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CHAPTER I

INTRODUCTION

For years man has known that the presence of one acoustic signal can have a variety of effects upon the perception of another acoustic signal. One such effect is a change in the listener's threshold for, or detection of, one signal in the presence of another. Several qualitative investigations of this phenomenon were undertaken in the 18th and 19th centuries. It was not until the 1920's, however, that the subject was investigated quantitatively (Boring, 1942, 352-392).

Since the 1920's, many investigators have studied the changes in the detectability for one signal in the presence of various moderate-level and high-level acoustic signals.[1] Generally, these studies have been concerned with the kind and degree of masking produced by the latter signals.[2] In a more uncommon approach, other investigators have studied the changes in the detectability for one signal in the presence of various other low-

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[1]For the purposes of this study, moderate-level signals range from a twenty decibel sensation level (20 dB SL) to 70 dB SL and a high-level signal is above 70 dB SL in human observers with normal hearing.

[2]For discussions and lists of references in this area, consult Ward (1963) and Harris (1967).

level signals.[3] In general, these studies have been concerned with the degree of sensitization or desensitization produced in the auditory system by such signals.[4]

The purpose of this investigation was to study, historically and experimentally, the phenomena of sensitization and desensitization in audition. The general questions asked in the investigation are when, to what degree, and why do sensitization and desensitization occur? It is realized that this one study cannot answer all of these questions completely, but it is hoped that this investigation will contribute to the eventual understanding of the sensitization and desensitization phenomena in audition.

A review of the sensitization and desensitization literature, which is discussed in detail in Chapter II, revealed that investigators have utilized on-going tones, brief tone pips, or brief noise pips as test signals. Many of these investigators have utilized one given sinusoid as the on-going, low-level, non-test signal. The frequency of the on-going sinusoid has varied from study to study, and it has varied within given studies as an experimental parameter. The use of a single

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[3]For the purposes of this study, a low-level signal is subliminal or below 20 dB SL in normal-hearing observers.

[4]For the purposes of this study, sensitization is an improvement in the detectability for a test signal in the presence of a different, on-going, low-level signal when compared to the detectability for the test signal presented alone. Conversely, desensitization is a worsening in the detectability for the test signal in the presence of a different, on-going, low-level signal when compared to the detectability for the test signal presented alone. Although there are exceptions, in most of the recent literature, the terms sensitization and desensitization have been reserved for perstimulatory effects and the terms facilitation and defacilitation have been reserved for post-stimulatory effects. Because this study deals with perstimulatory effects throughout, the former two terms are used.

sinusoid as the on-going, low-level, non-test signal has the advantage of simplicity. Thus, interpretations of the resulting auditory process are relatively easy when compared to the interpretations of auditory processes which result from more complicated signals. The review of the experimental literature in Chapter II is limited to investigations which have utilized on-going, low-level sinusoids as the non-test signal.

Some investigators of sensitization and desensitization have utilized other non-test signals. Some have used on-going noises of varying bandwidth and levels. Others have used brief sinusoids or brief noises of varying bandwidth set at various levels and presented simultaneously with the test signal.[5] Such approaches are not considered in this study because either the non-test signals have been relatively high in level or too broad in spectrum, leading to complex auditory processing.

Sensitization and desensitization have been studied with the test signal and the non-test signal presented monotically and/or with the two signals presented dichotically. Such investigations are reviewed in Chapter II of this study. In addition, diotic stimulation has been utilized to study binaural summation.[6] The latter studies are outside the scope of this investigation because sensitization and desensitization, as defined previously, require the detection of one signal in the presence of a different, on-going, low-level signal and not in the presence of a similar, on-going, low-level signal.[7]

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[5]For discussions and lists of references in this area, consult Dirks and Norris (1966) and Campbell and Laskey (1967).

[6]For references in this area, consult Deatherage (1966).

[7]For the purposes of this study, a similar signal has the same number of Hz as the test signal or causes beats in the presence of the test signal. A different signal does not meet such criteria.

Some authors have developed theories which attempt to explain the mechanism or mechanisms responsible for sensitization and desensitization. When monotic stimulation is considered, two general theories have been advanced: (1) that both sensitization and desensitization result from the mechanics of basilar membrane movement; (2) that both phenomena result from neural interaction. The only theory which has been advanced concerning dichotic stimulation is that of neural interaction. These theories also are presented and discussed in detail in Chapter II of this study.

It is well known that psychophysical threshold is quite variable despite strict control of the apparatus and procedure. One of the factors which contributes to this variability, and one which the classic psychophysical methods do not evaluate, is the response bias of the observer. A procedure based on the Theory of Signal Detectability allows for the evaluation of that factor. In addition, very subtle differences in performance can be observed with signal detection methods when they cannot be observed with classic psychophysical procedures (Clarke and Bilger, 1963). For these reasons, the two main experiments in this study evaluated the observers' detection of the test signals rather than their psychophysical thresholds for test signals. The test signals were brief noise pips presented alone or in the presence of an on-going, low-level, 50-Hz sinusoid set at various SL's. The experimental procedures, as well as the over-all design and the hypotheses of the study, are discussed in Chapter III. The balanced orders of treatments for the two main experiments are presented in Appendix A.

The data obtained from the experiments in this study are presented in Appendix B and in Chapter IV. These data have been evaluated with descriptive and inferential statistics. Summaries of these evaluations appear in Appendix B and Appendix C. The results of the study are presented and discussed in Chapter IV. A summary and the over-all conclusions of the study, as well as suggestions for further research, are presented in Chapter V.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The most pertinent investigations of the sensitization and desensitization phenomena, as these phenomena are described in Chapter I, are presented in this chapter. This literature survey follows a chronological sequence and is divided into two sections according to the mode of presentation. The behavioral studies in which the test and non-test signals were presented monotically are reviewed first. These studies are then discussed in view of anatomic and physiologic findings and/or theories. The behavioral studies in which the test and non-test signals were presented dichotically are reviewed second and they are discussed in the same manner. A summary of the historic findings is presented at the end of the chapter.

Monotic Presentations

Results of Behavioral Studies

Although most of their research dealt with the effects of on-going, moderate-level and high-level sinusoids upon the thresholds of other sinusoids, the first researchers who used quantitative methods to investigate the influence of an on-going, low-level sinusoid upon the threshold of a different auditory signal were Wegel and Lane (1924).

They presented the on-going, non-test sinusoid at a given SL and set another on-going test sinusoid at a subliminal level. Threshold for the test sinusoid was then determined by the experimenters with an ascending procedure. This technique was repeated with many frequency combinations, but only one observer was used.

Wegel and Lane found that an on-going, low-level sinusoid did not affect the observer's threshold for the test sinusoid unless the two signals were similar in frequency, but not similar enough to cause beats. In such cases, the threshold for the test signal increased. This effect was called masking, the amount of which was expressed in terms of the degree of the threshold shift. The masking effect that Wegel and Lane noted for one signal in the presence of an on-going, low-level sinusoid fits the definition of desensitization as it is used in the present study.

Of the frequency combinations investigated by Wegel and Lane, the amount of desensitization ranged from the equivalent of 0.0 dB to the equivalent of approximately 19.5 dB.[1] More desensitization was noted for the test tone in the presence of non-test tones of lower frequency than in the presence of non-test tones of higher frequency.

Inspection of Wegel and Lane's uncorrected data suggests that both sensitization and desensitization occurred for some test tones. The authors applied corrections to all data and no evidence of sensitization appears in the corrected figures. They pointed out that in their procedure a given minimum audible reference value in quiet was an average taken over a period of several days whereas a given minimum audible test

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[1]That amount of desensitization occurred for a 3500-Hz tone in the presence of an on-going, 20-dB SL, 3300-Hz tone.

value in the presence of any given sinusoid was the average of four observations taken in succession on the same day. They stated that on the day of the experimental run, any given threshold could have been better than the average value over a period of days; hence, the corrections were made. No mention was made of the fact that any given threshold had an equal chance of being poorer on the day of the experimental run and no corrections were made for that possibility. It appears that the corrected values do not demonstrate some slight sensitization which may have taken place but do demonstrate slightly more desensitization than probably did take place. As a result, the effects of a low-level sinusoid upon the thresholds of other sinusoids, as reported by Wegel and Lane, are open to some question.

Wegel and Lane explained their masking findings in terms of their interpretations of cochlear mechanics. They maintained that, because of the proximity of the individual neural structures, vibration of one would set the others close to it into vibration, producing neural impulses in all of the neural fibers in the area of stimulation. They believed that if one sinusoid of a given amplitude set a section of the basilar membrane into vibration, this would override the vibration associated with another sinusoid of less amplitude which set the same general area of the basilar membrane into vibration. Thus, according to Wegel and Lane, the second sinusoid would be masked by the first because the motion of the basilar membrane would not allow the brain to perceive the two stimuli separately.

The explanation of masking by Wegel and Lane placed considerable importance upon the movement of the basilar membrane as a peripheral mediator for that desensitization effect. No mention was made of the sensitization phenomenon except for a brief discussion of the beats that occurred when one threshold-level sinusoid and one slightly subliminal-level sinusoid of similar frequency were presented together.

Hughes (1940) reported the results of experiments that he conducted in the late 1930's. Using himself as the primary observer and one other person as an occasional observer, he measured the thresholds for test tones of varying frequency. He then observed the effects of on-going subliminal tones of varying frequency and of varying subliminal level upon these thresholds. Hughes did not specify which test tones were pulsed and which test tones were continuous but he implied that both kinds of presentations were utilized. The non-test tones were presented at 2, 3, and 4 dB below each observer's threshold.

For the primary observer, Hughes found a mean threshold improvement across frequencies of 1.31 dB when the subliminal tone was set at -2 dB SL, 1.22 dB when set at -3 dB SL, and 1.13 dB when set at -4 dB SL. The threshold improvements for the other observer were similar but slightly less than those of the primary observer, the greatest difference being 0.16 dB. Hughes tested many tonal combinations and differences occurred with narrow or wide separations in the frequencies of the two tones. He concluded that the intensity required for threshold is less in the presence of a tone from -2 to -4 dB SL than when presented alone, regardless of the frequency of the accompanying tone.

The improvement in threshold that Hughes observed in the presence of an on-going subliminal tone fits the definition of sensitization as it is used in the present study. Hughes believed that the improvement in threshold was a neural summation effect which was mediated by the central nervous system. He did not believe that the improvements in threshold could be a peripheral phenomenon because wide frequency differences existed between the tones during many of the presentations. This implied that different parts of the basilar membrane were stimulated by the two tones and that neither stimulation affected the other.

With a procedure similar to that described above, Hughes also studied the effects of 700-Hz tones upon the two observers' thresholds for a 1100-Hz tone when the former signals were presented at 2, 3, and 5 dB SL. No changes in the thresholds were noted. Hughes concluded that as the intensity of the low-level, non-test tone is raised to a level just above threshold, the improvement effect decreases until, finally, there is no improvement at all. He made no attempt to explain why neural summation occurred in the presence of low-level subliminal stimuli but not in the presence of low-level audible stimuli. None of Hughes' results provide evidence of desensitization.

Although Hughes utilized elaborate equipment to control the small changes in frequency and intensity necessary for his study, the experimental procedure that he used is open to several criticisms. His two observers were not given equivalent tasks. Thresholds for the test tone alone were always determined first while thresholds for the test tone in the presence of the non-test tone were always determined last. The psychophysical methods used to obtain the thresholds were not specified. At times the test tone was pulsed and at other times it was continuous, but the order of the two approaches was not balanced. Some frequency combinations of test tone and non-test tone were evaluated many times and others were evaluated only once but the mean of all determinations was used to describe the results. In view of these factors, it is possible that the small dB differences observed were due to procedural artifacts rather than sensitization effects.

Ehmer (1959) utilized a tracking task to study three observers' thresholds for pulsed tones from 100 to 8000 Hz in the presence of on-going sinusoids of 250, 500, 1000, 2000, and 4000 Hz. These on-going tones were presented at sensation levels of 20 dB to 100 dB. Only the non-beating effects of the 20-dB SL sinusoids are considered in this review.

The results showed that various degrees of desensitization occurred in the presence of each 20-dB SL sinusoid but no sensitization effects were noted. The greatest amount of desensitization (7 dB) occurred in the presence of the on-going, low-frequency, 20-dB SL sinusoids. In addition, the relative number of frequencies desensitized was greatest in the presence of the low-frequency sinusoids. Ehmer concluded that the only determinant of the desensitization observed could be the activity pattern in the cochlea which results from the on-going, low-level, sinusoidal stimulation. He supported this conclusion with essentially the same reasoning given by Wegel and Lane (1924).

Deatherage and Henderson (1967) hypothesized that the auditory system is most sensitive during the late stages of the downward deflection of the basilar membrane. To test this hypothesis, they examined two human observers' ability to detect 3150-Hz pulses as a function of the amount and direction of basilar membrane displacement. Each 3150-Hz pulse had a duration of approximately one millisecond. The position of the basilar membrane was controlled by an on-going, low-level, 50-Hz sinusoid.[2] The

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[2]According to Deatherage and Henderson, the condensation associated with a 50-Hz sinusoid moves the basilar membrane in an inferior direction and the rarefaction associated with a 50-Hz sinusoid moves the basilar membrane in a superior direction. Although they did not offer support for this contention, Bekesy (1947) showed that, except for the most apical portion, the entire basilar membrane vibrates in this manner for signals of 50 Hz or less.

tone pips were presented at varying phase angles of the 50-Hz sinusoid. Consequently, the investigators were able to stipulate the position of the basilar membrane during each pip presentation.

Prior to each of three, two-alternative forced-choice experiments, the observers' detectability scores for the pips, without the on-going 50-Hz tone, were obtained. The level of the pip presentations was adjusted until each observer obtained an 85 per cent (%) correct score which was considered the reference condition. The three experiments were then run in the presence of the on-going, low-level, 50-Hz sinusoid with the level of the pips equal to that of the reference condition. The investigators did not state whether or not a control condition was run for comparison purposes following the experimental conditions. Furthermore, they did not state the kind of earphone used not did they discuss the stability of their equipment.

In Experiment One, the 50-Hz sinusoid was adjusted to 20 dB SL. Detectability for the tone pips was then measured at various phase angles of that on-going tone and all per cent correct scores were compared with the scores at the 0° phase angle.[3] This revealed that the mean detectability score for the two observers varied by about $\pm 2.2\%$. The maximum scores occurred at phase angles from 90° to 120°, i.e., when the basilar membrane was in a downward position. The minimum scores occurred at phase angles from 270° to 330°, i.e., when the basilar membrane was in an upward position.

The 50-Hz sinusoid was set at 20, -5, and -90 dB SL in Experiment

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[3]The 0° phase angle was assumed to be the point at which no displacement of the basilar membrane occurred.

Two. At each level the tone pips were presented at 0^{o}, 90^{o}, and 270^{o} relative to (re) the on-going 50-Hz sinusoid. The results for the latter two phase-angle treatments were compared with the results for the 0^{o} treatment. For the -90-dB SL condition, there were no differences in detectability scores among the phase-angle treatments. This indicated that such an on-going sinusoid had the same effect as no on-going sinusoid.

During the 20-dB SL condition, there were differences in detectability scores among the phase-angle treatments. The 90^{o} treatment produced a mean increment (sensitization) of 5.70% and the 270^{o} treatment produced a mean decrement (desensitization) of -2.03%.

For the -5-dB SL condition, there were differences in detectability scores among phase-angle treatments, also. The mean sensitization effect for the 90^{o} treatment was 6.98%, approximately 1.25% greater than it was in the 20-dB SL condition. The mean desensitization effect for the 270^{o} treatment was -2.65%, approximately 0.60% greater than it was in the 20-dB SL condition.

Experiment Three explored the effects of the -5-dB SL sinusoid in more detail. The pips were presented at every 45^{o} of the on-going sinusoid. The greatest sensitization (approximately 6.80%) occurred at the 90^{o} phase angle. The greatest desensitization (approximately -2.90%) occurred at the 270^{o} phase angle.

The results of Deatherage and Henderson's study support their stated hypothesis. In addition, their results indicate that an inaudible 50-Hz sinusoid set at -5 dB SL can lead to sensitization or desensitization to the tone pips, depending upon the phase angle of the tone pips re the on-going sinusoid. The two investigators concluded their study by stating that a downward movement of the basilar membrane may induce a state of hypersensitivity in the neural elements, thus priming those neural elements for firing during the subsequent upward movement of the basilar membrane. Although they did not speculate upon the cause of the desensitization, the inference is that an upward movement of the basilar membrane induces a state of hyposensitivity in the neural elements, thus reducing the firing of those neural elements.

Deatherage and Henderson investigated sensitization in a different manner than Hughes (1940), but in the two investigations it was demonstrated that sensitization for one signal can occur in the presence of another on-going subliminal signal. Whereas Hughes did not demonstrate the presence of sensitization during an on-going supraliminal tone, Deatherage and Henderson did, although the degree of sensitization was somewhat less than it was in the presence of the subliminal tone.

Discussion

The authors of the preceding behavioral studies presented two explanations for sensitization and one explanation for desensitization of the auditory system to one acoustic signal in the presence of an on-going, low-level sinusoid in the same ear. For the sensitization effects, Hughes (1940) proposed the mechanism of neural summation while Deatherage and Henderson (1967) suggested that basilar membrane movement was responsible for the sensitivity changes. For the desensitization effects, Wegel and Lane (1924), Ehmer (1959), and Deatherage and Henderson (1967) proposed the mechanism of basilar membrane movement. Although none of these authors suggested the possibility of neural inhibition of one threshold stimulus by another on-going, low-level stimulus as a mechanism for desensitization, some neurophysiologic studies on animals suggest that possibility (Whitfield, 1967, 77-79; 124-154). The purpose of this discussion is to evaluate the role of these mechanisms as possible mediators of auditory sensitization and desensitization during monotic stimulation.

The role of neural interaction. In a study of cats, Derbyshire and Davis (1935) examined cochlear potentials and eighth-nerve-action potentials for low-level clicks in the presence of low-level, on-going sinusoids. The cochlear responses showed a simple summation of the electrical waves produced separately by the two stimuli but the action potentials associated with the clicks decreased in size whenever the on-going sinusoid was added. Similar results were obtained by Galambos and Davis (1943) who found that an on-going tone which was higher in frequency than the test tone was the most effective inhibitor. They stated, however, that on-going tones of lower frequency than the test tones also could produce inhibition. In addition, with the test signal presented at various phase angles of the on-going signal, Galambos and Davis found differential effects in the size of the action potentials but not in the size of the cochlear potentials. They did not state how much phase change they introduced nor did they stipulate what the magnitude of the observed changes were.

The fact that both of the above studies demonstrated desensitization in the eighth nerve but not in the cochlea suggested that some kind of neural desensitization took place during the presentation of the two low-level stimuli. These findings have been supported by more recent research but the actual mechanism responsible for desensitization in the auditory nerve still is unknown (Whitfield, 1967, 61-62). Although it is known that electrical stimulation of the crossed and uncrossed olivocochlear efferent fibers, as well as electrical stimulation of the reticular formation fibers, can lead to desensitization of a given low-level auditory signal, it is not known if that is what occurs during monotic stimulation (Fex, 1967; Whitfield, 1967, 77-79).

After reviewing the physiologic findings in audition, Davis (1951) concluded that electrical summation of two signals had never been observed in afferent-nerve-fiber potentials when it had not been observed also in cochlear potentials. According to Fex (1967), there is no substantial evidence that stimulation of efferent auditory fibers leads to sensitization.

The presence of adrenergic fibers in the auditory system was substantiated by the anatomic findings of Spoendlin and Lichtensteiger (1966). Other anatomic research by Nomura and Schuknecht (1965), Amaro, Guth and Wanderlinder (1966), and Ishii, Murakami and Balogh (1967), has indicated that some efferent auditory fibers may be cholinergic in their electrochemical-transmission characteristics. According to Whitfield (1967, 136-141) both adrenergic and cholinergic efferent auditory fibers have been discovered which, upon electrical stimulation, lead to enhancement of the electrical response to on-going peripheral signals. It is not known if this effect occurs during monotic acoustic stimulation, however.

