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Attentional processes in auditory discriminations

William A. Ahroon
Binghamton University--SUNY

ATTENTIONAL PROCESSES IN AUDITORY DISCRIMINATIONS

BY

WILLIAM A. AHROON, JR.

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NAME	DEPARTMENT	SIGNATURE	DATE
RICHARD E. PASTORE	PSYCHOLOGY	Richard E. Pastore	13 Jan '77
RICHARD G. BURRIGHT	PSYCHOLOGY	R. Burright	13 Jan '77
NORMAN E. SPEAR	PSYCHOLOGY	Norman E. Spear	1/13/77
H. STEPHEN STRAIGHT	ANTHROPOLOGY	H. Stephen Straight	13 Jan 1977

Preface

The experiments which comprise the body of this thesis were undertaken during the author's tenure at the State University of New York at Binghamton. The middle three chapters, which describe the five experiments, are written in manuscript form which could be submitted to professional journals such as The Journal of the Acoustical Society of America or Perception & Psychophysics. Therefore, each chapter has been written as a separate, self-contained unit with reference lists and footnotes at the end of each chapter. This approach also results in a certain amount of redundancy, such as the need to redefine terms, procedural variables, etc., in each chapter. Several minor variations from American Psychological Association and American Institute of Physics style guidelines have been made when these modifications resulted in a more readable thesis. Most of these exceptions involve the presentation (positioning, titling, numbering) of figures and tables.

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ATTENTIONAL PROCESSES IN AUDITORY DISCRIMINATIONS

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ABSTRACT

A set of experiments is described which assessed the ability of human observers to monitor two earphone channels in order to perform one or two independent frequency discriminations. Performance (d') was significantly poorer with dichotic stimulus presentation than in monaural control conditions. A detailed analysis of the data suggested that two factors were involved in the dichotic performance deficits. The first factor was a limited ability of the observers to perceptually separate the different stimuli presented to the two earphone channels. Under certain stimulus conditions, the channel-separation factor was significant enough to produce a low performance ceiling which overshadowed additional deficits caused by the second factor. This second factor was a limited ability to time-share between two channels to perform the frequency discriminations with the same efficiency as when attention was directed toward a single channel. When overshadowed by the performance floor caused by channel-separation limitations, the time-sharing limitations may be examined only by an analysis of performance conditional upon contralateral stimulus events.

Providing the observers with stimulus parameters which make the channels more dissimilar (i.e., spectral or temporal separation) improved performance when attention was directed to only one channel.

Sequential stimulus presentation was partially effective in increasing performance in selective- (or focused-) attention tasks, due to a unidirectional pattern of temporal interference, consistent with data on pitch recognition analogues to masking phenomena. The present investigation appears to make a significant step towards resolving an apparent controversy between several groups of researchers with regards to the nature of performance deficits in two-channel signal-detection paradigms.

Introduction

Attentional processes underlying the ability of a human observer to perform two independent, temporally-contiguous auditory signal detection or recognition tasks have received a great deal of experimental interest in recent years. Working from completely different theoretical frameworks, Pastore (1970) and Moray (1970a, 1970b) independently began research resulting in the current emphasis on binaural signal processing capacities of the human observer. The two groups of researchers which evolved from these first studies have made conclusions which appear to be contradictory. The British group, led primarily by Moray, maintains that time-sharing factors do limit performance in detection tasks involving pure tones as well as in tasks involving speech. However, the American group, which received impetus from the Pastore (1970) thesis, generally concludes that an observer _can_ monitor two earphone channels with little or no decrement in performance due to time-sharing limitations. Rather, since response errors usually occur on trials in which there is an actual or perceived signal in the contralateral channel, a cross-channel interference is hypothesized to be responsible for performance deficits in two-channel tasks. It is the purpose of this thesis to clarify this apparent controversy.

The British Group

Interest in simultaneous two-channel signal detection was initiated in Great Britain by two papers by Neville Moray (1970a, 1970b, see also Moray, 1969). Moray seems to have been motivated by a desire to extend the conclusions from the speech-shadowing and selective-listening experiments (see A. Treisman, 1969) to the processing of pure

tones. Indeed, Moray (1970b) states:

> The present paper marks the beginning of a program of research into the psychophysics of attention, or more generally, into the psychophysics of auditory time-shared signal detection, aimed hopefully towards establishing a quantitative basis of theory in this field. While most experiments have in the past concentrated on an Exclusive OR (XOR) mode of response, asking the listener to respond to one message and reject another, the present work follows the lead of Moray and O'Brien (1967) in using also the Inclusive OR (IOR) mode, in which the listener may be asked to detect targets simultaneously presented on two channels; that is, true time sharing has been measured. Treisman and Geffen (1967) have also used IOR mode, but their experiment was complicated by the use of speech and shadowing. The present study departs further from recent work in not merely rejecting shadowing, but also in using pure-tone stimuli. (p. 1071)

Moray's (1970a, 1970b) experimental design was a direct analogue to the selective-listening experiments of Moray and O'Brien (1967). Moray and O'Brien presented subjects with a stream of 1000 words to each ear with one-tenth of the words being letters and the remaining nine-tenths being numbers. The subjects' task was to press a button whenever they heard a letter. In this study, performance (d') in selective-attention conditions (where responses were required to stimuli in one channel only) was better than in divided-attention conditions (where responses were required in both channels). There was little

change in response bias (β).

Moray (1970a, 1970b) presented his subjects with a series of tone pulses, two per second, and asked them to detect changes in the loudness (or pitch) of the pulses.[1] There were 501 pulses per run [versus 1000 words per message in Moray and O'Brien (1967)] with 50 target stimuli. Half of the targets occurred when there was also a target in the contralateral channel. The frequency of the pulses in one ear was 2111 Hz and 3000 Hz in the other. In both of these studies, Moray observed a decrease in the number of targets detected in divided-attention conditions relative to single-channel listening conditions and concluded that "attentional time-sharing factors clearly alter the detectability even of pure tones," (Moray, 1970b, p. 1073).

M. Treisman (1972) took issue with Moray's conclusions. He noted that there were a number of factors that also would cause a decrease in the hit rate reported by Moray. These other factors included cross-channel masking (central or peripheral), uncertain frequency effects, and criterion variability. Treisman focused on the last of these factors, suggesting that Moray's failure to report false alarm rates in both his 1970 studies makes it impossible to separate sensitivity (d') changes from shifts in response bias (β). Treisman evaluated Moray's data in terms of a double-criterion model and concluded that criterion variability was the probable cause of Moray's reduced hit rates. (Criterion effects in Moray's research are discussed in more detail below.)

More current papers by Moray attempt to examine their data using a signal detection theory (TSD) approach (see Green & Swets, 1966; Egan, 1975) as used by Moray and O'Brien (1967) and attempt to satisfy

Treisman's (1972) objections to his earlier research. Moray, Fitter, Ostry, Favreau, and Nagy (1976) and Ostry, Moray, and Marks (1976) performed experiments using a TSD approach with pure tones (Moray et al., 1976) and speech (Ostry et al., 1976) stimuli. These studies are analogous to the Moray (1970a, 1970b) studies using pure tones and the Moray and O'Brien (1967) experiment using digits and letters. In these papers, Moray and his colleagues utilize a method of analysis developed by Pastore (1970, see the American group) in which performance is examined contingent on contralateral stimulus/response events. (This method of analysis also is used in the current investigation.) Using this analysis, both papers attempt to resolve the British-American controversy mentioned above.[2]

As has been pointed out by Pastore (1976), these latest studies by the British group suffer from several inabilities to fully satisfy the assumptions of the TSD model. Pastore has three objections to the use of TSD measures in these two papers. First, to use the d' measure in each channel, the probability of a target in each channel must be independently determined. But, both Moray's recent studies (Moray et al., 1976; Ostry et al., 1976) used an overall target probability (probability of a target being presented in either ear) of 0.1 along with the additional restriction that 50% of the targets (i.e., p = 0.05) occurred when a target was presented to both ears. To fully satisfy the assumptions of the TSD model, the probability of a target occurring in both ears should have been 0.01. [This objection also applies to experiments using an XOR procedure. Since the probability of a target occurrence is <u>not</u> independently determined (if a target occurs in one

channel it cannot, by definition of the XOR procedure, occur also in the other), d' should not be computed separately for each channel.]

The second, and probably the most important objection to the Moray studies [and alluded to by Treisman (1972, p. 629)], is that the hit and false alarm probabilities tend to be (negatively) correlated. The TSD model demands independent estimates of the probabilities of hits and false alarms. Since the subjects knew that a target could not occur for two pulses following another target, and since the authors used a two pulse-wide "hit window", there exists a negative correlation between hits and false alarms. Specifically, given a correct identification of a target (hit), the subjects knew that another target could not occur in the following two pulses--thus decreasing the probability of a false alarm (toward zero) immediately after a hit. Likewise, a false alarm immediately prior to a target event reduces the probability of a correct identification of that target.

A related methodological oversight that Pastore (1976) and Treisman (1972) note in Moray's experiments is the use of a "hit window" which could result in some portion of false alarms incorrectly being recorded as hits, hence resulting both in erroneous estimates of false alarms and in a negative correlation between the probabilities of hits and false alarms. Specifically, if the latency of a false alarm immediately prior to a target places that response in the overlapping "hit window" for the two successive pulses, the false alarm will be recorded as a hit.

The third objection to both these studies is that with only 10% of the trials containing signals, and with runs of 500 pulses or words,

it is likely that there is a rather large measurement error. That is especially true for the conditional probabilities where, for example, only approximately 12.5 targets in each block of trials (run) may be presented to the left (or right) ear alone. Moray et al. (1976) attempt to circumvent this problem by pooling across blocks to report data on at least 100 trials per condition. However, attempts to pool data across runs of trials creates an additional problem since criterion stability, an assumption of the TSD equal-variance model, cannot be assured across runs (see Pastore & Scheirer, 1974).

In summary, researchers from the British group generally have concluded that time-sharing factors alter the detectability of signals in a simultaneous two-channel signal detection paradigm. Their theoretical and methodological emphases have been from the speech-shadowing and selective-listening literature and their conclusions with regard to pure-tone stimuli follow those of the literature using speech stimuli. However, the design of the experiments from this group may suffer from methodological confounds which could have contaminated their data and therefore resulted either in improper conclusions or in misleading justifications for correct conclusions.

<u>The American Group</u>

Another major group thoroughly involved in the study of simultaneous two-channel signal detection includes Robert D. Sorkin and two generations of graduate students. Interest of this group in two-channel signal detection began with Sorkin's first doctoral student, Richard E. Pastore. Using a signal detection theory approach, Pastore (1970) concluded that observers can perform a two-channel signal detection

task with little or no deficit in performance relative to monaural detection performance.

Pastore's research in simultaneous two-channel signal detection was clearly independent of Moray's work and of the selective-attention research as typified by the British group as a whole. The impetus for his research was a 1965 paper by Eijkman and Vendrik involving internal noise. In that paper, Eijkman and Vendrik suggested a method for estimating the correlation of the internal noise across two input channels, thus determining the independence of signal processing. They used one visual and one auditory input channel and estimated the correlation of the internal noise for intensity and temporal discriminations. Pastore's (1970) thesis involved two auditory input channels and intensity discriminations similar to those of Eijkman and Vendrik (1965).

By the time Pastore's thesis appeared in a professional journal (Pastore & Sorkin, 1972), the two groups had already exchanged comments in the literature (Sorkin & Pastore, 1971) and the apparent contradictory results of the British and American groups had become the focal point of concern. The change in emphasis of the American group from problems of binaural signal processing and channel independence as exemplified by Eijkman and Vendrik (1965) mentioned above to a debate with the British group was further reinforced by M. Treisman's (1972) attack on Moray's design and conclusions (see above). Although the published version of Pastore's (1970) thesis (Pastore & Sorkin, 1972) was faithful to the initial impetus from Eijkman and Vendrik (1965), future research by the American group emphasized the ability of human observers to perform the two-channel tasks (more the emphasis of the

British group) rather than problems of internal noise, masking level differences, and the like.

Pastore and Sorkin (1972; also Sorkin & Pastore, 1971) report that with in-phase signals, observers can perform a two-channel signal detection task with little or no deficit in performance. In a subsequent experiment (Sorkin, Pastore, & Pohlmann, 1972), the use of narrow-band, binaurally correlated (S_o; S_π) and uncorrelated (S_u) noise signals resulted in a small performance decrement in the S_π and S_u conditions which was, the authors suggest, overcome due to the availability of lateralization information in the S_o condition. Other research by Sorkin and by his students has included two-channel detection of signals widely separated in frequency (Sorkin, Pohlmann, & Gilliom, 1973), successive two-channel signal detection (Gilliom & Sorkin, 1974), models of observer behavior in (exclusive-OR) two-channel signal detection (Sorkin & Pohlmann, 1973), two-channel gap detection (Gilliom & Mills, 1976), decision interactions in two-channel signal detection (Sorkin, Pohlmann, & Woods, 1976), three-channel signal detection (Pohlmann & Sorkin, 1976), and the present investigation. The overall conclusions of the experiments prior to the present series of studies have been that observers are able to monitor two earphone channels with little or no decrement in performance due to time-sharing limitations. Errors normally occurred on trials in which there was an actual or perceived signal in the contralateral ear. The American group, therefore, suggests that a processing interference, rather than attention (time-sharing) deficits, is responsible for performance decrements in two-channel tasks. Note that these conclusions are distinctly different

from those of the British group which contends that observers show poorer performance in two-channel tasks as the result of time-sharing factors. Recently, Moray et al. (1976) have suggested that procedural differences are responsible for the differences between the two groups.

The Present Investigation

The present series of experiments is designed as an attempt to clarify and/or resolve the apparent discrepencies between the conclusions from the British and American groups. A hybrid approach from the paradigms used by the groups may provide useful information concerning attentional processes in two-channel auditory tasks. All the research from the American group has involved the prothetic (additive) dimension of intensity (e.g., Stevens, 1961) and generally has employed signal (or gap) detection studies. On the other side of the Atlantic, a significant portion of the experiments by the British group has involved the metathetic (substitutive) continuum of frequency (pitch). Furthermore, all of the experiments by Moray and his colleagues have utilized discrimination paradigms in which observers are asked to recognize changes in the parameters of individual pulses (ΔI, Δf) in a train of pulses. The experiments which make up the body of this thesis all involve frequency discriminations and thus clearly detectable signals within a metathetic continuum. The design used throughout this investigation is a modification and extension of Pastore (1970).

