensity increments of 1.0-dB magnitude and brief duration are superimposed on a continuous background tone presented at 20-dB sensation level. The patient's task is to report whenever he detects the presence of an increment. Performance is scored from zero per cent to 100 per cent where zero per cent indicates that none of the increments was detected and 100 per cent indicates that all of the increments were detected. Jerger proposed that the test be interpreted as indicative of a cochlear site of lesion if the SISI score was 60 per cent or greater (32). Values less than this are difficult to interpret and may be associated with retrocochlear lesions.

Recently, Dallos and Carhart (10) have presented evidence which indicates that it is possible to predict mathmatically the number of DL's for intensity change that normals will cumulate between two different sensation levels. Horner (24) extended these observations to include a comparison of the performance of normal and hearing impaired individuals on this task. He found a significant difference between the number of DL's cumulated by these two groups with a larger number of DL's being cumulated by those with impaired hearing.

Finally, if their theory is correct, Carhart and Matkin's recent reports (5, 41) may force a sweeping reappraisal of the traditional clinical interpretation of audiologic data. They advance the hypothesis that the effect of selective neuronal damage in the cochlear nuclei resulting from icteric deposits may yield results on various audiological procedures that mimic those that typically have been associated with cochlear damage. This hypothesis has important implications for the use of clinical DLI procedures. First of all, of course, it indicates that heightened sensitivity to intensity change may not necessarily be associated with cochlear damage after all. Secondly, if lesions of the central auditory pathways at the level of the cochlear nuclei can affect sensitivity to intensity change it would appear pertinent to question whether or not other changes at this level could also affect intensive discrimination. Specifically, since there are numerous interconnections within the central auditory pathways between the neural fibers associated with each cochlea the possibility exists that the sensitivity of the normal system to intensity change may be altered by central interaction resulting from binaural stimulation. Later sections review the literature which explores this possibility.

Factors Affecting Differential Sensitivity for Intensity

The various procedures developed to assess differential sensitivity seem to yield DLI's of differing magnitude. An explanation for such poor agreement may be that the procedures measure different aspects of intensive differential sensitivity or that other variables which affect DLI magnitude are introduced into the experimental or clinical test situation because of the differences among procedures. The effects on the DLI of procedural differences, adaptation, and contralateral stimulation, are reviewed in the following sections.

Measurement Method

Harris (20) has performed perhaps the most comprehensive investigation of the DLI in recent times. He attempted to determine if loudness discrimination was " . . . a closely spaced domain such that all tests ostensibly of the ΔI were equally meaningful." He did not think that this was the case but, rather, that different DLI measurement procedures sampled different constituent areas of the loudness discrimination domain. Three distinct areas emerged as the primary constituents of the loudness discrimination area from a correlation matrix analysis composed of 17 different DLI and loudness tests. Harris called these areas Loudness-Modulation, Pure-Tone Loudness-Memory, and Loudness-Masking.

Loudness-Modulation.

The Loudness-Modulation area is tested by an amplitude-modulation technique. While the technique used may produce sinusoidal (15, 48), trapezoidal (28, 39) or other configurations of amplitude variation, all involve the detection of intensity fluctuations in a continuously presented signal.

The size of the DLI obtained by methods which sample the loudness-modulation area of the ΔI domain is strongly influenced by the overall intensity of stimulation and shows variations in DLI magnitude across frequency (20, 28, 34, 39, 48, 56). In addition, the rate of modulation used in such techniques has been shown to influence the size of the DLI (48, 54).

Pure-Tone Loudness-Memory.

The Pure-Tone Loudness-Memory area of the ΔI domain is sampled by tests which employ discrete pure-tone stimuli with some temporal separation between the standard and the variable stimuli. Any paired-tone comparison technique samples this area. According to Harris (20), the size of the DLI obtained with Pure-Tone Loudness-Memory techniques is greatly affected by the choice of judgmental response. If the subject is forced to make only "louder" or "softer" judgments a smaller DLI is obtained than when "equal" or "doubtful" judgments are also allowed. Pure-Tone Loudness-Memory tests are relatively insensitive to frequency and intensity differences when a forced-choice technique is used.

Loudness-Masking.

Harris (20) states that the Loudness-Masking area is assessed by any test using increments either of tone, noise or clicks, or by any test using immediately adjacent intensity levels of tone or noise for comparison. The best example of a test sampling this area is the quantal psychophysical method developed by Stevens, Morgan and Volkmann (53), in which increments are superimposed on a continuous background stimulus. Harris (20) investigated the effects of frequency and intensity on the size of the DLI obtained with a variant of this procedure. He found the Loudness-Masking area to be affected by the overall intensity of the stimulation so that the relative DLI decreased in size with increasing intensity. Furthermore, Harris noted a slight variation in DLI size across frequency at lower sensation levels. A larger relative DLI was obtained at the lower frequencies at presentation levels below 40-dB SL.

The effects of the duration and the rise-fall time of the increments on DLI size have also been investigated with regard to the Loudness-Masking factor. Harris (20) found an interaction between sensation level and duration of the increment on one hand and sensation level and rise-fall time on the other. Rise-fall times could be varied from five to 50 msec with little change in the size of the DLI at SL's of 20 dB and above. The DLI below 20-dB SL, however, became larger for longer rise-fall times. There was little variation in DLI size across sensation levels for increment durations of 300 msec and longer. The DLI tended to increase in size with decreasing sensation level for increment durations of less than 300 msec.

As noted in the preceding sections, the procedure selected to measure differential sensitivity to intensity change influences the size of the DLI obtained and, according to Harris (20), determines the area of the ΔI domain sampled. Two of these areas, namely, Loudness-Modulation and Loudness-Masking are sampled by measurement techniques which involve continuous stimulation of the test ear. Recently, evidence has been presented which indicates that adaptation, as a consequence of sustained stimulation, has a facilitative effect on differential sensitivity. The following section discusses this and related findings in more detail.

Effects of Adaptation and Fatigue on Differential Sensitivity

There are several distinctions between auditory adaptation and fatigue, all of which need not be mentioned in this discussion. Suffice it to say that both adaptation and fatigue result in a decrease in absolute threshold sensitivity. The effect of auditory fatigue, however, continues to accrue with continued stimulation while auditory adaptation reaches a limit beyond which threshold shift increases only slightly with continued stimulation (6, 23, 31). Moreover, more intense stimulation is required to produce auditory fatigue than to produce adaptation (19). In addition to its effect on absolute threshold, adaptation may result also in a "diminution of loudness (of a suprathreshold signal) as a function of continued acoustic stimulation . . ." (51).

Upton and Holway (57), Oldfield (43), Rawdon-Smith and Sturdy (46), and Endicott (17) found that adaptation results in improved differential sensitivity to intensity change. Elliott, Riach, and Silbiger (16) and Riach, Elliott and Reed (47) have found that the DLI is smaller at lower presentation levels of the test tone when the ear is fatigued.

Endicott (17) hypothesized that adaptation in normal ears would result in improved differential sensitivity to intensity measured at suprathreshold levels. He used two variants of the quantal method to test differential sensitivity at 500 and 4000 Hz. One variant consisted of increments superimposed on a continuous background tone. The other variant involved the detection of increments added to brief tonal pedestals. The continuous background was used to maintain adaptation produced by a pre-test adapting tone of eight minutes duration.

Endicott found larger difference limens at a 35-dB SPL presentation level for the continuous background pattern than for the interrupted pattern at 500 Hz, but the eight-minute adapting tone at this presentation level was found to have produced very little adaptation. Endicott proposed that the smaller DLI obtained with the interrupted procedure was the result of additional detection information afforded by the pedestals on which the increments were superimposed.

When the presentation level was raised to 70-dB SPL the DLI's for each procedure at 500 Hz were roughly equivalent in magnitude and much more adaptation was measured for the continuous background procedure. The continuous background consistently yielded smaller DLI's than the interrupted background at both presentation levels at 4000 Hz. There was also more adaptation measured at both presentation levels for the continuous background at 4000 Hz than there had been at 500 Hz.

In an attempt to explain his results, Endicott proposed that adaptation reduces the amount of "on-going" background neural activity and if the amount of neural activity is low at the moment of increment presentation, the additional neural activity initiated by the increment will be more easily detected. He concluded that adaptation has a definite facilitative effect on differential sensitivity for intensity at both frequencies tested.

Contralateral Stimulation

In addition to adaptation and fatigue, contralateral stimulation has been shown to affect several auditory measures, including intensive discrimination. The following review of the effects of contralateral stimulation on measures other than differential sensitivity was included to establish that the specific influence on the particular parameter studied appears to be highly dependent upon the temporal characteristics of the stimulus.

Effects on measurements other than differential sensitivity.

Absolute threshold. A stimulus delivered to one ear can result in an elevation of the threshold for another stimulus delivered to the opposite ear. This threshold elevation may result from either peripheral or central masking. Peripheral masking arises when the sound delivered to one ear is sufficiently intense to stimulate the opposite ear also, resulting in a threshold elevation for both ears. This is termed over-masking or crossmasking. Central masking, on the other hand, arises when a threshold shift in one ear is found in the presence of a sound delivered to the opposite ear at a level too low to be attributable to overmasking.

The earliest description of central masking is probably contained in Wegel and Lane's article on the masking of pure-tones by pure-tones (59). These investigators found a slight threshold shift for a test tone presented to one ear in the presence of a low sensation level masking tone delivered to the opposite ear. This effect was generally very small and Wegel and Lane attributed it to an interference occurring within the central nervous system, hence, the derivation of the term "central masking."

Several investigators have explored the effect of central masking on the thresholds for both pure tones (42, 44, 55) and speech (40). The amount of central masking produced depends upon a number of factors, i.e., the nature of the test signal, the type of masker, the intensity level of the masker, the amount of frequency separation between the test signal and the masker, and the temporal patterns of the masker and the masked sound.

Hughes (25) and Ingham (26, 27) found a significant variation in the amount of central masking with increasing intensity of the masker. Ingham used a steady masker and steady test tone both at 30-dB sensation level and found central masking in the order of 10 to 15 dB. He suggested that the central masking effect could be the result of inhibition caused by the central control of peripheral structures.

Sherrick and Albernaz (50) speculated that the discrepancy between the reports of Wegel and Lane, and Ingham concerning the amount of central masking produced by contralateral stimulation might be attributable to differences in the patterns of the masking and the masked sounds. They compared the amount of central masking produced by a pulsed masker with that produced by a continuous masker and found more threshold shift for the pulsed-masker/pulsed-test-signal condition than for the steady-masker/pulsed-test-signal condition.

On the basis of Sherrick and Albernaz's findings, Dirks and Malmquist (13) were led to extend the experimental conditions to include a comparison not only of a pulsed test-signal with either a pulsed or steady masker, but also of a steady test-signal with either a pulsed or a steady masker. Their results supported Sherrick and Albernaz to the extent that more central masking was found in the pulsed-masker/pulsed-test-signal condition than in the continuous-masker/pulsed-test-signal condition. However, Dirks and Malmquist found that as much central masking was produced when both the masker and test signal were continuous as when they were both pulsed. They offered the occurrence of adaptation or fatigue during the continuous-masker/continuous-test-signal condition as a possible explanation for the large amounts of threshold shift found under this condition.

It is apparent that the amount of threshold shift attributable to central masking is influenced by the method of presenting the test tone and the masker. Less threshold shift (3 dB or less) will be produced if the test tone is pulsed and the masker is continuous, or if the test tone is continuous and the masker is pulsed, than if both are either pulsed or continuous, in which case the shift may amount to 15 dB or more (13, 14, 50).

Loudness judgments. Prather (45), Vigran (58), and Rowley (49) have all investigated the effect of contralateral noise on the loudness of pure-tone stimuli. The former investigators used the monaural loudness balance technique in their investigations.

In Prather's study, the reference tone was presented at 20- and 80-dB sensation levels at 250, 500, 1000, 2000, and 3000 Hz. Contralateral noise was presented at 40 and 100-dB sensation levels. The results show a loudness increase for both reference-tone levels across all frequencies when the noise was presented at 40-dB SL. The reference tone, however, suffered a decrease in loudness in the presence of the 100-dB SL noise which was more pronounced for the lower frequency tones. Prather concluded that the 40-dB contralateral noise had a facilitative effect on loudness, while the loudness reduction caused by the 100-dB noise might be explained by contraction of the middle-ear muscles and by crossmasking.

Vigran found that the loudness of a comparison tone was increased at all frequencies from 300 to 1500 Hz although loudness shifts were more pronounced at the higher frequencies. He concluded that the loudness increase was the result of a central interaction, possibly in the nature of a summation effect.

Rowley used the method of "numerical magnitude balance" to investigate the effect of various levels of contralaterally-presented white noise on judgments of the loudness of a 1000-Hz pure tone. This method consists of two judgment tasks: magnitude estimation in which the subject is required to assign an arbitrary loudness value to a given presentation level and magnitude production in which the subject adjusts the level of the test stimulus to an arbitrarily-assigned loudness value. Both measurements are made without a designated reference loudness standard. Rowley's specific procedure consisted of presenting three-seconds-on and three-seconds-off bursts of a 1000-Hz pure tone to one ear and white noise to the opposite ear. Loudness judgments in quiet were compared to judgments obtained in the presence of a contralateral noise presented at 40-, 60-, 80-, and 100-dB SL. Rowley found that not only was the loudness of the 1000 Hz tone increased in the presence of contralateral noise compared to the quiet condition, but that the amount of loudness increase and the rate of loudness growth was affected more as the sensation level of the noise was increased. He concluded that a summation effect between the noise and test tone was responsible for the increase in loudness of the test tones in the presence of contralateral noise.

Békésy tracing width. Dirks and Malmquist (13), Dirks and Norris (14), and Blegvad (1) all have reported effects of contralateral masking on the Békésy tracing width at threshold. Dirks and Malmquist found the excursion width of the tracing to be significantly affected by the presence of a contralateral masker only when the test tone and the masker were both continuous. When the test tone was pulsed and the masker was either pulsed or continuous, no significant reduction in tracing width was noted. Dirks and Malmquist speculated that the continuous-tone/continuous-masker condition provided an opportunity for adaptation or fatigue to occur.

Dirks and Norris' results also show significant changes in tracing width only for the continuous-tone/continuous-masker condition. This effect was more evident at 1000 and 4000 Hz than at 250 Hz for both pure-tone and narrow or wide-band maskers. Blegvad (1), however, demonstrated a significant reduction in tracing amplitude for both pulsed and continuous test tones of 1000 and 4000 Hz when the contralateral masker was a continuous noise. More reduction in tracing width, however, was found for the continuous-masker/continuous-test-signal condition than for the continuous-masker/pulsed-test-signal condition.

<u>Effects on differential sensitivity for intensity</u>.