On the basis of the above information, it appears that some form of neural inhibition can lead to the desensitization of the system to one low-level signal in the presence of another low-level signal during monotic presentations of those signals. The actual neural mechanism responsible for this is unknown but there is evidence to suggest that stimulation of some efferent auditory fibers can lead to decreased sensitivity to on-going auditory signals. Whether the on-going, low-level signal can stimulate these efferent auditory fibers and decrease the response to another low-level auditory signal is unknown.

There is no direct evidence of neural interaction leading to auditory sensitization to one low-level signal in the presence of another low-level signal when the two signals are presented monotically. However, recent physiologic studies suggest that stimulation of some efferent auditory fibers can lead to sensitization of the system to on-going auditory signals. Whether such on-going signals can stimulate those efferent auditory fibers and enhance the response to another incoming auditory signal is unknown.

The role of the basilar membrane. Discussions by Bekesy (1960, 403-634) relative to his studies of cochlear specimens and cochlear models over a period of almost 40 years, serve as a background for this discussion. In general, Bekesy's studies revealed the presence of a pressure wave which moved toward the helicotrema following the footplate displacement associated with a moderate-level or high-level auditory signal. This pressure wave produced a pressure difference between the vestibular and tympanic scalae which, in turn, caused a transverse wave in the basilar membrane. This wave traveled from the base to the apex of the basilar membrane, the maximum amplitude appearing at a place on the membrane which resonated best to a particular input frequency. As mentioned previously, Bekesy's studies showed that for an input signal of 50 Hz or less, almost the entire basilar membrane vibrated in phase. For higher frequency inputs, the basilar membrane vibrated segmentally, some parts moving downward and other parts moving upward.

In his studies with simultaneously presented signals, Bekesy observed a decreased basilar membrane response to a moderate-level pulse in the presence of another moderate-level signal when compared to the basilar membrane response to the pulse alone. He believed that some neural fibers which normally transmit the impulses associated with the pulse alone become stimulated by the on-going signal when both signals are presented, especially if the two signals stimulate the same general area of the basilar membrane. Thus, the total number of neural fibers responding to the brief stimuli are reduced. This combination of mechanical and neural effects leads to a desensitization of the system to the pulsed signal. Bekesy did not state whether he believed that the same effects occur for low-level signals. Only if one assumes that simultaneous low-level signals affect the basilar membrane in the same way, can Bekesy's observations be considered supportive of the desensitization findings of Wegel and Lane (1924) and Ehmer (1959).

Peake and Kiang (1962) observed that the action potentials from the eighth cranial nerve of cats had larger amplitudes for moderate-level condensation clicks than for corresponding rarefaction clicks. They also observed that the action potential occurred only during upward movement of the basilar membrane, regardless of whether an initial condensation or rarefaction was responsible for that movement. Deatherage and Henderson (1967) found sensitization effects to low-level tone pips when they were presented during the condensation period of the 50-Hz tone. The latter authors examined their results in view of the former authors' observations and interpreted them to mean that the neural elements on the basilar membrane were sensitized during the downward excursion of the membrane in such a way that they yielded a greater output on the ensuing upward excursion of the membrane. In addition, Deatherage and Henderson found desensitization effects to the low-level pips when they were presented during the rarefaction period. They inferred that an upward movement of the basilar membrane induces a state of hyposensitivity in the neural elements, thus reducing the firing of those neural elements during a given rarefaction.

The above observations, findings, hypotheses, and inferences by Peake and Kiang (1962) and Deatherage and Henderson (1967) suggest that the movement of the basilar membrane may actually lead to sensitization or desensitization of the auditory system to one low-level signal in the presence of another low-level signal, depending upon the phase relationship of those two signals. This suggestion in no way refutes Bekesy's observations or theories because the latter investigator required moderate-level inputs in order to observe, directly, the movements and actions of the basilar membrane in response to simultaneous sounds.

The exact mechanical alterations of the basilar membrane that occur during low-level stimulation are only partially understood at this time. It is very likely that basilar membrane movement is much different in the presence of moderate-level signals than in the presence of low-level signals. Thus, the effects of basilar membrane movement upon other input signals probably depend upon the intensity of the original signal. Further neurophysiologic and behavioral investigations of sensitization and desensitization of the auditory system to one low-level signal in the presence of another low-level signal and further microscopic studies of cochlear specimens and cochlear models during such stimulation are indicated.

Dichotic Presentations

Results of Behavioral Studies

Wegel and Lane (1924) were the first researchers who used quantitative methods to investigate the influence of an on-going, low-level sinusoid upon the threshold of a different signal when the two signals were presented dichotically. Although they found evidence of a central masking effect[4] in the presence of an on-going, high-level sinusoid in the opposite ear, their results show no evidence of this effect in the presence of an on-going, low-level sinusoid in the opposite ear. Wegel and Lane did state, however, that central masking is probably always present to some degree during all bilateral stimulation.

Using the same general procedure as he did in his monotic investigations described earlier, Hughes (1938) measured the amount of threshold improvement for one signal in the presence of a subliminal sinusoid in the opposite ear. He conducted a series of such experiments with one observer. Several test tones were evaluated in the presence of various subliminal tones. There were many repetitions of each test tone and subliminal tone combination. The subliminal sinusoids were presented from 2.3 dB to 6.0 dB below threshold.

Hughes found that improvements in threshold occurred in the presence of all subliminal tones presented to the opposite ear, regardless of the frequency and level combinations utilized. The mean improvements in threshold across all subliminal tone combinations were 2.82 dB when the

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[4]Wegel and Lane described central masking as a slight worsening in threshold for one ear resulting from a conflict of sensations in the brain caused by the presence of auditory signals in both ears. Now it is regarded as an increase in threshold for an auditory signal in one ear which cannot be explained by peripheral masking when another signal is presented to the opposite ear.

on-going sinusoid was set at -3 dB SL, 2.19 dB when set at -4 dB SL, 1.65 dB when set at -5 dB SL, and 1.20 dB when set at -6 dB SL. Hughes concluded that threshold for one tone always improves in the presence of a subliminal tone in the opposite ear, regardless of the frequency of the subliminal tone. He explained this phenomenon by stating that neural summation occurred in the central nervous system during such stimulation.

In a later study, Hughes (1940) investigated the effect of an audible, on-going, low-level tone on the threshold of a different tone presented to the opposite ear. Once again, experiments were conducted with one observer and various test tone and on-going tone combinations were studied. The audible, on-going, low-level tones were presented at 2, 3, 5, 7, 10, and 15 dB SL. In no case was an appreciable change in threshold noted. The mean changes across frequency and level combinations were ±1.0 dB or less. On the basis of these findings, Hughes concluded that no improvement in the threshold for one tone occurs in the presence of a different, on-going, audible, low-level sinusoid in the opposite ear, regardless of frequency. He stated that a different mechanism comes into play in the presence of an audible low-level sinusoid presented contralaterally than in the presence of a subliminal low-level sinusoid presented contralaterally. He did not speculate upon what that mechanism might be, however.

Hughes' experimental procedures were essentially the same as those used in his monotic investigations except that only one observer was used and the two earphones went to separate ears rather than to a box held against one ear. Some of the criticisms expressed previously apply here as well. Thresholds for the test tone alone were always taken first and thresholds for the test tone in the presence of the on-going sinusoid were always taken second. Although the non-test tone was always on-going, sometimes the test tone was pulsed while at other times it was continuous. The presentations were not balanced for order. The psychophysical method or methods used to obtain thresholds were not specified. In view of the small differences noted among the scores for the various experimental treatments, there is some question whether these differences were due to treatment or whether they resulted from the experimental procedure.

In his study of interaural attenuation, Zwislocki (1953) noted that the presence of high-level stimuli in the non-test ear led to both central and peripheral masking of a tone in the test ear. His findings suggested that at such high levels the signal in the non-test ear stimulated the cochlea of the test ear by traveling through the head by bone conduction, causing peripheral masking of the test signal. In addition, his findings suggested that the signals in the two ears led to some kind of neural interaction which caused additional central masking amounting to a few dB more than could be accounted for by peripheral masking. Zwislocki also studied the effect of a low-level tone in the contralateral ear on threshold. When compared to the quiet condition, the presence of a continuous 1000-Hz tone at 20 dB SL did not lead to any change in the threshold of the contralateral ear. These results appear to agree with those of Wegel and Lane (1924) who found no evidence of central masking in the presence of low-level stimulation in the contralateral ear.

Ingham (1957) studied the monaural thresholds of 48 normal-hearing observers for a 1000-Hz tone in quiet and in the presence of an on-going, 10-dB SL, 400-Hz tone in the opposite ear. He found that the latter condition caused a slight increase in threshold for the test tone. He attributed this worsening in threshold to central inhibition or central control of the sensory end organ.

Although several central masking studies have been completed in the 1960's, most of them have utilized maskers which either were moderate to high in level or were not on-going sinusoids. Zwislocki et al. (1967) published the results of central masking studies which had taken place over several years. Two of those studies investigated thresholds for tone pulses in the presence of on-going, low-level sinusoids in the contralateral ear. In one of the studies the authors had one observer determine his own threshold by the method of adjustment. They found approximately a 0.9-dB elevation in threshold for a 1100-Hz pulsed tone in the presence of a 20-dB SL, 1000-Hz, on-going tone in the opposite ear when compared to the test-tone-alone condition. Thus, it appears that some degree of desensitization was noted in that experiment.

In the second study by Zwislocki et al. (1967), two observers tracked their thresholds for pulsed tones over continuously changing frequencies from 700-1500 Hz with a Bekesy-type attenuator. A 1000-Hz on-going tone was presented to the opposite ear at 10 dB SL and at 20 dB SL. In the presence of the 10-dB SL tone, the two observers experienced changes in threshold of -0.2 dB to 1.1 dB for frequencies from 700-900 Hz and 1100-1500 Hz.[5] In the presence of the 20-dB SL tone, the two observers experienced changes in threshold of 0.1 dB to 2.2 dB for the same

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[5]The results for frequencies within $\pm$100 Hz of the on-going tone were reported by Zwislocki et al. but are not presented here because binaural beats probably were responsible for some of the results obtained. The present study does not consider binaural beats.

frequencies. Thus, it appears that a slight degree of desensitization was noted in that experiment. Zwislocki et al. concluded that central masking is highly frequency selective, the threshold shift being maximal at or near the frequency of the masker and decaying rapidly at lower and higher frequencies. Throughout their article, Zwislocki et al. implied that central masking is caused by simultaneous stimuli from each ear leading to neural effects in the central nervous system.

Discussion

The authors of the behavioral studies reviewed above suggested that neural interaction is responsible for sensitization and desensitization of the auditory system to one signal in the presence of an ongoing, low-level, contralateral sinusoid. They implied that observer homogeneity, instructions to the observers, signal presentations, and the ability and motivation of the observers to perform the task were controlled. The suggestion of neural interaction assumes the existence of neuroanatomical connections between the two auditory systems, either directly or by way of common neural networks in the central nervous system. In addition, such a suggestion assumes that stimulation of one auditory system has a neurophysiologic effect upon the other auditory system. The purpose of this discussion is to evaluate these assumptions in view of neuroanatomic and neurophysiologic findings and/or theories.

Neuroanatomic factors. In his review of binaural interaction, Deatherage (1966) stated that there is ample evidence to support the existence of neural connections between the two ears by way of the central nervous system. These connections have been demonstrated at all levels of the auditory system from the accessory cochlear nucleus to the cortex. The connections include the efferent pathway from the cortex to the contralateral cochlea as reported by Rasmussen (1967), the reticular formation pathways and their connections with the auditory pathways as discussed by Hernandez-Peon (1961) and Goldstein (1967), the feedback system of one cochlea with the contralateral auditory pathway as reported by Fex (1967), and the high level brain stem and cortical connections as discussed by Galambos (1954) and Gacek (1967). It is not the purpose of the present investigation to trace each neuroanatomic connection. In view of the evidence, it appears that any or all of these neural connections could allow for interactions between the two ears.

Neurophysiologic factors. For some time it has been known that action potentials in response to a signal in one ear can be enhanced or decreased by the presence of another signal in the opposite ear (Ryan, 1940). According to Deatherage (1966), neurophysiologic research by many investigators has shown that interaction between the ears can be both excitatory and inhibitory in nature. It has not been possible to specify the conditions which produce these opposite effects (Ingham, 1957; Deatherage, 1966). The nature of the electrochemical activity in the fibers associated with dichotic stimulation is equally undetermined (Fex, 1967). For these reasons, there are no further discussions of the electrochemical and neurophysiologic findings beyond those already presented in the section of this chapter dealing with monotic stimulation.

As noted earlier, some authors have suggested that phase changes between two low-level signals presented monotically may lead to neural effects which cause sensitization or desensitization. The same may hold true for dichotic presentations of the two signals but this has not been reported in the literature. Research is needed in this area.

Summary

In this chapter, the most pertinent behavioral investigations of sensitization and desensitization of the auditory system to one signal in the presence of an on-going, low-level sinusoid were reviewed. In addition, the results of these investigations were discussed in view of important anatomic and physiologic findings and/or theories. The literature suggests that both sensitization and desensitization to one signal can occur in the presence of another on-going, low-level signal. Furthermore, the literature suggests that both effects can occur when the test and non-test signals are presented monotically or dichotically.

For monotic presentations, it appears that sensitization to the test signal is more apt to occur when the non-test signal is presented at a slightly subliminal level than when it is presented at a slightly supraliminal level, although some degree of sensitization has been found in the latter case. The literature suggests that the greater the level of the supraliminal non-test tone, the greater the likelihood of desensitization to the test tone. It appears that greater sensitization and greater desensitization occur when the non-test signal is low in frequency than when it is moderate or high in frequency. Recent research indicates that the phase relationship of the two signals may be a very important determinant of whether sensitization or desensitization to the test tone occurs. It appears that if a brief test signal is presented at or near a 90° phase angle of an on-going, low-level, low-frequency, non-test tone, sensitization to the test signal occurs. However, if a brief test signal is presented at or near a 270° phase angle of the non-test tone, desensitization occurs.

It is possible that both sensitization and desensitization occur as a result of neural interaction during monotic presentations of the two signals. However, there is little direct neurophysiologic support for this contention. It is also possible that both phenomena occur as a result of basilar membrane movement during monotic presentations. The mechanical alterations of the basilar membrane during low-level stimulation are not fully understood but there is some observational and neurophysiologic support for this contention.

For dichotic presentations, it appears that sensitization to the test signal only occurs when the non-test signal is presented at a subliminal level. Whenever the non-test signal has been presented at threshold or supraliminally, either there has been no effect upon threshold for the test tone in the opposite ear or there has been some degree of desensitization to that test tone. It appears that greater sensitization and desensitization occur when the non-test signal is low in frequency than when it is moderate or high in frequency. It is not known whether the phase relationship of the test signal to the non-test signal has a sensitization and/or a desensitization effect during dichotic stimulation. The lack of sensitization and desensitization data during dichotic signal detection tasks has led to the present experimental investigation, the design of which is discussed in Chapter III.

Researchers agree that sensitization or desensitization effects result from neural interaction of the impulses from the two signals when they are presented dichotically. There is ample evidence to support the existence of neural connections between the two ears by way of the central nervous system. Neurophysiologic research by many investigators has shown that interaction between the two ears can be both excitatory and inhibitory in nature. It has not been possible to specify the conditions which produce these opposite effects.

CHAPTER III

DESIGN OF THE INVESTIGATION

Introduction

The literature reviewed in Chapter II indicates that detectability for brief acoustic pips is influenced by the phase relationship of the pips to an on-going, low-level, low-frequency sinusoid presented to the same ear. After investigating many phase relationships for such presentations, Deatherage and Henderson (1967) found that a 90° phase relationship brought about the greatest sensitization of the auditory system to the pips while a 270° phase relationship brought about the greatest desensitization. It has been shown that detectability for one signal presented alone is either enhanced or decreased when that signal and a different, on-going, low-level sinusoid are presented dichotically (Wegel and Lane, 1924; Hughes, 1938; Ingham, 1957; Zwislocki et al., 1967). It is not known whether the phase relationship between the test and non-test signals contributes to sensitization or desensitization during such dichotic presentations.

The purpose of this study was to investigate whether the phase relationship between two low-level signals contributes to sensitization and/or desensitization of the auditory system to one of those signals during dichotic stimulation. The effects of an on-going, low-level 50-Hz sinusoid upon detectability for brief acoustic pips presented at 90° and 270° phase angles of the 50-Hz tone were studied. Because sensitization and desensitization were observed by other researchers when such signals were presented monotically, an investigation of the amount of sensitization and desensitization associated with the monotic and dichotic modes of presentation was included in the design of this study. Research reviewed in Chapter II indicated that the amount of sensitization or desensitization to the test signal was influenced by the level of the non-test signal. Thus, two intensity levels of the non-test signal were studied.

Interaural attenuation (IA) must be considered in research utilizing dichotic stimuli. Because no IA information was available for frequencies below 125 Hz, a study of IA at 50 Hz was considered necessary before the major study could be initiated. This study is referred to as Preliminary Study One. The fact that Deatherage and Henderson (1967) found that a -5-dB SL, on-going, 50-Hz tone could affect detectability for brief acoustic pips during monotic stimulation suggests that such an ongoing sinusoid presented at 5 dB below IA could influence the hearing for another signal presented to the opposite ear. It was not known how subliminal a 50-Hz tone must be before it no longer affects the detectability for pips when the signals are presented monotically. Determination of the extent of the Subliminal Sensitization Effect (SSE) was considered necessary before the major study could proceed. This study is referred to as Preliminary Study Two.

The designs for Preliminary Studies One and Two and the Major Study are presented in the remainder of this chapter. A description of the observers, the apparatus, and the procedures as well as the experimental hypotheses, are presented for each study.

Preliminary Study One: IA at 50 Hz

Observers

Five male patients who were seen at the Audiology and Speech Pathology Clinic of the Veterans Administration Hospital in Oklahoma City, Oklahoma, served as the observers in this study. These patients ranged from 27 to 55 years of age, the median age being 45 years. Each demonstrated a total loss of hearing in one ear and essentially normal hearing sensitivity for the low frequencies in the opposite ear.[1] All five patients had received clinical audiometric evaluations and no evidence of nonorganicity had been demonstrated at any time.

Room Apparatus

The experiment was conducted in an IAC model 400 sound treated room at the clinic mentioned above. The room contained two matched 10-ohm Telephonics TDH-39 earphones set in MX-41/AR cushions which were fed from the experimental apparatus located outside the sound treated room. Since the only frequency under test in this study was 50 Hz, the ambient noise levels at the octave bands centered at 31.5 and 63 Hz were evaluated under the ambient noise conditions of the experiment. A General Radio type 1551-C sound level meter coupled with a General Radio type 1558-C octave-band analyzer yielded levels of 46 and 44 dB SPL, respectively.

Threshold studies of 50-Hz tones under earphones in normal-hearing observers by Wegel, Riesz, and Blackman (1932), Bekesy in 1936, (Bekesy, 1960, 260), Carter and Kryter (1962), Yeowart, Bryan and Tempest

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[1]Normal hearing sensitivity for low frequencies is defined as being within 25 dB ISO at octave intervals of 125 to 1000 Hz as tested clinically with a calibrated Beltone model 15-C audiometer in an Industrial Acoustics Company (IAC) model 404-A sound treated room.

(1967), and Deatherage and Henderson (1967) show considerable disagreement, the normal-hearing values ranging from 53 to 84 dB SPL.[2] In the sound treated room used in the present study, the sum of the obtained ambient noise levels in the two octave bands surrounding 50 Hz was approximately 48.2 dB SPL. This is less than the minimum norm reported. The amount of attenuation provided by the experimental earphone and cushion at 50 Hz is not known. Even if it is assumed that no attenuation occurs at 50 Hz, it appears unlikely that such ambient noise levels interfered with the conduct of this study.