The current investigation will examine two-channel detection (i.e., recognition, discrimination) of frequency changes relative to both single-channel frequency difference limens, with monaural stimulus presentation, and single-channel performance during dichotic stim-

ulus presentation. Three conditions--monaural (M), selective attention (S), and divided attention (D)--are employed to assess the differences between simple cross-channel interference and cross-channel interference coupled with a time-sharing limitation. Time-sharing limitations alone should be evident in the divided-attention condition, but not in the selective-attention conditions. However, cross-channel interference effects should be manifest in a decrease in performance in both dichotic stimulus-presentation conditions (S, D) whether or not time sharing is required.

The present investigation utilizes a method of analysis developed by Pastore (1970; see also Pastore & Sorkin, 1972), which examines performance in one channel conditional upon the stimulus/response events in the contralateral channel. The data from the following experiments will be analysed especially with regard to performance when the stimulus events in the two channels are equivalent (i.e., "signal" event in both earphone channels or in neither channel) and nonequivalent (i.e., "signal" event in one earphone channel only). A complete summary of the raw data with respect to all possible contralateral events is included in the Appendix.

The initial experiment in the present investigation will assess performance of human observers in two-channel frequency difference-limen tasks (Chapter II) and is a frequency analogue to Pastore's (1970) intensity-discrimination experiments. The frequencies of the standard stimuli to the two earphone channels will be separated in frequency (although within the same critical band) to avoid any interactions with binaural fusion effects (see Perrott & Barry, 1969; Perrott, Briggs, &

Perrott, 1970). This is especially important since Sorkin et al., (1972) suggested that binaural interactions (e.g., lateralization) may obscure performance deficits caused by cross-channel interference.

Moray's (1970a, 1970b, Moray et al., 1976) observers are provided with frequency-separation cues[3] (2111- and 3000 Hz signals) in addition to earphone (localization) information in performing selective-attention tasks. The second and third experiments (Chapter III) will be frequency discrimination analogues to the Sorkin et al. (1973) and Gilliom and Sorkin (1974) signal-detection experiments utilizing spectral or temporal cues in the two-channel frequency discriminations. It is anticipated that the use of additional stimulus cues may alter the pattern of results in the two-channel tasks, and thus help specify the limitations in such listening tasks.

The last experiment (Chapter IV) empirically assesses the effect of the magnitude of the frequency change in the contralateral channel upon the sensitivity to a frequency change in the ipsilateral ear. Since Sorkin et al. (1972, 1973) have demonstrated that the presence of a barely detectable signal in the contralateral channel has a significant effect on ipsilateral performance, the magnitude of the contralateral event also may be a significant factor in two-channel frequency discriminations.

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Footnotes

[1] There are normally two experiments in each of Moray's studies. Subjects are asked to respond to changes in intensity (loudness) of the pulses in the first experiment, frequency (pitch) in the second.

[2] Since methodological issues make the conclusions of these studies questionable, they are not discussed in detail. Moray et al. (1976) suggest that the critical variable underlying the differences between his research and Sorkin's is the probability of target (signal) occurrence. Moray et al. (1976) correctly note that their subjects should have a tendency (response bias) to respond "signal" in one channel when they detect a target in the other. (The subjects know that if a signal occurs in one channel, the probability that a signal is also present in the other channel increases from 0.1 to 0.5--hence the shift in response bias with contralateral signal presentation.) Ostry et al. (1976) formulate a model which attempts to encompass the research involving both speech and pure-tone stimuli. They suggest that the processing time associated with rare versus frequent targets is different and that time pressure in conjunction with a single channel processor can account for most of the data resulting from using either speech or sinusoidal stimuli.

[3] The use of the term "cue" should not be confused with the contralateral-cueing literature (e.g., Taylor & Forbes, 1969). In the context of the present investigation, "cue" refers to a manipulation of stimulus parameters (such as frequency separation between the stimuli presented to the ears) which may make the channels more distinctive.

Chapter II

Selective Attention I. Two-Channel Simultaneous Frequency Difference Limen

Abstract

A set of experiments which assessed the ability of human observers to monitor two earphone channels for the purpose of performing one or two independent and simultaneous frequency difference limen tasks is described. Performance (d') was significantly poorer with dichotic stimulus presentation than with monaural, control conditions. Under dichotic presentation conditions, performance was equivalent whether the observers were instructed to listen to one or both channels. A detailed analysis of the data indicated that the observers could discriminate a change but seemed to have difficulty in identifying the channel in which the change occurred. Consistent with results reported in the simultaneous signal detection literature using intensity detection or discriminations, it was found that observers cannot successfully monitor more than one channel. It is suggested that when the dichotic stimulus presentation provides useful information which is not present during monaural tasks (e.g., lateralization cues), observers may be able, using this added information, to perform a divided-attention task with little or no apparent performance decrement relative to single-channel tasks.

Selective Attention I. Two-Channel Simultaneous Frequency Difference Limen.

In an early attempt to study simultaneous two-channel signal detection, Moray (1970a, 1970b) presented a train of tone pulses and instructed his observers to detect increments in the intensity or increases in the frequency of the pulses. Finding a decrement in the hit rate (correct identification of the changes in pulse parameters) when the observers were required to detect changes in both ears,[1] Moray (1970b) concluded that "attentional time-sharing factors clearly alter the detectability even of pure tones" (p. 1973). Treisman (1972) pointed out two problems with these studies. First, he suggested that Moray's choice of stimuli (2111 Hz for the left ear and 3000 Hz for the right ear) were separated sufficiently in frequency to suffer a confounding due to frequency uncertainty (see Green, 1961; Green & Swets, 1966; Swets, 1963; Tanner, 1958). Furthermore, Moray's failure to report false alarm rates made his data difficult to interpret, since one could not be sure whether the decrease in performance was the result of a reduced sensitivity to the stimuli or a change in response bias. Treisman (1972) concluded that a criterion shift, rather than a decrease in detectability, led to Moray's results.

Pastore and Sorkin (1972; also Sorkin & Pastore, 1971) performed a simultaneous two-channel intensity difference limen experiment which satisfied both of Treisman's (1972) objections to the Moray (1970a, 1970b) studies. They employed a same-different task using a fixed standard with the comparison either equal in intensity to the standard or incremented by a fixed amount. Using this design with signal detec-

tion measures (see Green & Swets, 1966; Egan, 1975), they concluded that subjects could perform a two-channel detection task with little or no performance decrement relative to monaural listening conditions when the (500 Hz) signals were in-phase. In an attempt to evaluate fixed lateralization cues inherent to phase-locked signals, Sorkin, Pastore, and Pohlmann (1972) performed a similar experiment using narrow band-passed noise signals from the same noise source filtered through a single narrow-band filter, (S_o); signals from the same source filtered through two matched narrow-band filters with the polarity reversed on one filter, (S_π); and signals from different noise sources filtered through the matched filters, (S_u). Both the S_π and S_u conditions resulted in significant performance decrements relative to monaural listening conditions. The authors suggested that these performance decrements were due to cross-channel interference rather than a limited time-sharing capacity of the observers. In the S_o condition, which showed no such performance deficit, the authors suggested that "the presence of lateralization information" (p. 1063) counteracted this cross-channel interference.

Human observers, therefore, can perform a two-channel signal detection task when signals to the two ears are identical in spectral composition and are in-phase. In order to determine the contribution of cross-channel masking and to assess the effects of frequency uncertainty in the Moray (1970a, 1970b) studies, Sorkin, Pohlmann, and Gilliom (1973) conducted a dichotic signal detection experiment with the signals to the two channels widely separated in frequency. In addition to the monaural single-frequency condition run in earlier

studies, they presented both sets of signals to the same ear in an "inclusive-OR" procedure (monaural two-frequency condition). No differences were found between monaural and dichotic two-frequency tasks, with performance in both two-frequency tasks significantly below the monaural single-frequency conditions. The authors suggest a parallel between these results and the uncertain frequency signal detection literature. Similarly, other authors have suggested that uncertain frequency signal detection may involve attentional or time-sharing components (e.g., Green, 1961; Green & Swets, 1966). Further examining their data, Sorkin et al. (1973) found that performance deficits in either channel were almost completely correlated with the actual or perceived presence of a signal in the other channel. They suggest a model based on an analogue to a computer interrupt-handling system whereby an interrupt on any one input channel will halt or delay the processing of another interrupt (Gilliom, 1972; Gilliom & Sorkin, 1974). A shift in response criterion (β) also was reported contingent on detecting signals in the other channel, yet the authors maintain that "there seems to be no way to determine whether the cross-channel decrement ... observed was due to a contingent criterion variability effect or come kind of interrupt-interference (attentional) effect," (p. 1049).

From this research on simultaneous two-channel signal detection we may infer that subjects cannot attend efficiently to more than one earphone channel unless some other information (e.g., laterality) is available. Given such added information, performance in dichotic listening conditions shows little or no difference from monaural

listening conditions.[2] The present study is designed to examine two-channel attentional processes within the framework of frequency discriminations. Moray (1970a, 1970b), in the first studies, attempted to examine the simultaneous detection in two channels of frequency changes in a pedestal but there were difficulties in interpreting his data (see above). The present study examines two-channel simultaneous frequency difference limens, similar to the intensity difference limen task of Pastore and Sorkin (1972). In addition, to better assess the limitation placed on the observers during dichotic listening tasks, I will ask them not only to perform the two-channel task, but also to focus their attention on one of the two channels. If performance in the selective- (focused-) and divided-attention conditions does not differ, then performance deficits in two-channel signal detection tasks may be due to the inability to separate input channels. However, if performance in the selective-attention conditions is better than in the divided-attention condition, then performance deficits reported in the literature may be due to the inability of observers to time-share adequately between two input channels.

Method

Observers

Three trained observers with normal hearing were run individually in a commercial double-walled sound-insulated chamber.

Procedure

A standard same-different task was employed. The observers were asked to discriminate a difference in frequency between two 200-msec segments of pure tones separated by 400 msec. In the monaural condi-

tion (M), only white noise was presented to the contralateral earphone channel, while in the dichotic [the selective- (S) and the divided- (D) attention conditions] stimuli were presented simultaneously to both earphone channels. The temporal sequence of stimulus events for each of the three conditions is illustrated in Figure 2-1. The standard

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Insert Figure 2-1 about here

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stimuli (1605 Hz for the left ear and 1739 Hz for the right ear) were chosen to be highly discriminable, to bear no simple harmonic relationship to each other, and to be in the same critical band [approximately 200 Hz wide in this frequency region (Zwicker, Flottorp, & Stevens, 1957)]. With 10 Log (E/N_o) of approximately 32.2, the (44 dbA) tones were clearly detectable over the continuous, low-level, broadband, binaurally uncorrelated noise (General Radio 1382 random-noise generators). All function generators were allowed to stabilize prior to the start of each session and were monitored constantly.

In the monaural (M) condition, the frequencies for the comparison stimuli were adjusted to yield stable values of d' of approximately 3.0 (right channel = 1739 + Δf_r; left channel = 1605 + Δf_l). Once performance had stabilized in the monaural conditions, appropriate stimuli were presented in both channels for the selective- and divided-attention conditions. With the same-different paradigm, the presence of a frequency change was randomly determined with independent probabilities of 0.5 in each channel. In the selective-attention (S) condition, the observers were asked always to respond to a specified, fixed earphone channel and to completely ignore the stimuli in the

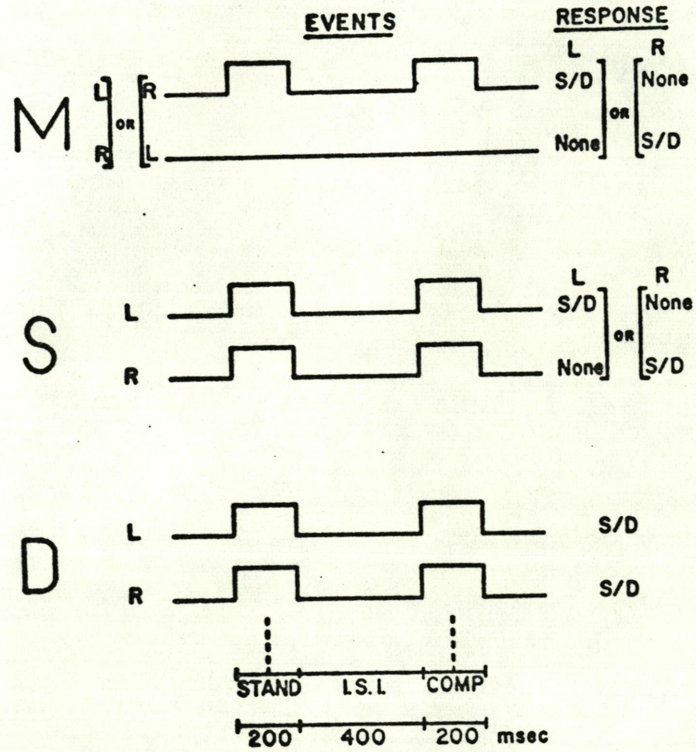

Figure 2-1. Stimulus and response contingencies for all conditions. Stimuli are presented to only one ear in the monaural (M) conditions. Dichotic presentation is used in the selective-attention (S) and divided-attention (D) conditions. In the selective-attention condition, observers were told to respond to only one earphone channel and to ignore the other. Observers performed both frequency difference limens in the divided-attention condition.

other earphone channel. In the divided-attention condition, the observers were required to perform the frequency difference limen tasks in both ears simultaneously. Sessions lasted two or three hours with the 150-trial blocks separated by frequent rest intervals to reduce effects of boredom and fatigue. All analyses are based upon at least ten 150-trial blocks per condition following stabilization.

In addition to using standard stimuli within the same critical band, one observer (W.A.) was run in the three conditions with a greater frequency separation between the signals to the left and right earphone channels. The base frequencies for the left and right channels thus were separated by two or three critical bands (R = 2039 Hz, L = 1305 Hz). All other independent variables were the same.

Results and Discussion

The mean d' measures for each observer are presented in Figure 2-2.