In 1935, Gage (18) investigated the effect of a continuous tone in one ear on the DLI obtained with a test tone of the same frequency delivered to the opposite ear. His instrumental arrangement produced five intensity increments per second in the ongoing stimulus while a tone of the same frequency was delivered continuously to the opposite ear. Gage tested at frequencies of 300, 500, and 800 Hz. He used various background levels of the test tone at each frequency in the presence of varying levels of tone in the opposite ear. His results show a slight tendency for the DLI to increase in size with increasing levels of contralateral tone. He also found less effect of contralateral tone on DLI size as the background level of the DLI measurement tone was increased and as the frequency of the background tone was increased. Gage stated that it was surprising that there was so little effect on the magnitude of the DLI as the tone to the non-test ear was made more intense than that to the test ear. He did not perform a statistical analysis of his data to determine the significance of the differences observed between the DLI's obtained with high and low levels of contralateral stimulation.

In a later study, Chocholle (7) measured intensive discrimination at 1000 Hz with a 1000-Hz tone delivered simultaneously to the opposite ear. In contrast to Gage, he used interrupted background and contralateral tones with a single increment superimposed upon each brief background pedestal. Chocholle found a significant increase in DLI size in the presence of increasing levels of contralaterally-presented tone compared to the quiet condition. He observed that there may have been a summation effect present but, since the DLI increased in magnitude rather than decreased in the presence of the contralateral stimulation, he suggested that the results might represent a central interference causing a lack of contrast between the increments and the background. In addition, he stated that the amount of increase in DLI magnitudes from quiet to those levels at which both the contralateral tone and the test tone were equal in intensity is less than would be expected from an actual binaural summation of the tones.

In 1959, Chocholle (8) again investigated the effect of contralateral stimulation on the monaural DLI by presenting tones that were higher or lower in frequency than the test tone to the contralateral ear. The stimulus pattern that Chocholle used in this study was the same that he had used previously, i.e., interrupted test tones on which brief amplitude increments were superimposed were presented simultaneously with interrupted tones to the opposite ear. The results indicated that the DLI was increased in size compared to the quiet condition when the contralateral tone was close in frequency to that of the test tone. When the contralateral tone was dissimilar in frequency, the DLI appeared to be smaller than that obtained in quiet. Based on these results it appears that contralateral stimulation with a pure tone dissimilar in frequency to that of the test tone has a facilitative effect on differential sensitivity.

The effect of a contralaterally-presented white noise on the DLI obtained with what appears to be a variant of the quantal stimulus pattern was investigated by Chocholle and Saulnier (9). The experimenters measured differential sensitivity for a 1000 Hz tone at a 10-dB sensation level in quiet and in the presence of a 40-dB sensation level noise presented to the opposite ear. Both the tone and noise were interrupted between incremental presentations. The rise-fall times of the increments and background tonal pedestals were described simply as being "abrupt." The duration of the test tone and the contralateral noise, as well as the occurrence of the increments, were under control of the subject. The subject was alerted visually to prepare himself to listen. When he was ready, he depressed a switch which presented the background tone and the noise to opposite ears. A second switch under his control caused a brief increment in amplitude to be added to the tone. After reporting his decision as to the presence or absence of an increment the subject returned the first switch to its original position thereby terminating the stimulation of both ears. A silent period of indeterminate length intervened between successive stimulus presentations.

Chocholle and Saulnier's results showed that in three out of four subjects differential sensitivity tended to deteriorate with contralateral noise stimulation. A statistically significant increase in DLI size, however, was found for only one of the subjects. The authors speculated that a central interference, perhaps in the form of a disturbance of "figure-ground" relationships, might form a possible explanation for their results.

Results almost completely opposite from those of Chocholle and Saulnier have been presented by Blegvad and Terkildsen (3) who also measured differential sensitivity with a variant of the quantal stimulus pattern in quiet and in the presence of contralaterally-presented noise. Unlike Chocholle and Saulnier, Blegvad and Terkildsen delivered the noise and the background tone continuously until a complement of twenty increments of the same magnitude had been presented. The subjects in this study did not have control over the background tone, the noise, or the increments. Test tones of 250, 1000, and 4000 Hz were presented at a 20-dB sensation level. The differential sensitivity of ten normal hearing subjects was assessed in quiet and in various levels of contralaterally-presented noise. Broad-band noise was presented to the opposite ear at 50-, 70-, and 90-dB SPL. The DLI was defined as the increment magnitude corresponding to the 50 per cent point on a rectilinear psychometric function.

Statistical analysis of Blegvad and Terkildsen's results showed that noise stimulation of the contralateral ear has an adverse effect on differential sensitivity at 250 Hz. All noise levels produced a significant increase in DLI magnitude at this frequency with respect to the result obtained under the quiet condition. Contralateral stimulation had the opposite effect on DLI magnitude at 1000 and 4000 Hz. The DLI became significantly smaller at these frequencies as the noise level was increased in the contralateral ear. Blegvad and Terkildsen speculated that adaptive processes might be responsible for the reduction of DLI magnitude in the presence of continuous contralateral stimulation.

Rationale for the Present Experiment

A review of the literature leads to the conclusion that virtually all aspects of auditory behavior may be affected, at least subtly, by acoustic stimulation of the opposite ear. Differential sensitivity for intensity is apparently not an exception to this generalization.

The nature of the effect of contralateral stimulation with pure tones on the DLI seems to depend on the relationship of the frequency of the test tone to that of the tone presented to the opposite ear. If the frequency of the tone presented to the other ear is the same as, or similar to, that of the test tone, the effect appears to be a deterioration of differential sensitivity regardless of the temporal characteristics of the measurement stimulus (7, 18). The presentation of tones of dissimilar frequency to the two ears, however, appears to result in an improvement of differential sensitivity, at least as tested with a procedure using stimuli of relatively short duration (8).

Based upon this information, it would seem difficult to predict the outcome of stimulating the opposite ear with broad-spectrum noise since it would contain components close to the frequency of the test tone as well as components progressively further removed from that frequency. Aside from being of considerable academic interest, knowledge of the precise result to be expected is important to the audiologist since it is common practice to use a contralateral broad-band masking noise while administering clinical procedures based upon measures of differential sensitivity. As an aside, it is ironic that delivering a masking noise to the non-test ear appears to affect the magnitude of the DLI since it is the very purpose of the noise to prevent the non-test ear from influencing the results through participation in the measurement task.

The two studies which have treated the effect of contralateral noise on the DLI have yielded diametrically opposed results (3, 9). The experiments were dissimilar in a number of important particulars, but the most salient difference appears to be in the temporal patterns associated with the test stimuli. One study (3), using a prolonged background stimulus, showed a reduction in magnitude of the DLI with the introduction of a contralateral noise stimulus. The other (9), using test stimuli of relatively short duration, showed a deterioration of performance upon the introduction of noise to the opposite ear.

In the face of a number of other procedural differences between the two studies, the dissimilarity in temporal pattern was viewed as the element most likely responsible for the conflicting results. This factor was singled out from among the others because of its recognized role in influencing other aspects of auditory behavior such as adaptation and central masking.

Consequently, the present experiment was undertaken to explore the possibility that contralateral noise stimulation may affect the DLI differently depending upon whether the measurement stimulus is continuous or discontinuous in nature. It was designed to reduce or eliminate the influence of other extraneous variables which might have played a part in earlier work conducted along these lines.

Summary

This chapter has reviewed the early investigations of intensive discrimination in normal-hearing listeners which indicated that variations in DLI magnitude were noted across frequencies and sensation levels. It was the opinion of several investigators that individuals with a hearing loss and manifesting recruitment would obtain DLI's of different magnitude than normal listeners. Several procedures were developed for clinical use in this respect, but considerable inconsistency between procedures and within procedures was noted. In addition, the use of DLI procedures to indicate the presence of recruitment was attacked on theoretical as well as procedural grounds. In spite of the arguments presented by some investigators, clinical DLI tests have fallen into general disuse and, justifiably, the importance of a test being a good indicator of site of lesion has gained precedence over the necessity that a test be an indicator of the presence of recruitment. It has been suggested, however, that the results of one such test, the SISI which has been considered a good indicator of site of lesion, may be modified by damage to the higher auditory pathways. This finding supports the observation that many factors may be important in determining the outcome of tests that assess sensitivity to intensity change. These factors may be related to procedural differences, to physiological effects generated by the temporal characteristics of the procedure used, and to contralateral stimulation. The effects of contralateral stimulation on the DLI have been found to be discrepant in several studies. These differences appear to be related to the temporal patterns of the test stimuli. The present investigation was designed to explore the possibility that the effect of contralateral noise on the magnitude of the DLI, measured with variants of the quantal stimulus pattern, may be dependent on the temporal characteristics of the background stimulus.

The next chapter contains a description of the procedure and instrumentation used in this investigation.

CHAPTER III

INSTRUMENTATION AND PROCEDURES

Introduction

Blegvad and Terkildsen (3) have reported that contralateral masking may have a facilitative effect on DLI magnitude. Their measurement procedure involved the detection of increments added to a continuous-background stimulus. Chocholle and Saulnier (9), however, found a trend in the opposite direction, i.e., toward a larger DLI in the presence of contralateral noise stimulation. Their stimulus pattern also consisted of increments added to a background tone, but the background and the contralateral noise stimulus were both interrupted between incremental presentations.

These studies seem to suggest that the influence which contralateral noise stimulation exerts on DLI magnitude, as measured with a quantal stimulus pattern, may differ depending on the temporal pattern of the background stimulus. It was the purpose of the present study to investigate this possibility.

The experimental design called for the use of two variations of the quantal stimulus pattern to obtain estimates of DLI magnitude in quiet and in the presence of a contralaterally presented noise. One of patterns consisted of amplitude increments superimposed on a continuous-background tone. The other pattern consisted of amplitude increments centered on brief, tonal pedestals, which were separated by intervals of silence. The latter constituted an interrupted background stimulus.

Subjects

Eight young adults between the ages of 18 and 30 were used as subjects in the present investigation. Three were male and five female. The subjects were selected from the students enrolled in the Department of Communication Disorders, University of Oklahoma Medical Center and from the undergraduate student body of Central State College, Edmond, Oklahoma. All subjects were required to pass a pure-tone screening test administered at 15-dB hearing level (ISO-1964) at octave intervals between 250 and 8000 Hz.

Apparatus

Acoustic Environment

Subject familiarization and data collection sessions were conducted in a two-room sound-isolated audiometric test suite located in the Speech and Hearing Center at the University of Oklahoma Medical Center, Oklahoma City, Oklahoma. The subject was seated in the test room of the suite while the experimental apparatus was situated in a separate control room. Visual communication between the subject and the experimenter was maintained through an acoustically-damped window in the wall separating the test and control rooms. Two-way verbal communication was accomplished by means of a "talk-back" system. The test room contained a standard headset with matched earphones, a push-button for registering responses, and a talkback microphone.

Screening Apparatus

The screening apparatus consisted of a pure-tone audiometer (Beltone, 15CX) connected to a pair of earphones (Telephonics, TDH-39 10Z) mounted in a standard headband and fitted with MX-41/AR cushions. The output of this audiometer was calibrated to the ISO-1964 standard.

Experimental Stimuli

Stimulus patterns-test ear.

Two variants of the quantal stimulus pattern were used to obtain measurements of differential sensitivity to intensity change. One variant consisted of a continuous background tone on which amplitude increments were superimposed at periodic intervals. The other variant consisted of an interrupted background tone made up of brief tonal pedestals separated by intervals of silence. Amplitude increments were superimposed on successive tonal pedestals. The increments and backgrounds for both stimulus patterns were of the same frequency and phase. The characteristics of the signal envelopes are represented diagrammatically in Figure 1.

As Figure 1 illustrates, each increment was of 200 msec duration at maximum amplitude with rise-fall times of 10 msec. The increments occurred at five-second intervals. Twenty increments of the same magnitude were presented during each individual test run. The background tone remained on for 120 seconds during the continuous background condition. During the interrupted-background condition each increment was superimposed on a tonal pedestal of 1950 msec duration at maximum amplitude with a rise-fall time of 50 msec. The pedestals were separated by 2950 msec

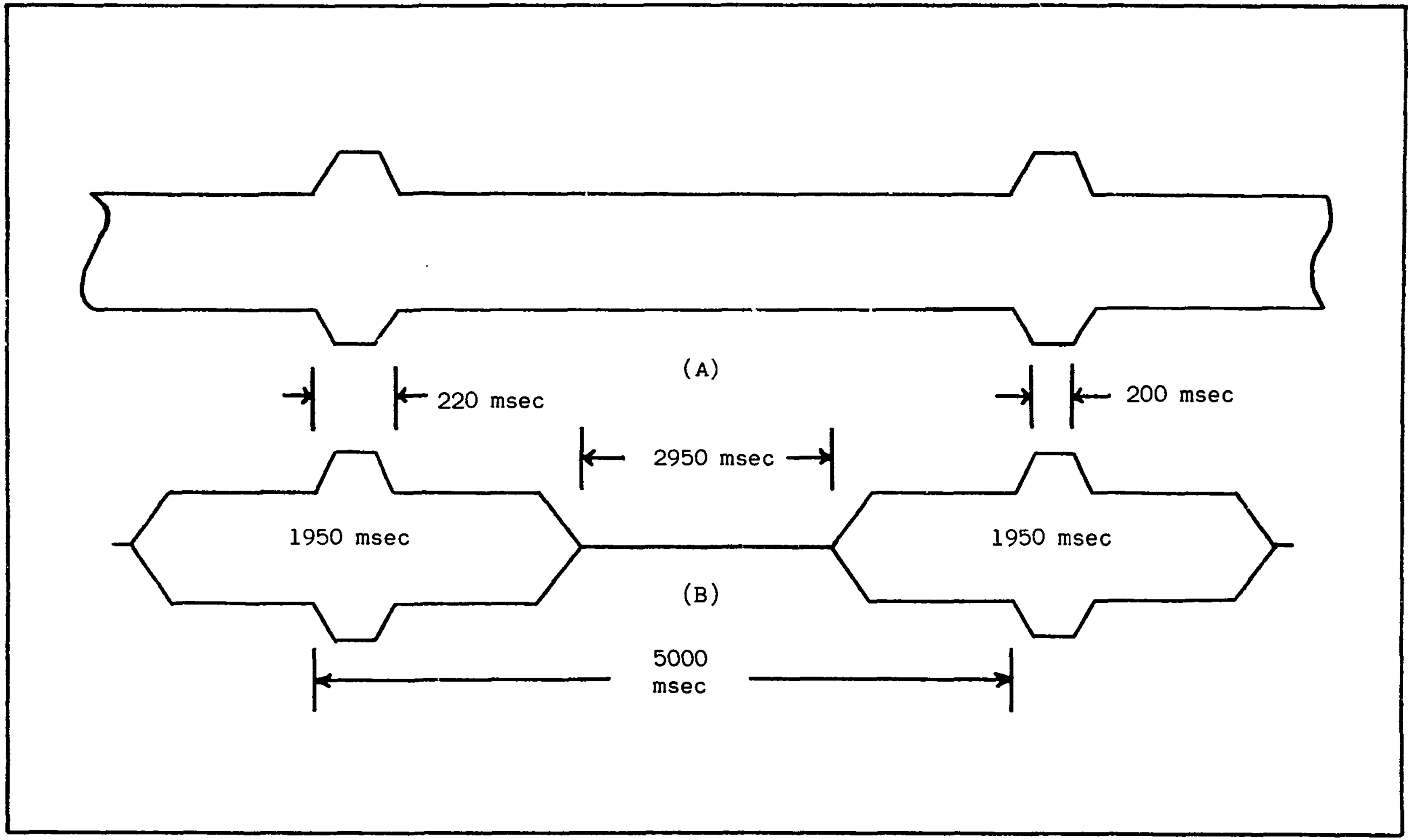


Figure 1. Diagrammatic representation of signal envelopes. (A) Continuous background with increments. (B) Interrupted background with increments.

of silence. The interrupted background pattern recycled for a total period of 120 seconds during each test run.