Experimental Apparatus

A 50-Hz signal was generated by a Hewlett-Packard model 200-ABR audio oscillator and was passed to a Grason-Stadler model 829-C electronic switch which was set for a repetition rate of one per second (sec) with a 10-millisecond (msec) rise-decay time and a 50% duty cycle. The signal was then passed to the external input of a Grason-Stadler model 162 speech audiometer used as an impedance matching device and an attenuator control for the 50-Hz signal. The signal then was fed through the wall to the earphones. The maximum output for the 50-Hz sinusoid at the earphones was 130 dB SPL as measured on an Allison model 300 artificial ear.

Procedure

Each observer was instructed to raise his finger as soon as he was just able to detect the presence of the 50-Hz sinusoid. That tone was presented to the better ear at approximately 100 dB SPL for acquainting purposes. A window in the sound treated room allowed the investigator

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[2]These differences appear to be related to the various methods of calibration that were utilized.

to observe the finger movement. The better ear was test first. Utilizing the potentiometer on the speech audiometer, a 2-dB step ascending method of limits procedure was used to establish threshold for the pulsed 50-Hz tone. Threshold was defined as that level which led to two responses out of four presentations. The same procedure was repeated with the signal presented to the poorer ear.

Hypothesis

Zwislocki (1953) and Olsen, Jabaley, and Pappas (1967) showed that when both ears were covered with standard earphones set in standard cushions, the IA was greatest at the high frequencies (means of 60 to 70 dB at 4000 and/or 8000 Hz) and least at the low frequencies (means of 40 to 50 dB at 125 and/or 250 Hz). It appears that IA decreases as frequency is lowered. It was hypothesized that IA at 50 Hz would be greater than 30 dB.

Preliminary Study Two: Extent of the SSE

Observers

Eight male graduate students in audiology at the Oklahoma University Medical Center in Oklahoma City, Oklahoma, served as observers for this study. Their ages ranged from 25 to 46 years, the median age being 30 years. Each observer had normal hearing sensitivity at the standard frequencies in the test ear.[3] In tests with the apparatus to be described below, each observer had normal hearing sensitivity in the test ear at 50 Hz.[4] All of the observers had negative histories of hearing problems

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[3]Normal hearing sensitivity at the standard frequencies is defined as being within 25 dB ISO at octave intervals of 125 to 8000 Hz as tested clinically with a calibrated Beltone model 15-C audiometer in an IAC model 404-A sound treated room.

[4]Normal hearing sensitivity at 50 Hz is defined as being no greater than 84 dB SPL as revealed by the studies cited earlier.

in the test ear and all were experienced listeners in auditory-threshold investigations.

Room Apparatus

This experiment was conducted in the same sound treated room, with the same earphones, cushions, and ambient noise conditions described in Preliminary Study One. In addition to a 50-Hz signal, however, brief acoustic pips were utilized. Each pip was produced by ringing the earphone once every four seconds with a 0.1-msec square-wave pulse of positive polarity.

There was some question whether or not the ambient noise in the test room would interfere with the detectability of the pips. Within the range of 50 to 8000 Hz, the frequency spectrum of the pips was studied with a General Radio type 1900-A wave analyzer in conjunction with the General Radio type 1521-A graphic-level recorder. This revealed that the pips had a broad frequency spectrum with a peak amplitude in a band between 3200 and 3700 Hz. In addition, the earphone with its pip signal output was coupled to the Allison model 300 artificial ear, the output of which was monitored on a Tektronix model 561-A oscilloscope. The maximum peaks of the waveforms which the pips produced on the face of the oscilloscope were similar to those produced by 3400-Hz sinusoids. It is interesting to note that, based upon the data of Zwicker, Flottorp, and Stevens (1957), the 3200- to 3700-Hz band corresponds closely to the critical band around a 3400-Hz signal. These facts, together with the fact that the 3200- to 3700-Hz band is within the region of greatest hearing sensitivity, suggest that it was the 3200- to 3700-Hz portion of the pip signal that was heard in the detectability task to be described.

The ambient noise at the octave band centered at 4000 Hz and which extends from 2828 to 5656 Hz, was evaluated under the ambient noise conditions of this experiment with the same noise analysis equipment described in Preliminary Study One. The analysis revealed a level of 16 dB SPL in that octave band. The attenuation offered by a standard earphone set in MX-41/AR cushions at that octave band is approximately 33 dB,[5] leaving the noise level at the ear in that octave band at approximately -17 dB SPL. Normal hearing sensitivity for the critical band surrounding a 3400 Hz tone is approximately 7.3 dB SPL.[6] Thus, it appears that the ambient noise level in the octave band surrounding the 3200- to 3700-Hz band did not interfere with the detectability of the acoustic pips in question.

Experimental Apparatus

Figure 1 is a block diagram representing the instrumentation used in Preliminary Study Two. The discussion of the experimental apparatus is divided into four sections: (1) Signal aparatus; (2) Timing apparatus; (3) Control apparatus; (4) Data collection and reinforcement apparatus.

Signal apparatus. A 50-Hz signal was generated by a model 200-ABR, Hewlett-Packard audio oscillator and was passed to a custom-made splitter. One portion of the split signal was used as the on-going 50-Hz sinusoid. That portion of the signal went from the splitter, through a Hewlett-Packard model 350-C attenuator to one half of a double-pole

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[5]This level was abstracted from a graph presented by Zwislocki (1957).

[6]This level was interpolated from data presented by Cox and Bilger (1960) and Davis and Kranz (1964) in view of the critical band information of Zwicker, Flottorp, and Stevens (1957).

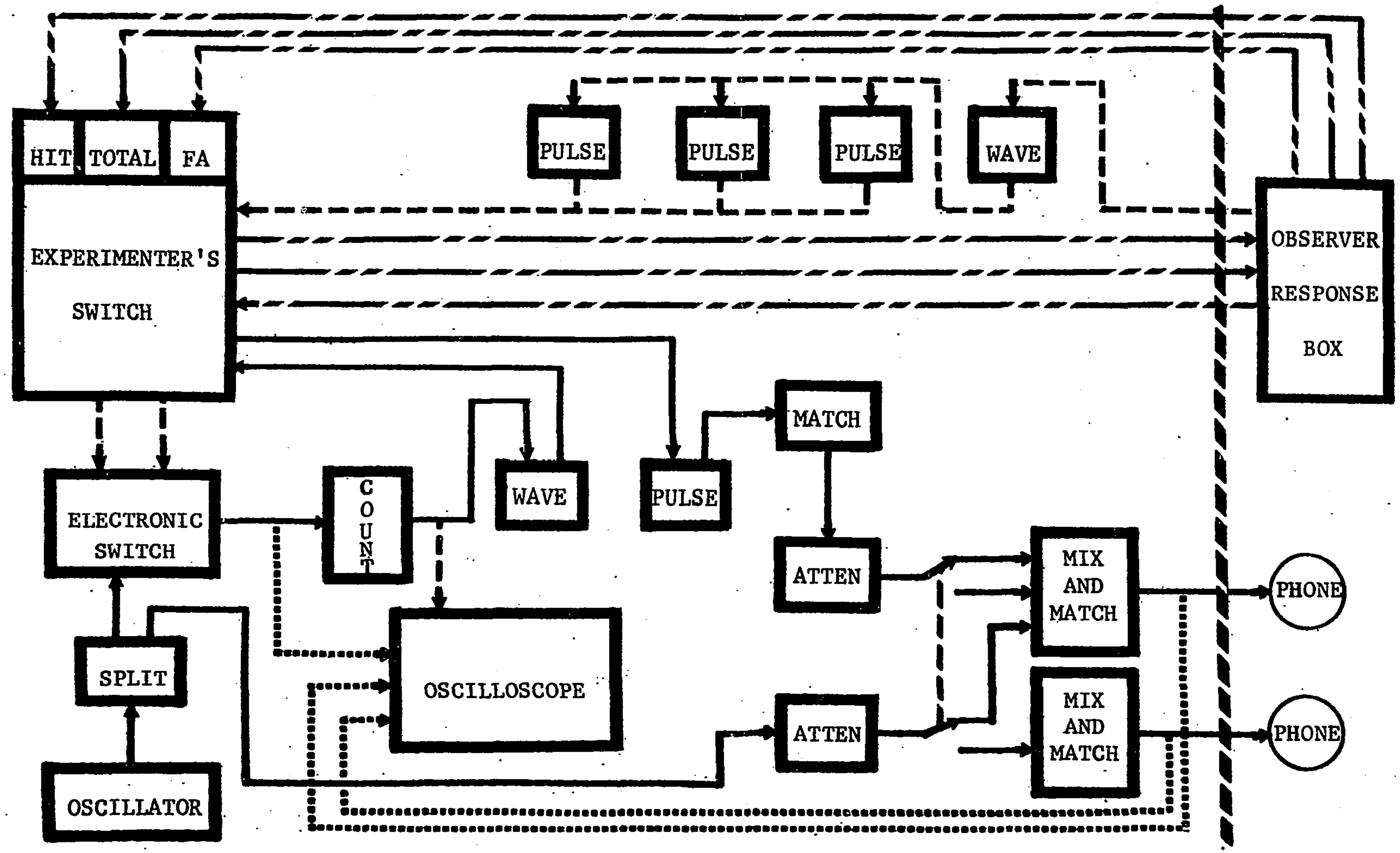

Figure 1. Simplified block diagram of experimental apparatus.

double-throw switch which controlled whether the 50-Hz signal and the pip signal were presented monotically or dichotically. The monotic position of this switch directed the signal to a UTC LS-32 mixing-matching transformer where the pip was added to the on-going sinusoid. This combined signal was then directed to a 10-ohm, TDH-39 earphone on the test ear. In the dichotic position, this switch passed the on-going sinusoid directly through an identically loaded mixing-matching transformer to a matched earphone on the contralateral ear. Only the monotic switch position was used in Preliminary Study Two.

The other portion of the split 50-Hz signal was used to trigger the brief acoustic pip. The 50-Hz signal went from the splitter to a Grason-Stadler model 829-C electronic switch which was turned on and off following a time delay initiated by the observer's response.[7] The output of the electronic switch was delivered to a Transistor Specialties Incorporated (TSI) model 361 universal counter which was set in the "Period A" mode. The trigger level and the trigger slope adjustments were set to trigger the counter at a consistent voltage level of the input stimulus.

A Tektronix model 561-A oscilloscope, in parallel with the counter and triggered by it, allowed the output of the electronic switch to be monitored while the appropriate trigger level of the counter was set. In addition to triggering the oscilloscope, the pulse output of the counter triggered a Tektronix type 162 waveform generator adjusted to produce a 20-msec sawtooth wave. That wave then passed to the experimenter's switch which controlled whether or not a pip was added to the on-going sinusoid. The experimenter turned that switch to the YES position or the NO position

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[7]This is discussed more fully in the Timing apparatus section which follows.

according to one of many quasi-random lists of presentations which precluded that the two switch positions had an equal likelihood of occurrence. In the NO position the wave did not pass. In the YES position the wave passed and triggered a Tektronix type 161 pulse generator. The 0.1 msec positive square wave pulse produced by that pulse generator was adjusted to coincide with either a 90° or a 270° phase angle of the on-going 50-Hz sinusoid.[8] The pulse was delivered through a custom-made impedance matching pad to a Hewlett-Packard model 350-C attenuator. The pulse went from the attenuator to the opposite half of the previously described double-pole, double-throw, monotic-dichotic switch.

Timing apparatus. The first pip presentation was initiated by the experimenter who pushed the one-cycle button on a Tektronix type 162 waveform generator which was adjusted to produce a 4.0-sec sawtooth wave. The output of that generator triggered three Tektronix type 161 pulse generators, each of which closed an electromechanical relay for 0.1 sec. The first relay closed 3.0 sec after the initiation of the sequence and during the closed period, it lit a WARNING lamp. The second relay closed 3.5 sec after the initiation of the sequence. During its closed period it lit a LISTEN lamp and, in addition, it turned the electronic switch on and then off. After 4.0 sec the third relay closed and during its closed period it lit the RESPOND lamp. The WARNING, LISTEN and RESPOND lamps were located in the observer's response box. The observer responded by pushing his response switch to YES if he thought he heard the pip or to NO if he did not. Either response by the observer triggered the waveform generator associated with the signal apparatus and the above timing

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[8]This phase adjustment is discussed more fully in the Control apparatus section which follows.

sequence was re-cycled automatically.

Control apparatus. Before each run the frequency of the on-going sinusoid was adjusted to 50 Hz by setting the oscillator while observing the period of the sinusoid through the use of the counter. The period of that sinusoid was monitored with the counter during and following each run. It varied by less than ±1.2 msec of 20 msec throughout the study. Before and after each session, the intensity of the 50-Hz on-going sinusoid was determined at the 0 dB attenuator setting with the artificial ear and was found to vary by no more than ±1.4 dB during any session.

Prior to each session, the intensity of the pip produced by ringing the earphone with the 0.1-msec positive square-wave pulse was adjusted to equal that produced in the same earphone by an on-going 1000-Hz tone at 106 dB SPL. Following each session, the intensity of the pip was studied and was found to differ by no more than ±7.5% of its initial voltage. That much of a voltage change corresponds to less than a ±0.7-dB variation in the intensity of the pip. The pip intensity studies were conducted by placing the earphone with its pip output on the artificial ear and observing the output of the artificial ear on the oscilloscope.

In order to set the phase relationship of the acoustic pip with respect to the on-going 50-Hz sinusoid at the beginning of each session, both signals were mixed and led to the earphone which was placed on the artificial ear. The output of the artificial ear was displayed on the oscilloscope. The time delay on the pulse generator which produced the signal was adjusted so the pip produced in the earphone would appear at the desired phase angle of the on-going 50-Hz sinusoid. The two signals were observed in the same manner at the end of each session to ensure that the phase relationship had not shifted appreciably. During each run, the phase relationship of the two signals was monitored on the oscilloscope from the output of the mixing-matching transformer. Throughout all of the runs, a given phase relationship did not vary by more than approximately $\pm 9^{o}$.

Data collection and reinforcement apparatus. The experimenter was seated in front of a panel containing three electromechanical counters and a YES-NO switch that controlled whether or not a pip was presented. During each response interval the observer reported whether or not he believed that a pip was present by throwing a YES-NO switch on his response box. If the pip was presented and was identified correctly, a circuit from the observer's switch through the signal and timing apparatus to the counted labeled HIT was completed and the response was recorded. If the pip was absent and was falsely identified, a similar circuit to the FALSE ALARM counter was completed and that response was recorded. Every time the observer responded, whether correctly or incorrectly, a circuit was completed and his response was recorded on the counter labeled TOTAL.

Whenever the observer's judgment was correct a circuit was completed from the switch in the response box, through the signal and timing apparatus, and back to a green light in the response box. A similar circuit was completed from the switch in the response box back to a red light in the response box whenever the observer's judgment was incorrect. In either event, the light remained on for as long as his switch was thrown.

Procedure

Psychophysical threshold for the pip was taken in the test ear and psychophysical thresholds for the 50-Hz tone were taken in each ear separately at the beginning of the session and after a break period midway through the session. A 1.0-dB step ascending method of limits, with two responses out of four presentations defining threshold, was used to find the psychophysical thresholds for both signals. The signal apparatus, as described above, was utilized for the threshold determinations of each signal. One pip per sec was presented during the ascending pip-threshold determinations. The tone was on continuously during the ascending 50-Hz threshold determinations. These psychophysical studies of threshold were necessary in order to determine the starting levels of both signals for the yes-no signal detection task described below.

The eight observers were trained for the yes-no signal-detection procedure in the pips-alone (no 50-Hz tone) condition. In these training sessions, as well as in the actual experimental session, each observer was seated comfortably in the sound treated room and the following instructions were given:

> You are going to listen for a series of very faint acoustic pips. When the WARNING light comes on, get ready. Than, as the LISTEN light comes on, listen for a pip. When the RESPOND light comes on, push the switch to YES if you think that you heard it or to NO if you do not think that you heard it. The sequence will continue over and over again. The pip will be there only half of the time and in random fashion. Do not guess wildly. If you are completely unsure whether or not it was there, push the switch to NO. Do as well as you can.

The earphones were then placed on the observer in such a way that a tight seal was ensured. The response box was handed to the observer, the door to the sound treated room was closed and the one cycle button on the waveform generator was pressed to begin the sequence.

Each observer was presented a series of practice runs of 100 trials each. Initially, the pips were presented at one or two dB above psychophysical threshold but, as the observer became more sophisticated, the level was reduced from one to five dB until he obtained a score of between 75 and 85% correct. It was assumed that such a score would allow for comparisons of higher or lower scores across treatment conditions because such a score is between chance and perfection. The period of training continued until the following response criteria were met: (1) the total score for one run was within $\pm$5% of the score on the preceding run; (2) no more than ten false alarms occurred in any run.

Each observer participated in Preliminary Study Two on a day subsequent to training. One or two practice runs, two reference runs, two control runs and four experimental runs were conducted. Each run contained 120 trials, the first twenty for practice and the remaining for actual data collection. Of the 100 data collection trials, 50 contained the pip signal and 50 did not contain the pip signal according to one of several quasi-random presentation schedules.

The results of the runs were recorded in accordance with the constructs of signal-detection design. When each run was completed, the number of hits and the number of false alarms were copied from the electromechanical counters. Later, the number of misses and the number of correct rejections were computed. The correct-response percentage for each run was determined by adding the hit and correct rejection numbers.

There was a three to five minute break period between runs with at least a twenty minute break period midway through the procedure. It was during the latter break period that the earphones were removed for the first time in the session. Thresholds for the pips and the 50-Hz tone were re-established following the break period and the earphones remained in place until the session terminated.

The practice, reference, and control runs involved the presentation of the acoustic pips with no on-going 50-Hz tone. In the four experimental runs, the acoustic pips were always presented at a 90° phase angle with respect to the 50-Hz tone, but the level of the on-going tone was varied. Experimental Condition One presented the 50-Hz tone at -10 dB SL. Experimental Conditions Two, Three, and Four presented that tone at -20, -30, and -40 dB SL, respectively. The four experimental conditions were presented in four balanced orders. Two observers received each order, one listening with the right ear and one with the left ear. The presentation orders are illustrated in Appendix A.

Hypotheses

Deatherage and Henderson (1967) found a SSE for pips presented at a 90° phase angle re an on-going, -5-dB SL, 50-Hz tone. It was not known whether this effect would be observed with the 50-Hz tone presented at lower levels. A general pilot study was undertaken with two observers while the experimental apparatus for this study was being perfected. The results of that pilot study indicated that the SSE occurred when the 50-Hz tone was presented at -10 dB SL but not when it was presented at -20 dB SL. It was hypothesized that the SSE would not occur when the 50-Hz tone was presented at -20 dB SL or lower. In addition, it was hypothesized that there would be no difference in performance between the right ear and the left ear groups of observers.

Major Study

Introduction

As mentioned earlier in this chapter, the Major Study investigated sensitization and desensitization of the auditory system to acoustic pips presented at 90° or 270° re a subliminal or supraliminal on-going, low-level, 50-Hz tone when the pip and the tone were presented monotically or dichotically. On the basis of the results of Preliminary Studies One and Two, which are discussed in Chapter IV, the level of the supraliminal 50-Hz tone was set at 5 dB SL and the level of the subliminal 50-Hz tone was set at -10 dB SL.

Observers

The same eight male graduate students who served as observers in Preliminary Study Two were the observers for this study. Each observer used the same test ear that he used in Preliminary Study Two. As noted earlier, each observer had normal hearing sensitivity in the test ear at 50 Hz and at octave intervals of 125 to 8000 Hz. It was necessary to test the observers' hearing in the ear opposite the test ear since they would receive the on-going 50-Hz tone in each ear on different occasions. The criteria for normal hearing and the equipment used to evaluate the observers' hearing for the test ear in Preliminary Study Two were used to evaluate their hearing for the contralateral ear in this study.

Six of the eight observers had no history of hearing difficulty in the ear opposite the test ear and their hearing was normal at 50 Hz and at octave intervals of 125 to 8000 Hz. Two of the observers had histories of hearing difficulty in that ear. Both of these observers heard normally at 50 Hz and at octave intervals of 125 to 2000 Hz but both had hearing losses of 25 to 55 dB ISO at 4000 and 8000 Hz. However, the losses were not deemed extensive enough to exclude the two observers from the study.