Insert Figure 2-2 about here

The values of d' in this figure represent the overall performance in a single channel for each condition independent of the stimulus and response events in the contralateral channel. The Δf's obtained for the three observers in the monaural conditions (see Figure 2-2) are consistent with Henning's (1967) data for these approximate frequencies, signal-to-noise ratios, and levels of performance. Since performance in each earphone channel was manipulated independently in the monaural conditions to yield approximately equal values of d', each earphone channel was analyzed separately in a simple one-way analysis of variance with multiple comparisons to determine individual condition ef-

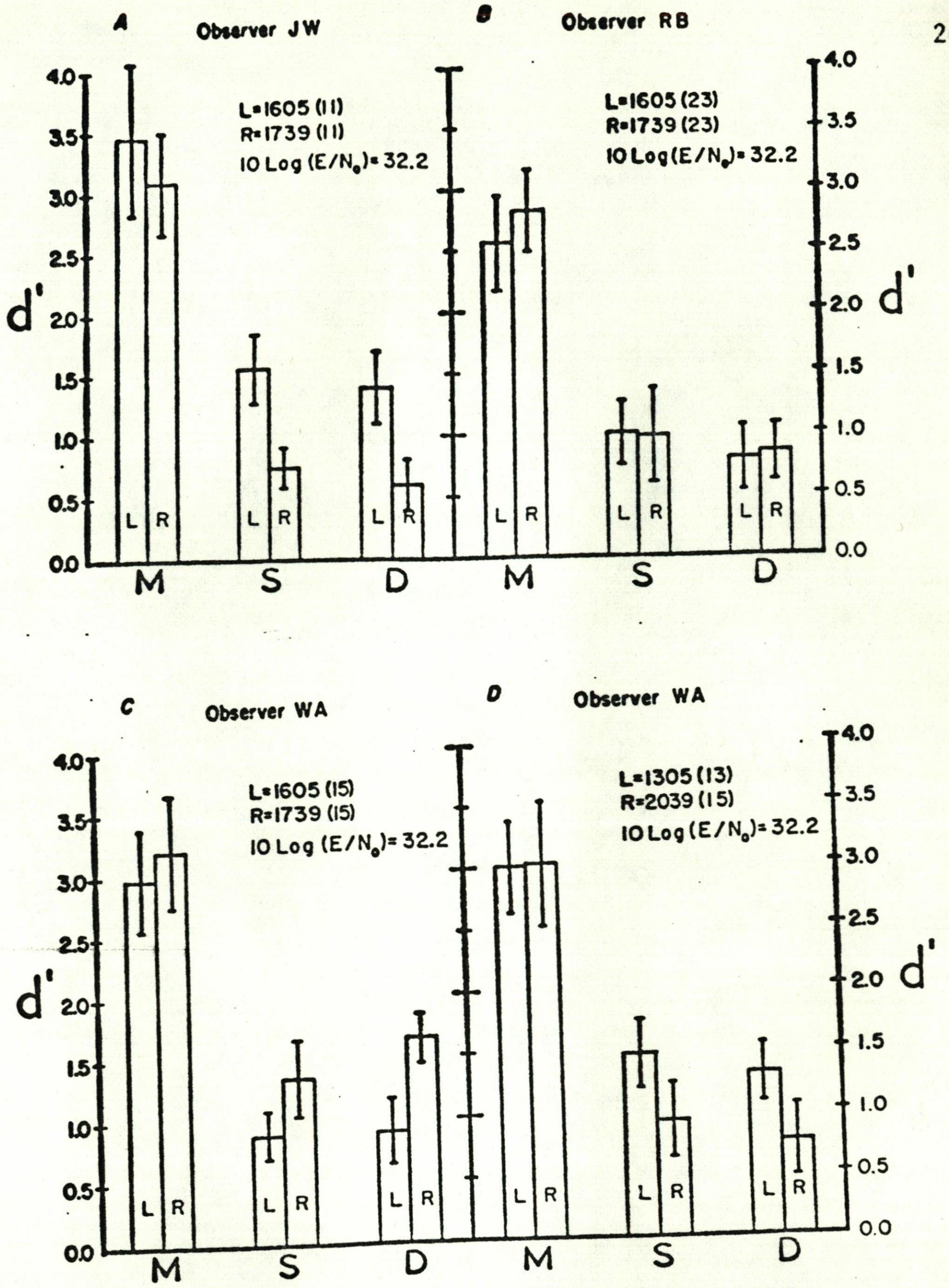

Figure 2-2. (a-c) Overall performance for all observers on the monaural (M), selective-attention (S), and divided-attention (D) tasks. One standard deviation is plotted above and below the mean value of d'. Change in frequency (in Hz) is indicated in parentheses beside each base frequency. (d) The mean values of d' and standard deviations for observer W.A. with the base frequencies separated by two or three critical bands.

fects. As is evident from the figure, both dichotic conditions (selective-attention and divided-attention) showed a significant decrement in performance relative to monaural performance for all observers. However, there were no consistent differences between the selective- and divided-attention conditions. The performance decrement in the divided-attention condition relative to monaural performance appears to be consistent with the simultaneous two-channel detection literature summarized above. As suggested by Moray's (1970a, 1970b) hit data, observers could not successfully discriminate increases in frequency when required to monitor both earphone channels. It is unlikely that any laterality information existed in this task and, therefore, these results parallel the Sorkin et al. (1972) data using uncorrelated noise signals, although the magnitudes of the performance deficits in the present experiment were greater than any reported in the earlier research.

Since performance in the selective- and divided-attention conditions did not differ, these deficits may be the result of the inability of the observers to successfully separate the input channels. The specific probabilities of hits and false alarms conditional upon the stimulus events in the other channel are consistent with this hypothesis. Table 2-1 presents these probabilities for the selective-attention condition. When the stimulus events in the attended and unat-

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Insert Table 2-1 about here

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tended channel were equivalent, observers made very few errors [P(Hit|Contralateral Change) = .91; P(Correct Rejection|No Contralateral

Table 2-1

Hit and False Alarm Probabilities for the Selective Attention Condition Given Change or No Change in the Contralateral Channel

	P(Hit)				P(False Alarm)			
	Change		No Change		Change		No Change	
Obs.	L	R	L	R	L	R	L	R
W.A.	.94	.92	.46	.59	.67	.49	.06	.06
J.W.	.95	.91	.66	.54	.43	.71	.08	.18
R.B.	.80	.86	.50	.48	.43	.48	.11	.10
W.A.*	.93	.93	.60	.56	.44	.68	.05	.11
Mean	.91	.91	.56	.54	.49	.59	.08	.11

* Indicates conditions in which the signals to the two channels were separated by two to three critical bands.

Change) = 1 - P(False Alarm|No Contralateral Change) = .91]. However, performance was near chance when the events in the two channels were not equivalent [P(Hit|No Contralateral Change) = .55; P(Correct Rejection|Contralateral Change) = .46]. It would seem that the observers could discriminate a change in frequency much more easily than they could identify the source of change. This pattern of results also is evident in the divided-attention condition summarized in Table 2-2.

Insert Table 2-2 about here

Errors usually occurred when: 1) observers identified the source of change incorrectly; or when 2) they decided that there was a change in both channels when there was actually a change in only one channel.[3]

Examining the results of Observer W.A., it is evident that the pattern of results is the same whether the signals to each earphone channel are within the same critical band or are separated by two or three critical bands. I conclude that the failure of the observers to successfully perform the selective- and divided-attention tasks probably is not directly related to the concept of the critical band. These data confirm that, with respect to frequency discriminations, Moray's (1970a, 1970b) conclusions probably are valid in spite of the interpretational difficulties inherent in his design. Given the findings summarized above, it would appear that Moray's conclusions are valid for those two-channel time-sharing tasks in which the use of dichotic stimuli provided no information other than that normally available during monaural tasks. However, if such information is available, observers may be able to perform two channel tasks with no

Table 2-2

Hit and False Alarm Probabilities for the Divided-Attention Condition Given Change or No Change in the Contralateral Channel

	P(Hit)				P(False Alarm)			
	Change		No Change		Change		No Change	
Obs.	L	R	L	R	L	R	L	R
W.A.	.83	.92	.50	.66	.57	.40	.10	.03
J.W.	.83	.79	.57	.42	.35	.62	.05	.14
R.B.	.78	.83	.53	.51	.41	.48	.22	.16
W.A.*	.89	.88	.69	.47	.51	.64	.12	.10
Mean	.83	.86	.57	.52	.46	.54	.12	.11

* Indicates conditions in which the signals to the two channels were separated by two to three critical bands.

apparent performance decrement due to time-sharing limitations, (see Footnote 2.)

The lack of consistent differences between dichotic listening conditions suggests that the cross-channel interference reported by Pastore and Sorkin (1972; Sorkin et al., 1972, 1973) probably is the major factor involved in the present results. In the present study and in the simultaneous detection literature, it is unclear what "cross-channel interference" actually involves. Cross-channel masking is probably not responsible for this interference, since critical band effects are not evident in any of the present data or in that of Sorkin et al. (1973). It does not appear that binaural fusion, as it is described in the literature (Perrott & Barry, 1969; Perrott, Briggs, & Perrott, 1970), is responsible for our results. Although a fused image was reported by the observers, this image is not a single, simple percept as usually reported by observers in binaural fusion tasks. Rather, the image is a complex tonal pattern. The observers may attempt to perform the dichotic task by discriminating among the different binaural patterns produced by the stimuli. However, the use of non-frozen stimuli in the present study makes this strategy extremely difficult due to variability within any class of binaural events. If the observers are discriminating between binaural patterns, the variability in a given set of stimulus events across trials possibly could be one source of interference in this study. It is clear, however, that this interference is not well understood and should be the subject of future investigations.

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Footnotes

[1] In these studies, an inclusive-OR (IOR) procedure is used when an event defined as "signal" may occur in either, neither, or both channels. Since the probabilities of selecting a "signal" are determined independently for each channel, the measure of performance, d', may be used appropriately. In exclusive-OR (XOR) conditions, where a signal cannot occur in both channels, d' should not be used as a measure of individual channel performance, since the events in the two channels are not independent.

[2] The additional cues need not be the primary source of information by which the observers perform the task. If the observers can use information from all sources, then the additional cues serve to reduce any performance deficit which might occur due to time-sharing limitations. For example, if detection performance is better than lateralization (localization) by approximately two decibels, as Egan and Benson (1966) have suggested, then a two decibel decrement in performance as a result of time-sharing limitations may allow lateralization cues to become equi-potent with detection cues in respect to the observers' decisions on any trial. Given the existence of two sets of equivalent cues, performance could increase relative to a single cue situation, provided the two cues both can be processed by the observers.

[3] This conclusion is justified further by the pattern of the other conditional probabilities. Specifically, the probability of being correct was near chance when the observer answered that a change occurred in only one channel [P(Hit|Perceived No Contralateral Change) =

.51; P(Correct Rejection|Perceived Contralateral Change) = .44]. At the same time, the probability of being correct in any channel was greater than chance when observers perceived that the events in the two channels were equivalent [P(Hit|Perceived Contralateral Change) = .76; P(Correct Rejection|Perceived No Contralateral Change) = .81].

Chapter III

Selective Attention II. Channel Separation in Two-Channel Frequency Discriminations

Abstract

A set of two experiments was performed to estimate the relative contributions of cross-channel interference, perceptual-separation and time-sharing limitations on two-channel frequency discriminations. The results indicate that observers cannot perform two independent frequency discriminations with the same efficiency they can perform one. Performance deficits appear to be the result of both a limited ability to perceptually separate the inputs to the two ears and a requirement to perform two tasks simultaneously (i.e., time share). The first factor, a perceptual fusion of the dichotic stimuli, may produce a performance ceiling which, in turn, obscures performance deficits due to a limited capacity to time share. Deficits due to time-sharing factors are found in the analysis of performance conditional upon relative contralateral stimulus events, where perceptual-separation limitations are minimized. Attempts to provide observers with spectral or temporal information in addition to lateralization cues appear to produce a greater degree of perceptual separation, but has little effect on time-sharing capacities.

Selective Attention II. Channel Separation in Two-Channel Frequency Discriminations.

In experiments on auditory time sharing, Moray (1970a, 1970b) asked human observers to recognize increments in loudness or pitch of tones in monaural or dichotic pulse trains. Finding a decrease in performance (i.e., proportion of detected increments) in the dichotic two-channel tasks, he concluded that "attentional time-sharing factors clearly alter the detectability even of pure tones, although not so great an extent as when verbal signals are used, and the way is therefore open to a psychophysics of time sharing and to quantitative theories of auditory attention" (Moray, 1970b, p. 1073).

Working independently from a different theoretical framework, Pastore (1970; Pastore & Sorkin, 1972) arrived at different conclusions. When signal were in-phase, Pastore's observers showed no performance (d') deficit in divided-attention conditions relative to monaural, control conditions.[1] However, when the pure-tone signals to the two earphone channels were phase-shifted 180^{o} (Pastore & Sorkin, 1972) or when the narrow-band noise signals were inverted or uncorrelated (Sorkin, Pastore, & Pohlmann, 1972), performance deficits in divided-attention conditions were evident. A detailed analysis of performance revealed that most of the performance deficit occurred when there was an actual or perceived signal in the contralateral channel. Sorkin et al. (1972) conclude that performance deficits in two-channel signal detection tasks are caused by cross-channel masking or inhibition[2] and that "constraints on signal detectability due to a limited processing capacity appeared to be negligible" (p. 1960). A recent study by Moray,

Fitter, Ostry, Favreau, and Nagy (1976) supports the conclusions of Sorkin et al. (1972; Sorkin, Pohlmann, & Gilliom, 1973). Using a similar conditional analysis as used by Pastore (1970), Moray et al. (1976) also found that most of their performance deficits were the result of errors on trials on which there was an actual or perceived signal in the contralateral earphone channel, and suggest that procedural differences are responsible for the discrepancies between their and Sorkin's et al. (1973) conclusions.

The studies of Moray and his colleagues have used, as signals, increments in loudness or pitch of tones in a train of tone pulses (Moray, 1970a, 1970b; Moray et al., 1976). Thus, they have used a recognition or discrimination paradigm. For the most part, Sorkin's research used threshold detection paradigms (Sorkin et al., 1972, 1973; Gilliom & Sorkin, 1974; Pohlmann & Sorkin, 1976). In the previous experiment (Chapter II), I have described data from a two-channel frequency discrimination paradigm which does not support the conclusions of either Sorkin et al. (1973) or Moray et al. (1976). In a frequency discrimination analogue to the Pastore (1970) study, large performance deficits were found in divided-attention conditions relative to monaural tasks. Unlike Sorkin et al. (1972, 1973), there appeared to be no reliable differences between performance conditional upon the presence and absence of a contralateral "signal" event (i.e., frequency change). Moreover, unlike the Moray (1970a, 1970b; Moray et al., 1976) studies, there was a large deficit in performance in selective-attention conditions with the deficit being equivalent to that in the divided-attention condition.

Pastore and Sorkin (1972), in their analysis of decision spaces, found no differences in binaural detection measures with both in-phase and phase-shifted signals when intensity increments were present either in both channels or in neither channel. In the first experiment (Chapter II), I suggested that performance in the two-channel frequency discrimination task also seemed to be dependent upon or correlated with the stimulus events in the two channels being equivalent or nonequivalent.[3] That is, I noted that there was little or no performance deficit in dichotic tasks if the stimulus events were equivalent in the two channels, but that performance was near chance when the stimulus events in the two channels were nonequivalent. This observation led to the conclusion that an inability to perceptually separate the signals to the two earphone channels was the most significant factor in those results.[4] Performance in both dichotic stimulus presentation conditions was near a d' value of 1.0 for all three observers in the earlier study (Chapter II). This value may be reflective of a performance ceiling caused by the limited ability of the observers to perceptually separate the input channels.[5] Given the existence of a performance ceiling caused by a limited ability to perceptually separate the input channels, does not negate the likely possibility of time-sharing limitations as well. However, a performance ceiling near a d' value of 1.0 may obscure differences in performance as the result of time-sharing requirements in the divided-attention condition, unless the effect of time-sharing is large relative to limitations on perceptual separation.