Noise stimulus-contralateral ear.

The other auditory stimulus was a broadband thermal noise. This noise was presented to the ear contralateral to the test ear continuously for 120 seconds when called for by the experimental design. The introduction of the noise occurred simultaneously with the initiation of the tonal background pattern in the opposite ear, and after 120 seconds the noise was terminated concurrently with the end of the tonal background pattern.

Experimental Test Equipment

The following sub-sections describe the equipment comprising the signal and noise channels as well as that used for the selection and timing of the temporal characteristics of the test stimuli. Additional subsections describe the response tabulation equipment, subject-experimenter communication system, and the power supplies required by certain components of the timing and programing apparatus.

Signal channel.

Figure 2 presents a block diagram of the equipment comprising the signal channel. The pure-tone signals forming the incremental and background stimuli were produced by an audio-frequency oscillator (Hewlett-Packard, 201 CR). The signal from the oscillator was split by means of a resistive network, the ports of which were terminated by the inputs of two electronic switches. One of these switches (Grason-Stadler, 829 E, designated ES1) controlled the temporal characteristics

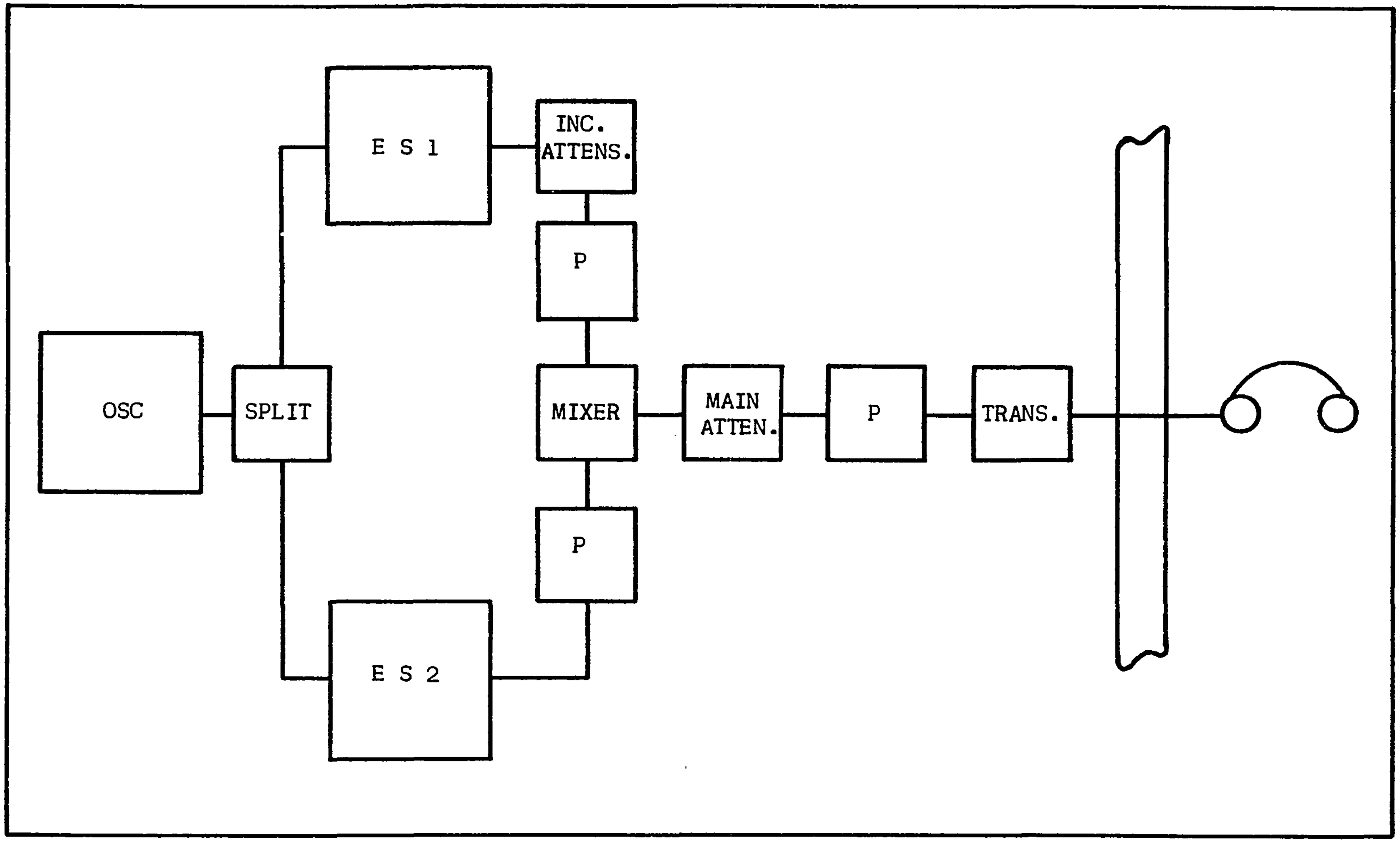


Figure 2. Simplified block diagram of the experimental equipment comprising the signal channel.

of the increments added to the background signal. The other electronic switch (Grason-Stadler, 829 C, designated ES2) controlled the temporal characteristics of the background signal.

The output from ES1 was routed through one of two continuously-variable attenuators (Mallory, T-600) which controlled the magnitudes of the incremental signals. The output from ES1 could be switched manually by means of a three-position switch to one or the other of the two attenuators during each experimental run. The incremental and background signals passed through separate 20-dB isolation pads (Daven, 1030-G, labeled P) prior to being combined by means of a resistive network (mixer). These pads eliminated signal interaction so that any change in the level of the incremental signal did not result in a change in level of the background signal.

After the incremental and background signals were combined in the mixer, the composite signal passed through an attenuator (Hewlett-Packard, 350 D) with which the experimenter established the overall intensity of the signals during difference limen measurements. This level was held constant at 60-dB SPL for all measurements. The attenuated signal then passed through an isolation pad (labeled P) and an impedance-matching transformer (UTC, LS-33) to an earphone (Telephonics, TDH-39 10Z), mounted in an MX-41/AR cushion.

Noise channel.

A block diagram of the equipment comprising the noise channel appears in Figure 3. A broad-band thermal noise produced by a noise generator (Grason-Stadler, 455 C) was used in those experimental conditions requiring contralateral stimulation. The output from the noise generator

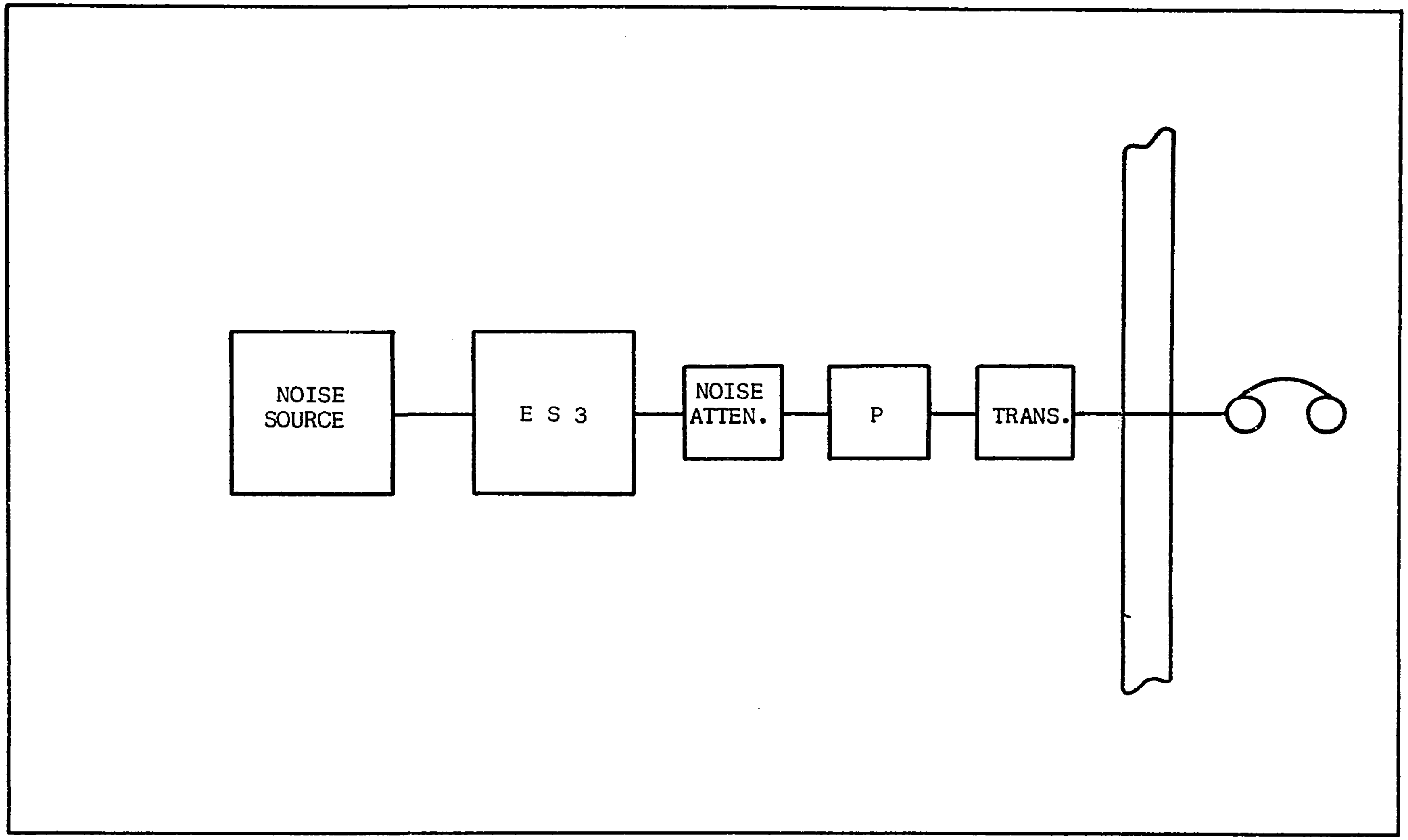


Figure 3. Simplified block diagram of the experimental equipment comprising the noise channel.

was routed to a third electronic switch (Grason-Stadler, 829 C, designated ES3) which controlled the duration of the noise. The noise signal passed from this electronic switch through an attenuator (Hewlett-Packard, 350 D) which controlled the output level of the noise. The attenuated signal then passed through an isolation pad (Mallory, T-600) and an impedance-matching transformer (UTC, LS-33) to a second earphone (Telephonics, TDH-39 10Z).

Programming apparatus.

The programming system consisted of four sensitive relays, two 115 V relays, three 6 V relays, a latching relay and several manual switches. The subject's pushbutton switch initiated the program by energizing the latching relay which, in turn, permitted the electronic timing apparatus (Tektronix, 160 series) to cycle. The timing apparatus will be discussed in more detail in a later section. After the program was begun this pushbutton served to record subject responses on an electromechanical counter. The initiation of the program was accomplished by shorting one set of contacts on the latching relay across the pushbutton contacts of waveform generator A (WFG-A) after the mode control of the waveform generator had been set to the "manual-continuous" position. In this fashion, WFG-A continued to cycle at five-second intervals for as long as the latching relay contacts remained closed. Once during each timing cycle, a pulse was sent to a sensitive relay which energized another electromechanical counter. This counter recorded the total number of increments presented during a test run. It was possible to interrupt the pulse to the counter whenever a catch trial was inserted so that the counter recorded only the number of increments presented to the subject.

After 20 increments had been counted, the experimenter actuated a push-button switch which threw the latching relay to the open position terminating the experimental sequence.

A two-position switch on the control panel of the programming device allowed for selection of a continuous or an interrupted background tone by either permitting a pulse generator to turn ES2 off or not, depending upon the position to which it was thrown. A second switch on the control panel permitted the noise from ES3 to be presented continuously during the course of an experimental run or to be omitted by controlling the presentation of the initiating pulse to ES3. ES3 was turned off at the termination of an experimental run by the latching relay shorting across its "B on" terminals.

Timing equipment.

The precise timing and sequencing of the three electronic switches was controlled by means of the circuit illustrated in Figure 4. This system was composed of three waveform generators (Tektronix, 162) and six pulse generators (Tektronix, 161). The waveform generators were operated in a cascaded fashion in order to optimize the stability and accuracy of the timing sequence for each of the subroutines. Specifically, waveform generator A established a basic repetition rate of five seconds for the entire system, WFG-B established a 2050 msec base for the tonal pedestal, and WFG-C governed the 210 msec interval during which the increment rose to maximum amplitude and remained on for 200 msec. The timing relationships pertaining among the waveform and pulse generators are illustrated schematically in Figure 5.