Room Apparatus

This study was conducted in the same sound treated room with the same earphones, cushions, observer response box, and noise conditions described in Preliminary Study Two.

Experimental Apparatus

The signal, timing, data collection, and reinforcement apparatus utilized in Preliminary Study Two were used in this study. The only difference was that the monotic-dichotic switch on the experimenter's rack was placed in the monotic position during all of the practice, control, and reference runs and during half of the experimental runs. That switch was placed in the dichotic position during the other half of the experimental runs.

The control apparatus was used as it was in Preliminary Study Two. However, additional control procedures were required for the Major Study. The Allison model 300 artificial ear was coupled to one earphone and another Allison model 300 artificial ear was coupled to the other earphone. Both artificial ear output signals were led to the Tektronix oscilloscope, one tracing being superimposed on the other. Each earphone then was placed on the opposite artificial ear and the same procedure was repeated. The frequency, amplitude, and phase of the on-going 50-Hz signal were identical in both earphones as far as could be determined visually.

The two artificial ears were utilized again to ensure that the phase relationship between the pip and the 50-Hz tone was the same for the dichotic and monotic presentations. In the dichotic mode, the pip signal from the earphone on one artificial ear and the 50-Hz signal from the earphone on the other artificial ear were led to the oscilloscope and superimposed. Each earphone then was placed on the opposite artificial ear and the same procedure was repeated. The phase relationships between the two signals appeared the same in both situations. In the monotic mode, the phase relationship of the pip signal and the 50-Hz signal from one artificial ear looked exactly the same on the oscilloscope as it had in the dichotic mode.[9]

The frequency of the 50-Hz sinusoid, the intensity of the acoustic pip, and the phase relationship of the pip with respect to the 50-Hz tone varied within the ranges observed in Preliminary Study Two.

Procedure

The experimental procedure of the Major Study was modeled after that used in Preliminary Study Two. The instructions given to the observers were the same. The experimental procedure followed a balanced yes-no signal detection design but this time each observer took part in four experimental sessions. Each session took place on a separate day and each contained one or two practice reference runs, two reference runs, two control runs, and the four experimental runs. At the beginning of each session and during a break period midway through each session, psychophysical thresholds were taken in the same way. The break periods occurred at the same points and for the same periods of time as they did in Preliminary Study Two. The practice reference runs were used for

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[9] It should be pointed out that the Allison model 300 artificial ear has an odd number of amplification stages in its circuit. As a result, the output of the artificial ear was 180° out of phase with the input to the artificial ear. Therefore, when the phase relationship of one signal to another was evaluated, a 90° phase relationship looked like a 270° phase relationship and vice versa.

level-setting purposes in the same way and for the same reasons. The four sessions of the Major Study followed the training sessions and the one experimental session associated with Preliminary Study Two.

Each run contained 120 trials, the first 20 for practice and the remainder for actual data collection. The schedule of the YES-NO presentations was treated as it was in Preliminary Study Two. The pips were presented without the on-going 50-Hz tone during the reference and control runs. In Experimental Condition One, the pips were presented at 90° re the on-going tone and the two signals were presented monotically, whereas in Experimental Condition Two, the two signals were presented dichotically. In Experimental Condition Three, the pips were presented at 270° re the on-going tone and the two signals were presented monotically, whereas in Experimental Condition Four, the two signals were presented dichotically.

The eight observers were divided equally into two groups. During the experimental conditions, Group A received the 50-Hz tone at 10 dB below psychophysical threshold (Subliminal Group) and Group B received it at 5 dB above psychophysical threshold (Supraliminal Group). Of the four observers in each group, two listened for the pips with the right ear and two listened for the pips with the left ear. The balanced order of treatments by observers is presented in Appendix A. The correct-response percentage for each run was determined in the same manner as described in Preliminary Study Two.

Hypotheses

When compared to the "pips alone" conditions, it was hypothesized that monotic presentations of the two signals in question would lead to increased pip detectability during the 90° phase-angle treatment and decreased pip detectability during the 270° phase-angle treatment. Furthermore, it was hypothesized that there would be no differences in the amounts of sensitization or desensitization for the two levels of the 50-Hz tone during the monotic presentations. In addition, it was hypothesized that there would be no difference in performance between the right ear and left ear groups of observers.

It was hypothesized that dichotic presentations of the two signals in question would bring about no sensitization or desensitization at either phase-angle treatment. It also was hypothesized that during the dichotic presentations no difference in performance would be observed between the subliminal and supraliminal groups of observers or between the right and left ear groups of observers.

Summary

The purpose of this study was to investigate whether the phase relationship between two low-level signals contributes to sensitization and desensitization of the auditory system to one of those signals during dichotic stimulation. A study of the effects of an on-going, low-level, 50-Hz tone upon the detectability of brief acoustic pips presented at 90° and 270° re the 50-Hz tone was planned in this chapter. Specifically, investigations of the amounts of sensitization and desensitization associated with the monotic and dichotic modes of presentation and with two levels of 50-Hz tone presentations were designed.

It was not known at what levels the 50-Hz tone could be used in the dichotic conditions without it crossing to the opposite ear and interfering with the detection of the pips. For that reason, two Preliminary

Studies were necessary before the Major Study could proceed. The purpose of Preliminary Study One was to investigate IA at 50 Hz. The purpose of Preliminary Study Two was to determine the Subliminal Sensitization Effect (SSE) for the pips in the presence of various levels of the on-going, subliminal, 50-Hz sinusoid when the pips and the sinusoid were presented monotically.

This chapter described the observers, the apparatus, the procedures, and the hypotheses for the two Preliminary Studies and for the one Major Study in this experimental investigation. The results of these studies are presented and discussed in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSIONS

Introduction

The purpose, the design, and the hypotheses of the studies within this experimental investigation were discussed in Chapter III. The results and discussions of the Preliminary Studies and the Major Study are presented in this chapter. A section on additional findings also is included.

Most of the data obtained in the investigation appear in Appendix B, although some data are listed in this chapter. Summaries of the descriptive and inferential statistics used in the evaluations of the data appear in Appendixes B and C.

Preliminary Study One: IA at 50 Hz

The IA values at 50 Hz were evaluated with the TDH-39 earphones and the MX-41/AR cushions which were to be used in the Major Study. Five unilateral hearing loss patients with no measurable hearing in one ear and essentially normal hearing sensitivity for the low frequencies in the other ear served as observers. The results of the study are shown in Table 1.

Only two of the five observers were aware of the 50-Hz tone-pulse presentations to the poor ear at the maximum output of the equipment (approximately 130 dB SPL). One observer had an IA of 36 dB and the other had an IA of 46 dB. None of the other three observers heard the tone pulses when they were as high as 38 to 48 dB above the threshold of the good ear.

TABLE 1

INTERAURAL ATTENUATION DATA AT 50 Hz FOR FIVE UNILATERAL HEARING LOSS PATIENTS

Observer Number	Good Ear	Good Ear Threshold (dB SPL)	dB SPL in Poor Ear when Tone Heard in Good Ear	Difference (dB)
1	Left	92.0	No Response through 130[a]	38.0[b]
2	Left	89.0	No Response through 129[a]	40.0[b]
3	Right	86.0	122.0	36.0
4	Right	78.5	124.5	46.0
5	Left	90.0	No response through 130[a]	40.0[b]

[a]Maximum output of the equipment on the day of the test.
[b]No true IA demonstrated at that level or below.

Previously, it was hypothesized that the IA at 50 Hz would be greater than 30 dB. That hypothesis is supported by the results of Preliminary Study One. In fact, the results indicate that when TDH-39 earphones and MX-41/AR cushions are used, the acoustic isolation between ears at 50 Hz is 35 dB or greater. However, further study utilizing equipment with a higher output capability and a greater number of observers is indicated before a more representative figure can be expressed with any degree of confidence.

Preliminary Study Two: Extent of the SSE

Introduction

Eight normal-hearing male graduate students in audiology served as observers in this experimental investigation. As discussed in Chapter III, the observers were required to perform a yes-no signal-detection task for which a period of training was required. Considerable practice time was necessary for all of the observers before they met the response criteria listed in Chapter III. Of the eight observers, one required 3710 trials and one required 1040 trials. Each of the remaining observers required a number of trials between these two values. The median number of training trials was 1245.

The actual experiment consisted of two reference conditions, two control conditions, and four experimental treatment conditions. During the reference and control conditions, the acoustic pips were presented without the on-going 50-Hz sinusoid. During Experimental Treatment Conditions One, Two, Three, and Four, the on-going 50-Hz sinusoid was presented at -10, -20, -30, and -40 dB SL, respectively. During the experimental conditions, the acoustic pips were presented at the 90° phase angle of the on-going 50-Hz tone while the pips and the tone were presented monotically. The experimental runs were presented in four different orders and two observers received each order. For each group of two observers receiving the same order, one received the signals in the right ear and the other received the signals in the left ear. The presentation order for this experiment appears in Appendix A.

The per cent correct score data from this study appear in Table 8 in Appendix B. The ranges of scores as well as the mean and median scores made by the two groups of observers and by all eight observers are shown across conditions. The mean and median scores show very good agreement throughout, the greatest difference being 1.50%. Thus, only the means are used for data representation. The data are presented and discussed in terms of the variables studied.

Results

Effect of treatment order. As discussed previously, the conditions of this study were presented in a balanced order. It was assumed that this procedure would reduce the influence of any order effect on the mean data. The results obtained for the eight periods over the eight observers, irrespective of the conditions during any of the periods, are presented in Table 2. As can be seen from that table, the range of the mean scores for the eight periods was from 82.50% to 87.38%, a difference of only 4.88%.

The order effect was evaluated with an analysis of variance procedure. This analysis, a summary of which appears in Table 11 in Appendix C, revealed that order was not a significant variable at the 0.05 level. It appears that the order of treatments was not an important variable in this study.

Comparison of reference and control values. Inasmuch as the observers were trained until the response criteria were met, it was assumed that an observer's performance in the reference and control conditions would remain essentially the same. The difference between the largest and smallest values, as shown in Table 8, is less than 1.40% when the mean reference and control values are compared across all eight observers.

The reference values were tested against the control values with the Sign Test. That analysis, a summary of which appears in Table 10 in

Appendix C, revealed no significant difference in the direction of scores at the 0.05 level. Therefore, the assumption of essentially equivalent observer performance in the reference and control conditions was supported. Because of that finding, subsequent sections of Preliminary Study Two utilize the mean of the mean reference and control values (hereafter referred to as the "mean reference-control value") when comparing the reference and control scores with the treatment scores.

TABLE 2

PER CENT CORRECT SCORES OBTAINED AT EACH PERIOD ACROSS OBSERVERS IN PRELIMINARY STUDY TWO, IRRESPECTIVE OF THE CONDITIONS DURING THE PERIODS

Observers	Periods							
	1	2	3	4	5	6	7	8
1	86	93	96	84	84	84	89	87
2	82	88	85	84	80	85	82	82
3	85	94	83	84	83	88	85	83
4	81	81	85	83	87	84	92	86
5	87	89	94	87	88	92	99	87
6	84	90	92	84	85	84	84	87
7	79	79	80	78	77	89	85	79
8	81	81	80	76	76	84	83	80
Mean	83.13	86.87	86.87	82.50	82.50	86.25	87.38	83.38

Effect of ear. Preliminary Study Two was balanced in such a way that four observers listened for the pips in the right ear and four listened for the pips in the left ear. The data obtained during each condition for each observer are presented in Table 8. In addition, that table presents the means, medians, and ranges of scores for the right ear group, the left ear group, and the entire group of observers. The mean reference and control values for the groups were computed from Table 8. This revealed mean reference-control values of 83.63% for the right ear group, 82.38% for the left ear group, and 83.00% for the entire group of eight observers. The mean value for each group under each experimental treatment condition was taken from Table 8 and compared to the mean reference-control value for each respective group. The results of this procedure are illustrated in Figure 2.

Inspection of Figure 2 suggests that the observers who listened with the right ear gave higher relative detectability scores across conditions than those who listened with the left ear. However, for both groups the direction of the detectability score changes was the same. Both groups had their maximum detectability scores when the on-going 50-Hz tone was presented at -10 dB SL. The detectability scores decreased for both groups as the SL of the on-going tone decreased.

The differences between ears across treatment conditions were tested with an analysis of variance procedure and were found to be significant at the 0.05 level. A summary of this analysis can be seen in Table 11 in Appendix C. It was previously hypothesized that no difference in performance between the right and left ear groups of observers would occur. In view of the experimental results, that hypothesis was not supported. However, since the direction of difference appears the

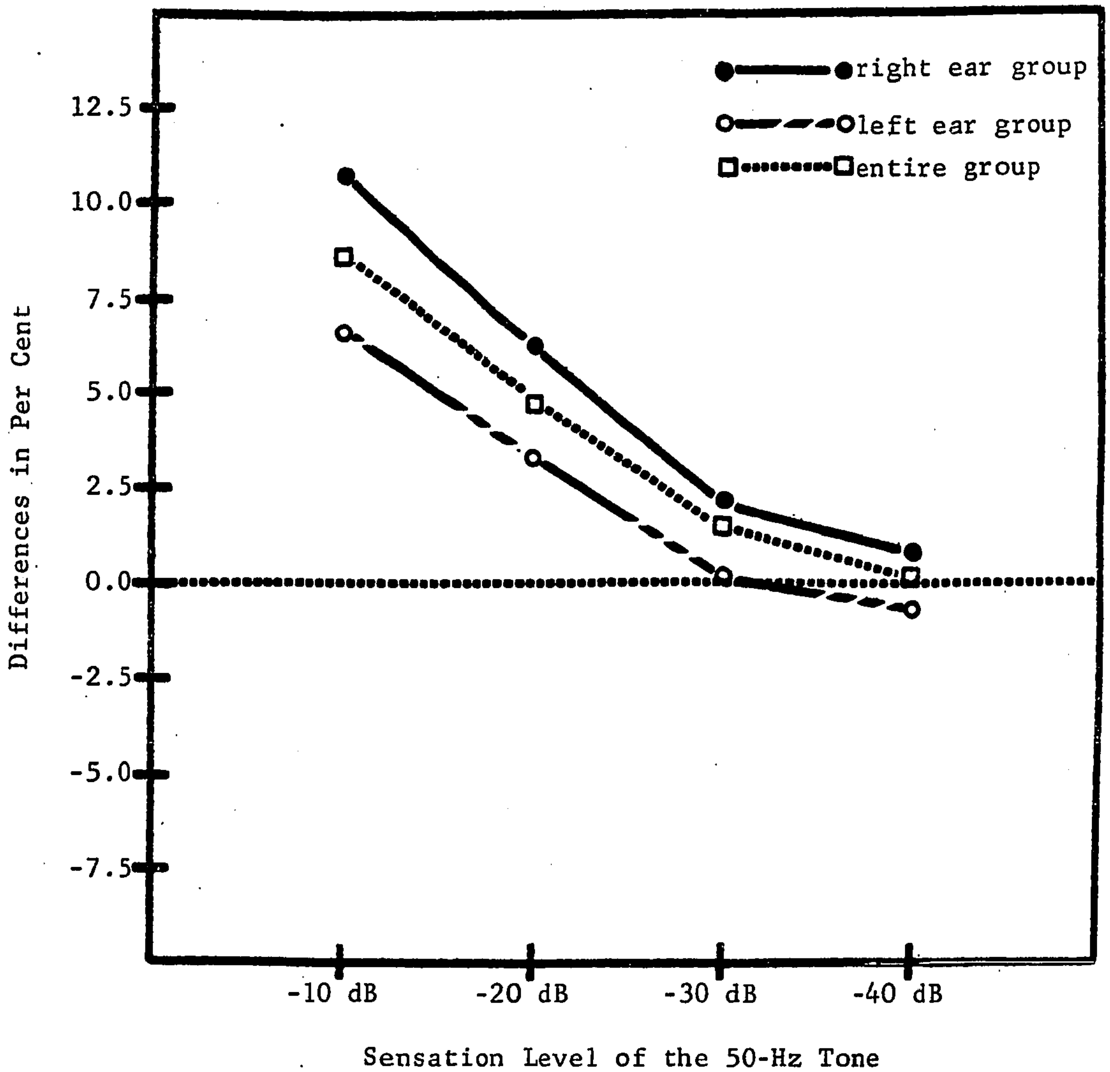

Figure 2. Mean monotic sensitization (positive) scores for the observer groups studied, as a function of the sensation levels of the 50-Hz tone. The scores are expressed in terms of the differences in per cent re the mean reference-control value for each group of observers.

same for both groups in each condition, the results from the entire group of eight observers were combined and analyzed together in the evaluation of the effect of subliminal level.

Effect of subliminal level. The center curve in Figure 2 illustrates the relative differences among the mean performance values for all observers in each experimental treatment condition re the mean reference-control value for all observers. That curve suggests that the greater the intensity of the subliminal tone, the greater the improvement in the detectability of the pips.

Figure 2 suggests that neither the -40- nor the -30-dB SL conditions led to sensitization or desensitization but that the -20- and -10-dB SL conditions led to sensitization. These suggestions are supported by the results of the Sign Test, a summary of which may be seen in Table 10. The results indicate that the performances during the -40- and -30-dB SL conditions were not very different from each other and that the -10-dB SL condition led to greater sensitization than the -20-dB SL condition. The latter two indications are supported by the results of an analysis of variance procedure, the results of which appear in Table 11. From Figure 2 it can be seen that the amount of sensitization observed during the -20-dB SL condition was greater than that observed during the -30-dB SL condition, the difference value (3.20%) being almost as great as the difference value (3.92%) noted between the -10- and -20-dB SL conditions. The significance of the difference in sensitization between the -20- and the -30-dB SL conditions was not evaluated statistically.

From the results of this study, it appears that the -10-dB SL sinusoid brought about a relatively large SSE, the -20-dB SL tone brought about a moderate SSE, and the -30- and -40-dB SL tones brought about little or no SSE. This suggests that the SSE broke down when the 50-Hz sinusoid was between -20 and -30 dB SL. It was hypothesized previously that the SSE would not occur when the 50-Hz tone was presented at -20 dB SL or lower. The results suggest that the extent of the SSE was greater than anticipated.

Discussion

The analyses of treatment order and reference and control comparisons indicated that order was not a significant variable and that the reference and control values were not significantly different. Thus, it appears that no further learning by the observers for the detection task took place during the course of the study. Furthermore, it appears that any differences observed resulted from the effects of the treatments.

The ear differences observed in Preliminary Study Two were not expected. Originally, the eight observers were divided into two groups of four observers according to the presentation ear only to balance the experiment. Although studies in cerebral dominance employing acoustic signal-detection tasks have not been reported, other experiments in the area of cerebral dominance and hearing have been completed. The reports of Kimura (1961) and Milner (1962) suggested that observers' performance for verbal material was better if that material was presented to the ear opposite the dominant hemisphere for speech and language (the right ear in the vast majority of cases). Their reports and the results obtained by Chaney and Webster (1966) suggested that the presentation of nonverbal material would have just the opposite effect.

Research findings by Inglis (1965) and Oxbury, Oxbury, and Gardiner (1967) did not support the Kimura-Milner hypothesis. The authors of both studies found that at the beginning of their experiments, observers usually were better able to identify those stimuli previously presented to the right ear than those previously presented to the left ear, regardless of whether the stimuli were verbal or nonverbal. They found that when the experiments were balanced and when numerous verbal and/or nonverbal items were presented over a period of several sessions the ear effect was eliminated.

In the present study, the right ear group of observers showed more sensitization than the left ear group during a nonverbal detectability task following a relatively long practice session in which the response criteria for the study were met. Statistical analyses of the data indicated that no practice effect occurred during this investigation. Thus, the results of the study do not support either group of investigators mentioned. The consistency of this present finding in subsequent runs is discussed later in this chapter.