In the first study (Chapter II), I reported the probabilities of

hits and false alarms in the same-difference frequency discriminations conditional upon equivalent and nonequivalent stimulus events. By examining the conditional performance (d') in the selective- and divided-attention tasks, one can assess time-sharing limitations independent of the channel-separation problems so evident in the first experiment. Table 3-1 presents performance with equivalent and nonequivalent stimulus events for the observers in the earlier paper and two additional observers (Ahroon, 1976). From the table it is clear

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Insert Table 3-1 about here

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that performance is near chance with nonequivalent stimulus events. However, performance is significantly above chance for all observers with equivalent stimulus events and, in the selective-attention conditions, is near monaural performance levels for all observers but one. Furthermore, there is a significant performance decrement from selective- to divided-attention conditions with equivalent stimulus events. Since performance was already at chance with nonequivalent stimulus events, additional performance deficits as the result of time-sharing limitations could not be demonstrated. Hence, time-sharing limitations are evident in two-channel frequency difference limens only by an examination of conditional performance, even though overall performance (without regard to contralateral stimulus events) is similar for selective- and divided-attention conditions. This observation supports the notion that a performance ceiling caused by a limited ability to perceptually separate the channels in the dichotic stimulus presentation conditions is responsible for the overall performance similarity in

Table 3-1

Performance Conditional Upon Contralateral Stimulus

Events with 1605- and 1739 Hz Signals

	Selective Attention				Divided Attention			
	Equivalent		Nonequiv.		Equivalent		Nonequiv.	
Obser.	L	R	L	R	L	R	L	R
J.W.	3.01	2.51	0.61	-0.48	2.75	1.98	0.58	-0.51
R.B.	2.24	2.43	0.19	0.00	1.05	1.44	0.21	-0.03
W.A.	3.33	2.91	-0.56	0.31	2.31	3.44	-0.19	0.69
W.A.†	3.45	2.91	0.43	0.33	2.57	2.60	0.51	-0.48
E.B.*	3.50	3.13	0.01	0.10	2.78	2.22	0.09	0.19
J.V.*§	1.24	1.78	-0.73	0.76	0.04	1.44	-0.21	1.25

† 1305- and 2039 Hz signals

* From Ahroon (1976)

§ Observer with ear dominance (see appendix)

the first study.

Moray et al. (1976) have reported an apparent contridictory finding in which selective-attention performance levels did not seem to differ from monaural performance. Given the observation that almost all of the errors by my observers occur during nonequivalent stimulus events, it is clear why my results fail to parallel those of Moray. In the 1976 Moray et al. study, hit rat will remain approximately constant in monaural and selective-attention conditions, if one assumes that the observers tend to respond "signal" when a target is presented to either channel--an assumption supported by Moray (1970a). Moray used an overall target probability of 0.10, which is also the maximum proportion of nonequivalent stimulus events. If false target detections occur primarily due to guessing when there are nonequivalent stimulus events [as suggested by the present data (see Table 3-1)], then out of a run of 250 pulses (trials), one may expect a maximum increase of approxiately eleven false detections [0.9 x 12.5, assuming a strong bias toward responding "signal" (see above)] due to channel-separation limitations. This figure, divided by the total number of non-target pulses (90% of 250 pulses) leads to a maximum increase in false-alarm probability of 4.9%. Therefore, channel-separation limitations upon Moray's et al. (1976) observers will result in essentially no change in hit rate coupled with a very small maximum increase in false-alarm rate and, therefore, little change in performance as measured by d'.

The present data suggest that there are, in fact, two factors involved in two-channel frequency discrimination experiments. The first

factor is a performance ceiling (d' $\simeq$ 1.0) which is probably the result of the observers' limited ability to perceptually separate the two earphone channels during dichotic stimulus presentation. The second factor is a performance deficit in divided-attention tasks which, even though overshadowed by a performance ceiling, is evident in an examination of performance conditional upon contralateral stimulus events. This factor is probabily a limitation imposed by the time-sharing requirements of the divided-attention task.

The present series of experiments is designed to investigate the role of both time-sharing limitations and perceptual-separation limitations on performance in two-channel frequency discriminations. As noted above, Moray (1970a; Moray et al., 1976) consistently finds little or no performance deficit in selective-attention conditions for both intensity and frequency increments. M. Treisman (1972) noted that Moray's use of signals widely separated in frequency (2111- and 3000 Hz signals) introduced uncertain frequency detection confounds into the Moray procedure (see Green, 1961). (Since Moray has used a recognition or discrimination procedure, this may or may not be a valid criticism.) However, the use of signals separated in frequency may provide Moray's observers with an additional means (i.e., spectral separation) by which they could direct their attention to a specific earphone channel. If this is the case, the addition of spectral separation in the first experiment may increase perceptual separation of the signals to the two channels in the two-channel frequency difference limen task (Chapter II), and result in an increase in performance in selective-attention conditions. If the addition of spectral

separation allows the observers to better perceptually separate the input channels, the addition of other stimulus parameters (i.e., temporal separation) also may effect better channel separation (c.f., Gilliom & Sorkin, 1974). Therefore, the two experiments reported in the present chapter utilize spectral and temporal separation to facilitate channel separation, thereby raising the hypothesized performance ceiling, and allowing for the expression of time-sharing limitations in the divided-attention conditions.

General Procedure

Observers

Trained psychophysical observers were run singly or in pairs in a sound-attenuating chamber. Each had normal hearing and was paid an hourly wage plus a bonus upon completion of the experiment. The author served as an observer in the second experiment.

Method

The procedure used in the present series of experiments was similar to that in the first study (Chapter II), employing standard, same-different frequency discrimination tasks. Continuous, wide-band {limited only by earphone [Telephonics TDH-39(300)] characteristics}, binaurally uncorrelated noise was present during all conditions. Signals were gated on and off at positive-zero crossings. There were three listening conditions. In the monaural (M) condition, the observers performed the frequency discrimination in one ear, with only noise presented to the other. The two dichotic stimulus presentation conditions employed two standard and comparison stimuli, one pair presented to each ear. In the selective-attention (S) condition, the observers were

instructed always to listen and respond to only one ear while ignoring the stimuli presented to the other. In the divided-attention condition, they were instructed to respond to frequency discriminations in both ears. (See Figure 2-1 in Chapter II for a schematic representation of the stimulus and response contingencies in these experiments.)

The comparison stimulus of the same-different task was either the same frequency as the standard (f) or increased by a fixed amount (Δf) with an independent probability in each ear of 0.50. In the monaural condition, the frequency of the "different" comparison stimulus was adjusted to yield stable values of d' of approximately 3.0. Following stabilization of performance in the monaural conditions, the selective-attention conditions were run, followed by the divided-attention condition. Performance was allowed to stabilize on each of the dichotic stimulus presentation tasks prior to beginning another condition.

After the divided-attention condition was completed, psychometric functions were generated for several observers in the selective-attention conditions by systematicly increasing the frequency change (when "different") in the attended channel until monaural performance levels were reached. Values of Δf in the nonattended channel were held constant at the value required for $d' \simeq 3.0$ in the monaural condition.

Data were gathered in blocks of 150 trials with each block taking approximately 8.75 minutes. Rest intervals between several blocks of trials served to diminish effects of boredom and fatigue on performance.

Experiment I

It was suggested in Chapter II that an inability to successfully separate the input channels is a major limiting condition in these experiments. The present experiment investigates this channel separation and attempts to identify some of the factors which might facilitate the perceptual distinctiveness of the earphone channels. Toward this aim, frequency separation as well as earphone (localization) separation is made available to the observers in the first experiment. In Chapter II, I noted that the performance deficit with dichotic stimulus presentation conditions was probably not related to the classical concept of critical bands. However, there is no reason to assume that a critical band-like phenomenon for recognition either exists or would be similar to that for detection. Thus, even though a separation of several hundred Hertz did not affect channel-separation, there is no reason to expect that a much wider separation also will have no effect. The present experiment uses extreme frequency separation in an attempt to provide spectral information which could be used to increase channel separation. With increased channel separation, the hypothesized performence ceiling may be raised, allowing for the expression of time-sharing limitations in the overall performance data. If the pattern of performance deficits is altered, then one of the characteristics of this limiting factor will have been identified.

Method

Three well-trained psychophysical observers were used. The same-different frequency discriminations involved a 200-msec standard stimulus which was fixed in frequency (f) at 1305 Hz for the left ear and

3339 Hz for the right. The 200-msec comparison stimulus was either the same frequency as the standard (f) or, with a probability of 0.5, increased by a fixed amount (Δf). The interval between the standard and comparison stimuli was 400-msec in duration. For each observer, the value of Δf in a given earphone channel was adjusted in the monaural (M) condition to yield values of d' approximately 3.0. The signals were clearly audible with 10 Log (E/N_o) approximately equal to 42.5.

Results and Discussion

The performance data for all observers are shown in Figure 3-1.

Insert Figure 3-1 about here

The values of d' in this figure represent mean performance values irrespective of stimulus/response events in the contralateral channel. The (monaural) values of Δf (shown in parentheses) are consistent with Henning's (1967) data using similar frequencies, signal-to-noise ratios, and levels of performance. As in the first experiment, performance in the monaural (M) condition was manipulated independently in each ear for all observers, and the performance data were analysed using separate one-way analyses of variance with multiple contrasts to determine individual condition effects. As can be seen from Figure 3-1, there was a significant decrement in performance from monaural to dichotic (S, D) stimulus presentation conditions. These results are similar to those reported in Chapter II. However, unlike the previous experiment, there is a significant difference between the selective-attention (S) and divided-attention (D) performance levels, dem-

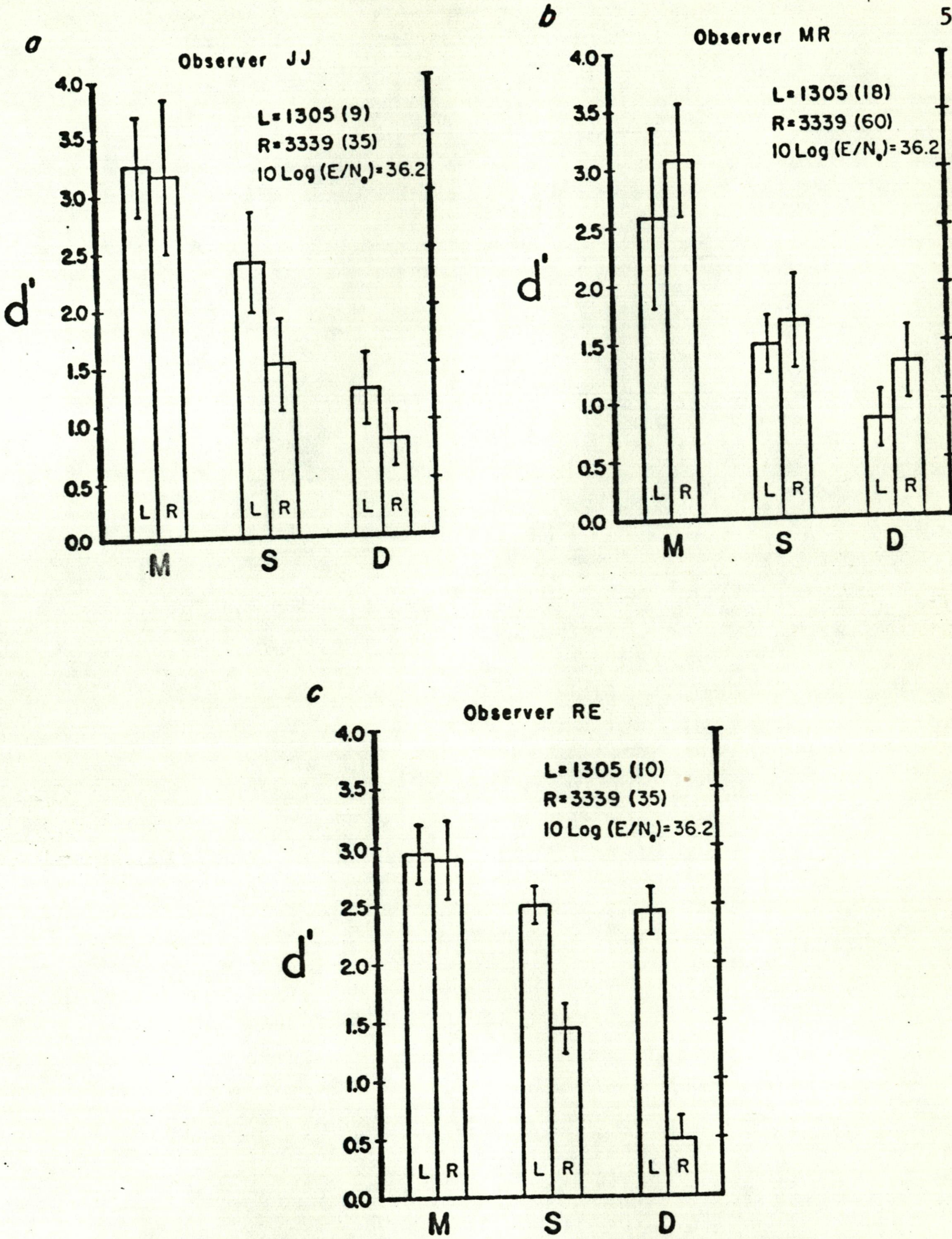

Figure 3-1. (a-c) Overall performance for all observers on the monaural (M), selective-attention (S), and divided-attention (D) tasks for Experiment I. One standard deviation is plotted above and below the mean values of d'. Change in frequency (in Hz) is indicated in parentheses beside each base frequency.

onstrating a time-sharing as well as a channel-separation limitation. Since the overall level of performance in the selective-attention condition is higher than in the previous chapter, the observers probably have been able to use the frequency separation of the stimuli to obtain some degree of perceptual separation between the two channels. However, performance in the selective-attention condition was still below monaural performance levels. Thus, I must conclude that complete channel separation was not obtained.

The psychometric functions for two observers in the selective-attention condition are presented in Figures 3-2 and 3-3. Increases

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Insert Figures 3-2 and 3-3 about here

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in Δf from 9 to 11 Hz (22%) and from 35 to 67 Hz (91%) are required for the first observer (Figure 3-2) in the left and right ears to equate performance to monaural stimulus condition levels. For the second observer, increases in the left ear from 10 to 13 Hz (30%) and in the right ear from 35 to 65 Hz (86%) are required for monaural levels of performance (Figure 3-3). In so far as comparisons across two experiments are valid, these increases are substantially lower than the approximate 280% for another observer reported by Ahroon (1976, see Figure 3-7 in the appendix to this chapter). This comparison further supports the suggestion that the observers in the present experiment had a greater ability to separate the input channels than the observers in the earlier chapter.