The 2050 msec waveform produced by WFG-B was used to control

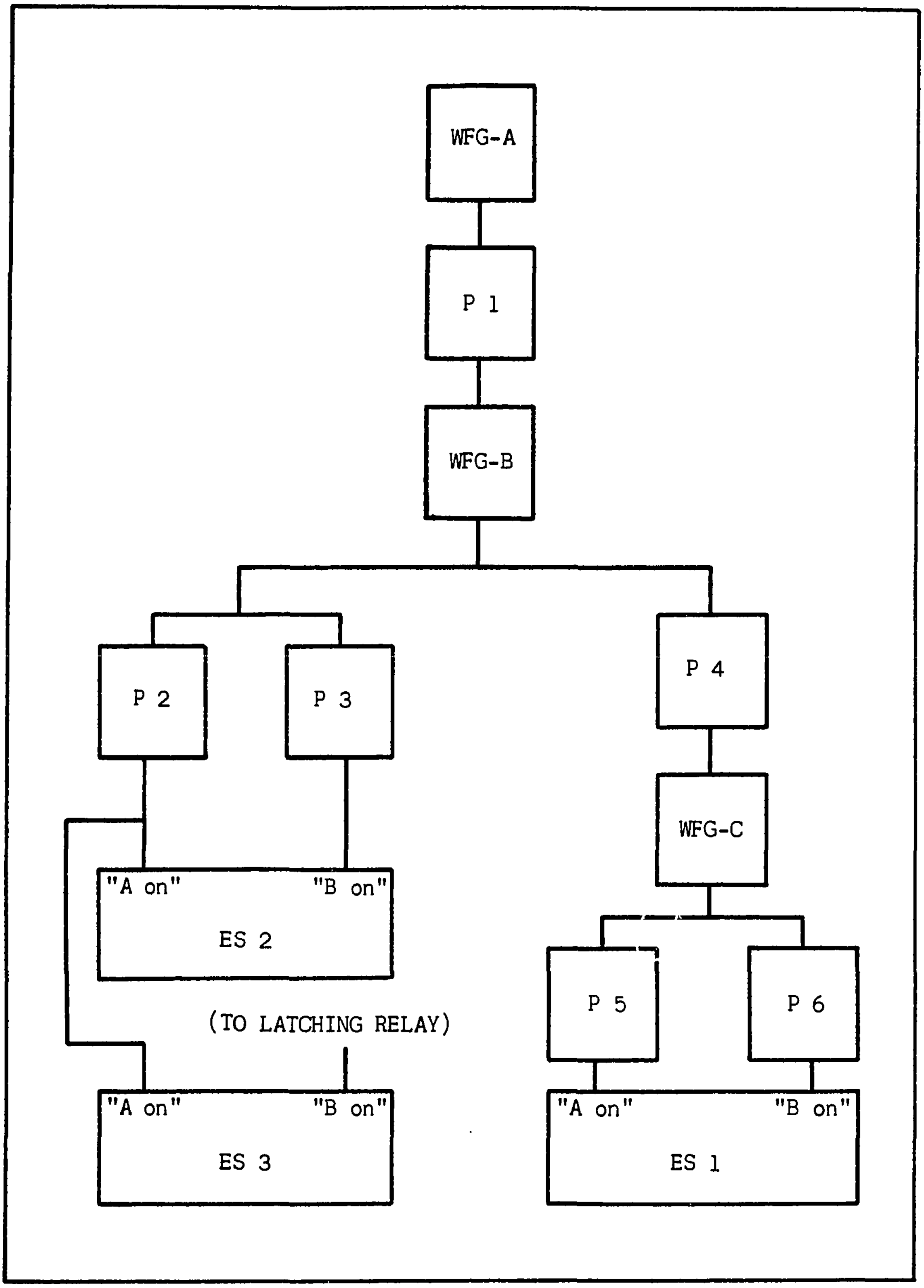
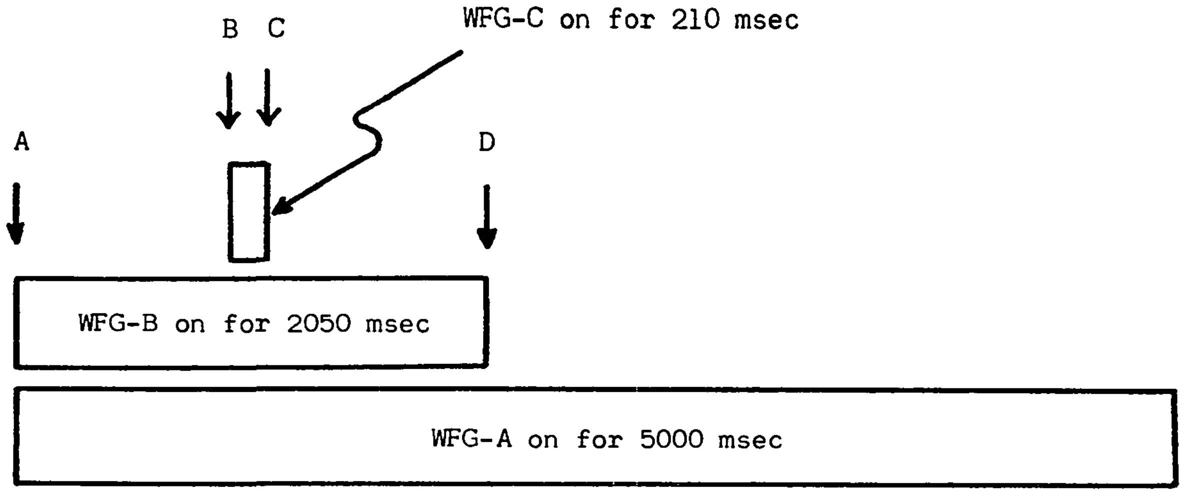


Figure 4. Simplified flow diagram of the basic timing apparatus for controlling the background, increments, and noise.



A -- Pulse Generators 1 and 2 fire at initiation of waveform from WFG-A and WFG-B, respectively.

B -- Pulse Generators 4 and 5 fire 920 msec after Pulse Generator 2.

C -- Pulse Generator 6 fires 210 msec after Pulse Generator 5.

D -- Pulse Generator 3 fires 2050 msec after Pulse Generator 2.

Figure 5. Illustration of cascaded waveform generator operation depicting the durations of sawtooth waveforms produced by waveform generators A, B, and C and the portion of the waveforms on which pulse generators 1, 2, 3, 4, 5, and 6 were activated.

the switching cycle of ES2 for the interrupted background test condition. Pulse generator 2 (PG-2) triggered ES2 on at the initiation of this 2050 msec waveform. Following a 2050 msec delay PG-3 turned ES2 off. Electronic switch 3 was also activated by PG-2, but it was turned off by momentarily shorting across its "B on" terminals at the end of a test run.

The 210-msec waveform produced by WFG-C was used to control the switching cycle of ES1 which determined the temporal characteristics of the increments. PG-5 turned ES1 on at the initiation of the 210-msec waveform, and PG-6 turned ES1 off at the termination of the waveform.

Accessory functions.

Response tabulation. Subject responses during each test run were cumulated by means of an electromechanical counter. Activation of the counter depended on the concurrent operation of the subject response button and a sensitive relay in the programming device. The sensitive relay was energized by waveform generator D operating within the timing pattern established by waveform generator A. The contacts of the relay were held closed by WFG-D for a 1600 msec interval beginning immediately after an increment had been presented. If the response pushbutton switch was closed during the 1600 msec interval the counter was energized. This represents, in terms of circuit logic, an "and gate" operation. If the response switch was closed outside the 1600 msec interval, however, the activating pulse was redirected to the latching relay throwing it to the open position and immediately terminating the program.

The purpose of the "and gate" circuit and the definition of a specific response interval was to reduce the possibility of recording false positive responses. The validity of responses obtained during each test run was also checked by randomly inserting four catch-trials throughout the twenty incremental presentations. A spring-loaded toggle switch on the control panel of the programming device allowed the experimenter to prevent the presentation of an increment at any point during a test run. Responses made during the catch-trials caused the program to be terminated in the same manner as responses made outside the response interval.

Subject-experimenter communication. Two-way verbal communication between the experimenter and the subject was accomplished by means of a specially-fabricated talkback and talkover system. This system also permitted the experimenter to monitor both the signal and the noise channels auditorily without affecting the stimuli reaching the subjects.

Power supplies.

Two power supplies (Tektronix, 160A) provided the voltages necessary for the operation of the four waveform and six pulse generators. A DC power supply was used for the operation of the subject-response circuit, 117 Volts AC was used for the operation of two of the relays in the programming device and 6 V AC was used for two other relays. The sensitive relays in the programming device were energized by the pulse and gate outputs of certain waveform and pulse generators.

Procedures

Experimental Control

The influence of experimental error was reduced by careful attention to the following controls: (1) frequent calibration checks on the acoustic output of the experimental equipment; (2) monitoring and resetting of the various timing sequences associated with the production of the increments and the pedestals before each session; (3) continuous monitoring of the frequency of the test tones; (4) the use of standard instructions for each subject; (5) thorough familiarization of each subject with both the interrupted and the continuous background DLI measurement procedures in quiet and in the presence of the contralaterally-presented noise.

General Description of Experimental Procedure

Estimates of DLI magnitude were obtained for each subject at 500 and 4000 Hz. The background stimulus was presented at 60-dB SPL at both test frequencies. The measurements at each frequency were obtained in quiet and in the presence of a continuous contralateral noise presented at 60-dB SPL. Two different quantal stimulus patterns were used in the measurement of differential sensitivity. One pattern involved the addition of increments to a continuous background tone while the other involved the addition of increments to brief tonal pedestals separated by periods of silence constituting an interrupted background pattern. The difference limen for intensity was obtained for the right ear of each subject and the noise was presented in every case to the left ear.

Test Sequence

Testing of each subject was completed in two or three different sessions with not more than three days elapsing between the initial and final test session. Prior to the presentation of each experimental condition, each subject was familiarized with the test stimuli and the detection and response tasks. A counterbalancing schedule was used to determine the order of presentation of each of the experimental conditions. After the individual subject's position in the counterbalancing schedule had been determined, the purpose of the study was explained to him and he was instructed for the familiarization runs. The instructions were as follows:

> In this procedure we are attempting to measure your ability to detect small increases in the intensity of a pure-tone stimulus. These small increases or pips will be added to a continuous tone in some conditions and to an interrupted or discontinuous tone in other conditions. In all conditions, however, the tones will be presented to your right ear. We are interested in comparing your ability to detect these increases in the two patterns of tone presentation in quiet with your detection ability when a continuous noise is presented simultaneously to the opposite ear.
>
> We will begin the measurement procedure with a run in which small increments or pips will be added to (condition to be presented first as dictated by counterbalance schedule). I want you to report verbally whenever you hear a pip. I will adjust the magnitude of the intensity increases until I can obtain a general idea of the size of pips to which you can respond. This will serve as a basis for selecting other pip magnitudes in subsequent runs. Following this, the tone (and noise) will cease and I will tell you to rest briefly.

After a limited range of increment magnitudes had been explored the instructions for the familiarization segment continued:

> We will now begin a series of practice runs to familiarize you with the detection task and to acquaint you with the response procedure. After I indicate that the equipment is ready you can initiate a run whenever you wish by pressing this button (indicating subject pushbutton). After the run has started, this button will serve to register your response each time you press it. If you press the button, however, and a pip has not been presented, a warning light will flash and the run will be automatically terminated. The run will be terminated abruptly in this manner simply in the interest of saving time, since the only useful runs for our purpose are those free of false-positive responses. It would serve no purpose to complete a run in which a false-positive response had been given. For this reason, you should be fairly confident a pip has been presented before you respond. In addition, there is a time restriction placed on your decision as to the presence of a pip. If you wait too long to make your response, it may fall outside the response interval and thereby prematurely terminate the run. Are there any questions?

After the subject had been familiarized with the detection and response tasks and a general range of response magnitude for two different increment sizes had been established, the subjects were instructed for the experimental runs in the following manner:

> Now we will begin the experimental runs. These will be presented in pairs using different sized pips. In your case, the first pair of runs will consist of a run using a relatively [large, small] pip, followed almost immediately by a run using a relatively [small, large] pip. The next pair of runs will reverse this order of pip sizes and so on for all subsequent pairs. Because of this changing pip size between runs, your ability to detect the pips will vary. Sometimes it will be very [easy, difficult] to detect the pips while on the immediately following run it may be very [difficult, easy].

Brief rest periods were provided between each experimental run. Longer rest periods were provided between experimental conditions.

Counterbalancing of Experimental Conditions

The order of presentation of the frequencies, the stimulus patterns, and the noise were counterbalanced according to the schedule presented in Table 1 in order to reduce the effects of any systematic biases on the data. Four of the eight subjects participating in this study were tested with the interrupted background pattern presented first and four with the continuous pattern presented first. In addition, four were tested in the quiet condition first and four with the contralateral noise first. Four of the subjects were tested at 500 Hz first and four at 4000 Hz first. It will be noted by reference to Table 1 that within frequency the various combinations of increment magnitude order, procedure order, and noise level order are also counterbalanced.

Measurement Technique

The subjects were familiarized with the detection task and the

TABLE 1

COUNTERBALANCING SCHEDULE FOR TREATMENT CONDITIONS

Subject	Increment Magnitude Order[a]	Frequency Order[b]	Procedure Order[c]	Noise Level Order[d]
1	S-L	12	12	12
2	L-S	12	12	21
3	L-S	12	21	12
4	S-L	12	21	21
5	S-L	21	12	12
6	L-S	21	12	21
7	L-S	21	21	12
8	S-L	21	21	21

[a]S = small; L = large.

[b]Frequency: 1 = 500 Hz; 2 = 4000 Hz.

[c]Procedure: 1 = interrupted background; 2 = continuous background.

[d]Noise: 1 = quiet; 2 = 60-dB SPL thermal noise.

response procedure prior to the actual experimental runs for each condition. The experimenter varied the size of the increments presented in the initial part of the familiarization period until it was judged that a particular increment magnitude was being detected approximately half the number of times it was presented. The magnitude of this increment was then measured and the two increment attenuators were adjusted so that one of the attenuators yielded an increment that was 0.2-dB below the incremental value that was detected approximately 50 per cent of the time while the other attenuator yielded an increment that was 0.2-dB greater than the incremental value which was detected approximately 50 per cent of the time. This 0.4-dB range was adequate for most of the subjects to attain response scores less than 50 per cent but greater than 20 per cent for the lower increment value and response scores greater than 50 per cent but less than 80 per cent for the higher increment value. The experimental runs were begun after a number of trials with these two increment values.

The two increment values selected for the experimental runs were presented consecutively in pairs. The order of presentation of the small increment first or the large increment first was counterbalanced across subjects and across conditions. Four of these pairs of increment magnitudes were presented to each subject under each condition. The first and third pair were presented in the same order, and the second and fourth pair were presented in reverse order from that of the first and third pair. An example of the counterbalanced presentation schedule of the four pairs is as follows: Pair 1 (small-large); Pair 2 (large-small); Pair 3 (small-large); and Pair 4 (large-small). In each pair the first increment value was presented twenty times and the number of correct responses recorded. The attenuator controlling this increment was then switched out of the line and the second attenuator inserted by means of the switching arrangement previously described. The second increment of the pair was then presented twenty times and the number of correct responses to it was recorded.

A function was constructed for each of the four trial pairs by plotting response score in per cent against increment magnitude and the increment magnitude corresponding to the 50 per cent point on each line was interpolated. The four interpolated incremental values corresponding to the 50 per cent response point were obtained in this manner for every subject under each of the experimental conditions. These four incremental values were then averaged to obtain the DLI of each subject under each condition.

The decision to use only four pairs of increments was based on the results of a pilot investigation which was undertaken to determine the practical number of two-point functions that would be required to yield a satisfactorily precise estimate of DLI magnitude. In the pilot investigation standard deviations were computed based on sample sizes of two, four, and nine two-point functions for a single subject. The standard deviations were .045 dB for two functions; .032 dB for four functions; and .022 dB for nine functions. It was decided to use four two-point functions. This decision was based on two practical considerations. First, the standard deviation computed for four functions was smaller than that computed for two functions. Second, the duration of the test would have had to have been inordinately prolonged to achieve the slight gain in precision afforded by the use of nine functions.