During the actual experimental treatment presentations of this investigation, the pip signals were presented at a 90° phase angle of an on-going 50-Hz tone of various subliminal levels. When compared to the mean reference-control value, detectability for the pips was significantly better during the -10- and -20-dB SL experimental treatment conditions. Such results demonstrate the presence of a SSE and support the results obtained by Deatherage and Henderson (1967) who demonstrated a SSE for similar pips presented at 90° re an on-going, -5-dB SL, 50-Hz tone.

When the results of the present study are examined in terms of the level of the on-going 50-Hz tone, it is interesting to speculate on the reason or reasons why the SSE broke down when it did. In view of the literature reviewed in Chapter II, it appears that the movement of the basilar membrane may be responsible for this kind of sensitization. Perhaps a 50-Hz on-going sinusoid between -20 and -30 dB SL no longer moves the basilar membrane sufficiently and, as a result, that membrane does not affect the perception of another incoming signal. Alternatively, at a level between -20 and -30 dB SL, the noise floor of the test chamber may have been reached and the 50-Hz tone may have had no more effect upon the basilar membrane than the noise in a frequency band around 50 Hz. In regard to the latter speculation, it is important to note that the mean threshold of the 50-Hz sinusoid was approximately 73 dB SPL for the group of observers used in this experiment.[1] The noise level of the octave bands around 50 Hz in the test room was about 48 dB SPL, nearly 25 dB below the mean threshold for the observers. Perhaps when the level of the 50-Hz tone diminishes to the spectrum level of the tones in those octave bands it no longer has the same effect upon the basilar membrane. Then, perhaps it contributes only to an overall random movement of the basilar membrane caused by the noise in those bands. This hypothesis may be investigated by replicating the study in quieter surroundings.

Whatever the cause of the SSE, the findings have several implications. For monotic presentations, an on-going, low-frequency, subliminal signal as low as -20 to -30 dB SL can influence the detectability of other brief acoustic signals. Care should be taken not to phase-lock brief acoustic signals to an on-going, low-frequency signal because false impressions of detectability or threshold are likely to occur. The results of Deatherage and Henderson (1967) suggest that considerable difficulty still could arise if the brief acoustic pips are not phase-locked to an

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[1]See the Additional Findings section of this chapter.

on-going sinusoid. In such a situation, the pips would occur at various phase angles of the sinusoid. Considerable variability in detectability for individual signals could result because of the different effects of the various phase angles upon the detectability of the pips if sufficient specified background noise levels are not used.

In view of the fact that on-going low-frequency signals are encountered frequently in auditory research projects,[2] thorough analyses of the sounds present in the earphones and in the research chamber are essential for all signal detection and threshold experiments involving very brief acoustic signals. Perhaps the maximum allowable noise levels in sound treated rooms used for such studies should be re-evaluated since subliminal tones can affect detectability or threshold.

For dichotic presentations to sophisticated normal-hearing observers, there is a chance that a low-frequency signal in one ear could affect detectability for brief acoustic pips in the opposite ear. The results of Preliminary Study One suggested that an IA of 35 dB did not seem unreasonable with TDH-39 earphones set in MX-41/AR cushions. The results of the present study indicate that a 50-Hz tone of -20 to -30 dB SL can affect detectability for brief acoustic pips in the same ear. Together, these studies suggest that a 50-Hz tone greater than 5 dB SL in one ear could affect the detectability for brief acoustic pips in the opposite ear because it could be greater than -30 dB SL in that pip ear (assuming an IA of 35 dB). Therefore, a 50-Hz tone which is greater than 5 dB SL should be avoided in dichotic studies with normal-hearing observers if the investigator does not wish to run the risk of contaminating

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[2]The problematical "60 cycle" is the most notorious example.

the detectability scores for the brief acoustic pips presented to the opposite ear.[3]

There is need for further research in this area. Various on-going sinusoids should be studied to determine the range of frequencies over which the SSE can be observed. Studies of various low noise levels in the octave bands around 50 Hz are needed to establish whether or not the level of the noise determines the level at which the SSE breaks down.

Major Study

Introduction

The eight normal-hearing male graduate students who served as observers in Preliminary Study Two were the observers for this study. Like the preceding study, this experimental investigation utilized the yes-no signal detection technique. Four of the eight observers arbitrarily were placed into the Subliminal Group and four arbitrarily were placed into the Supraliminal Group. During the four experimental treatment conditions, the observers in the former group received the on-going 50-Hz tone at -10 dB SL while those in the latter group received the on-going tone at 5 dB SL. Two observers in each group received the pips in the right ear and two observers in each group received them in the left ear. Each observer received the pips in the same ear as he did in Preliminary Study Two.

The experiment consisted of two reference runs, two control runs, and four experimental treatment runs in each session. There were four sessions, each on a separate day. The reference and control runs were

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[3]This reasoning led to the limitation of the level of the supraliminal 50-Hz tone to 5 dB SL for the dichotic treatments in the major study, the results and discussions of which follow.

identical to those in Preliminary Study Two in that the pips were presented without the on-going 50-Hz tone. During Experimental Treatment Condition One the pips were presented at 90^{o} re the on-going tone and the two signals were presented monotically, whereas in Experimental Treatment Condition Two the two signals were presented dichotically. In Experimental Treatment Condition Three the pips were presented at 270^{o} re the on-going tone and the two signals were presented monotically, whereas in Experimental Treatment Condition Four the two signals were presented dichotically.

The presentation order of the four experimental treatment conditions was balanced. The observers received the experimental treatment conditions in one of four different orders in each of the four sessions. Furthermore, the four observers in each group received different orders of experimental treatment conditions in any given session. The presentation order for this experiment is shown in Table 7 in Appendix A.

For six of the eight observers, each session lasted from 90 to 120 minutes of one day, exclusive of the break period midway through each session which lasted from 20 to 180 minutes. Two of the eight observers took part in only one half-session per day because of various time conflicts. The length of time between the half-sessions for these two observers ranged from one to seven days, the median length of time being 2½ days. For all observers, there was at least an 18-hour period between whole sessions.

The per cent correct score data from this study are presented in Table 9 in Appendix B. The mean and median scores, as well as the range of the scores, are presented for each condition across sessions for each group of four observers and for the entire group of eight observers. The means and medians for each condition show very good agreement, the largest difference being less than 1.50%. Table 9 also presents the mean and median scores, as well as the range of the scores, for all eight observers for each condition, session by session. The means and medians for each condition show good agreement, the largest difference being 4.25%, except for the supraliminal group of observers during the 90° Dichotic Treatment Condition of Session I. For that particular treatment, the mean value was 8.75% higher than the median value. Despite the one instance of disagreement between the two values, they are considered in good agreement for the study as a whole. In the following section of the chapter, only the mean values are used when the results for the two groups of observers are presented or when the results for the whole group of eight observers are presented.

Results

<u>Effect of treatment order</u>. As previously mentioned, the order of treatments in the major study was balanced in an attempt to reduce the influence of any order effect on the mean data. The results obtained for the 32 periods over the eight observers, irrespective of the condition during any of the periods, are presented in Table 3. That table shows that mean scores for the 32 periods ranged from 73.63% to 86.25%, except for period 7 where the mean score was 69.88%. The median of the 32 mean scores was 81.13%

The order effect was evaluated with an analysis of variance procedure, the results of which may be seen in Table 13 in Appendix C. This analysis revealed that order was not a significant variable at the 0.05 level. It appears that the order of treatments was not an important

TABLE 3

PER CENT CORRECT SCORES OBTAINED AT EACH PERIOD ACROSS OBSERVERS IN THE MAJOR STUDY, IRRESPECTIVE OF THE CONDITIONS DURING THE PERIODS

Period	Observer								Range	Means
	1	2	3	4	5	6	7	8		
Session I										
1	89	80	89	88	90	85	85	81	80 - 90	85.88
2	93	60	84	90	93	73	87	78	60 - 93	82.25
3	83	85	78	92	50	86	86	88	50 - 92	31.00
4	86	84	91	89	86	88	82	84	82 - 91	86.25
5	85	79	91	82	92	83	84	75	75 - 92	83.88
6	80	53	98	71	93	52	93	54	52 - 98	74.25
7	73	84	87	54	54	80	77	50	50 - 87	69.88
8	88	78	89	79	94	84	87	78	78 - 94	83.38
Session II										
1	80	80	87	80	89	80	74	84	74 - 89	81.75
2	76	50	97	89	49	78	72	90	49 - 97	75.13
3	78	51	96	67	84	70	87	68	51 - 96	75.13
4	78	81	84	85	90	84	75	80	75 - 90	82.13
5	79	80	87	83	85	80	78	83	78 - 87	81.88
6	70	83	79	90	53	88	67	79	53 - 90	76.13
7	88	86	81	58	98	88	68	54	54 - 98	77.63
8	76	82	81	78	88	83	82	80	76 - 88	81.25
Session III										
1	91	78	83	85	88	80	81	82	78 - 91	83.50
2	81	77	86	59	62	82	97	64	59 - 97	76.00
3	83	84	75	90	66	87	84	86	66 - 90	81.88
4	90	78	83	82	84	82	82	79	78 - 90	82.50
5	92	82	85	83	86	82	74	78	74 - 92	82.75
6	97	60	85	52	92	67	80	56	52 - 97	73.63
7	89	64	80	87	89	61	69	78	61 - 89	77.13
8	90	83	83	79	84	80	81	71	71 - 90	81.38
Session IV										
1	82	85	84	86	89	88	80	78	78 - 89	84.00
2	81	90	84	70	99	94	53	71	53 - 99	80.25
3	90	60	98	68	97	75	68	62	60 - 98	77.25
4	84	84	82	89	89	86	75	81	75 - 89	83.75
5	86	80	75	80	82	78	81	78	75 - 86	80.00
6	72	84	78	76	65	82	74	82	65 - 84	76.63
7	73	70	99	88	60	68	89	70	60 - 99	77.13
8	81	82	79	83	87	77	82	75	75 - 87	80.75

variable in this study.

Comparison of reference and control values. It was assumed that the observers' performance in all conditions without the 50-Hz tone would be essentially the same. The mean reference values and the mean control values for the eight observers noted in Table 9 appear quite similar when they are compared across sessions. The mean reference and control scores ranged from 80.00% to 86.25%. The median score of the 16 mean reference-control scores was 82.63%.

The mean reference values were tested against the mean control values with the Sign Test and there was no significant difference in the direction of scores at the 0.05 level. Thus, the assumption of essentially equivalent performance in all conditions without the 50-Hz tone was supported. A summary of the statistical analysis appears in Table 12 in Appendix C. Because of this finding, all subsequent comparisons of the experimental treatment values were made against the mean of the mean reference and control condition values (hereafter referred to as the "mean reference-control value").

Effect of session. This study required each observer to complete four repetitions of the experiment in four different orders during four different sessions which occurred on separate days. As discussed previously, the observers were well trained by the time they took part in this experiment. Nevertheless, there was some question whether or not there would be a practice effect which would result in improved scores as the days progressed.

Figure 3 illustrates the differences, in per cent, among sessions for the mean scores made by the eight observers during each of the experimental treatment conditions. The difference values for each session under

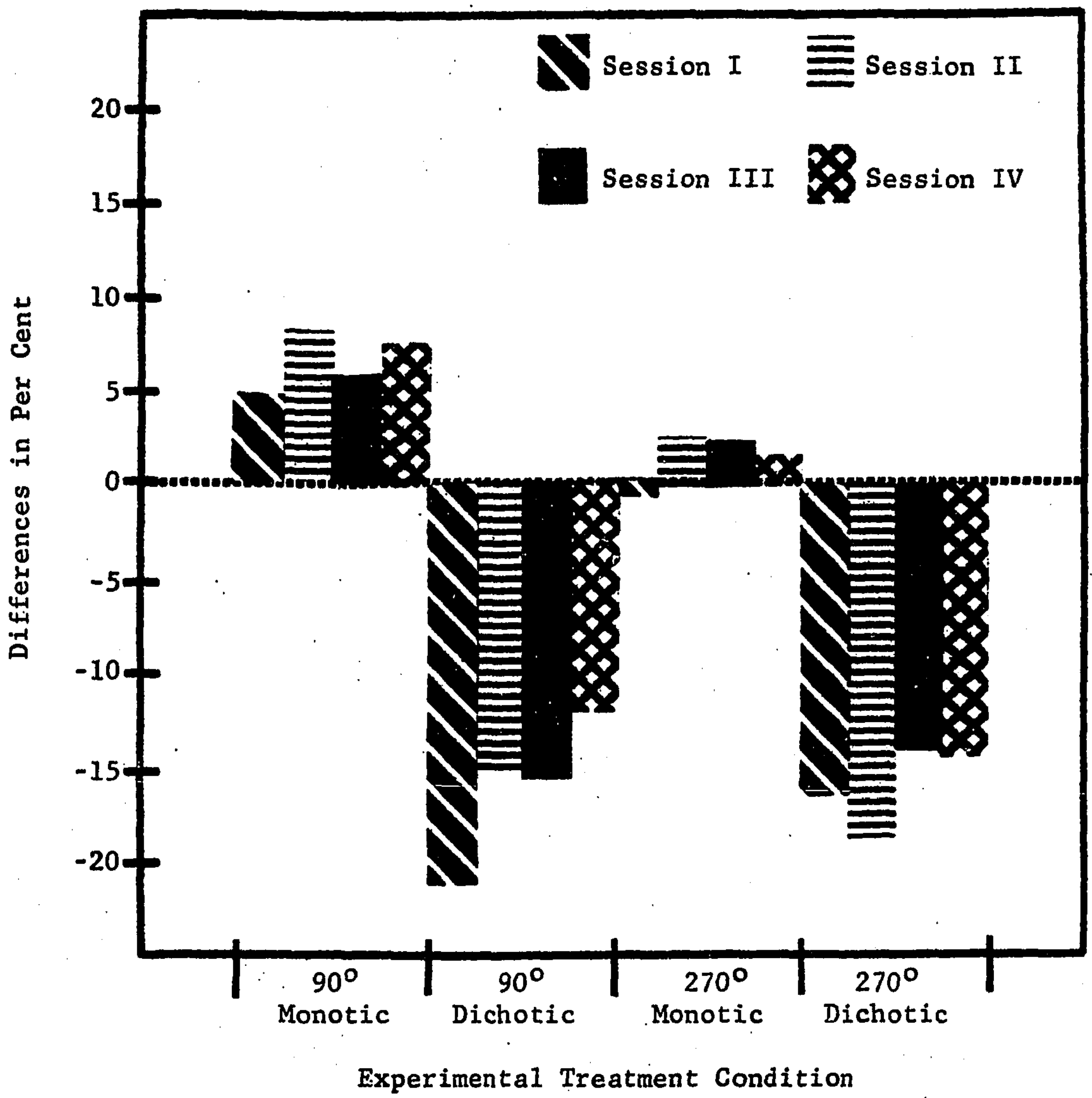

Figure 3. Mean sensitization (positive) and desensitization (negative) scores for all observers during each session for each experimental treatment condition. The scores are expressed in terms of the differences in per cent re the mean reference-control value for each session.

each treatment condition are relative to the mean reference-control values for each session. Inspection of Figure 3 suggests that within the 90° Monotic, the 270° Monotic, and the 270° Dichotic treatment conditions, there was very little difference across sessions. The greatest relative difference across sessions within these treatment conditions was approximately 4.75% and that occurred during the 270° Dichotic treatment condition. Figure 3 also indicates that a greater degree of relative change in performance occurred across sessions during the 90° Dichotic treatment condition where performance appeared to improve by approximately 9.00% between the first and last sessions.

The effect of sessions was evaluated with an analysis of variance procedure, the results of which may be seen in Table 13. The analysis revealed no significant session effect at the 0.05 level. Thus, it does not appear that there was a significant practice effect in this experiment.

Effect of level. In this experiment, the eight observers were divided into two groups on the basis of the level of the on-going 50-Hz sinusoid during the experimental treatment conditions. Table 9 in Appendix B lists the mean detectability scores for each group of observers at each condition during each session. In addition, it lists the mean of those mean scores for each group of observers across the four sessions. Figure 4 illustrates the differences, in per cent, between the mean scores of the two groups of observers across sessions under each of the experimental conditions. The difference values for each group at each treatment condition are relative to the mean reference-control values for each group of four observers across the four sessions.

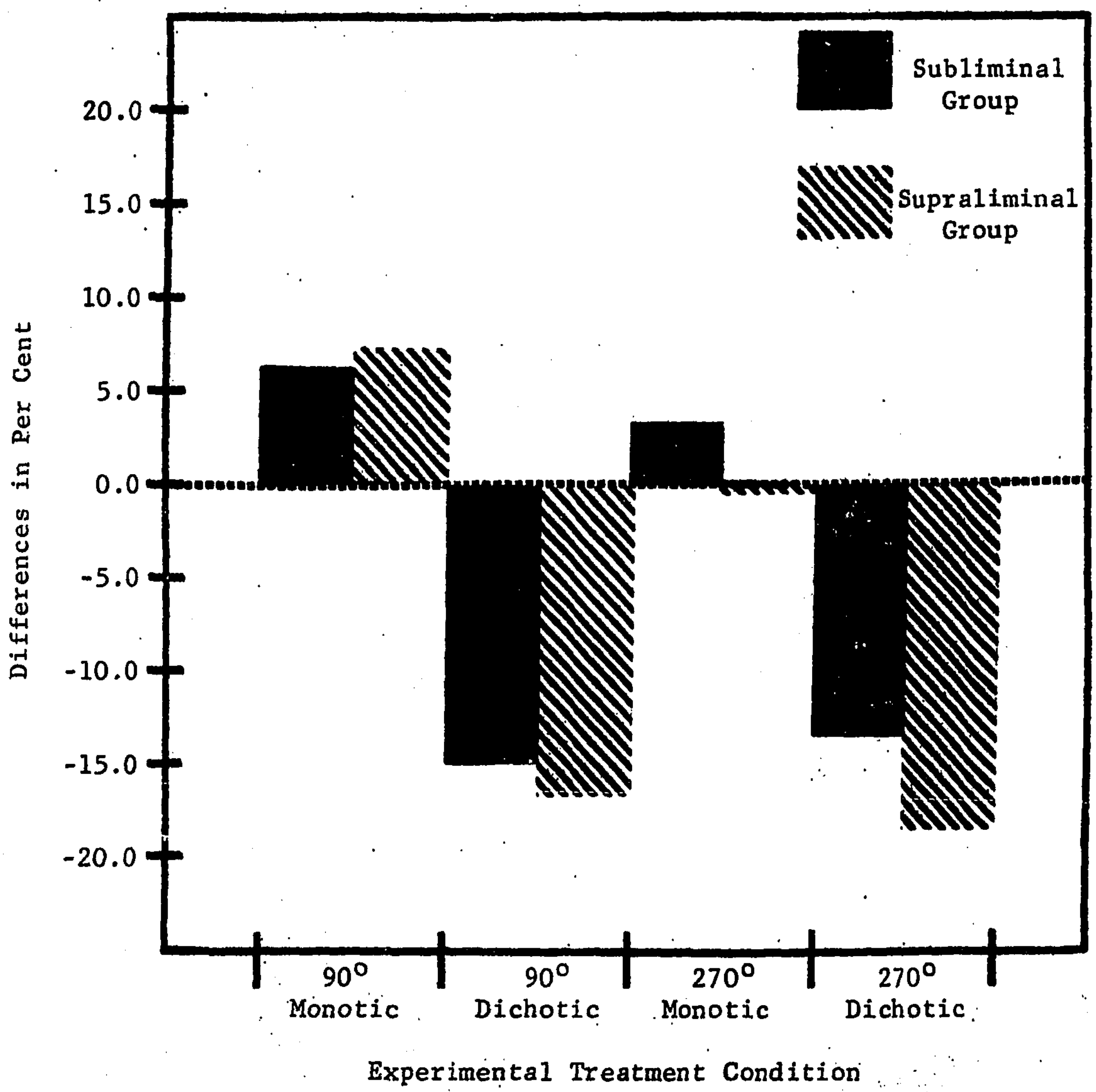

Figure 4. Mean sensitization (positive) and desensitization (negative) scores for the subliminal and supraliminal groups of observers during each treatment condition across sessions. The scores are expressed in terms of the differences in per cent re the mean reference-control value for each 50-Hz level group.