<u>Conditional</u> <u>Performance</u>.-The results of the first chapter suggested that a performance ceiling may have been responsible for overall

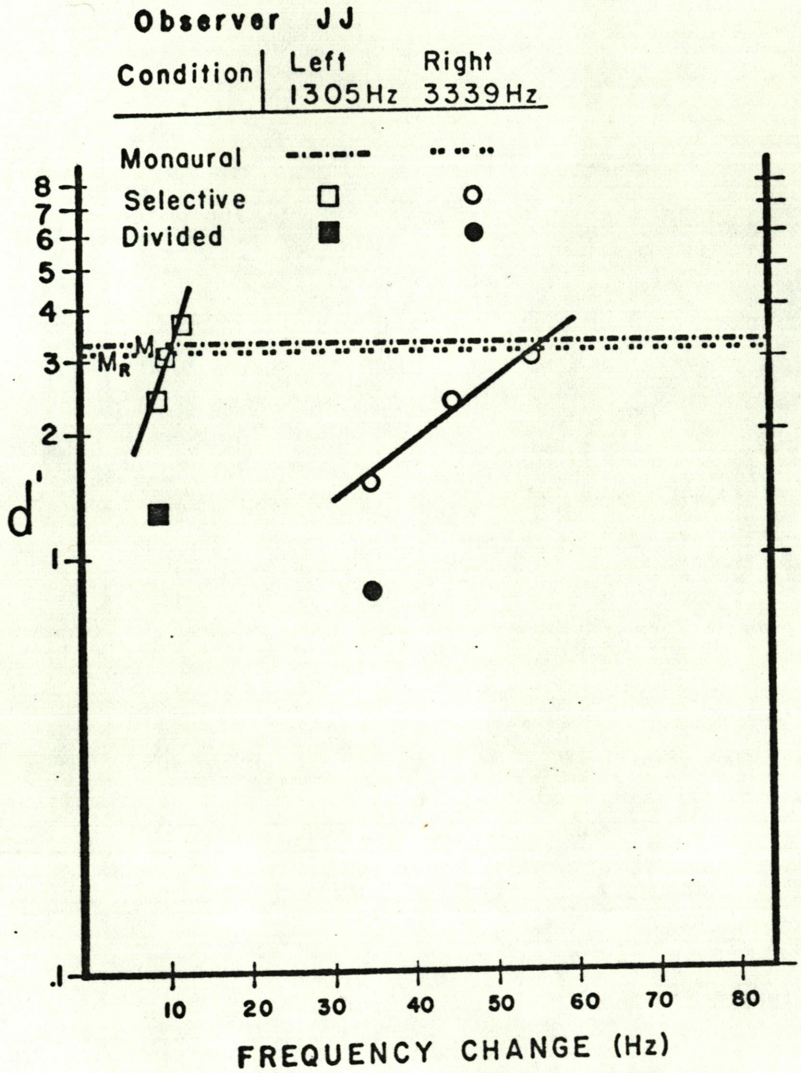

Figure 3-2. Psychometric functions for frequency discriminations in the selective-attention condition for Observer J.J.

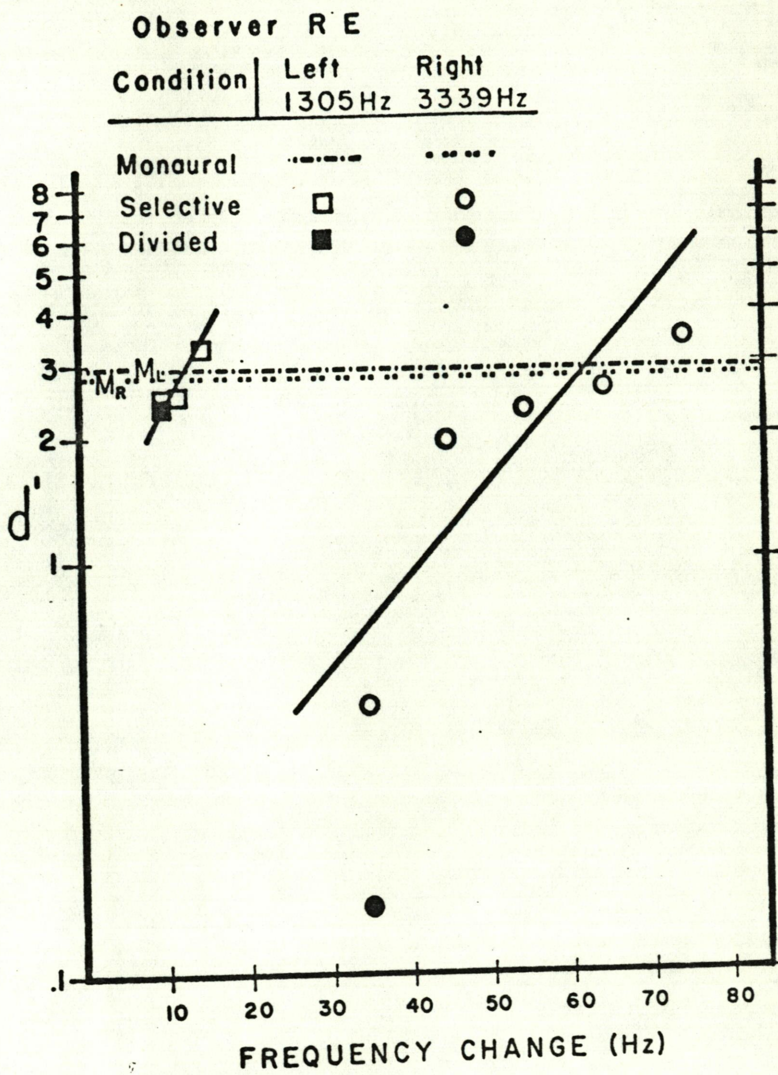

Figure 3-3. Psychometric functions for frequency discriminations in the selective-attention condition for Observer R.E.

performance similarity between the selective-attention and divided-attention conditions. The performance ceiling of approximately 1.0 (in d' units) was the result of chance performance when the stimulus events in the two ears were nonequivalent along with relatively high performance when the stimulus events were equivalent. In the present experiment, the observers appear to have achieved some degree of channel separation and therefore, one might expect this increase to allow better-than-chance performance with nonequivalent stimulus events in the selective-attention condition. Table 3-2 presents the performance conditional upon equivalent and nonequivalent stimulus events in the two channels for all observers in this experiment. Ex-

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Insert Table 3-2 about here

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amining the data for the selective-attention condition, performance is significantly greater than chance with nonequivalent stimulus events for both ears of all three observers. With equivalent stimulus events, performance in both channels was at or near monaural performance levels in the selective-attention condition for all observers, as in the earlier experiment (see Table 3-1).

Differences between selective-attention and divided-attention conditions, which are probably the result of time-sharing factors, should be evident in a change in conditional performance in the two dichotic stimulus conditions. In the first study (Chapter II), there were differences between the two conditions in the values of d' conditional upon equivalent stimulus events in the two ears. However, with non-equivalent stimulus events, since performance was already at chance

Table 3-2

Performance Conditional Upon Contralateral

Stimulus Events with Frequency Separation

	Selective Attention				Divided Attention			
	Equivalent		Nonequiv.		Equivalent		Nonequiv.	
Obser.	L	R	L	R	L	R	L	R
J.J.	3.67	2.59	1.76	0.80	2.11	1.72	0.66	0.10
M.R.	2.96	2.55	0.59	1.13	2.53	3.09	-0.10	0.34
R.E.	3.58	2.30	1.93	0.83	3.01	0.86	2.00	-0.03

in the selective-attention condition, divided-attention performance could not have been decreased by requirements to monitor two channels simultaneously. In the present experiment, performance conditional upon both equivalent and nonequivalent stimulus events was poorer in the divided-attention than in the selective-attention condition--thus mirroring the overall performance differences between these two listening conditions. Once again, I conclude that a wide frequency separation of the signals to the two channels did provide an additional means by which the observers were able to better perceptually separate the input channels.

Experiment II

In the first experiment, frequency separation did appear to provide some relief from channel-separation limitations in two-channel frequency discriminations. Another stimulus separation (e.g., temporal separation of the stimulus presentation to the ears) also may provide a means by which an observer can perceptually distinguish the two earphone channels. Gilliom and Sorkin (1974), in reviewing the two-channel signal detection literature, concluded that sequential stimulus presentation procedures produce smaller overall performance deficits in divided-attention tasks than simultaneous presentation. This experiment examines the effect of sequential presentation (i.e., temporal separation) on two-channel frequency discriminations.

Method

Three well-trained psychophysical observers were used. The author served as one of these observers. In this experiment, the standard and comparison stimuli were 100 msec in duration with the offset of

one channel concurrent with the onset of the other. The inter-stimulus-interval for a single channel was 500 msec. These temporal relationships functioned to split the 200-msec observation intervals from the last experiment in half, assigning each half to a separate input channel. The standard stimuli were fixed at 1605 Hz for the left ear and 1739 Hz for the right. The signals were clearly audible with 10 Log (E/N_o) equal to 39.5. All three observers initially ran with the left channel leading the right in time. Two of the observers (W.A. & J.V.) also performed the dichotic conditions with the opposite temporal relationships (i.e., the right channel preceding the left).

Results and Discussion

The performance data for all observers are shown in Figure 3-4.

Insert Figure 3-4 about here

In this figure, the leading ear is on the left of each pair of bars and the trailing ear is on the right. There appears to be a unidirectional temporal interference of one channel upon the other with the trailing-ear (on the right of each pair of bars) performance better in the selective-attention condition than in the divided-attention condition. This pattern is not repeated in the leading ear, where there are generally no differences between selective-attention and divided-attention performance.

Elliott (1971) has demonstrated that backward masking is more effective than forward masking. Although her data represent a threshold-type phenomenon, the signal-masker relationships are similar to the present experiment. Moreover, with clearly detectable signals,

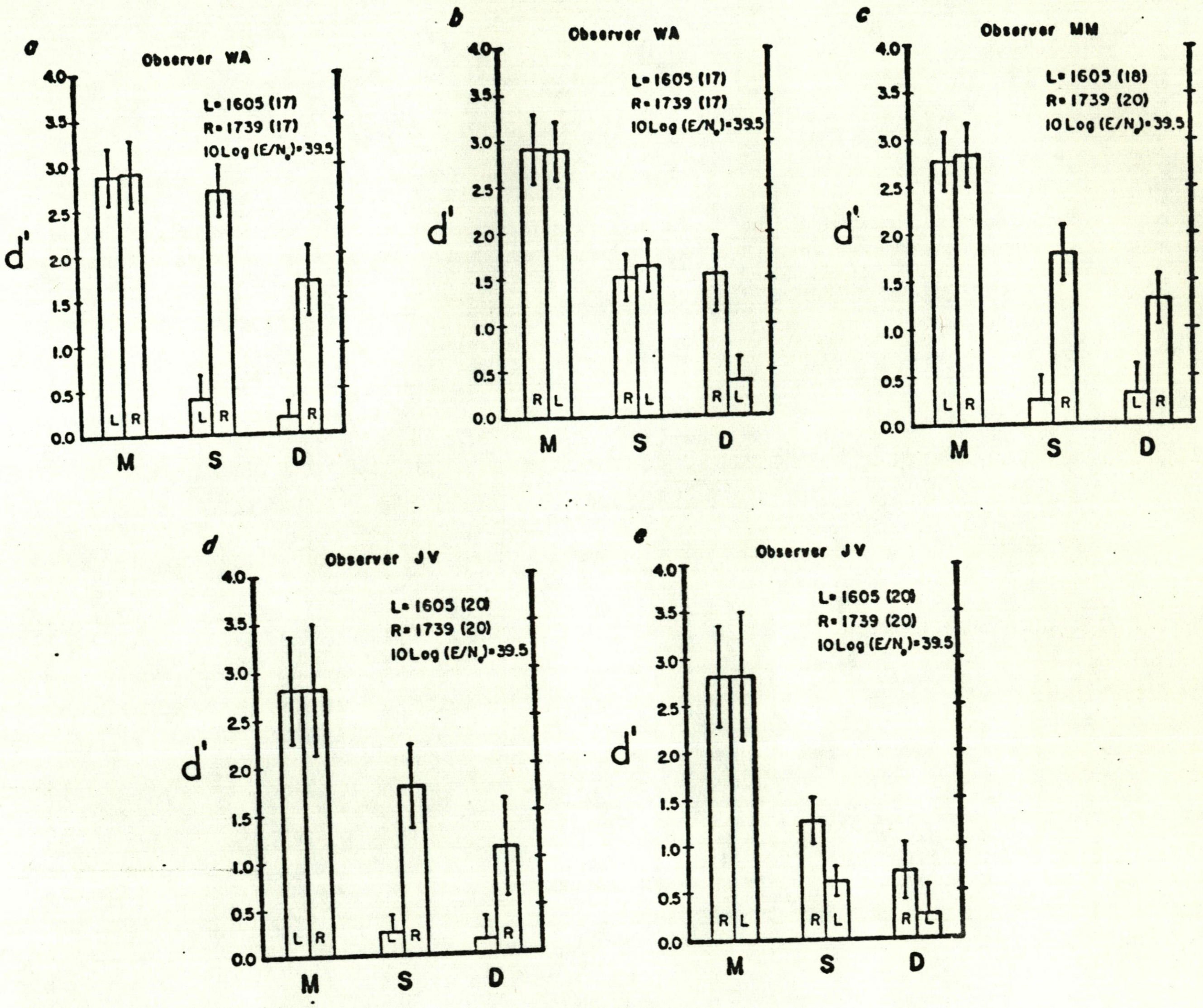

Figure 3-4. (a-e) Overall performance for all observers on the monaural (M), selective-attention (S), and divided-attention (D) tasks for Experiment II. One standard deviation is plotted above and below the mean values of d'. Change in frequency (in Hz) is indicated in parentheses beside each base frequency. The left bar of each pair of bars represents performance in the leading channel, the right bar--the trailing channel.