Calibration

The output of the screening audiometer and the pure-tone and noise channels of the experimental equipment was measured by coupling the respective screening and experimental earphones to a Western Electric 640 AA Condenser Microphone by means of an NBS 9A coupler. The condenser microphone was in turn coupled to a Western Electro-Acoustic Laboratory Condenser Microphone Complement, Type 100 D/E. A true-RMS, vacuum-tube voltmeter (Ballantine, 321) served as the readout device for this measurement system.

The magnitudes of the increments were set visually by observing the difference between the background signal alone (ES2 switched on) and the background signal plus the increment signal (both ES1 and ES2 switched on). This difference was determined on the decibel scale of a true-RMS, vacuum-tube voltmeter (Ballantine, 321) paralled across the input to the overall level attenuator. The scale of this meter is marked off in 0.2-dB steps. The visual error in setting the increments was estimated as being not greater than 0.05 dB. During the setting of the increment magnitudes the output level attenuator was adjusted to full attenuation so that the tones were inaudible.

Statistical Analysis

The data obtained from this study were treated statistically by means of an analysis of variance procedure derived from a 2 x 2 x 2 factorial design with repeated measurements on each factor. Sub-analyses of variance were also performed as an aid in the interpretation of the results. The .05 level of confidence was adopted as the cutoff point for rejecting the null hypothesis. The results of this investigation and a discussion of their significance are presented in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This experiment was undertaken to investigate the possibility that the influence of contralateral noise stimulation on DLI magnitude is dependent, at least in part, on the temporal pattern of the measurement stimulus. To this end estimates of DLI magnitude were obtained at two different test frequencies with a continuous and with a discontinuous quantal stimulus pattern in quiet and in the presence of contralateral noise stimulation. The following sections of this chapter include a detailed description of the treatment of the data and a discussion of the results in light of the pertinent literature.

The Estimates of the DLI Obtained in the Study

The averaged estimates of the DLI computed from the data of each subject under each experimental condition appear in Table 2. The column means in Table 2 represent the DLI's averaged over all eight subjects for each experimental condition. The individual DLI estimates which appear in the body of the table were submitted to an analysis of variance, the results of which are reported later.

TABLE 2

INDIVIDUAL AVERAGED DLI ESTIMATES IN dB FOR EACH SUBJECT UNDER EACH EXPERIMENTAL CONDITION AND MEAN DLI's FOR EACH EXPERIMENTAL CONDITION AVERAGED OVER ALL EIGHT SUBJECTS

Subject	Condition							
	500 Hz				4000 Hz			
	Continuous		Interrupted		Continuous		Interrupted	
	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise
1	1.243	1.225	1.210	1.545	1.206	1.062	1.400	1.605
2	.967	1.100	.853	.959	.742	.683	.944	.988
3	1.305	1.310	1.071	1.278	.918	.697	.813	.784
4	.951	1.161	.769	1.079	.725	.585	1.075	1.115
5	.732	1.083	.674	.880	.465	.491	.737	.805
6	1.493	1.281	.973	.904	.436	.442	1.050	1.344
7	.931	.839	.865	1.122	.830	.638	1.018	1.253
8	1.090	.940	.842	.874	.628	.554	.767	1.141
Grand Mean	1.089	1.117	.907	1.080	.744	.644	.976	1.129

Precision of Estimation of the DLI

The measurement procedure employed in this investigation yielded estimates of the intensive difference limen for each subject under eight experimental conditions. The estimates were obtained by averaging the incremental values associated with the 50 per cent response points on four separate psychometric functions. The individual increment values are reported in the Appendix. Thirty-two psychometric functions were constructed for each subject and each function was based upon two data points. The points for each function were determined in the following manner. Two increment values were presented to each subject under each experimental condition. One increment was selected to yield a percentage of correct responses greater than 50 per cent but less than 80 per cent. The other increment was selected to yield a percentage of correct responses less than 50 per cent but greater than 20 per cent. Each pair of increment values was selected separately for each experimental condition and presented to a subject four successive times. Each pair of the two increment values and their corresponding percentage of correct responses were plotted on graph paper. The increment value corresponding to the 50 per cent point on each of the four resulting two-point functions was interpolated and the mean of these four increment values was taken as an estimate of the DLI. The precision of these estimates is reflected in the standard error of the mean. This statistic gives the magnitude of deviation that could be expected between the obtained DLI and the means of other samples of the same size.

The standard errors of the mean for each subject under each experimental condition are presented in Table 3. The row averages in this table represent the mean standard error for each subject averaged across all experimental conditions. The column averages represent the mean standard error for each experimental condition averaged across all subjects. Although these values were not treated statistically, the precision of DLI estimation attained by the procedure described was considered to be acceptable.

Analysis of the Data

In order to describe more completely the results of the experiment it was necessary to treat the data in several different ways. An overall analysis of variance was performed to evaluate the significance of factor main effects and interactions. Subsequent to the overall ana-

TABLE 3

STANDARD ERRORS OF THE MEAN IN dB BASED ON FOUR SEPARATE ESTIMATES OF THE DLI YIELDED BY EACH SUBJECT UNDER EACH EXPERIMENTAL CONDITION

Subject Number	500 Hz				4000 Hz				Avg.
	Continuous		Interrupted		Continuous		Interrupted		
	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise	
1	.026	.009	.036	.045	.018	.053	.000	.058	.031
2	.022	.049	.063	.037	.009	.029	.066	.042	.040
3	.021	.027	.039	.027	.009	.024	.009	.031	.023
4	.029	.041	.035	.047	.013	.022	.022	.013	.028
5	.000	.027	.040	.050	.013	.013	.013	.027	.024
6	.056	.009	.042	.030	.030	.029	.009	.057	.033
7	.027	.032	.009	.037	.009	.013	.030	.020	.022
8	.030	.032	.032	.027	.033	.013	.046	.040	.032
									Grand Mean
Avg.	.026	.028	.037	.038	.017	.025	.026	.035	.029

lysis of variance, certain sub-analyses were performed. The aim of these was to clarify the specific influence of certain of the variables with particular respect to their contributions toward the significant interactions shown in the overall analysis.

Overall Analysis

The data from this experiment were treated as being derived from a 2 x 2 x 2 factorial design with repeated measurements on each factor. This design represents a modification of the method outlined by Winer (60) for analysis of a four-factor experiment. In this design, the appropriate error terms are the subject interactions associated with each main effect and factor interaction term.

The results of this analysis, presented in Table 4, show that the three main effects, frequency, background, and contralateral noise level are significant at the .025 level of confidence. Significant interactions between frequency and background, background and noise level, and among frequency, background, and noise level were found at the .01 level of confidence. Only the interaction between frequency and noise level failed to attain statistical significance. The lack of interaction between frequency and noise level indicates that frequency and contralateral noise level act independently of each other in their effects on DLI magnitude.

Sub-Analyses of Treatment Interactions

In a multifactor experiment such as this one in which the information relative to the effect of any one factor is obtained by averaging across all levels of the other factors, it is necessary to evaluate any interactions which may exist. Significant interactions indicate that the factors treated are not independent of one another. That is, the effect of one factor may not be equivalent for all levels of the other factors. For this reason, the main effects in this study, which were found to be significant in the overall analysis, can not be interpreted as if they were derived from separate single factor experiments. It was necessary to perform sub-analyses as a means of determining what combinations of factor levels best explained the significant differences among the data obtained under various levels of frequency, background, and noise level. It should be borne in mind that comparisons of data in this manner are performed at the expense of replication and are not independent of one another. Therefore, the probability levels attained in these com-

TABLE 4

SUMMARY OF THE RESULTS OF THE OVERALL ANALYSIS OF VARIANCE PERFORMED ACCORDING TO A 2 x 2 x 2 FACTORIAL DESIGN WITH REPEATED MEASUREMENTS ON EACH FACTOR

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Subjects	7	1.565		
Frequency	1	.492	.492	10.25[a]
Subjects x Frequency	7	.338	.048	
Background	1	.248	.248	10.78[a]
Subjects x Background	7	.160	.023	
Noise Level	1	.066	.066	11.00[a]
Subjects x Noise Level	7	.042	.006	
Frequency x Background	1	.876	.876	15.64[b]
Subjects x Frequency x Background	7	.390	.056	
Frequency x Noise Level	1	.021	.021	.91
Subjects x Frequency x Noise Level	7	.164	.023	
Background x Noise Level	1	.158	.158	13.17[b]
Subjects x Background x Noise Level	7	.084	.012	
Frequency x Background x Noise Level	1	.013	.013	13.00[b]
Subjects x Frequency x Background x Noise Level	7	.005	.001	

[a]Significant at the .025 level of confidence.

[b]Significant at the .01 level of confidence.

parisons are only approximate.

Frequency x background interactions.

The significant interaction between frequency and background demonstrated in the overall analysis implies that differences in DLI magnitude across frequency are dependent on the stimulus pattern used to determine the DLI. Figure 6 depicts this interaction graphically. The grand mean DLI values for each experimental condition reported in Table 2 were used to compute each of the four data points shown in this figure. The data points labeled C represent the combined averages of the DLI's obtained in quiet and noise with the continuous-background stimulus of 500 Hz and of 4000 Hz. The data points labeled I represent the combined averages of the DLI's obtained in quiet and noise with the interrupted-background stimulus of 500 Hz and 4000 Hz.

It may be seen from the figure that the difference between the DLI's obtained with the interrupted-stimulus pattern of 500 Hz and 4000 Hz is not large but that there is a considerable difference between the DLI's obtained with the continuous-stimulus pattern at the two test frequencies. It appears, then, that the significant main effect for frequency is based primarily on the marked difference between the magnitudes of DLI's obtained at 500 Hz and 4000 Hz with the continuous-background stimulus.

Figure 6 also presents information relevant to the significance of the main effect for backgrounds noted in the overall analysis. It appears from this graph that the significant difference between background-stimulus patterns may be attributable primarily to the differences between the results obtained with the continuous and interrupted stimulus

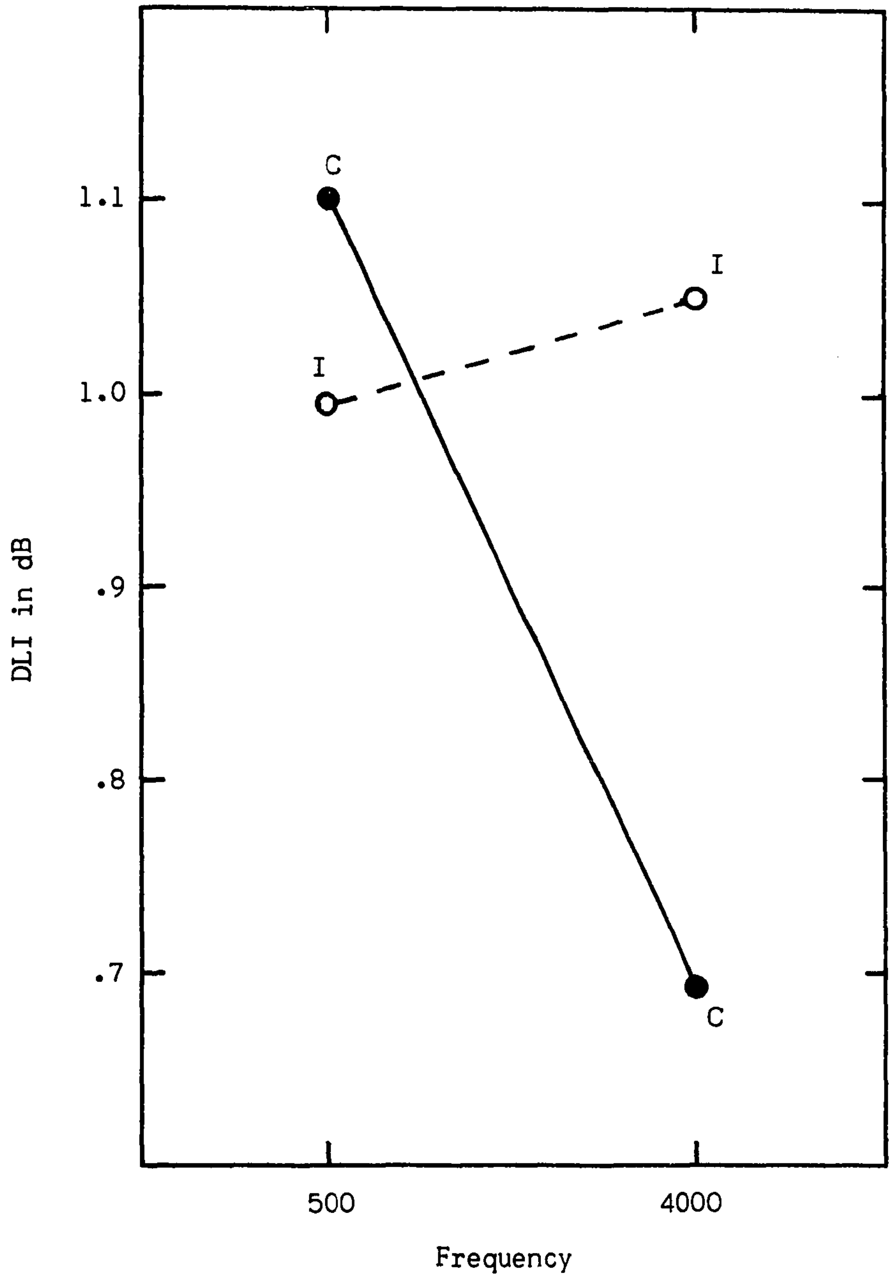


Figure 6. Plot of frequency x background interaction. Points labeled C and I represent mean DLI's averaged across noise levels and obtained with the continuous and interrupted backgrounds, respectively, at each test frequency.

patterns at 4000 Hz. A sub-analysis of variance was performed to permit evaluation of the differences obtained with the two stimulus patterns separately at each test frequency. This analysis is presented in Table 5 which shows that the difference between the two backgrounds at 500 Hz is not statistically significant. There is, however, a significant difference between the two backgrounds at 4000 Hz where a smaller DLI was obtained with the continuous-background stimulus. The outcome of the test was found to be significant beyond the .005 level of confidence.

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE OF FREQUENCY x BACKGROUND INTERACTION IN WHICH THE DATA OBTAINED WITH THE CONTINUOUS BACKGROUND ARE COMPARED WITH THE DATA OBTAINED WITH THE INTERRUPTED BACKGROUND ACROSS NOISE LEVELS AT 500 Hz AND AT 4000 Hz

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
C vs I within 4000 Hz	1	1.028	1.028	22.348[a]
Subjects x Background within 4000 Hz	7	.320	.046	
C vs I within 500 Hz	1	.097	.097	2.939
Subjects x Background within 500 Hz	7	.230	.033	

[a]Significant beyond the .005 level of confidence.

Background x noise level interaction.