Figure 4 suggests that the subliminal and supraliminal groups of observers behaved similarly during each condition. There was less than a 3.50% relative difference between the mean scores of the two groups under all conditions except the 270° Dichotic treatment condition. There, the relative difference was approximately 5.25%. The differences in the scores between the two groups were tested with an analysis of variance procedure. The results revealed no significant difference at the 0.05 level, thus supporting the observation that both groups behaved similarly. A summary of the analysis of variance appears in Table 13.

Previously, it was hypothesized that the performances of the subliminal and supraliminal groups of observers would not be different across experimental treatments. That hypothesis was supported by the results obtained. Because of this finding, the remaining variables were evaluated over the entire group of eight observers rather than over the subliminal and supraliminal groups separately.

Effect of ear. In Preliminary Study Two, observers who listened with the right ear had significantly better detectability scores than observers who listened with the left ear. This effect was studied further in the present investigation. Four observers received the pips in the right ear and four received them in the left. Table 4 presents the mean scores for these two groups of observers in each experimental treatment condition across the four sessions and the mean reference-control values for each group of four observers across the four sessions. Figure 5 illustrates the differences, in per cent, between the mean scores made by the right-ear and left-ear groups during each experimental treatment condition. The difference values for each group at each treatment condition are relative to the mean reference-control values across sessions.

TABLE 4

MEAN PER CENT CORRECT SCORES IN THE MAJOR STUDY FOR RIGHT-EAR AND LEFT-EAR GROUPS ACROSS SESSIONS

Condition	Right-Ear Group	Left-Ear Group
Reference-Control	84.31	81.47
90° Monotic	93.31	85.75
90° Dichotic	72.69	61.31
270° Monotic	84.81	83.81
270° Dichotic	70.88	63.06

Table 4 and Figure 5 indicate that the relative differences between the right-ear and left-ear groups was less than 4.75% for the 90° and 270° Monotic treatment conditions, the right-ear group performing better in the former condition and the left-ear group performing better in the latter condition. However, Table 4 and Figure 5 also indicate that the right-ear group yielded relatively better detectability scores than the left-ear group in the 90° and 270° Dichotic treatment conditions, the relative differences being 8.54% and 6.29%, respectively. It should be remembered that these differences were the mean differences that occurred over the four sessions and not over one session as was the case in Preliminary Study Two. There was some question whether or not the differences observed would be significant.

The scores obtained from the right-ear group were evaluated

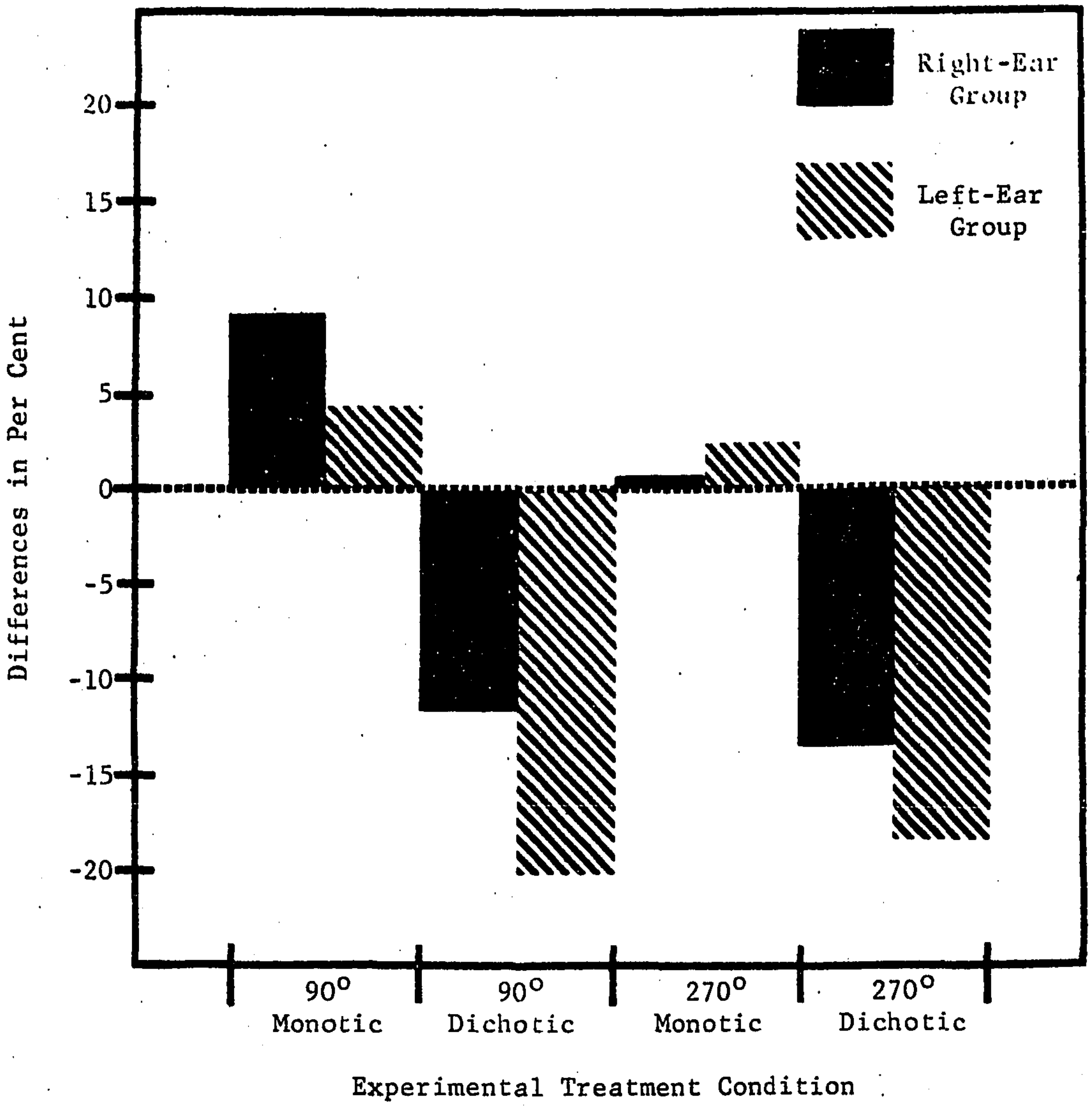

Figure 5. Mean sensitization (positive) and desensitization (negative) scores for the right-ear and left-ear groups of observers during each treatment condition across sessions. The scores are expressed in terms of the differences in per cent re the mean reference-control value for each ear group.

against the scores obtained from the left-ear group with an analysis of variance procedure. This revealed no difference at the 0.05 level of significance. The results of that analysis may be seen in Table 13. It was hypothesized in Chapter III that no difference would be observed between the performances of the right-ear and left-ear groups. Although the mean scores made by the right-ear group were somewhat better than the mean scores made by the left-ear group in the dichotic treatment conditions, the differences were not great enough to be significant in this experiment. Therefore, the hypothesis was supported. In view of the outcome of this study, the remaining variables were evaluated for all eight observers together rather than for the right-ear and left-ear groups separately.

Effect of level by ear interaction. There was a possibility of interactions between the two levels of the 50-Hz tone presentations and the two ears used to detect the pips, but it appeared unlikely in view of the level and ear effects described above. A level-by-ears interaction test was completed with an analysis of variance procedure, the results of which may be seen in Table 13. The results of that analysis were not significant at the 0.05 level. This suggests that there was no significant interaction between the level of the 50-Hz tone and the ear used to detect the pips.

Effect of phase. During the experimental treatment conditions of this investigation, the eight observers received acoustic pips presented at a 90° phase angle and a 270° phase angle re the on-going 50-Hz tone. The extent of the differences in the scores of the entire group of observers under each phase angle treatment was evaluated, irrespective of the other variables in the experiment.

A mean value of 82.89% for all reference and control conditions was calculated from the data in Table 9. Means of 78.27% and 75.64% also were obtained from that data for all 90° and 270° treatments, respectively. The relative differences among these means are portrayed graphically in Figure 6 which shows that the relative difference between the mean reference-control value and the mean 90° phase-condition value was less than 5.00%. In addition, the figure suggests that the relative difference between the mean 90° phase-condition value and the mean 270° phase-condition value was less than 3.00%. However, Figure 6 illustrates that the relative difference between the mean reference-control value and the mean 270° phase-condition value was approximately 7.25%. There was some question whether or not these differences would be significant.

The results of this phase comparison were studied by an analysis of variance procedure, the results of which may be seen in Table 13. This analysis revealed that the mean scores for the 90° and 270° treatments were not different at the 0.05 level of significance. From this finding it would appear that phase itself was not a significant variable in this investigation.

Effect of mode of presentation. The eight observers received the acoustic pips and the on-going 50-Hz tone monotically and dichotically during the experimental treatment conditions of this investigation. The extent of the differences in the scores of the entire group of observers under each mode of presentation was evaluated, irrespective of the other variables in the experiment. From the data in Table 9, means of 86.92% and 66.99% were obtained for all monotic and dichotic treatment conditions, respectively. A mean of 82.89% for all reference and contol conditions was reported earlier. Figure 7 illustrates the relative differ-

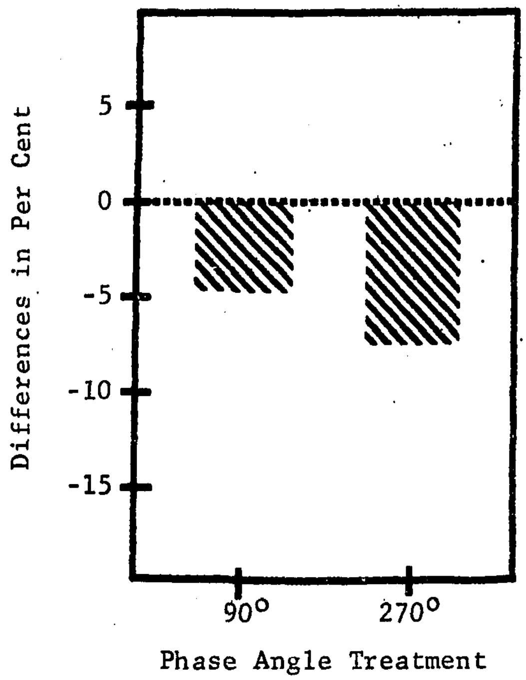

Figure 6. Mean desensitization (negative) scores for all observers at each phase-angle treatment, irrespective of presentation modes, levels, or ears. The scores are expressed in terms of the differences in per cent re the overall mean reference-control value for all observers.

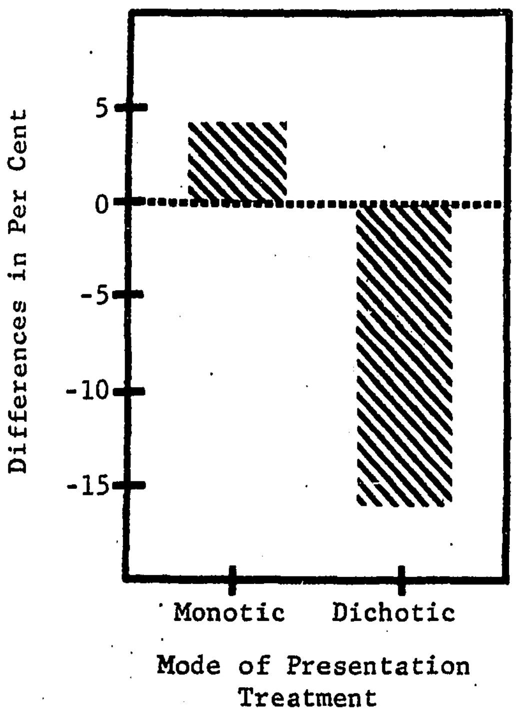

Figure 7. Mean sensitization (positive) and desensitization (negative) scores for all observers at each mode of presentation treatment, irrespective of phase, levels, or ears. The scores are expressed in terms of the differences in per cent re the overall mean reference-control value for all observers.

ences among those means.

Figure 7 shows that the relative differences between the mean reference-control value and the mean monotic condition value was approximately 4.00%. In addition, the figure suggests that the relative difference between the mean monotic condition value and the mean dichotic condition value was approximately 20.00%. Furthermore, Figure 7 illustrates that the relative difference between the mean reference-control value and the mean dichotic condition value was approximately 16.00%. The extent of these differences suggests that the mode of presentation was an important variable in this investigation.

The mean monotic score and the mean dichotic score were compared with the mean reference-control value through the use of an analysis of variance procedure, a summary of which may be seen in Table 13. This analysis revealed a significant difference among the modes of presentation at the 0.05 level. This result confirms the impression gained from examination of Figure 7.

Effect of mode by phase interaction. In view of the findings already reported throughout this study, the possibility of interactions among the two modes of presentation and the two phase angles used in this experiment appear likely. Table 9 list the mean scores of all observers for each experimental treatment condition. These values and the mean reference-control value for all observers (82.89%) were utilized in the construction of Figure 8.

Figure 8 shows that, relative to the mean reference-control value, the scores were higher during the 90^{o} Monotic treatment condition and considerably lower during the 90^{o} and 270^{o} Dichotic treatment conditions. From the graph it appears that the score for the 270^{o} Monotic

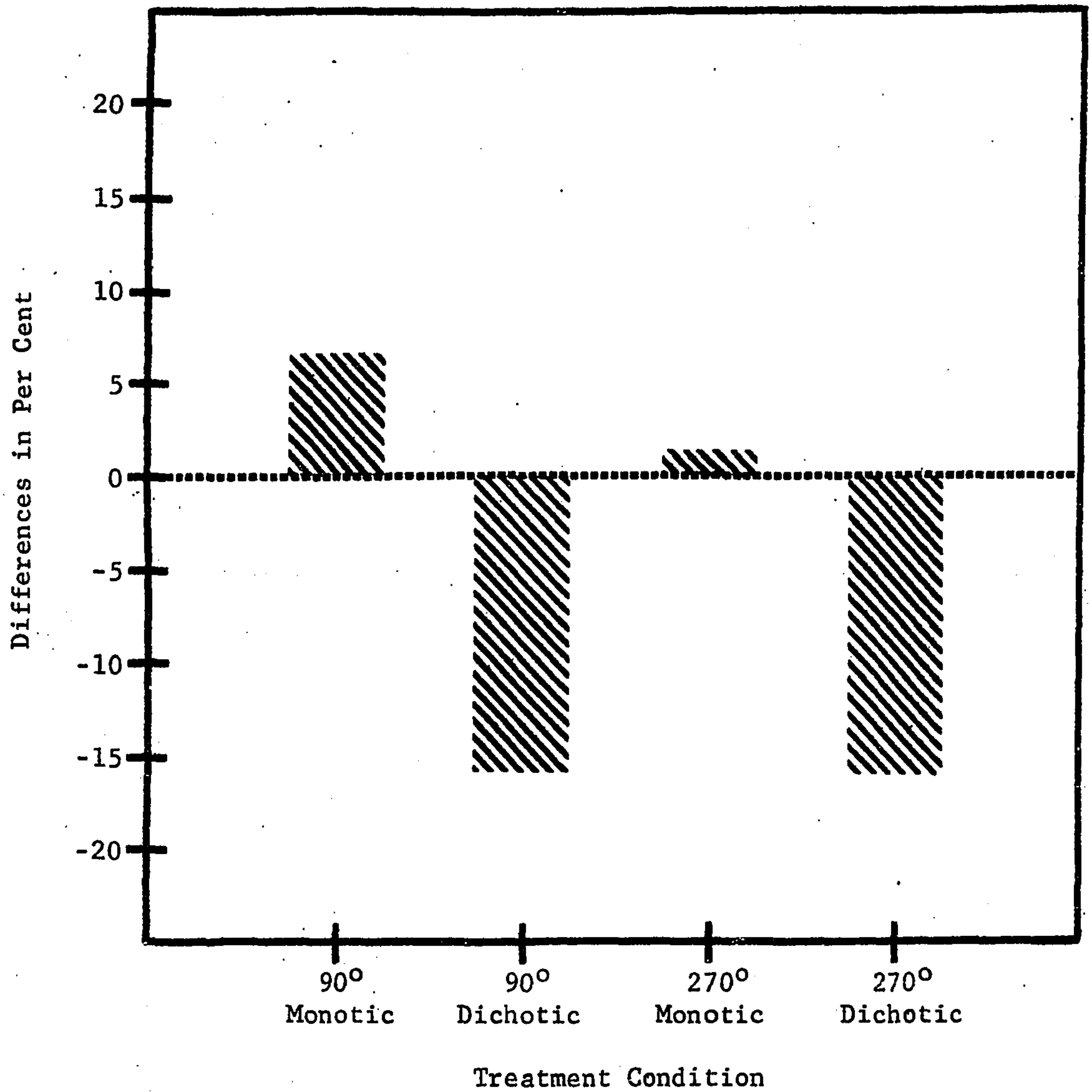

Figure 8. Mean sensitization (positive) and desensitization (negative) scores for all observers at each treatment condition, irrespective of levels or ears. The scores are expressed in terms of the differences in per cent re the overall mean reference-control value for all observers.

treatment condition was essentially the same as the mean reference-control value. The relative enhancement in performance scores for the 90° Monotic treatment condition amounted to approximately 6.50%. The relative decrease in performance under the two Dichotic conditions amounted to approximately 16.00%. The relative change for the 270° Monotic treatment condition was less than 2.00%.

The mode by phase interaction results were studied by an analysis of variance procedure, the results of which may be seen in Table 13. That analysis revealed a significant interaction at the 0.05 level. Thus, it appears that the relationships among the mode of presentation and the phase-angle variables were of extreme importance in this investigation.

It was hypothesized in Chapter III that monotic presentations of the two signals in question would lead to sensitization during the 90° phase-angle treatment and desensitization during the 270° phase-angle treatment. The former hypothesis was supported by the results of this investigation but the latter hypothesis was not. In addition, it was hypothesized that dichotic presentations of the two signals would bring about no sensitization or desensitization at either phase angle. In view of the considerable amount of desensitization observed in both phase-angle treatments during dichotic stimulation, that hypothesis was not supported by the results of this study.

Discussion

The analyses of treatment-condition presentation order and reference and control comparisons indicated that there was no order effect and that the reference and control values were not significantly different. Thus, it appears that no further learning of the task by the observers took place during the course of the Major Study. In addition, it appears that any differences observed resulted from the effects of treatments.

In the present investigation, no significant differences in results were noted between the -10- and 5-dB SL groups in the 90° Monotic treatment conditions. This finding agrees with that of Deatherage and Henderson (1967) who found essentially the same sensitization effects during 10-dB SL and -5-dB SL 90° phase-angle treatment conditions. Regardless of the mechanism for sensitization, it appears that during 90° Monotic treatment conditions the -10-dB SL 50-Hz tone has the same effect upon detectability for brief acoustic pips as the 5-dB SL 50-Hz tone.

Little or no SSE was observed in Preliminary Study Two when the 50-Hz tone was presented at -40 and -30 dB SL during the 90° Monotic treatment condition. On the other hand, some degree of SSE was noted when the tone was presented at -20 dB SL while a greater degree of SSE was noted in the presence of a -10-dB SL 50-Hz tone.[4] On the basis of the results obtained in the Major Study, it appears that by the time the 50-Hz tone reaches 5 dB SL, it has no more influence upon detectability for the pips than it does at -10 dB SL. This suggests a need for further studies with the 50-Hz tone presented at -10 to 5 dB SL in order to determine whether the function actually is asymptotic between those levels.

Unlike the monotic presentations, the dichotic presentations in the Major Study led to no sensitization and a remarkable degree of desensitization, irrespective of the two phase-angle treatments. These findings do not support the results of Hughes (1938) who found sensitization

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[4]The SSE noted for the 90° Monotic -10-dB SL treatments in Preliminary Study Two and in the Major Study showed very close agreement, the differences being less than 2.5% over the entire group of observers.

effects in similar situations. However, this finding adds to the information obtained by Zwislocki et al. (1967) which was discussed in Chapter II.