Massaro (1970, 1973) has reported significant interference due to the presence of a temporally leading or trailing contralateral stimulus. Leshowitz and Cudahy (1973; see also Ronken, 1972; Cudahy & Leshowitz, 1974) failed to replicate these results and suggested that Massaro's use of untrained observers and possible improper use of signal detection theory (TSD) measures may have accounted for his results. Results of the present experiment with highly practiced observers do not support the conclusions of Leshowitz and Cudahy and only partially support Massaro's. A significant methodological difference in both the present experiment and Massaro's research from that of Leshowitz and Cudahy is the addition of stimulus change in the contralateral channel (i.e., stimulus uncertainty), with the change adjusted to be well above threshold. The presence of stimulus change has been hypothesized to be a contributing factor in backward and forward masking effects (Pastore & MacLatchy, 1974, 1975; Pastore, Puleo, & MacLatchy, 1975) and interference effects (Pastore, Ahroon, Wolz, Puleo, & Berger, 1975). Watson and Spiegel (1976) and Watson, Espinoza-Varas, and Kelly (1976) also have implicated stimulus uncertainty as a significant variable in auditory discrimination paradigms. Further, in a speeded reaction-time study, frequency discriminations were significantly impaired by the addition of both a forward or backward changing interference stimulus relative to conditions in which the interference stimulus was held constant (Pastore, Ahroon, Puleo, Crimmins, Golowner, & Berger, 1976). Although these stimulus changes were ipsilateral, it seems clear that stimulus change is a factor in the present results. Furthermore, Pastore and Friedman (in preparation) suggest that contralateral change

also may have a significant masking-like effect. Based upon Massaro's analysis, we would predict that performance in a channel coupled with a backward-interference stimulus should be depressed relative to either channel when coupled with a forward-interference stimulus. An examination of Figure 3-4 supports this prediction generally only when the left ear is leading.

The unidirectional temporal interference may be confounded by an additional variable. The psychometric functions for two observers in the selective-attention conditions are presented in Figures 3-5 and 3-6. Note that the psychometric functions for the leading ear are

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Insert Figures 3-5 and 3-6 about here
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shifted to the right of the trailing ear, but that the slopes appear to remain relatively constant within a channel. The shift in psychometric functions gives further support for the suggestion that backward interference has a greater effect on successive frequency discriminations than does forward interference. However, the psychometric functions for the left channel are both lower and flatter than for the right channel. The most likely explanation for the differences in slope of the psychometric functions involves a design artifact caused by the choice of the relative frequencies and direction of change used in the present study. That is, since observers were always listening for an <u>increase</u> in frequency (in the same-different tasks), higher frequencies in the contralateral channel may have produced more confusion than lower frequencies.

<u>Conditional Performance</u>.-In the first experiments, I found that

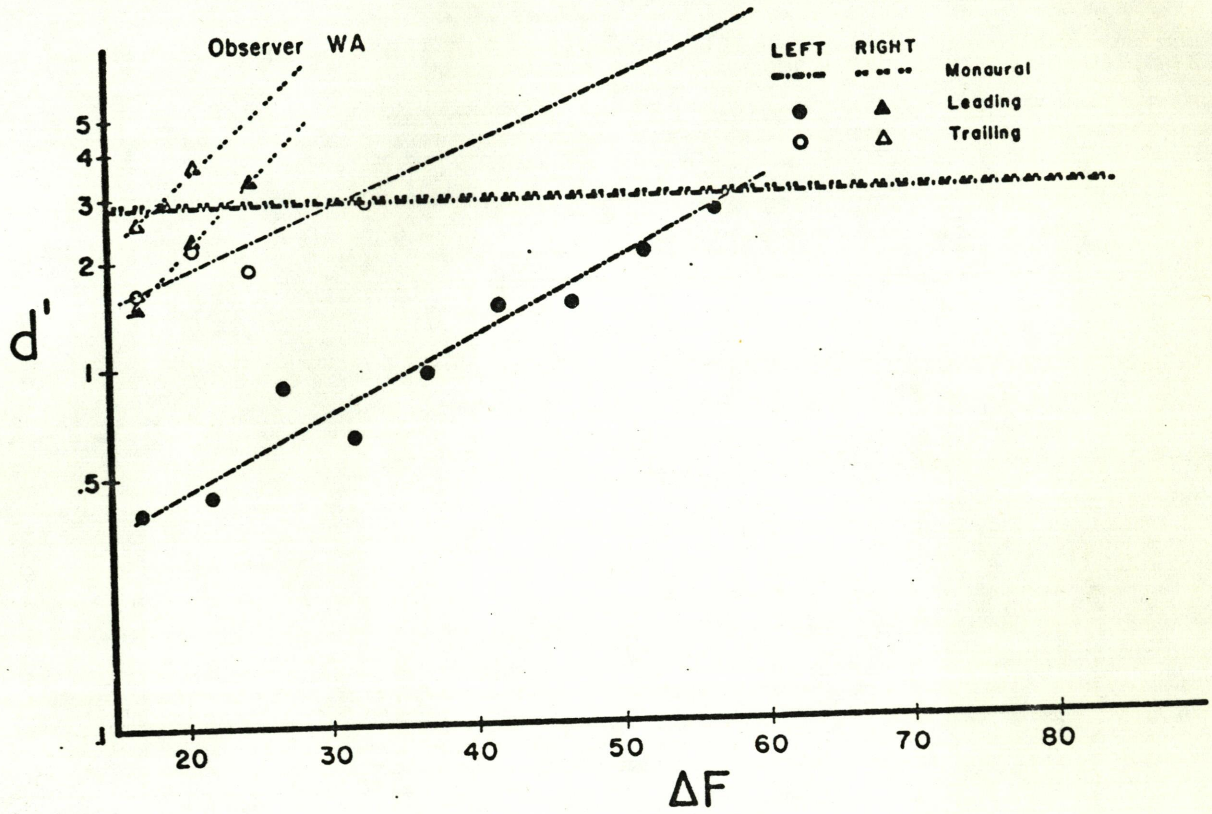

Figure 3-5. Psychometric functions for Observer W.A. in the selective-attention conditions. Solid symbols represent performance in leading channels; open symbols represent trailing channels.

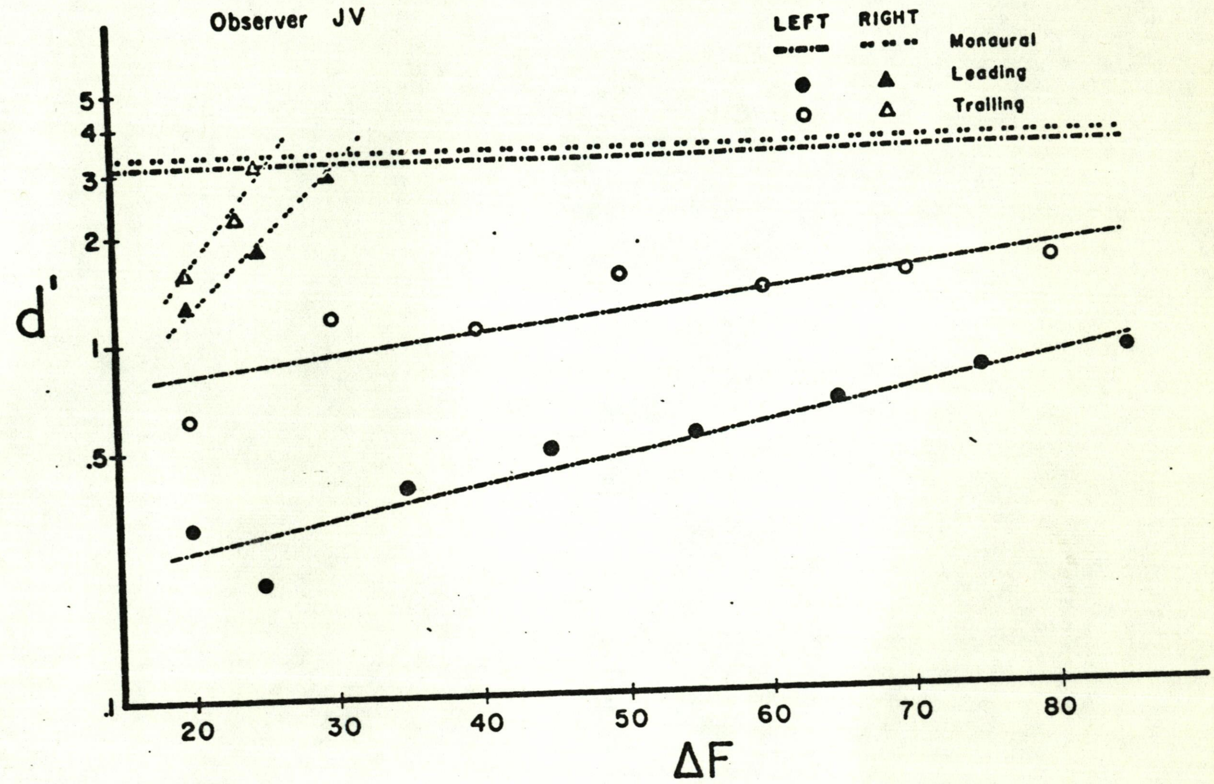

Figure 3-6. Psychometric functions for Observer J.V. in the selective-attention conditions. Solid symbols represent performance in leading channels; open symbols represent trailing channels.

performance is higher in a single channel when stimulus events in both channels are equivalent than when they are nonequivalent. Table 3-3 presents the performance conditional upon equivalent and nonequivalent stimulus events for all observers in this experiment. An examination

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Insert Table 3-3 about here

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of the table further supports this finding for the present experiment for all observers, channels, temporal orders, and time-sharing requirements. This pattern of results seems to indicate that there remains some degree of perceptual fusion with sequential stimulus presentation. Furthermore, the effect of requiring the observers to perform both tasks is evident in decreased performance from selective- to divided-attention conditions with equivalent stimulus events in both channels. A similar performance decrement conditional upon nonequivalent stimulus events generally is apparent only in the trailing channel. These results further support the suggestion that time-sharing factors are involved in sequential two-channel frequency discriminations as well as in simultaneous discriminations.

Summary

The present experiments describe two factors involved in two-channel frequency difference limens. The first factor is an apparent limited ability of human observers to perceptually separate the clearly audible inputs to different ears. This factor is most evident when the signals to the two ears are relatively close in frequency and where the observers appear to be able to recognize that a change in frequency occurred, yet could not report in which ear the change occurred. The

Table 3-3

Performance Conditional Upon Contralateral

Stimulus Events with Temporal Separation

	Selective Attention				Divided Attention			
	Equivalent		Nonequiv.		Equivalent		Nonequiv.	
Obser.	L	T	L	T	L	T	L	T
W.A.*	2.58	3.64	-1.40	2.31	1.73	2.07	-1.32	1.37
W.A.†	2.50	3.06	0.89	0.76	2.07	1.99	0.92	-0.80
M.M.*	1.58	1.94	-1.08	1.69	1.02	1.67	-0.55	0.95
J.V.*	1.51	2.04	-1.27	1.64	0.51	1.13	-0.34	1.10
J.V.†	1.74	1.46	0.85	-0.38	0.80	0.59	0.65	-0.17

* Left Ear Leading

† Right Ear Leading

second factor is a decrease in performance as a result of the requirement to monitor two sources of stimulation simultaneously.

The limited ability of observers to perceptually separate two input channels to perform frequency discriminations was clearly altered by both frequency and temporal separation. Frequency separation was effective in increasing a hypothesized ceiling and allowed a demonstration of time-sharing limitations in two-channel frequency discriminations in which performance in the divided-attention conditions was significantly poorer than in the selective-attention conditions.

Using sequential stimulus presentation (i.e., temporal separation), time-sharing limitations in the form of lower performance in divided- than in selective-attention conditions were also demonstrated. The presence of contralateral backward interference on the frequency discrimination in the leading channel appeared to prevent any increase in the level of the performane ceiling and therefore in essentially equal performance in the dichotic stimulus presentation conditions. The present data are consistent with the two-channel detection literature by Sorkin and Moray and their colleagues when examining performance deficits as the result of both channel-separation (cross-channel interference) and time-sharing limitations.

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Footnotes

[1] Throughout this paper, I refer to the following stimulus/response conditions: Monaural--stimuli presented to only one earphone; Divided Attention--independent stimuli presented to both earphones and the observer asked to respond to both sets of stimuli; Selective Attention--independent stimuli presented to both earphone channels, but the observer asked to respond to one specific earphone.

[2] The nature of the cause of the performance deficit was modified to a cross-channel processing interference when Sorkin, Pohlmann, & Gilliom (1973) continued to find these performance deficits when the signals were separated in frequency and a intensity levels at which contralateral and/or remote masking should have been ineffective.

[3] Equivalent stimulus events are defined as a frequency change either in both channels or in neither channel. On the other hand, nonequivalent stimulus events are defined as a frequency change in only one channel.

[4] The central perceptual image that the observers have reported in two-channel frequency discriminations (Chapter II) clearly is not an example of lateralization or binaural fusion as described in the literature (Perrott & Barry, 1969; Perrott, Briggs, & Perrott, 1970) since the frequency range in which the present observers are listening is orders of magnitude different from that used in the binaural fusion research. However, since the observers can easily hear a change in frequency, but are not able to localize the change, some sort of perceptual fusion must be involved in these experiments using clearly audible signals.

[5] Given a <u>complete</u> inability to separate the channels, only the trials with nonequivalent stimulus events in the two channels would be affected. [Performance with equivalent stimulus events should be near monaural levels (i.e., $P(C) \simeq .90$ to $.95$.] Since approximately 50% of the trials contained nonequivalent stimulus events, one might expect that average performance to be approximately 75% correct, corresponding to a value of d' near 1.0.

Appendix

In the current investigations, the pattern of results from at least two (possibly three) observers (J.V., R.E., & M.M.) appears to be substantially different than that from other observers. Initially, there were large performance differences between the two ears under simultaneous, dichotic stimulus presentation conditions (e.g., Figure 3-1c). This difference clearly was <u>not</u> the result of differential sensitivity of the two ears since there were no significant differences in monaural performance levels within or between observers, and Δf values were all similar. The observers with large differences in dichotic performance also often complained of an inability to "hear" the stimuli to one ear. (A post-hoc analysis of loudness revealed no differences between ears.) These two factors suggest that, for these observers, there was an asymmetrical contribution to the overall perceptual array of the stimuli to the two ears.