In addition to the interaction of background with frequency, the overall analysis shows that a significant interaction also exists between background and noise level. In other words, the magnitude of the DLI obtained with either of the two stimulus patterns depends upon whether or not noise is presented to the contralateral ear. Figure 7 is a graph of the relationship in question. The grand mean DLI's for each experimental condition reported in Table 2 were again used to compute each of the four data points shown. The data points labeled N represent an average of the mean DLI's obtained in noise at both test frequencies with the continuous-background stimulus and with the interrupted-background stimulus. The data points labeled Q represent the average of the mean DLI's in quiet at both frequencies obtained with the continuous-background stimulus as well as with the interrupted-background stimulus. Therefore, the points N represent the data obtained under the contralateral-noise condition averaged over both frequencies, while the points Q represent the data obtained during the quiet experimental conditions averaged over both test frequencies.

It appears from the graph that the effect of contralateral noise on the DLI is not the same for both background patterns. A sub-analysis of variance was performed to elucidate the background x noise level interaction and to determine if the observed differences were of statistical significance. This analysis is presented in Table 6. The table shows that only the difference between noise levels under the interrupted-background condition is significant. The value of F yielded by the analysis is significant beyond the .005 level of confidence. Any difference existing between the quiet and noise conditions for the continuous-background stimulus failed to achieve significance at the .05 level of confidence.

It would appear from the results of this analysis that the effect of contralateral noise is significant only for the DLI's obtained

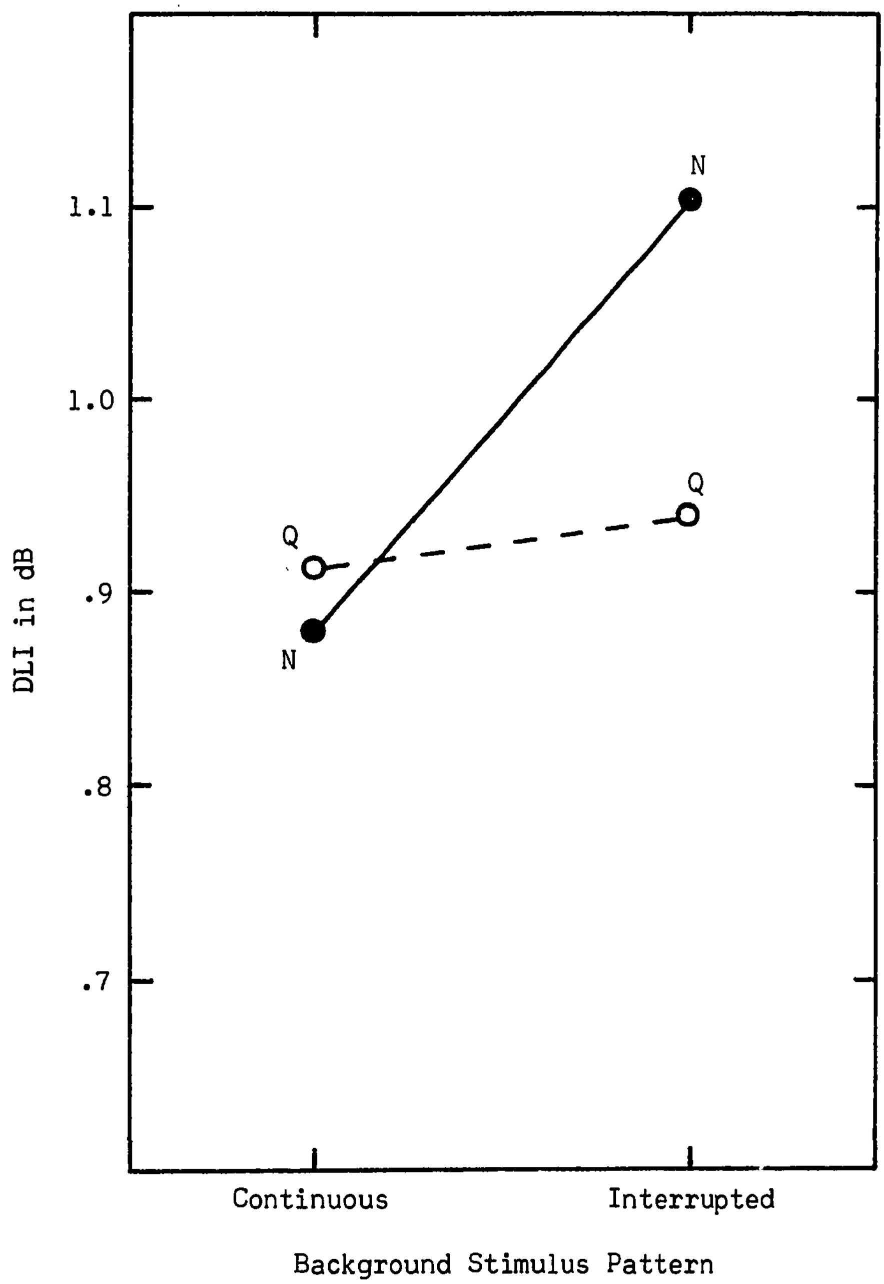


Figure 7. Plot of background x noise level interaction. Points labeled Q and N represent mean DLI's averaged across both frequencies and obtained in quiet and in noise, respectively, with the continuous and interrupted procedures.

TABLE 6

SUMMARY OF ANALYSIS OF VARIANCE OF BACKGROUND x NOISE LEVEL INTERACTION IN WHICH THE DATA OBTAINED IN QUIET ARE COMPARED WITH THE DATA OBTAINED IN NOISE AVERAGED OVER FREQUENCY WITHIN THE CONTINUOUS BACKGROUND AND WITHIN THE INTERRUPTED BACKGROUND CONDITIONS

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Noise vs Quiet within Continuous	1	.011	.011	.846
Subjects x Noise Level within Continuous	7	.089	.013	
Noise vs Quiet within Interrupted	1	.214	.214	42.800[a]
Subjects x Noise Level within Interrupted	7	.037	.005	

[a]Significant beyond the .005 level of confidence.

with the interrupted background. However, in a subsequent analysis which is presented later a significant difference was found between DLI's obtained in quiet and noise with the continuous background at 4000 Hz. The analysis presented in Table 6, of course, is based on DLI's averaged across both test frequencies and it is this averaging which obscures the significant difference between noise levels for the continuous background at 4000 Hz. Figure 8 illustrates this point and shows that the mean DLI obtained with the continuous background decreases in magnitude from the quiet to noise conditions at 4000 Hz, but there is a slight increase in magnitude of the mean DLI at 500 Hz from quiet to noise. In contrast, the mean DLI increased in magnitude from the quiet to noise conditions at both test frequencies. Therefore, averaging these relationships across frequencies tends to obscure the change in DLI size brought about by the

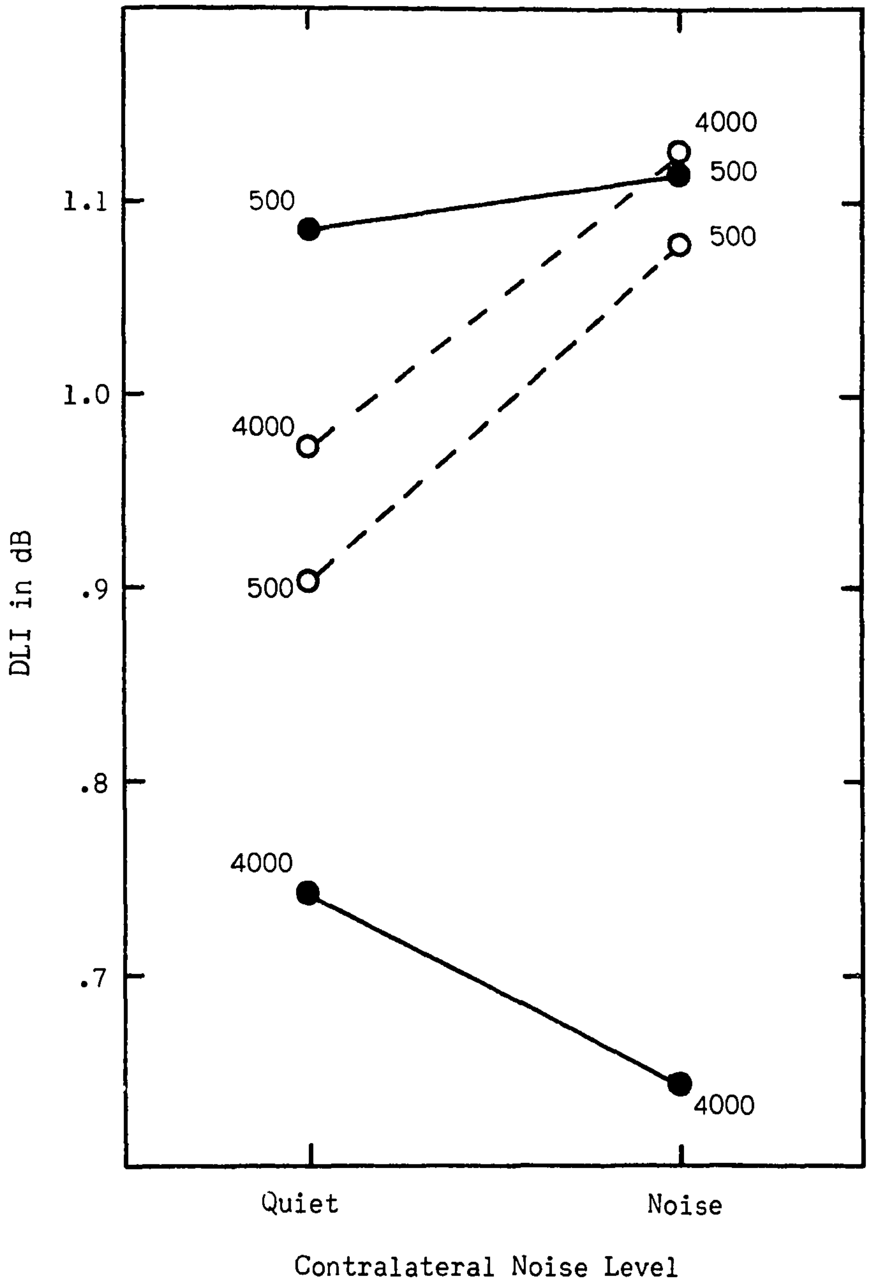


Figure 8. Plot of the grand mean DLI in dB for each experimental condition averaged across all subjects. Solid lines connect the DLI's obtained with the continuous background and the dashed lines connect the DLI's obtained with the interrupted background. The frequency at which each DLI was obtained is also indicated on each line.

influence of contralateral noise on the continuous background at 4000 Hz, while the changes in DLI size from quiet to noise for the interrupted background are not similarly affected by averaging.

Frequency x background x noise level interaction.

Figure 8 also shows that the mean DLI's obtained with the continuous-background stimulus at 500 Hz are larger in quiet and noise than the mean DLI's obtained with the interrupted background, but the mean DLI's obtained at 4000 Hz with the interrupted background are larger at both noise levels than those obtained with the continuous background. This reversal of relationship for backgrounds and noise levels at the two frequencies appears to account for the significant second order interaction found in the overall analysis of variance.

As mentioned previously, the presence of significant interaction indicates that the simple effects of a factor differ from level to level of another factor so that interpretation of a factor's influence necessitates an examination of its simple effects at each level. In like manner, the interpretation of the significant second order interaction necessitates the evaluation of the simple interaction of two factors within the levels of the remaining factor. Toward this end, an analysis of variance was performed comparing the interaction of backgrounds and noise levels within each of the test frequencies. The results of the analysis are presented in Table 7.

This analysis shows a significant simple interaction between background and noise level at the .05 level of confidence within 500 Hz and at the .005 level of confidence within 4000 Hz. Thus, the significant frequency x background x noise level interaction reported in the overall analysis highlights the fact that the DLI's obtained with the continuous background are larger than those obtained with the interrupted background at 500 Hz, but are smaller than those obtained with the interrupted background at 4000 Hz in both the quiet and noise conditions.

TABLE 7

SUMMARY OF ANALYSIS OF VARIANCE OF THE BACKGROUND x NOISE LEVEL SIMPLE INTERACTION WITHIN 500 Hz AND WITHIN 4000 Hz

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Background x Noise Level within 500 Hz	1	.041	.041	5.857[a]
Subjects x Background x Noise Level within 500 Hz	7	.052	.007	
Background x Noise Level within 4000 Hz	1	.129	.129	25.800[b]
Subjects x Background x Noise Level within 4000 Hz	7	.038	.005	

[a]Significant at .05 level of confidence.

[b]Significant at .005 level of confidence.

Analysis of the Effect of Contralateral Noise on DLI Magnitude

The main concern of this investigation was to determine if contralateral noise stimulation affects the magnitude of the DLI obtained with variations of the quantal stimulus pattern differently, depending upon whether the background stimulus is continuous or discontinuous in character. A final analysis of variance was performed first to test the significance of the differences observed between the DLI's in quiet and in noise for each background at each test frequency. This also permitted overall analysis highlights the fact that the DLI's obtained with the continuous background are larger than those obtained with the interrupted background at 500 Hz, but are smaller than those obtained with the interrupted background at 4000 Hz in both the quiet and noise conditions.

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Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Background x Noise Level within 500 Hz	1	.041	.041	5.857[a]
Subjects x Background x Noise Level within 500 Hz	7	.052	.007	
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The differences observed among the mean DLI values presented in Table 2 suggest that differential sensitivity for intensity as measured with the interrupted background was adversely affected by contralateral noise at both 500 and 4000 Hz. When DLI's were obtained with the continuous background, however, contralateral noise appeared to have a facilitative effect on DLI magnitude at 4000 Hz, but a slightly adverse effect at 500 Hz. To evaluate the statistical significance of these changes in DLI magnitude an analysis of variance was performed in which the DLI's obtained in quiet were compared with those obtained in the presence of contralateral noise stimulation. The results of this analysis appear in Table 8. The results show the differences between the DLI's obtained in quiet and in noise to be significant at the .025 level of confidence for both background patterns at 4000 Hz and for the interrupted background at 500 Hz. The difference between DLI's obtained in quiet and in noise with the continuous background at 500 Hz failed to achieve significance at the .05 level of confidence.

These results are generally in agreement with the findings of both Blegvad and Terkildsen (3) and Chocholle and Saulnier (9). Comparisons with the results of each of these earlier investigations are presented in the next section.

Comparison of the Results of the Present Study with Those Obtained by Blegvad and Terkildsen and by Chocholle and Saulnier

It will be recalled that Blegvad and Terkildsen used a continuous-background quantal stimulus pattern to measure intensive discrimina-

TABLE 8

SUMMARY OF ANALYSIS OF VARIANCE COMPARING THE DLI's MEASURED IN QUIET WITH THOSE MEASURED IN NOISE FOR EACH COMBINATION OF BACKGROUND AND FREQUENCY

Source	Degrees of Freedom	Sum of Squares	Mean Square	F
Quiet vs Noise within Continuous at 4000 Hz	1	.040	.040	10.00[a]
Subjects x Noise Level within Continuous at 4000 Hz	7	.028	.004	
Quiet vs Noise within Interrupted at 4000 Hz	1	.095	.095	9.50[a]
Subjects x Noise Level within Interrupted at 4000 Hz	7	.071	.010	
Quiet vs Noise within Continuous at 500 Hz	1	.004	.004	.222
Subjects x Noise Level within Continuous at 500 Hz	7	.127	.018	
Quiet vs Noise within Interrupted at 500 Hz	1	.119	.119	11.90[a]
Subjects x Noise Level within Interrupted at 500 Hz	7	.070	.010	

[a]Significant at the .025 level of confidence.

tion. They obtained DLI's (defined as the fifty per cent point on a rectilinear psychometric function) in quiet and with three levels of contralateral noise stimulation. Their results at 1000 and 4000 Hz show that the addition of noise to the contralateral ear resulted in a significant reduction in DLI magnitude while the contralateral stimulation caused a significant increase in the magnitude of the DLI at 250 Hz.