The subliminal group performed slightly better than the supraliminal group but the differences were not enough to be statistically significant. The two Preliminary Studies indicated that under the conditions of the investigation, a 50-Hz sinusoid of 5 dB SL or less would not produce a mechanical effect in the contralateral ear of normal-hearing observers. It appears that any effect the 50-Hz tone had upon the detectability of pips in the contralateral ear was neural rather than mechanical in nature. Desensitization of this nature often is called central masking (Zwislocki et al., 1967). Since essentially the same amounts of desensitization were observed when the 50-Hz tone was set at -10 and 5 dB SL during dichotic presentations, further research on the effects of contralateral presentations of various low-level 50-Hz sinusoids is indicated.

In the Major Study the right-ear group of observers yielded higher relative per cent correct scores than the left-ear group of observers in three out of four experimental-treatment conditions. The difference between ear groups was not significant as it was in Preliminary Study Two. Nevertheless, a trend in the same direction is observable. Further studies should be conducted in an attempt to resolve this question. It would behoove the investigator to require all observers to listen for the pips in each ear during one-half of the presentations in future research of this kind. Then, if differences in detectability between the two ears occur, the differences would be more meaningful than they were when only half of the observers listened with one ear and half listened with the other. Balanced signal-detection studies of ear differences across a single group of observers are suggested because signal detection techniques allow the investigator to observe very subtle differences in performance.

Results of the Major Study indicate that the variables of mode of presentation and mode by phase interaction were the most important of those investigated. For monotic presentations, detectability for the pips presented at 90° re the on-going 50-Hz tone was significantly better than detectability for the pips in the no-tone conditions. This finding supports the results obtained by Deatherage and Henderson (1967). However, the 270° treatment resulted in neither an enhancement nor a decrease in the detectability of the pips. This finding does not support the results obtained by Deatherage and Henderson (1967) but the reason for the disagreement is unknown at this time. Detectability studies with other phase relationships of the two signals in question should be completed.

Detectability scores for the pips were essentially the same at both phase relationships during the dichotic treatment conditions of the Major Study. These scores were significantly poorer than the scores in the reference and control conditions. In other words, about the same amount of desensitization occurred at the two phase angles when averaged across observers. In this study every attempt was made to keep the on-going 50-Hz tone from crossing over to the test ear during dichotic stimulation. On the basis of the literature reviewed in Chapter II and the findings obtained in Preliminary Studies One and Two, it is believed that the observed desensitization resulted from neural interaction. Within the limitations of this study, the phase relationship of the pips to the on-going 50-Hz tone does not appear to have an important effect upon neural interaction during dichotic stimulation. However more studies of this kind should be completed with other phase relationships before a definite conclusion can be reached relative to the role of phase on the detectability of pips during such dichotic stimulation.

Additional Findings

During Preliminary Study Two and the Major Study, each of the eight observers had his right-ear and left-ear thresholds evaluated a total of ten times at 50 Hz with an ascending method of limits procedure. The mean threshold for each observer and the mean of means for the right and left ears of all observers are presented in Table 5.

TABLE 5

MEAN THRESHOLDS IN dB SPL AT 50 Hz FOR RIGHT AND LEFT EARS OF ALL OBSERVERS

	Observers								Mean of Means
	1	2	3	4	5	6	7	8	
RE Means	73.39	69.13	70.12	66.62	76.06	69.89	75.91	73.39	71.80
LE Means	77.98	74.51	78.57	65.91	81.32	68.57	76.63	71.46	74.40

In 1936, Bekesy reported normal threshold at 50 Hz to be slightly less than 1 dyne. He used a thermophone and a manometer ". . . so that sound pressures could be measured directly at the eardrum for a 50-cps tone at threshold." (Bekesy, 1960, 257-267). With the TDH-39 earphone set in MX-41/AR cushions, the present results for the right ear are 2.0 dB more sensitive than Bekesy reported. For the left ear, the present results are 0.6 dB less sensitive than he reported. It appears reasonable to conclude, however, that the present results support Bekesy's findings.

Summary

The results of Preliminary Studies One and Two and the Major Study which made up this experimental investigation were presented and discussed in this chapter. The results of Preliminary Study One suggest that the IA value at 50 Hz is 35 dB or greater. Further study utilizing equipment with greater output capability and a larger number of observers is indicated before a more representative figure can be expressed.

In Preliminary Study Two, the 90° Monotic treatment led to a Subliminal Sensitization Effect (SSE) in the detectability of pips in the right- and left-ear groups of observers. However, analyses of ear differences revealed that the right-ear group demonstrated a significantly greater SSE than the left-ear group. When the effect of the level of the on-going 50-Hz tone was evaluated, it was learned that the SSE broke down when the tone was between -20 and -30 dB SL. Implications relative to these findings were discussed.

The fact that the 90° Monotic treatment led to a SSE in the detectability of pips was confirmed in the Major Study. However, the 270° Monotic treatment led to neither sensitization nor desensitization. The effect of the 90° Monotic treatment upon detectability was essentially the same whether the 50-Hz tone was presented at -10 dB SL or 5 dB SL. Similarly, the effect of the 270° Monotic treatment was essentially the same at those two sensation levels. The 90° and 270° Dichotic treatments led to significant and essentially equal amounts of desensitization of the auditory system to the pips. The effects of the 90^{o} and 270^{o} Dichotic treatments were essentially the same whether the 50-Hz tone was presented at -10 dB SL or 5 dB SL. No significant difference in performance was noted between the observers who listened with the right ear and those who listened with the left. Implications relative to the findings were discussed.

CHAPTER V

SUMMARY AND CONCLUSIONS

There have been few well-controlled investigations of sensitization and/or desensitization of the auditory system to one signal in the presence of a different, on-going, low-level signal. Recently, however, Deatherage and Henderson (1967) found that the amount of sensitization or desensitization to acoustic pips is influenced by the phase relationship of those pips to an on-going, low-level, 50-Hz sinusoid presented to the same ear. Most of the behavioral investigators who have studied the two phenomena with monotic presentations of the two low-level signals believe that the mechanics of basilar membrane movement are responsible for the effects noted (Wegel and Lane, 1924; Ehmer, 1959; Deatherage and Henderson, 1967). This point of view draws support from the physiologic findings of Bekesy (1960, 403-634) and Peake and Kiang (1962). However, the mechanical alterations of the basilar membrane that occur during low-level stimulation are only partially understood at this time. Further anatomic and physiologic studies of cochlear specimens, cochlear models, and cochlear responses during low-level stimulation are needed for a better understanding of this mechanism.

Hughes (1938) noted slight amounts of sensitization and Zwislocki et al., (1967) noted slight amounts of desensitization to threshold-level pure tones during stimulation by various on-going low-level sinusoids in the opposite ear. Neither study investigated whether the phase relationship between the tone pulses and the sinusoids affected the amounts of sensitization or desensitization observed during such dichotic presentations. Nearly all of the behavioral investigators who have studied the two phenomena with dichotic presentations of the two low-level signals believe that neural interactions of the impulses from the two ears are responsible for the effects noted (Hughes, 1938; Zwislocki, 1953; Ingham, 1957; Zwislocki et al., 1967). This point of view draws support from neuroanatomic and neurophysiologic findings mentioned by Galambos (1954), Deatherage (1966), Rasmussen (1967), Goldstein (1967), Fex (1967) and Gacek (1967). However, further neuroanatomic and neurophysiologic studies of the effects of one low-level signal upon the detectability for other signals are indicated.

The purpose of this experimental study was to investigate whether the phase relationship between two low-level signals contributes to sensitization and desensitization of the auditory system to one of those signals during dichotic stimulation. The effects of an on-going, low-level, 50-Hz sinusoid upon the detectability of brief acoustic pips presented at 90° and 270° re the 50-Hz tone were studied. Because sensitization and desensitization were observed by Deatherage and Henderson (1967) when such signals were presented monotically, an investigation of the amount of sensitization and/or desensitization associated with monotic and dichotic modes of presentation was included in the design of this study.

It was not known at what levels the 50-Hz sinusoid could be used in the dichotic conditions without it crossing to the opposite ear with an intensity sufficient to interfere peripherally with the pip signal. For that reason, two Preliminary Studies were necessary before the Major Study could proceed. The purpose of Preliminary Study One was to investigate interaural attenuation (IA) at 50 Hz. Using five observers and the apparatus and procedures described in Chapter III, the 50-Hz tone was presented first to the better ear and then to the poorer ear and the differences in thresholds between the two ears were recorded. The results of Preliminary Study One suggest that the IA value at 50 Hz is 35 dB or greater with the experimental earphones (TDH-39) and cushions (MX-41/AR). Further study utilizing equipment with greater output capability and a larger number of observers is indicated before a more representative figure can be expressed.

The purpose of Preliminary Study Two was to determine the Subliminal Sensitization Effect (SSE) for brief acoustic pips in the presence of an on-going, low-level, 50-Hz sinusoid. Using eight observers and the apparatus and procedures described in Chapter III, the acoustic pips were presented at a 90° phase-angle re a 50-Hz sinusoid. The pips were presented at a level which produced from 75 to 85% correct responses in the absence of the 50-Hz tone. In the experimental conditions the pips were presented at that same level while the 50-Hz tone was presented at various subliminal levels and to the same ear as the pips. Four of the observers received the pips in the right ear and four received them in the left.

A SSE was noted for each of the observers. This finding supports the results of Deatherage and Henderson (1967). When the effect of the level of the on-going 50-Hz tone was evaluated, it was noted that the SSE broke down when the 50-Hz tone was between -20 and -30 dB SL. These results suggest that the SSE is present at lower intensity levels of the on-going 50-Hz sinusoid than previously anticipated. Analyses of ear differences revealed that the right-ear group of observers demonstrated a significantly greater SSE than the left-ear group. This result was unexpected and a reason for the outcome could not be established.

Speculations are offered relative to the reasons why the SSE was not observed at lower levels. On the basis of the literature reviewed in Chapter II, it was assumed that the movement of the basilar membrane is responsible for the SSE during monotic stimulation. Perhaps at a level between -20 and -30 dB SL, a 50-Hz on-going sinusoid no longer moves the basilar membrane sufficiently and, as a result, the perception of another incoming signal may not be affected. Alternatively, the noise floor of the test chamber in the octave bands around 50 Hz was reached at a level between -20 and -30 dB SL in this experimental study. As a result, the 50-Hz tone may have had no more effect upon the basilar membrane than the noise in a frequency band around 50 Hz.

Whatever the cause of the SSE, the findings in Preliminary Study Two have several implications. An on-going, low-frequency, subliminal signal as low as -20 to -30 dB SL can influence the detectability of other brief acoustic signals during monotic stimulation. Thus, thorough analyses of the sounds present in the earphones and in the research chamber are essential for all signal-detection and threshold experiments involving very brief acoustic signals. Since subliminal tones can affect detectability or threshold, perhaps the maximum allowable noise levels in sound treated rooms used for such studies should be re-evaluated.

The results of Preliminary Studies One and Two suggest that a 50-Hz tone greater than 5 dB SL in one ear could affect the detectability of brief acoustic pips in the opposite ear because it could have an intensity greater than -30 dB SL in the pip ear (assuming an IA of 35 dB).

There is need for further research in this area. Various on-going sinusoids should be studied to determine the range of frequencies over which the SSE can be observed. Studies of various low-noise levels in the octave bands around 50 Hz are needed to find if the level of the noise in those bands determines the level at which the SSE breaks down.

The Major Study was designed to investigate the effects of the phase relationship between the pips and the on-going 50-Hz tone during monotic and dichotic presentations. The same apparatus, procedures, and observers were utilized as those utilized in Preliminary Study Two. Acoustic pips were presented to one ear at 90° and 270° re a 50-Hz tone presented to either the ipsilateral or contralateral ear. Four of the observers received the 50-Hz tone at -10 dB SL and four received it at 5 dB SL during the experimental-treatment runs. Two observers in each group received the pips in the right ear and two in each group received them in the left.

The finding that the 90° Monotic treatment led to a SSE was confirmed in the Major Study. However, the 270° Monotic treatment resulted in neither sensitization nor desensitization. The latter result does not support the findings of Deatherage and Henderson (1967). The effect of the 90° Monotic treatment upon detectability was essentially the same whether the 50-Hz tone was presented at -10 or 5 dB SL. Similarly, the effect of the 270° Monotic treatment was essentially the same at those two sensation levels. The 90° and the 270° Dichotic treatments led to significant and essentially equal amounts of desensitization whether the 50-Hz tone was presented at -10 or 5 dB SL. In this study, no significant differences in performance were noted between the observers who listened with the right ear and those who listened with the left ear.

The results obtained during the Major Study suggest that, whatever the mechanism for sensitization, during the 90° Monotic treatments the -10-dB SL 50-Hz tone had the same effect upon the detection of the brief acoustic pips as the 5-dB SL 50-Hz tone. Apparently, by the time the 50-Hz tone reaches 5 dB SL, it has no more influence upon the detection of the pips than it does at -10 dB SL. This suggests a need for further studies with the 50-Hz tone presented at -10 to 5 dB SL in order to determine whether the function actually is asymptotic between those levels.

Unlike the monotic presentations, the dichotic presentations led to a remarkable degree of desensitization. This finding does not support the dichotic sensitization findings of Hughes (1938) but adds to the dichotic desensitization findings of Zwislocki et al. (1967). Since essentially the same amounts of desensitization were observed for the supraliminal and subliminal groups of observers during dichotic presentations, further research on the effects of contralateral presentations of various low-level 50-Hz sinusoids is indicated. Approximately the same amount of desensitization occurred at the two phase angles during dichotic presentations. It is believed that the observed desensitization resulted from neural interaction. Within the limitations of this study, the phase relationship of the pips to the on-going 50-Hz tone does not appear to have an important effect upon neural interaction during dichotic stimulation. However, more studies of this kind should be completed with other phase relationships before a definite conclusion can be reached relative to the role of phase on the detectability of pips during such dichotic stimulation.

A significant difference in performance between the right-ear and left-ear groups of observers did not occur in the Major Study as it had in Preliminary Study Two. Nevertheless, a trend in the same direction was observed. Further studies should be conducted in an attempt to resolve this question. In future research of this kind, it would behoove the investigator to allow all observers to listen to the pips in each ear during half of the presentations. Balanced signal detection studies of ear differences across a single group of observers are suggested because signal detection techniques allow the investigator to observe very subtle differences in performance.

SELECTED REFERENCES

Amaro, J., P. S. Guth, and L. Wanderlinder, Inhibition of auditory nerve action potentials by acetylcholine and physostigmine. Brit. J. Pharmacol. Chemother., 28, 207-211 (1966).

Bekesy, G. von, The variation of phase along the basilar membrane with sinusoidal vibrations. J. Acoust. Soc. Amer., 19, 38-40 (1947).

Bekesy, G. von, Experiments in Hearing (translated and edited by E. G. Wever). New York: McGraw-Hill (1960).

Boring, E. G., Sensation and Perception in the History of Experimental Psychology. New York: D. Appleton-Century Co. (1942).

Campbell, R. A. and Elaine Z. Lasky, Masker level and sinusoidal signal detection. J. Acoust. Soc. Amer., 42, 972-976 (1967).

Carter, N. L. and K. D. Kryter, Masking of pure tones and speech. J. Aud. Res., 2, 66-98 (1962).

Chaney, R. B. and J. C. Webster, Information in certain multidimensional sounds. J. Acoust. Soc. Amer., 40, 447-455 (1966).

Clarke, F. R. and R. C. Bilger, The theory of signal detectability and the measurement of hearing. Chapter 10, 371-408 (in) Modern Developments in Audiology (J. Jerger, ed.). New York: Academic Press (1963).

Cox, J. R. and R. C. Bilger, Suggestion relative to the standardization of loudness-balance data for the Telephonics TDH-39 earphone. J. Acoust. Soc. Amer., 32, 773-774 (1960).

Davis, H., Psychophysiology of hearing and deafness. Chapter 28, 1116-1142 (in) Handbook of Experimental Psychology (S. S. Stevens, ed.). New York: Wiley (1951).

Davis, H. and F. W. Kranz, The international standard reference zero for pure-tone audiometers and its relation to the evaluation of impairment of hearing. J. Sp. Hrng. Res., 7, 7-16 (1964).

Deatherage, B. H., Examination of binaural interaction. J. Acoust. Soc. Amer., 39, 232-249 (1966).

Deatherage, B. H. and D. Henderson, Auditory sensitization. J. Acoust. Soc. Amer., 42, 438-440 (1967).

Derbyshire, A. J. and H. Davis, The action potentials of the auditory nerve. Amer. J. Physiol., 113, 476-504 (1935).

Dirks, D. D. and Jane C. Norris, Shifts in auditory thresholds produced by ipsilateral and contralateral maskers at low intensity levels. J. Acoust. Soc. Amer., 40, 12-19 (1966).

Ehmer, R. H., Masking patterns of tones. J. Acoust. Soc. Amer., 31, 1115-1120 (1959).

Fex, J., The olivocochlear feedback systems. Chapter 6, 77-86 (in) Sensorineural Hearing Processes and Disorders (A. B. Graham, ed.). Boston: Little, Brown and Co. (1967).

Gacek, R. K., Afferent auditory neural system. Chapter 4, 49-59 (in) Sensorineural Hearing Processes and Disorders (A. B. Graham, ed.). Boston: Little, Brown and Co. (1967).

Galambos, R., Neural mechanisms of audition. Physiol. Rev., 34, 497-528 (1954).

Galambos, R. and H. Davis, The response of single auditory-nerve fibers to acoustic stimulation. J. Neurophysiol., 6, 39-57 (1943).

Goldstein, R., Electroencephalic audiometry. Chapter 24, 305-312 (in) Sensorineural Hearing Processes and Disorders (A. B. Graham, ed.). Boston: Little, Brown and Co. (1967).

Harris, J. D., Some phenomena of masking. Chapter 12, 139-151 (in) Sensorineural Hearing Processes and Disorders (A. B. Graham, ed.). Boston: Little, Brown and Co. (1967).

Hernandez-Peon, R., Reticular mechanisms of sensory control. Chapter 26, 497-520 (in) Sensory Communication (W. A. Rosenblith, ed.). Cambridge, Massachusetts: M.I.T. Press (1961).

Hughes, J. W., The monaural threshold: effect of a subliminal contralateral stimulus. Proc. Roy. Soc. London, 124 B, 406-420 (1938).

Hughes, J. W., The monaural threshold: the effect of subliminal and audible contralateral and ipsilateral stimuli. Proc. Roy. Soc. London, 128 B, 144-152 (1940).

Ingham, J. G., The effect upon monaural sensitivity of continuous stimulation of the opposite ear. Quart. J. Exptl. Psych., 9, 52-60 (1957).

Inglis, J. Dichotic listening and cerebral dominance. Acta Oto-laryngol. (Stockh), 60, 231-238 (1965).

Ishii, T., Y. Murakami, and K. Balogh, Acetylcholinesterase activity in the efferent nerve fibers of the human inner ear. Ann. Otol., Rhinol., Laryngol., 76, 69-82 (1967).

Kimura, Doreen, Cerebral dominance and the perception of verbal stimuli. Canad. J. Psych., 15, 166-171 (1961).

Milner, Brenda, Laterality effects in audition. Chapter 9, 177-195 (in) Interhemispheric Relations and Cerebral Dominance (V. B. Mountcastle, ed.). Baltimore: John Hopkins Press (1962).

Nomura, Y. and H. F. Schuknecht, The efferent fibers in the cochlea. Ann. Otol., Rhinol., Laryngol., 74, 289-302 (1965).

Olsen, W. O., T. A. Jabaley, and N. J. Pappas, Interaural attenuation for a TDH-39 earphone in an MX-41/AR cushion and for an insert receiver. Unpublished paper delivered at the 1967 convention of the American Speech and Hearing Association, Chicago, Ill., November 4, 1967.

Oxbury, Susan, J. Oxbury, and Jane Gardiner, Laterality effects in dichotic listening. Nature, 214, 742-743 (1967).