Figures 3-7 and 3-8 present the psychometric functions in the selective-attention conditions for two observers [taken from Ahroon (1976)]--one normal observer (Figure 3-7) and one whose performance is described above (Figure 3-8). The asymmetrical influence of one

Insert Figures 3-7 and 3-8 about here

ear upon the other appears to cause a flattening of the psychometric function in one ear and may cause a steepening of the function in the other--both relative to the psychometric functions for the normal observer. Therefore, the stimuli presented to Observer J.V.'s right ear appear to interfere greatly with frequency discriminations in her left

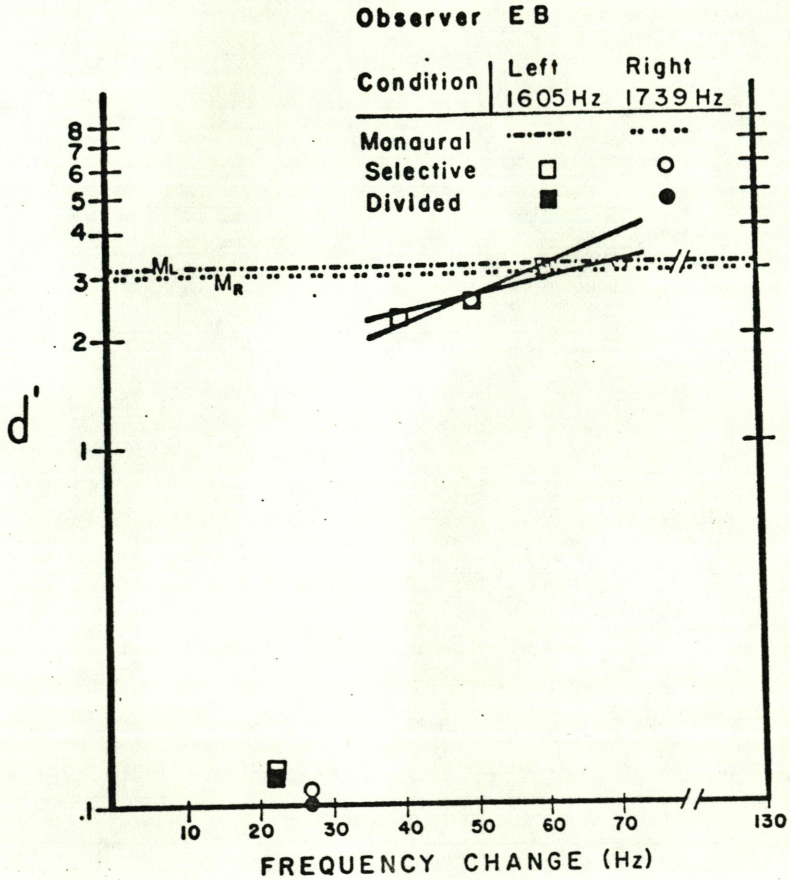

Figure 3-7. Psychometric functions for frequency discriminations in the selective-attention condition for Observer E.B.

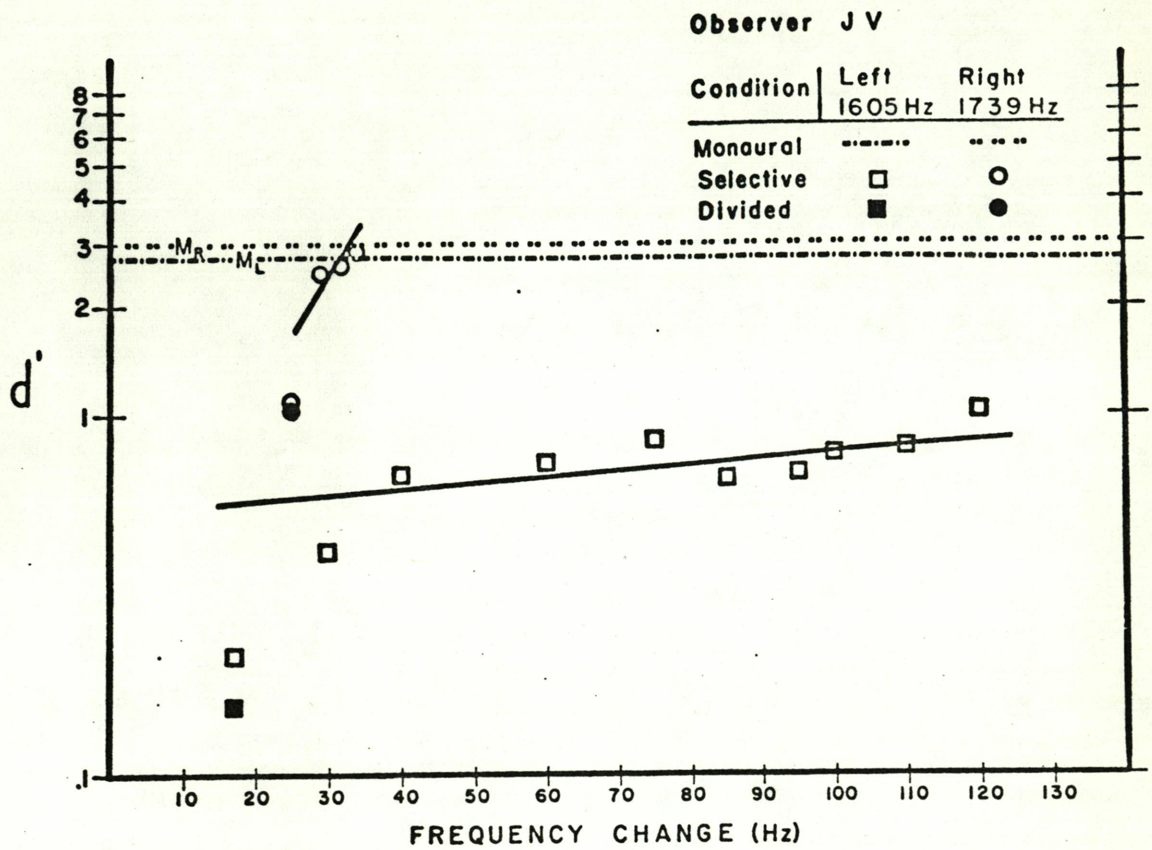

Figure 3-8. Psychometric functions for frequency discriminations in the selective-attention condition for Observer J.V.

ear.

One explanation for the large performance differences between the two ears suggests that experimental artifacts are responsible for both performance differences and changes in the slope of the selective-attention psychometric functions. Observer W.A., Experiment II, shows psychometric functions quite similar to those of Observer J.V., an observer who had demonstrated a large ear difference previously (Ahroon, 1976). However, Observer W.A. has not shown any ear differences in simultaneous two-channel frequency discrimination tasks (e.g., Figure 2-2c,d; Chapter II). Therefore, it is likely that W.A.'s ear differences are related to differences in experimental design between the first experiment (Chapter II) and Experiment II in the present chapter. Furthermore, the asymmetrical contribution to the overall perceptual array (as inferred from ear differences and subjective reports) seems to have no effect on the psychometric functions in the selective-attention condition for Observer R.E. (Experiment I) where spectral separation has been added to the two-channel tasks.

Other explanations for the differences between observers are that these particular observers with ear differences may have an ear advantage as described by Kimura (1969) or an ear dominance for pitch information similar to that described by Efron and Yund (1974, 1976) and House (1975). An ear dominance by some of the observers could explain much of the between-observer variability in the results. For example, in Experiment I, the only instance in which selective-attention performance was not improved relative to divided-attention performance was for such an observer (R.E.). In this case, performance

in the divided-attention condition appeared to be raised relative to the other observers. Since an ear dominance would increase the perceptual salience of the stimuli to the dominant ear (in dichotic tasks), one might expect an increase in performance in divided-attention conditions for that ear, at the expense of the other. Likewise, in Experiment II, the non-dominant ear produced less performance decrement as a backward-interference stimulus than the dominant ear, and therefore performance was improved in the selective-attention condition when the leading ear was dominant (see Observer J.V., Figure 3-3e). Whether an ear dominance, an experimental design artifact, or some other factor is involved in the apparent asymmetric influence of one ear on frequency discriminations in the other, it seems clear that this variable should be the subject of additional research.

Chapter IV

Frequency Sensitivity with Simultaneous Contralateral Stimulation

Abstract

The ability of human observers to perform a same-different frequency discrimination in the presence of independent, simultaneous contralateral tones was assessed. Performance (d') decreased to chance as the magnitude of stimulus change in the contralateral earphone was increased. The performance deficit was attenuated either when the contralateral stimuli were separated in frequency from the ipsilateral stimuli by 2000 Hz, or when stimulus uncertainty was reduced. Response bias (log β) increased as the contralateral change magnitude increased up to about 1.5 to 3 percent of the base frequency. With larger contralateral changes, response bias was reduced to a value of β near 1.0. The results are discussed in terms of the effects of stimulus uncertainty upon pitch discriminations in the presence of contralateral tones.

Frequency Sensitivity with Simultaneous Contralateral Stimulation.

I have been investigating the ability of human observers to simultaneously perform two independent frequency discriminations (Chapters II and III) and attempted to define the factors involved in two-channel listening tasks. In a paper examining methodological considerations in these two-channel frequency discriminations (Ahroon, 1976), I noted changes of the psychometric functions for frequency discriminations in one ear when the magnitude of the frequency change in the contralateral ear was increased. These data suggested that the ability of the observers to perform the single-channel frequency discriminations was affected not only by the presence of a competing set of contralateral, same-different stimuli, but also by the magnitude of the change in the contralateral earphone channel.

In earlier papers (Chapter II) I also have noted that performance was at or near monaural (single-channel) performance levels when stimulus events were equivalent in the two channels (i.e., both "same" or both "different" in the two-channel same-different frequency discriminations) and near chance when the stimulus events in the two channels were nonequivalent (i.e., one channel "same" and the other "different"). A correllary to this observation is that there seemed to be significant changes in response bias depending on whether or not there was a contralateral change on any trial. That is, false alarms (false reports of frequency change) were more prevalent with contralateral change, while misses occurred more often when there was no contralateral change. It is the purpose of this brief report to assess empirically, under selective- or focused-attention conditons (similar to the earlier

chapters), the effect of contralateral change on both absolute sensitivity (d') and response bias (β) by systematically manipulating the magnitude of the frequency change in the contralateral channel.

Method

Observers

Four trained observers were run singly or in pairs in a sound-attenuating chamber. Each had normal hearing and was paid an hourly wage plus a bonus upon completion of the experiment.

Procedure

The observers were asked to perform a monaural same-different frequency discrimination, ignoring a second set of (same-different) stimuli which were presented in the contralateral earphone channel. The onsets and offsets of the standard (and comparison) stimuli in the two channels were simultaneous. [Note that this is the selective-attention condition (S) of several of the earlier studies (see Chapter II, Figure 1).]

All stimuli were 200 msec in duration, gated on and off with 5-msec rise-fall times (Grason-Stadler 1287B electronic switches). The interval between the standard and comparison stimuli of the same-different task was 400 msec. Continuous, wide-band, binaurally uncorrelated noise was present under all stimulus conditions (Grason-Stadler 2585 noise generators). All signals were clearly audible with 10 Log (E/N_o) approximately equal to 45. In the channel to be monitored, the frequency of the standard stimulus was 1000 Hz and the comparison was either 1000 Hz or 1010 Hz selected with a probability of 0.50. In separate 150-trial blocks, the frequency of the standard

(i.e., base frequency) in the contralateral earphone was 1000 Hz, 1044 Hz, or 3044 Hz. The comparision stimulus frequency was increased by 0, 5, 10, 20, 50, 100, 200, or 500 Hz (relative to the standard frequency) with a probability of 0.50 or 1.00 (also in separate blocks). (An additional frequency increase of 1500 Hz was used with the 3044 Hz contralateral base frequency.) A monaural condition also was run where there were no contralateral stimuli.

Following an extensive set of initial practice sessions, sets of sixteen 150-trial blocks were run per day. Each day the magnitude of contralateral frequency change was increased. In the first eight blocks, the probability of a frequency change in the contralateral channel was 1.00. In the second eight blocks, the probability was 0.50. Within each set of eight blocks, the first three blocks were considered practice. Therefore, the data reported in this chapter represent the average performance on five blocks of 150 trials each. Three observers ran with the 1000 Hz contralateral base frequency; two with the 1044 Hz; and three with the 3044 Hz.

Results and Discussion

Signal Detectability

The mean performance ($\bar{d}'$) for each stimulus condition is plotted in Figure 4-1. The most striking feature of this figure for all three

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Insert Figure 4-1 about here

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contralateral base frequencies (1000-, 1044-, and 3044 Hz) and both probabilities of contralateral change (50% and 100%) is the decrease in performance as the magnitude of the contralateral change increased.

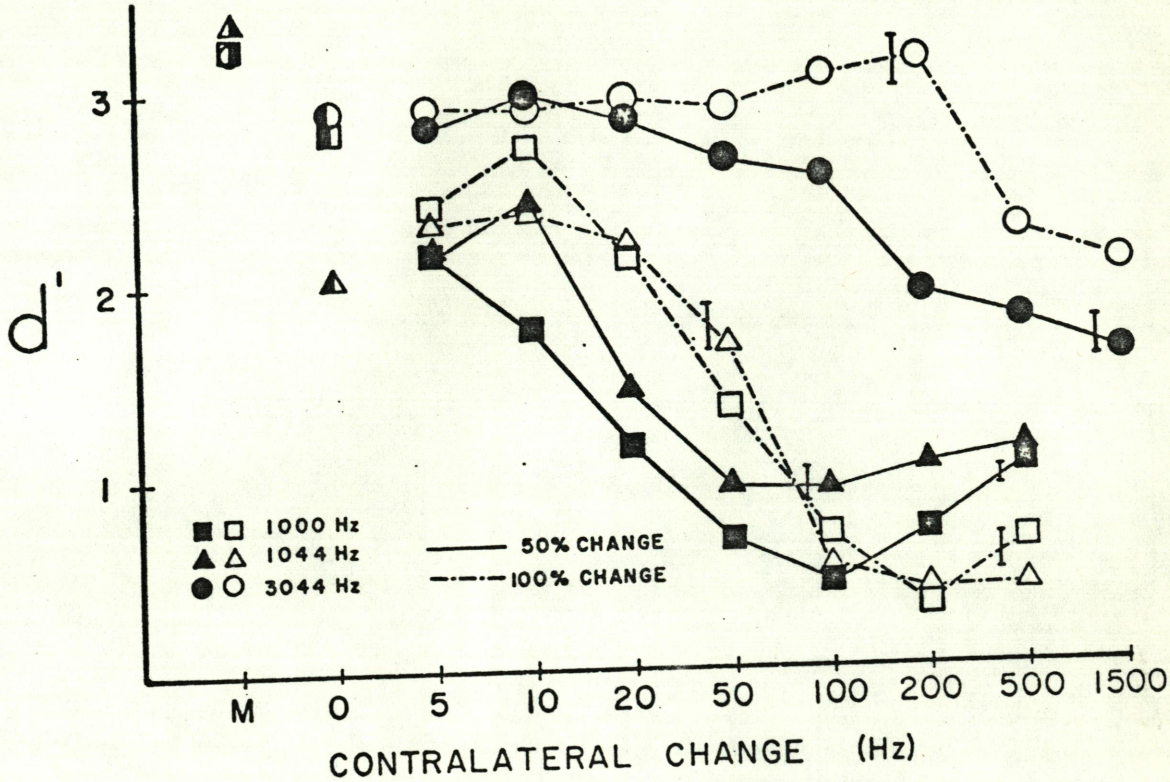

Figure 4-1. Mean performance of all observers in the present experiment. The broken lines (connecting open symbols) represent overall performance under conditions in which there was a frequency change in the contralateral channel on every trial. The solid lines (connecting filled symbols) represent performance when there was a contralateral change on only 50% of the trials. The squares represent conditions in which the contralateral base frequency was 1000 Hz; the triangles, 1044 Hz; and the circles, 3044 Hz.