In the present study, a similar effect was noted at 4000 Hz, the only frequency common to both studies. The DLI at this frequency was found to be significantly reduced in magnitude in the presence of contralateral noise stimulation for the continuous-background stimulus. A significant difference was not found between the DLI's obtained in quiet and in noise with the continuous background at 500 Hz. It is interesting to note that this frequency lies between 1000 Hz where Blegvad and Terkildsen found a slight facilitative effect and 250 Hz where they found a deterioration in performance.

Chocholle and Saulnier (9), on the other hand, used a discontinuous quantal stimulus pattern to measure intensive discrimination at 1000 Hz. They found a tendency for the DLI to be larger in the presence of interrupted contralateral noise stimulation than in quiet, but a statistically significant difference was found for only one of their four subjects.

The results of the present investigation at both test frequencies show a shift in DLI magnitude from quiet to noise similar to that found by Chocholle and Saulnier. Specifically, the DLI's obtained in noise were larger than those in quiet for the interrupted-background stimulus of either 500 Hz or 4000 Hz. The differences were found to be statistically significant at the .025 level of confidence at both frequencies.

Taken together, the results of Chocholle and Saulnier and the present investigation suggest that contralateral noise stimulation has an adverse effect on differential sensitivity over a wide frequency range when the background stimulus is interrupted. In contrast, the joint results of Blegvad and Terkildsen and of the present study suggest a frequency-dependent characteristic for contralateral noise stimulation's facilitative effect on differential sensitivity. A facilitative effect on DLI magnitude appears to result only when the test frequency is approximately 1000 Hz or above, while a deterioration of performance appears to obtain for lower test frequencies.

Discussion

The results of the analyses of variance emphasize the complexity of the influence of frequency, background, and noise level on DLI magnitude. Nevertheless, the following generalizations may be drawn:

(1) Differences in DLI magnitude were observed between measures obtained at the two test frequencies. The differences appeared to be related to the temporal characteristics of the measurement stimulus.

a. The interrupted-background stimulus yielded measures that varied only slightly in magnitude across frequencies.

b. The continuous-background stimulus yielded measures that varied significantly in magnitude across frequencies. Smaller DLI's were obtained at 4000 Hz than at 500 Hz for both noise levels.

(2) The presence of contralateral noise stimulation during DLI measurements affected differently the magnitudes of the DLI's obtained with the interrupted-background stimulus versus the continuous-background stimulus.

a. The introduction of noise to the opposite ear under the interrupted-background condition caused a significant deterioration of differential sensitivity at both 500 and 4000 Hz. The magnitudes of the changes were similar at the two experimental frequencies.

b. The introduction of noise to the opposite ear under the continuous-background condition produced contrasting results at the two experimental frequencies. There was no significant change in differential sensitivity at 500 Hz compared to that measured in quiet, whereas differential sensitivity at 4000 Hz in the presence of contralateral noise was significantly superior to the performance in quiet.

In general, the results support an affirmative answer to the question, "Does the introduction of contralateral noise affect the magnitude of the DLI differently depending upon whether the measurement stimulus is interrupted or continuous in character?" The nature of the processes underlying the observed behavior, however, is open to speculation.

The first generalization outlined above appears to be consonant with the observation of Harris (20) concerning the variation in DLI magnitude across frequency. Harris found that the DLI obtained with either Loudness-Modulation or Loudness-Masking techniques involving relatively prolonged stimulation is affected by differences in test frequency, while that obtained with the Pure-Tone Loudness-Memory task in which the stimuli are presented for relatively short periods of time is less influenced by frequency differences. The continuous-background stimulus used in the present study constitutes a Loudness-Masking task, while the interrupted-background stimulus shares the characteristic of relatively brief stimulus duration with the Loudness-Memory task. It would appear, then, that the variation in DLI magnitude across frequency may depend, in part, on whether the test procedure involves prolonged or relatively short-term stimulation of the test ear.

Portions of the results of the current investigation are also in excellent agreement with those of Endicott (17) who employed stimulus patterns with temporal characteristics similar to those used in the present investigation. Endicott found smaller DLI's at 4000 Hz with a continuous-background pattern than with an interrupted pattern. He attributed this difference to adaptation, since he demonstrated that more adaptation had taken place during the continuous condition than during the interrupted condition. Endicott concluded that adaptation has a facilitative effect upon intensive discrimination and speculated that adaptation results in a reduced level of background neural activity against which the neural activity generated by the amplitude increments is more easily perceived. This speculation is consonant with the findings of both Hood (23) and Jerger (30). Hood observed that on-effect normality may be maintained in the presence of adaptation. Jerger reported that increments superimposed on a background tone may remain detectable despite the decay of the background tone beyond the threshold of audibility. Based on these findings, it seems reasonable to assume that the difference observed in the present study between the results obtained with the dissimilar background patterns at 4000 Hz may, at least in part, be attributable to a greater amount of adaptation being produced at this frequency by the continuous-background stimulus.

The second generalization described above characterizes the results obtained when contralateral noise stimulation was introduced into the test situation. It would seem reasonable to suppose that whatever effect might be attributable to contralateral noise was added to or superimposed upon the effect attributable to the tonal stimulus alone, since the stimuli presented to the test ear were identical in both the quiet and noise conditions.

In an effort to explain the results of their investigation, Blegvad and Terkildsen (3) suggested the possibility that contralateral noise stimulation exerted its influence on differential sensitivity by means of an adaptive process. The notion is appealing, particularly in light of Endicott's conclusions (17) and might suffice to explain the present results obtained under the continuous background condition. It does not appear adequate, however, to account for the significant deterioration of differential sensitivity associated with the introduction of noise under the interrupted condition.

In order to account adequately for both sets of data, a single mechanism would apparently have to be capable of causing a deterioration of differential sensitivity when stimuli of relatively brief duration are used on the one hand, but facilitation of differential sensitivity when prolonged stimulation is used on the other. A search of the literature failed to disclose evidence for the existence of such a mechanism. This prompted a thorough reconsideration of the characteristics of the measurement stimuli which revealed that apart from the obvious difference in duration between the two experimental stimuli another important distinction existed.

Specifically, the temporal relationship between the onset of the background stimulus and the onset of the increments differed radically in the two quantal patterns. Under the interrupted-background condition, the increment always occurred after a brief, fixed delay with respect to the onset of the background stimulus. Under the continuous-background condition, however, the increments occurred at progressively longer delays with respect to the single onset of the background stimulus. Thus, each increment under the interrupted-background condition was closely preceded by the onset of the pedestal, while only the first few increments occurred close to the onset of the background under the continuous-background condition and most arose from a steady-state background. This difference between the two stimulus patterns suggested that the location of an increment with respect to background onset may also be an important variable affecting the measurement of differential sensitivity.

Within this context, the results seemed to reflect the existence of a mechanism which produces an initial disruptive effect that eventually subsides into an opposite kind of behavior. Hind, Goldberg, Greenwood and Rose (21) described just such a mechanism in their investigation of neural spike activity in the inferior colliculus of the cat during monaural and binaural acoustic stimulation. An excerpt from their discussion may be illuminating:

> Some observations suggest that a stimulus which causes a net inhibitory result may exert, at least for an initial period of time, an effect which is usually interpreted as the result of excitation. Thus, when binaural stimulation results in fewer spikes than are produced by monaural stimulation, the binaural stimulation may nevertheless cause an onset burst with a shorter latent period and probably a larger number of spikes in the onset burst than is the case for the monaural excitatory stimulus.

Here is a process which appears to exhibit the characteristics necessary to explain the results obtained in noise. If, as Endicott suggests, increment detectability varies with the level of background neural activity, then it is conceivable that contralateral stimulation exerts its influence on detectability by altering or in some manner modifying such background activity, perhaps through the mechanism of binaural excitation and inhibition as described by Hind and his colleagues.

If contralateral noise does, indeed, cause a more vigorous neural response to the onset of the background than that produced by the background in quiet, the increased amount of neural activity resulting from this interaction could render the closely following increment more difficult to detect during the interrupted-background condition. During the continuous-background condition, on the other hand, the initial burst of neural activity soon would subside into a net inhibitory effect so that while the detectability of the first few increments in a series might be adversely affected by the onset activity, that of the remaining increments might be enhanced by virtue of the reduction of background neural activity over and above that attributable to simple adaptation.

This discussion concerning the possibility that the results of the experiment may be explained on the basis of a binaurally produced excitative-inhibitive interplay of neural elements is, of course, entirely speculative. Moreover, information pertinent to the hypothesis that the temporal relationships existing between the onset of the background stimulus and the increments may constitute a critical factor in determining the effect of contralateral noise stimulation on the DLI appears to be lacking in the psychoacoustic literature.

Consequently, in the interest of completeness a sub-experiment was undertaken to investigate the problem directly. The experimental stimuli selected resembled those used in the main experiment except for the timing of the introduction of the increments. These were introduced variously at zero, 250, and 1000 msec delays with respect to the onset of the background tone. The rise time of the background tone was revised from 50 msec to 10 msec to avoid a discontinuity in the envelope of the composite signal under the zero-delay condition. The duration of the background tone was maintained at 2000 msec.

A fourth condition was introduced to represent detection performance after a prolonged delay. Originally, this took the form of a delay of several seconds between the onset of the background and that of the increment, but this posed several problems. Specifically, it prolonged the test procedure inordinately and the subjects, using the method of adjustment, tended to "lose their place" in the adjustment task and were unable to arrive at a criterion setting within a reasonable period of time. Consequently, the continuous-background stimulus as used in the main experiment was substituted. While this did not represent an exact extension of the stimulus used for the other conditions, it did represent a situation in which most of the increments were temporally remote from the onset of the background.

Eight young adults, seven of whom had sat for the main experiment, served as experimental subjects. The stimulus patterns described above were presented at 500 and 4000 Hz, both with and without contralateral noise and according to a counterbalanced schedule. Each stimulus pattern was recycled until the subject indicated that his attenuator was set to the position at which the increment was just barely detectable. Only a single run was accomplished under each experimental condition.

Figure 9 summarizes the results observed at 500 Hz. The DLI's

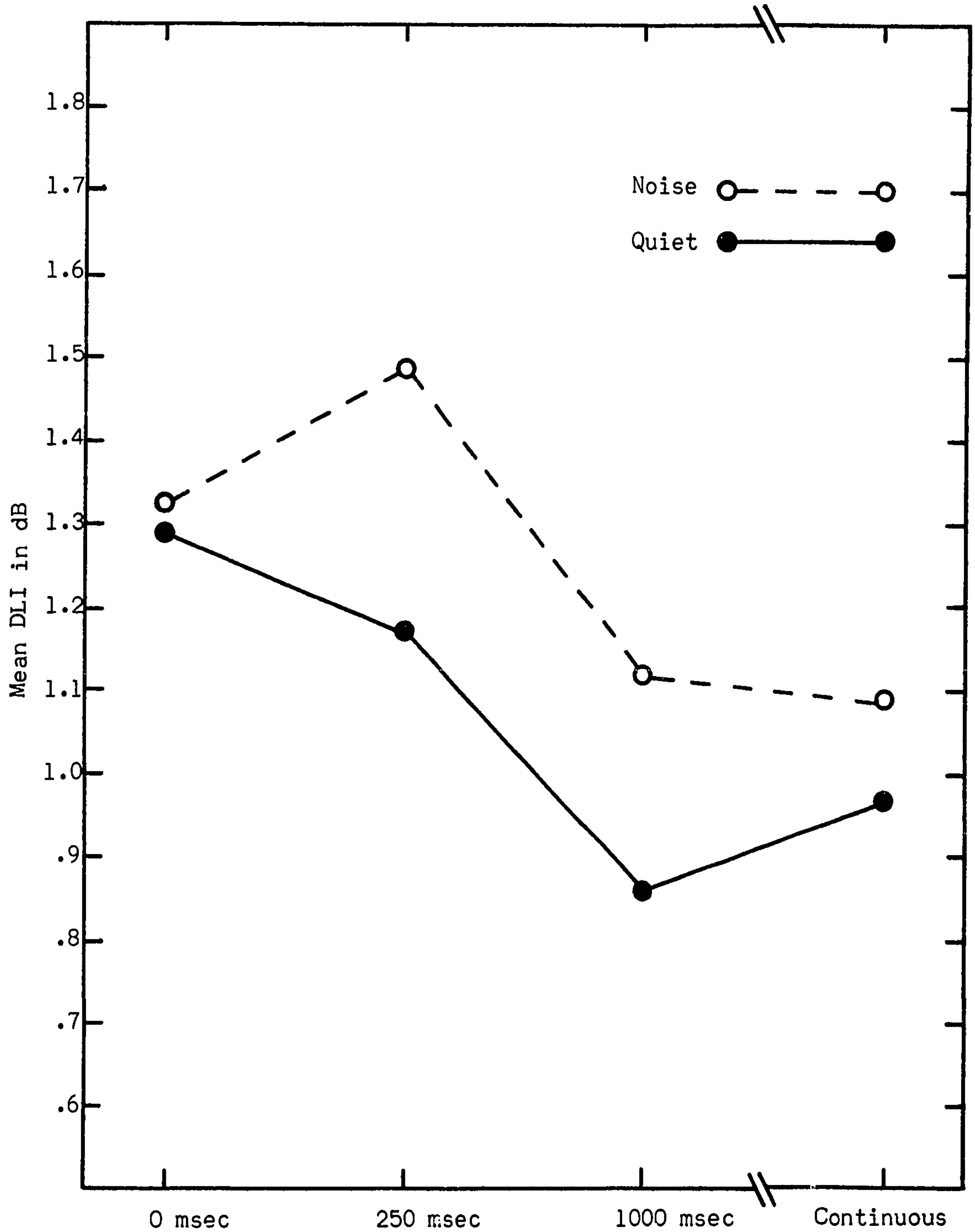

Figure 9. Illustration of the results of the sub-experiment in which the mean DLI's in dB for 500 Hz in quiet and noise are plotted as a function of increment delay from background onset.

obtained in the presence of contralateral noise are seen to be larger than those obtained in quiet under all four conditions of delay. The results are in very good agreement with those yielded by the main experiment under the interrupted and continuous conditions which correspond closely to the 1000-msec delay condition and the continuous condition used in the sub-experiment.