Peake, W. T. and N. Y-S Kiang, Cochlear responses to condensation and rarefaction clicks. Biophys. J., 2, 23-34 (1962).

Rasmussen, G. L., Efferent connections of the cochlear nerve. Chapter 5, 61-75 (in) Sensorineural Hearing Processes and Disorders (A. B. Graham, ed.). Boston: Little, Brown and Co. (1967).

Ryan, T. A., Interrelationships of the sensory systems. Psych. Bull., 37, 659-698 (1940).

Siegel, S., Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill (1956).

Spoendlin, H. and W. Lichtensteiger, The adrenergic innervation of the labyrinth. Acta Oto-laryngol., (Stockh), 61, 423-434 (1966).

Ward, W. D., Auditory fatigue and masking. Chapter 7, 240-286 (in) Modern Developments in Audiology (J. Jerger, ed.). New York: Academic Press (1963).

Wegel, R. L. and C. E. Lane, The auditory masking of one pure tone by another and its probable relation to the dynamics of the inner ear. Physic. Rev., 23, 266-285 (1924).

Wegel, R. L., R. R. Reisz, and R. B. Blackman, Low frequency thresholds of hearing and feeling in the ear and ear mechanism. J. Acoust. Soc. Amer., 4, 6 (1932).

Whitfield, D. C., The Auditory Pathway. Baltimore: Williams and Wilkins Co. (1967).

Winer, B. J., Statistical Principles in Experimental Design. New York: McGraw-Hill (1962).

Yeowart, N. S., M. E. Bryan, and W. Tempest, The monaural M.A.P. threshold of hearing at frequencies for 1.5 to 100 c/s. J. Sound Vib., 6, 335-342 (1967).

Zwicker, E., G. Flottorp, and S. S. Stevens, Critical band width in loudness summation. J. Acoust. Soc. Amer., 29, 548-557 (1957).

Zwislocki, J., Acoustic attenuation between the ears. J. Acoust. Soc. Amer., 25, 752-759 (1953).

Zwislocki, J., Ear protectors. Chapter 8 (in) Handbook of Noise Control (C. M. Harris, ed.). New York: McGraw-Hill (1957).

Zwislocki, J., E. N. Damianopoulos, E. Buining, and J. Glantz, Central masking: some steady-state and transient effects. Percept. and Psychoph., 2, 59-64 (1967).

APPENDIX A

BALANCED ORDERS OF TREATMENTS

TABLE 6

BALANCED ORDER OF TREATMENTS BY OBSERVERS
IN PRELIMINARY STUDY TWO

Observer Number	Test Ear	Treatment* Order Across Periods							
		1	2	3	4	5	6	7	8
1 6	Right Left	R	2	1	C	R	4	3	C
3 2	Right Left	R	1	3	C	R	2	4	C
5 4	Right Left	R	4	2	C	R	3	1	C
7 8	Right Left	R	3	4	C	R	1	2	C

* R - Reference Condition
C - Control Condition
1 - Experimental Condition One
2 - Experimental Condition Two
3 - Experimental Condition Three
4 - Experimental Condition Four

TABLE 7

BALANCED ORDER OF TREATMENTS BY OBSERVERS
IN THE MAJOR STUDY

Per-iod		Group A (Subliminal)				Group B (Supraliminal)			
	Observer Number	1	2	3	4	5	6	7	8
	Test Ear	R	L	R	L	R	L	R	L
Session I									
1		R	R	R	R	R	R	R	R
2	Order	1	4	2	3	1	4	2	3
3	of	2	3	4	1	2	3	4	1
4	Treat-	C	C	C	C	C	C	C	C
5	ments*	R	R	R	R	R	R	R	R
6	Across	3	2	1	4	3	2	1	4
7	Periods	4	1	3	2	4	1	3	2
8		C	C	C	C	C	C	C	C
Session II									
1		R	R	R	R	R	R	R	R
2	Order	4	2	3	1	4	2	3	1
3	of	3	4	1	2	3	4	1	2
4	Treat-	C	C	C	C	C	C	C	C
5	ments*	R	R	R	R	R	R	R	R
6	Across	2	1	4	3	2	1	4	3
7	Periods	1	3	2	4	1	3	2	4
8		C	C	C	C	C	C	C	C
Session III									
1		R	R	R	R	R	R	R	R
2	Order	2	3	1	4	2	3	1	4
3	of	4	1	2	3	4	1	2	3
4	Treat-	C	C	C	C	C	C	C	C
5	ments*	R	R	R	R	R	R	R	R
6	Across	1	4	3	2	1	4	3	2
7	Periods	3	2	4	1	3	2	4	1
8		C	C	C	C	C	C	C	C
Session IV									
1		R	R	R	R	R	R	R	R
2	Order	3	1	4	2	3	1	4	2
3	of	1	2	3	4	1	2	3	4
4	Treat-	C	C	C	C	C	C	C	C
5	ments*	R	R	R	R	R	R	R	R
6	Across	4	3	2	1	4	3	2	1
7	Periods	2	4	1	3	2	4	1	3
8		C	C	C	C	C	C	C	C

*R - Reference Condition
C - Control Condition
1 - Experimental Condition One
2 - Experimental Condition Two
3 - Experimental Condition Three
4 - Experimental Condition Four

APPENDIX B

INDIVIDUAL OBSERVER DATA

TABLE 8

PER CENT CORRECT SCORES FOR RIGHT-EAR, LEFT-EAR, AND BOTH GROUPS OF OBSERVERS IN PRELIMINARY STUDY TWO

Groups	Observers	Statistic	Reference One	-10 dB SL	-20 dB SL	Control One	Reference Two	-30 dB SL	-40 dB SL	Control Two
Right Ear	1		86	96	93	84	84	89	84	87
	3		85	94	88	84	83	83	85	83
	5		87	99	94	87	88	92	89	87
	7		79	89	85	78	77	79	80	79
		Range	79-87	89-99	85-94	78-87	77-88	79-92	80-89	79-87
		Mean	84.25	94.50	90.00	83.25	83.00	83.75	84.50	84.00
		Median	85.50	95.00	90.50	84.00	83.50	86.00	84.50	85.00
Left Ear	2		82	88	85	84	80	85	82	82
	4		81	92	85	83	87	84	81	86
	6		84	92	90	84	85	84	84	87
	8		81	84	83	76	76	81	80	80
		Range	81-84	84-92	83-90	76-84	76-87	81-85	80-84	80-87
		Mean	82.00	89.00	85.75	81.75	82.00	83.50	81.75	83.75
		Median	81.50	90.00	85.00	83.50	82.50	84.00	81.50	84.00
Both		Range	79-87	84-99	83-94	76-87	76-88	79-92	80-89	79-87
		Mean	83.13	91.75	87.88	82.50	82.50	84.63	83.13	83.88
		Median	83.00	92.00	86.50	84.00	83.50	84.00	83.00	84.50

TABLE 9

PER CENT CORRECT SCORES FOR SUBLIMINAL AND SUPRALIMINAL GROUPS OF OBSERVERS IN THE MAJOR STUDY (SESSION ONE)

Group	Observer	Statistic	Reference One	90° Monotic	90° Dichotic	Control One	Reference Two	270° Monotic	270° Dichotic	Control Two
SUBLIMINAL	1		89	93	83	86	85	80	73	88
	2		80	84	53	84	79	85	60	78
	3		89	98	84	91	91	87	78	89
	4		88	92	54	89	82	90	71	79
		Range	80-89	84-98	53-84	84-91	79-91	80-90	60-78	78-89
		Mean	86.50	91.75	68.50	87.50	84.25	85.50	70.50	83.50
		Median	88.50	92.50	68.50	87.50	83.50	86.00	72.00	83.50
SUPRALIMINAL	5		90	93	50	86	92	93	54	94
	6		85	80	52	88	83	86	73	84
	7		85	93	87	82	84	77	86	87
	8		81	88	50	84	75	78	54	78
		Range	81-90	80-93	50-87	82-88	75-92	77-93	54-86	78-94
		Mean	85.25	88.50	59.75	85.00	83.50	83.50	66.75	85.75
		Median	85.00	90.50	51.00	85.00	83.50	82.00	63.50	85.50

TABLE 9 (Continued)

PER CENT CORRECT SCORES FOR SUBLIMINAL AND SUPRALIMINAL GROUPS OF OBSERVERS IN THE MAJOR STUDY (SESSION TWO)

Group	Ob-server	Statistic	Reference One	90° Monotic	90° Dichotic	Control One	Reference Two	270° Monotic	270° Dichotic	Control Two
SUBLIMINAL	1		80	88	70	78	79	78	76	76
	2		80	83	50	81	80	86	51	82
	3		87	96	81	84	87	97	79	81
	4		80	89	67	85	83	90	58	78
		Range	80-87	83-96	50-81	78-85	79-87	78-97	51-79	76-82
		Mean	81.75	89.00	67.00	82.00	82.25	87.75	66.00	79.25
		Median	80.00	88.50	68.50	82.50	81.50	88.00	67.00	79.50
SUPRALIMINAL	5		89	98	53	90	85	84	49	88
	6		80	88	78	84	80	88	70	83
	7		74	87	68	75	78	72	67	82
	8		84	90	68	80	83	79	54	80
		Range	74-89	87-98	53-78	75-90	78-85	72-88	49-70	80-88
		Mean	81.75	90.75	66.75	82.25	81.50	80.75	60.00	83.25
		Median	82.00	89.00	68.00	82.00	81.50	81.50	60.50	82.50

TABLE 9 (Continued)

PER CENT CORRECT SCORES FOR SUBLIMINAL AND SUPRALIMINAL GROUPS OF OBSERVERS IN THE MAJOR STUDY (SESSION THREE)

Group	Ob-server	Statistic	Reference One	90° Monotic	90° Dichotic	Control One	Reference Two	270° Monotic	270° Dichotic	Control Two
SUBLIMINAL	1		91	97	81	90	92	89	83	90
	2		78	84	64	78	82	77	60	83
	3		83	86	75	83	85	85	80	83
	4		85	87	52	82	83	90	59	79
		Range	78-91	84-87	52-81	78-90	82-92	77-90	59-83	79-90
		Mean	84.25	88.50	68.00	83.25	85.50	85.25	70.50	83.75
		Median	84.00	86.50	69.50	82.50	84.00	87.00	70.00	83.00
SUPRALIMINAL	5		88	92	62	84	86	89	66	84
	6		80	87	61	82	82	82	67	80
	7		81	97	84	82	74	80	69	81
	8		82	78	56	79	78	86	64	71
		Range	80-88	78-97	56-84	79-84	74-86	80-89	64-69	71-84
		Mean	82.75	88.50	65.75	81.75	80.00	84.25	66.50	79.00
		Median	81.50	89.50	61.50	82.00	80.00	84.00	66.50	80.50

TABLE 9 (Continued)

PER CENT CORRECT SCORES FOR SUBLIMINAL AND SUPRALIMINAL GROUPS OF OBSERVERS IN THE MAJOR STUDY (SESSION FOUR)

Group	Ob-server	Statistic	Reference One	90° Monotic	90° Dichotic	Control One	Reference Two	270° Monotic	270° Dichotic	Control Two
SUBLIMINAL	1		82	90	73	84	86	81	72	81
	2		85	90	60	84	80	84	70	82
	3		84	99	78	82	75	98	84	79
	4		86	76	70	89	80	88	68	83
		Range	82-86	76-99	60-78	82-89	75-86	81-98	68-84	79-83
		Mean	84.25	88.75	70.25	84.75	80.25	87.75	73.50	81.25
		Median	84.50	90.00	71.50	84.00	80.00	86.00	71.00	81.50
SUPRALIMINAL	5		89	97	60	89	82	99	65	87
	6		88	94	75	86	78	82	68	77
	7		80	89	74	75	81	68	53	82
	8		78	82	71	81	78	70	62	75
		Range	78-89	82-97	60-75	75-89	78-82	68-99	53-68	75-87
		Mean	83.75	90.50	70.00	82.75	79.75	79.75	62.00	80.25
		Median	84.00	91.50	72.50	83.50	79.50	76.00	63.50	79.50

TABLE 9 (Continued)

PER CENT CORRECT SCORES FOR SUBLIMINAL AND SUPRALIMINAL GROUPS OF OBSERVERS IN THE MAJOR STUDY (ACROSS SESSIONS)

Group	Observer	Statistic	Reference One	90° Monotic	90° Dichotic	Control One	Reference Two	270° Monotic	270° Dichotic	Control Two
SUBLIM	1 - 4	Range	78-91	76-99	50-87	78-91	75-92	77-98	51-86	76-90
		Mean	84.19	89.50	68.44	84.38	83.06	86.56	70.13	81.94
		Median	84.25	89.25	69.00	83.25	82.50	86.50	70.50	82.25
SUPRALIM	5 - 8	Range	74-90	78-98	50-87	75-90	74-92	68-99	49-86	71-94
		Mean	83.38	89.56	65.56	82.94	81.19	82.06	63.81	82.06
		Median	83.00	90.00	64.75	82.75	80.75	81.75	63.50	81.50
BOTH	1 - 8	Range	74-91	76-99	50-87	75-91	74-92	68-99	49-86	71-94
		Mean	83.78	89.53	67.00	83.66	82.12	84.31	66.97	82.00
		Median	84.00	89.75	68.50	83.00	81.50	85.00	66.75	82.00

APPENDIX C

STATISTICAL ANALYSES

APPENDIX C

STATISTICAL ANALYSES

Preliminary Study Two: Extent of the SSE

The Reference scores for all observers were tested against the Control scores for all observers with the Sign Test (Siegel, 1956, 68-75). The scores of all observers obtained in the -10-dB SL, -20-dB SL, -30-dB SL, and -40-dB SL treatments also were tested against the Reference and Control values with the Sign Test. The latter procedure was accomplished by examining the difference between a treatment score and the Reference score when that treatment occurred at Period 2 or Period 6 and by examining the difference between a treatment score and the Control score when that treatment occurred at Period 3 or Period 7. A summary of the Sign Test analysis appears in Table 10 which follows.

The Reference and Control values for all observers were adjusted by obtaining the mean of the one Reference score and the one Control score in each half-session. This value was then subtracted from each of the two treatment scores in that half-session. An Analysis of Variance with Repeated Measurements (Winer, 1962, 554-562) was performed on these differences. The effect of treatment order also was studied in that analysis. Furthermore, the scores of the four right-ear observers were compared with the scores of the left-ear observers. In addition, the ear by treatment interaction was evaluated. A summary of the results of this Analysis of Variance appears in Table 11.

TABLE 10

SIGN TEST COMPARISONS OF REFERENCE, CONTROL, AND TREATMENT SCORES FOR PRELIMINARY STUDY TWO

Comparison	P
Control vs Reference	NS
-10 dB SL vs Reference and Control	0.004
-20 dB SL vs Reference and Control	0.004
-30 dB SL vs Reference and Control	NS
-40 dB SL vs Reference and Control	NS

TABLE 11

ANALYSIS OF VARIANCE OF PRELIMINARY STUDY TWO WITH REPEATED MEASUREMENTS USING THE MEAN OF THE REFERENCE AND CONTROL DATA AS THE BASIS FOR COMPARISON

Source	df	SS	MS	F	P
Among Observers	7	73.47			
Ears	1	47.53	47.53	11.00	0.025
Error	6	25.94	4.32		
Within Observers	24	422.75			
Order (time)	3	6.59	2.16	<1.00	NS
-10 & -20 vs -30 & -40	1	325.50	325.50	94.90	0.005
-10 vs -20	1	31.60	31.60	9.21	0.010
-30 vs -40	1	0.80	0.80	<1.00	NS
Ear X Treatment	3	14.03	4.68	1.36	NS
Error	13	44.60	3.43		

Major Study

The Reference scores for all observers were tested against the Control scores for all observers with the Sign Test (Seigel, 1956, 68-75). The scores of all observers obtained in the 90° Monotic, 90° Dichotic, 270° Monotic, and 270° Dichotic treatments also were tested against the Reference and Control values with the Sign Test. The latter procedure was accomplished in the same manner that it was in Preliminary Study Two. A summary of the Sign Test analysis appears in Table 12 which follows.

TABLE 12

SIGN TEST COMPARISON OF REFERENCE, CONTROL, AND TREATMENT SCORES FOR MAJOR STUDY

Comparison	P
Control vs Reference	NS
90° Monotic vs Reference and Control	0.001
90° Dichotic vs Reference and Control	0.001
270° Monotic vs Reference and Control	NS
270° Dichotic vs Reference and Control	0.001

The Reference and Control values for all observers were adjusted by obtaining the mean of the one Reference score and the one Control score in each half-session. This value was then subtracted from each of the two treatment scores in that half-session. Another Analysis of Variance with Repeated Measurements (Winer, 1962, 349-351) was performed. The values obtained in the Monotic and Dichotic modes were compared. The scores obtained at the 90° and 270° phase angles were compared, also. The mode by phase interaction was evaluated. The effect of treatment order was evaluated in that analysis as was the effect of sessions (days).

This particular analysis allowed comparisons among the scores obtained by the four subliminal-level observers and those obtained by the four supraliminal-level observers. In addition, the scores of the four right-ear observers were compared with the scores of the four left-ear observers. The level by ears interaction was evaluated. The mode by levels, the mode by ears, and the mode by levels by ears interactions were studied. Furthermore, the phase by levels interaction, the phase by ears interaction, and the phase by levels by ears interaction were evaluated. The mode by phase by levels, the mode by phase by ears, and the mode by phase by levels by ears interactions were studied, also. The order by levels interaction, the order by ears interaction, and the order by levels by ears interaction were evaluated. Finally, the session by levels, the session by ears, and the session by levels by ears interactions were studied. A summary of the results of this Analysis of Variance appears in Table 13 which follows.

TABLE 13

ANALYSIS OF VARIANCE OF THE MAJOR STUDY WITH REPEATED MEASUREMENTS USING THE MEAN OF THE REFERENCE AND CONTROL DATA AS THE BASIS FOR COMPARISON

Source	df	SS	MS	F	P
Among Observers	7	2409.12			
Levels (sub vs supra)	1	173.45	173.45	<1.00	NS
Ears (right vs left)	1	556.95	556.95	1.99	NS
Levels X Ears	1	556.94	556.94	1.99	NS
Error	4	1121.78	280.45		
Within Observers	120	19406.07			
Mode (Monotic-Dichotic)	1	12640.50	12640.50	40.60	0.01
Mode X Levels	1	38.28	38.28	<1.00	NS
Mode X Ears	1	231.12	231.12	<1.00	NS
Mode X Levels X Ears	1	586.54	586.54	1.88	NS
Mode X (S/Cells)	4	1245.31	311.33		
Phase (90^{o} vs 270^{o})	1	244.76	244.76	3.70	NS
Phase X Levels	1	86.13	86.13	1.30	NS
Phase X Ears	1	233.81	233.81	3.53	NS
Phase X Levels X Ears	1	4.14	4.14	<1.00	NS
Phase X (S/Cells)	4	264.97	66.24		
Mode X Phase	1	215.28	215.28	23.15	0.01
Mode X Phase X Levels	1	2.53	2.53	<1.00	NS
Mode X Phase X Ears	1	18.01	18.01	1.94	NS
Mode X Phase X Level X Ear	1	1.12	1.12	<1.00	NS
Mode X Phase X (S/Cells)	4	37.19	9.30		
Order (time)	3	100.16	33.39	1.51	NS
Order X Levels	3	151.79	50.50	2.28	NS
Order X Ears	3	7.16	2.05	<1.00	NS
Order X Levels X Ears	3	89.79	29.93	1.35	NS
Order X (S/Cells)	12	265.79	22.15		
Sessions (days)	3	278.71	92.90	1.22	NS
Sessions X Levels	3	157.21	52.40	<1.00	NS
Sessions X Ears	3	24.71	8.24	<1.00	NS
Sessions X Levels X Ears	3	331.59	110.53	1.46	NS
Sessions X (S/Cells)	12	910.09	75.84		
Residual	48	1189.38			