Figure 10 summarizes the results obtained at 4000 Hz. It may be seen that the zero-delay condition yielded a much larger DLI in the presence of contralateral noise than in quiet. As the delay between the onset of the background and the introduction of the increment was increased to 250 msec and then to 1000 msec the difference in magnitude decreased progressively until under the continuous condition the relationship is reversed and the DLI obtained with contralateral noise became smaller than that obtained in quiet. Once again, the results are in excellent agreement with the outcome of the main experiment under the conditions which are common to the two experiments. Specifically, the DLI is slightly larger in noise under both the 1000-msec delay condition in the sub-experiment and under the interrupted condition (involving a measured 920-msec delay) in the main experiment. Under the two continuous conditions, both experiments show the DLI to be smaller in the presence of contralateral noise than in quiet at 4000 Hz.

The results of the sub-experiment appear to support the hypothesis that contralateral noise exerts its influence on increment detection by producing an initial disruptive effect which eventually subsides as the onset of the increments is delayed with respect to the initiation of the background stimulus. For prolonged delays, represented in the

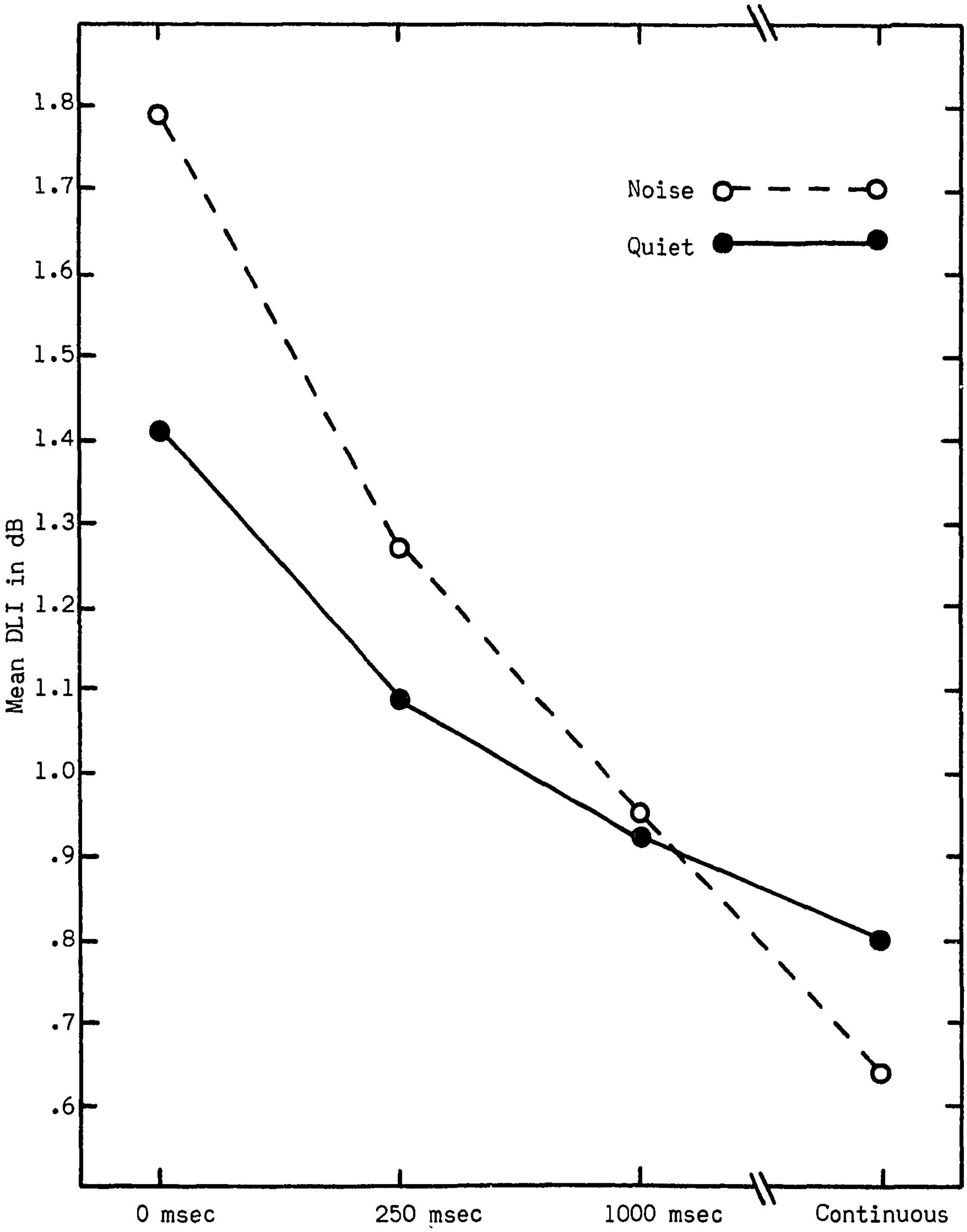

Figure 10. Illustration of the results of the sub-experiment in which the mean DLI's in dB for 4000 Hz in quiet and noise are plotted as a function of increment delay from background onset.

experiment by the use of a continuous background, there appears to be a frequency-dependent effect. That is, the DLI obtained at 500 Hz with contralateral noise simply tends to approach that obtained in quiet. At 4000 Hz, however, the noise appears to exert a significant facilitative effect on detectability, resulting in a diminution of the DLI compared to that obtained in quiet.

Clinical Implications of the Effect of Contralateral Noise on DLI Magnitude

It is hazardous to generalize results obtained on one category of subjects to predict the behavior of other individuals. Nevertheless, it would appear that differential sensitivity can be modified by contralateral noise stimulation and results analogous to those observed in the laboratory may possibly be obtained in the clinical setting if contralateral masking is employed during the assessment of sensitivity to intensity change.

Blegvad and Terkildsen (3) have shown that contralateral noise stimulation improves differential sensitivity at 1000 and 4000 Hz in normal-hearing subjects when the DLI is measured with a quantal pattern employing a continuous-background stimulus. In another investigation (2), the same authors found the SISI score for three out of five hearing-impaired subjects to be dramatically improved in the presence of continuous contralateral masking.

The results of the present investigation support the findings of Blegvad and Terkildsen that contralateral noise improves differential sensitivity at 4000 Hz and indirectly supports their finding of improved SISI scores in the presence of contralateral masking. The average improvement in increment detection projected for the normal hearing subjects in the present study was approximately fifteen per cent with a range of from six to thirty-two per cent.

CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

The effect of a noise stimulus delivered to one ear on the difference limen measured at the opposite ear has not been extensively investigated, although intensive differential sensitivity has received considerable attention in the area of psychophysical research, and assessments of differential sensitivity have been used as a clinical tool for many years. The limited information presented in the literature appears to be in direct conflict as to whether the DLI is made larger or smaller as a result of contralateral noise stimulation.

Blegvad and Terkildsen (3) found that the DLI at two of three test frequencies was significantly smaller in the presence of noise than in quiet, while Chocholle and Saulnier (9) found a tendency for the DLI at a single test frequency to be larger in noise than in quiet. The two experiments differed in at least one important particular. Specifically, the temporal characteristics of the measurement stimuli were different in the two studies. The investigators who had found a facilitation of differential sensitivity on the introduction of contralateral noise had used a continuous-background stimulus, while those who showed an adverse effect had employed a discontinuous-background stimulus.

Experimental Design

Taken together, the results of the two investigations suggested the possibility that the effect that contralateral noise exerts on DLI measurement might depend upon the temporal characteristics of the test stimulus. The present study was undertaken to explore this possibility by investigating the effect of contralateral noise stimulation on the DLI's obtained with variations of the quantal stimulus pattern employing continuous versus discontinuous-background tones. Intensive difference limens were obtained with the two stimulus patterns, both in quiet and in the presence of a contralaterally-presented thermal noise.

Eight normal young adults served as subjects for the experiment. Estimates of DLI magnitude were obtained with both stimulus patterns for each subject at test frequencies of 500 and 4000 Hz in quiet and in the presence of contralateral noise. Both the tonal stimuli and the noise were presented at 60-dB SPL. The order of presentation of the eight different experimental conditions was counterbalanced across the eight subjects to reduce the effects of any systematic biases on the data. The estimates of DLI magnitude obtained for each subject under each experimental condition represented the mean of four incremental values corresponding to the fifty per cent correct response point on four separately determined psychometric functions.

Results

The data obtained in the investigation were submitted to an analysis of variance procedure derived from a 2 x 2 x 2 factorial design with repeated measurements on each factor. The results of the analysis showed that the main effects consisting of frequency, background, and noise level were all significant at the .025 level of confidence. Significant interactions between frequency and background, background and noise level, and among frequency, background, and noise level were obtained at the .01 level of confidence. Whatever interaction existed between frequency and noise level was not significant at the .05 level of confidence.

In the presence of significant factor interactions the main effects could not be evaluated as if they had been derived from separate single factor experiments. For this reason, various sub-analyses of variance were performed on the significant factor interations in order to clarify the details of the significant main effects.

The results of the investigation are summarized below:

(1) Differences in DLI magnitude were observed between measures obtained at the two test frequencies. The differences appeared to be related to the temporal characteristics of the measurement stimulus.

a. The interrupted-background stimulus yielded measures that varied only slightly in magnitude across frequencies.

b. The continuous background yielded measures that varied significantly in magnitude across frequencies. Smaller DLI's were obtained at 4000 Hz than at 500 Hz for both noise levels.

(2) The presence of contralateral noise stimulation during DLI measurements affected differently the magnitudes of the DLI's obtained with the interrupted-background stimulus and the continuous-background stimulus.

a. The introduction of noise to the opposite ear under the interrupted-background condition caused a significant deterioration of differential sensitivity at both 500 and 4000 Hz. The magnitudes of the changes were similar at the two experimental frequencies.

b. The introduction of noise to the opposite ear under the continuous-background condition produced contrasting results at the two experimental frequencies. At 500 Hz there was no significant change in differential sensitivity compared to that measured in quiet. At 4000 Hz, differential sensitivity was significantly improved over the performance observed in quiet.

The effects produced by contralateral stimulation in the present investigation could not be accounted for entirely by the model of a simple adaptive-like process suggested by Blegvad and Terkildsen. Accordingly, it was speculated that the results might be attributable to a neuronal excitative-inhibitory interplay resulting from binaural stimulation. This line of thought stimulated a reconsideration of the details characterizing the two measurement patterns, whereupon it became readily apparent that apart from the obvious difference in duration existing between the two experimental stimuli the temporal relationships pertaining between the onset of the background tones and the onset of the increments differed radically in the two patterns.

A sub-experiment was undertaken to evaluate the role which this factor might have played in the outcome of the main experiment. The results suggested that differential sensitivity improves, both in quiet and in the presence of contralateral noise, as the onset of the stimulus increments is delayed with respect to the onset of the background tone. In general, contralateral noise stimulation results in poorer increment detection compared to that measured in quiet when the onset of the increments is relatively near the onset of the background stimulus. Detection in noise undergoes a gradual improvement, however, as the delay between the onsets of the background and the increment is made progressively longer. Eventually, at least at 4000 Hz, this results in performance superior to that measured in quiet. In general, the results complemented the results of the main experiment that were obtained under analogous conditions.

Conclusions

The major conclusion derived from the study is that contralateral noise stimulation affects the magnitude of the DLI differently depending upon whether the measurement stimulus employs a background pattern which is continuous or discontinuous in nature.

In addition, the results of the sub-experiment appear to support the hypothesis that contralateral noise exerts an influence on differential sensitivity by causing an exaggeration of the initial disruptive effect produced by the onset of the background stimulus. This gradually subsides into what may become a facilitative effect, at least at 4000 Hz.

Finally, contralateral stimulation appears to result in an significant improvement of differential sensitivity when the stimulus pattern employs a continuous-background tone. This may hold important implications for the use of contralateral masking during the administration of such clinical procedures as the SISI test.

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APPENDIX

INDIVIDUAL SUBJECT DATA

TABLE 9

INDIVIDUAL SUBJECT DATA IN dB USED TO COMPUTE THE DLI FOR EACH SUBJECT UNDER EACH EXPERIMENTAL CONDITION. THE DATA ARE THE INCREMENT VALUES CORRESPONDING TO THE 50 PER CENT RESPONSE POINTS OBTAINED FROM FOUR SEPARATE PSYCHOMETRIC FUNCTIONS CONSTRUCTED FOR EACH SUBJECT UNDER EACH EXPERIMENTAL CONDITION

Subject Number	500 Hz				4000 Hz			
	Continuous		Interrupted		Continuous		Interrupted	
	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise
1	1.200	1.199	1.191	1.668	1.166	.989	1.400	1.753
	1.228	1.233	1.131	1.520	1.187	.981	1.400	1.467
	1.222	1.233	1.300	1.458	1.250	1.211	1.400	1.600
	1.321	1.233	1.219	1.533	1.220	1.068	1.400	1.600
2	.933	1.168	.980	1.068	.768	.750	.867	1.001
	1.028	1.083	.802	.933	.733	.689	1.035	1.101
	.934	1.181	.701	.900	.736	.681	1.075	.915
	.973	.968	.930	.935	.729	.613	.800	.934
3	1.368	1.311	.960	1.215	.950	.756	.829	.715
	1.272	1.350	1.134	1.333	.922	.717	.800	.829
	1.300	1.343	1.080	1.313	.901	.668	.800	.751
	1.279	1.234	1.111	1.250	.900	.646	.822	.841
4	.900	1.090	.690	1.034	.700	.601	1.100	1.117
	.900	1.240	.801	.980	.750	.634	1.129	1.076
	1.001	1.223	.734	1.101	.750	.528	1.034	1.138
	1.001	1.090	.850	1.200	.701	.576	1.037	1.130

TABLE 9--Continued

Subject Number	500 Hz				4000 Hz			
	Continuous		Interrupted		Continuous		Interrupted	
	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise
5	.719	1.000	.720	.734	.439	.460	.701	.800
	.716	1.100	.560	.900	.500	.500	.679	.783
	.736	1.112	.734	.951	.463	.509	.786	.772
	.755	1.121	.682	.933	.459	.493	.781	.866
6	1.501	1.282	.850	.900	.450	.522	1.061	1.301
	1.620	1.300	.986	.823	.368	.390	1.072	1.437
	1.350	1.261	1.021	.934	.511	.424	1.033	1.437
	1.500	1.279	1.033	.957	.416	.433	1.033	1.202
7	.978	.841	.882	1.219	.841	.639	.972	1.300
	.950	.841	.851	1.135	.816	.661	.962	1.242
	.946	.760	.846	1.045	.834	.650	1.069	1.268
	.851	.912	.879	1.090	.830	.600	1.069	1.200
8	1.130	1.003	.828	.836	.634	.517	.726	1.152
	1.100	.968	.817	.834	.688	.568	.900	1.183
	1.000	.935	.789	.950	.651	.550	.742	1.201
	1.130	.853	.934	.874	.538	.580	.700	1.029