This finding is consistent with the observation made in an earlier paper (Ahroon, 1976) that a change in the magnitude of contralateral change may shift the psychometric function for the frequency difference limen in a selective-attention condition.

Also evident in Figure 4-1 is the fact that the functions are shifted both upward and to the right as the contralateral base frequency increased from 1000 Hz to 3044 Hz. The shift to the right probably reflects a relatively constant contralateral Weber fraction and was not unexpected. That is, with a constant value of Δf, $\Delta f/f$ (and thus the perceived magnitude of contralateral change) decreases and is less disruptive to pitch discriminations in the ipsilateral ear. The upward shift, also expected, probably represents a decrease in the ability of higher frequencies to interfere with the frequency discriminations around 1000 Hz. I have noted in an earlier paper (Chapter III) that extreme frequency separation (as represented by the 3044 Hz functions) results in an increase in performance in selective-attention tasks relative to conditions in which the frequencies to the two earphone channels are within the same critical band (as represented by the 1044 Hz functions). The increase in performance in the past and present experiments probably is the result of an increased ability of the observers to perceptually separate (from the overall perceptual array) the inputs to the two earphone channels (see Chapter III).

Considering the conditions when there was a contralateral frequency change on every trial, performance generally seems to be better than in conditions in which there was a change on only 50% of

the trials. This may represent either the fact that the observers had only two possible perceptual events to discriminate when stimuli in the contralateral channel changed on every trial (and therefore less uncertainty), or that a constant stimulus may have been easier to ignore [or filter out; c.f., Broadbent(1958)]. In addition to the factors mentioned in the previous chapters, the present results (regarding stimulus-change probability) may be consistent with Moray's data because of the low ($p = 0.10$) contralateral stimulus uncertainty inherent in his tasks.

In the earlier chapters I have used an analysis of performance conditional upon stimulus/response events in the contralateral channel. As noted above, I have demonstrated significant differences in performance between conditions in which the stimulus events in the two channels were equivalent or nonequivalent. Unlike earlier studies on two-channel signal detection (Pastore & Sorkin, 1972; Sorkin, Pastore, & Pohlmann, 1972; Sorkin, Pohlmann, & Gilliom, 1973), I have not found significant differences in performance conditional upon the actual or perceived presence of a signals (i.e., frequency change) in the contralateral channel.

Figure 4-2 presents performance conditional upon a change or no change in the contralateral channel. Performance at a one percent

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Insert Figure 4-2 about here

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contralateral frequency change is similar whether or not there is contralateral change. This magnitude of Δf in the contralateral channel is roughly the same as the frequency change utilized in the earlier

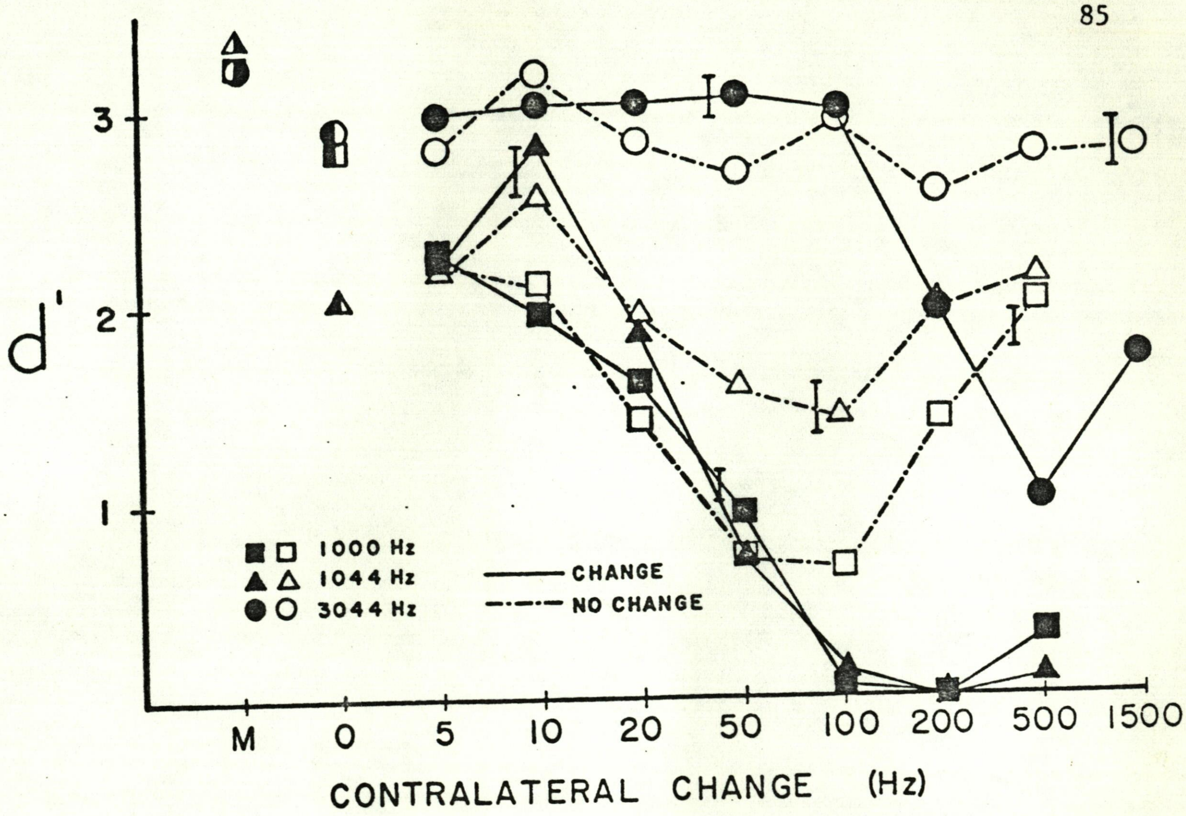

Figure 4-2. Mean performance conditional upon a change or no change in the contralateral earphone. The solid lines and filled symbols represent the trials on which there was a contralateral change while the broken lines and open symbols represent performance conditional upon no contralateral change. The squares represent conditions in which the contralateral base frequency was 1000 Hz; the triangles, 1044 Hz; and the circles, 3044 Hz.

chapters. Therefore, the present results support the observations of the lack of performance differences with this conditional analysis.

It is apparent from Figure 4-2 that, as the magnitude of the contralateral change increases in the 1000- and 1044 Hz conditions, d' decreases toward chance given a contralateral change, but not as drastically with no contralateral change. Also, with large frequency changes using a contralateral base frequency of 3044 Hz, it appears that almost the entire performance deficit depicted in Figure 4-1 (solid lines connecting filled circles) may be accounted for by performance when there was a change in the contralateral channel. These results appear to parallel those of Sorkin et al. (1973) who report that most of the performance deficit in their selective-attention experiments results from trials on which there was an actual or perceived signal in the contralateral channel.

Response Bias

In the earlier chapters, I had not examined response bias in a systematic manner. In each case, there appeared to be no systematic changes in overall bias (i.e., mean log $\beta \simeq 0.00$). However, one purpose of the present experiment was to examine changes in response bias as a result of contralateral change. Figure 4-3 presents the mean log β for each stimulus condition, subject to contralateral change and no change. The mean log β for overall performance under both proba-

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Insert Figure 4-3 about here

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babilities of contralateral change (0.50 and 1.00) was at or near zero (i.e., no bias) and is not plotted. This observation supports the

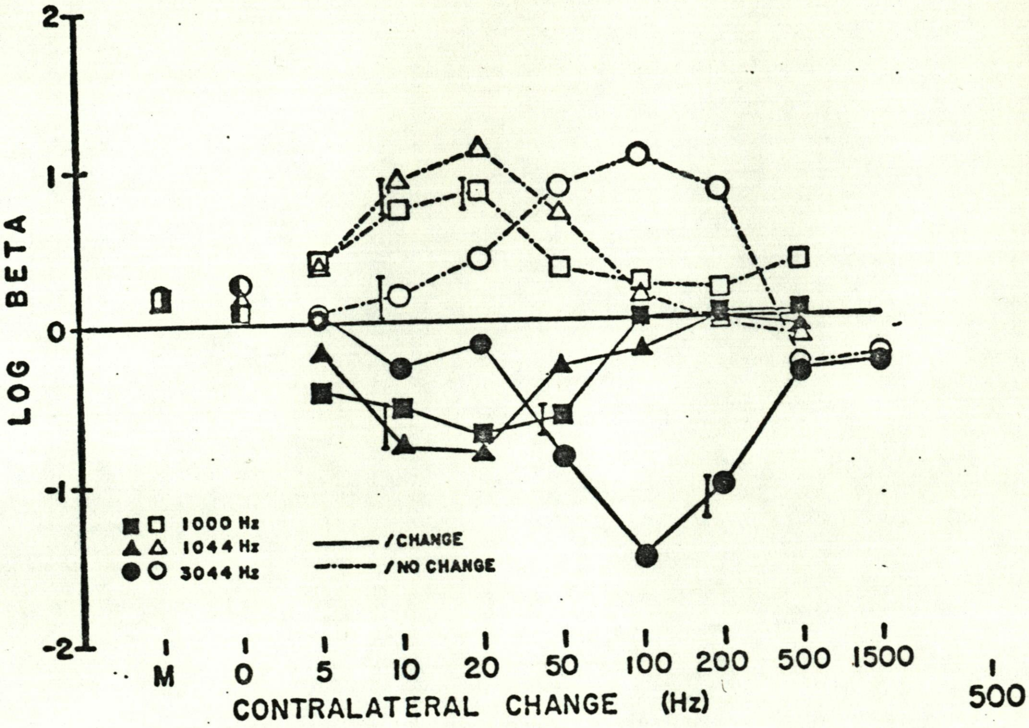

Figure 4-3. Mean log beta conditional upon a change or no change in the contralateral earphone. The solid lines and filled symbols represent the trials on which there was a contralateral change while the broken lines and open symbols represent performance conditional upon no contralateral change. The squares represent conditions in which the contralateral base frequency was 1000 Hz; the triangles, 1044 Hz; and the circles, 3044 Hz.

conclusions concerning response bias in our earlier experiments.

The upper set of functions in Figure 4-3 represent mean log β for trials on which there was no contralateral change. The almost exact mirror-image functions represent response bias for trials on which there was a contralateral change. It is clear from the figure that there exists a nonmonotonic relationship between conditional response bias and contralateral change magnitude as well an an apparent (negative) correlation between log β for contralateral-change and no-change trials. All functions appear to peak when the change in frequency of the contralateral ear is 1.5 to 3 percent of the base frequency (15-30 Hz for the 1000- and 1044 Hz base frequency and 50-100 Hz for the 3044 Hz function). One may assume, therefore, that at this value the stimulus change is fairly detectable ($d' \simeq 2.0$), but there is the maximum amount of confusion regarding the location of the stimulus change. Given this confusion, when a change is heard in either channel, the observers apparently respond that a change occurred in the ipsilateral ear. Furthermore, when there was no contralateral change, the observers appeared to miss the ipsilateral changes.

As the frequency change in the contralateral ear is increased further, the response bias decreases. The decrease is probably the result of two factors. First, when there is a change in only one earphone, the observers begin to discriminate differences in the magnitude of the frequency changes, such that a small change represents an ipsilateral change and a large change represents a contralateral change. This discriminability was not apparent when the magnitudes of stimulus change in the two ears were relatively equal (i.e., the contralateral

change magnitude was detectable, yet not recognizable (c.f., Hawkins & Stevens, 1950; Pastore, 1973)]. Second, given the depressed performance for conditions in which the magnitude of the contralateral change was relatively large (see Figure 4-2), it is likely that the return of the functions in Figure 4-3 to a mean of 0.00 is caused by guessing (with no systematic bias toward one of the response buttons). Note that the functions for the 1000- and 1044 Hz contralateral base frequencies return to a value of 0.00 at the same contralateral frequency change that performance (d') was reduced to chance. Hence, the large contralateral change appears to perceptually mask the smaller, ipsilateral change. Since both conditional functions return to a value of β reflecting little or no response bias, both factors probably are operating to reduce bias with large frequency changes in the contralateral channel.

Summary

The present study has examined performance and response bias changes in selective-attention conditions within a two-channel, simultaneous frequency difference limen paradigm. Performance deficits in these experiments for the selective-attention conditions have been attributed previously to an inability of the observers to perceptually separate the inputs from the two earphone channels. The present study has demonstrated a drastic decrease in performance as the magnitude of the frequency difference increased in the contralateral channel. Further, considering response bias conditional upon change and no change in the contralateral channel, the present study has demonstrated a non-monotonic function relating bias and magni-

tude of contralateral change. These observations are consistent with the earlier results of two-channel frequency discrimination experiments.

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Chapter V

Summary and Conclusions

Summary and Conclusions

The present series of experiments represent a hybrid design of the approaches of the British and American groups discussed in the introduction (Chapter I), and appear to resolve the apparent controversy between these two groups. It is highly probable that the emphasis of the American group on threshold phenomena (detection) with discrete-trial procedures and the British group's emphasis on discrimination of clearly detectable signals (recognition) within tone-pulse trains have caused the differences in conclusions. The use of discrete-trial procedures and a method of analysis in which performance is assessed conditional upon contralateral stimulus/response events has allowed the American group to isolate the apparent source of errors within their paradigm. Since these errors have occured primarily on trials in which there was an actual or perceived contralateral signal, the American group has concluded that the (actual or perceived) contralateral signal interfers in some way with the perception of the ipsilateral signal (Sorkin, Pohlmann, & Gilliom, 1973). Although this finding recently has been confirmed by the British group (Moray, Fitter, Ostry, Favreau, & Nagy, 1976), Moray and his colleagues attribute such performance changes to the lack of response bias shifts due to the relatively high proportion of "signal" events in Sorkin's research, and continue to stress time-sharing limitations in divided-attention tasks.

The present investigation has identified two major factors (i.e., perceptual-separation and time-sharing limitations) that are involved in two-channel frequency discriminations and, by inference, possibly

in all two-channel listening tasks. In the absence of time-sharing requirements (i.e., selective attention), there is a performance deficit (relative to monaural tasks) which appears to be related to a limited ability to perceptually separate the stimuli to the two earphone channels. The perceptual-separation limitation appears to impose a ceiling upon performance in dichotic stimulus presentation conditions (selective and divided attention). If that ceiling is relatively low ($d' \simeq 1.00$), then the perceptual-separation limitation overshadows any effect of time sharing in the divided-attention conditions. In the presence of that low performance ceiling, time-sharing limitations are evident only through a partitioning of performance with equivalent and nonequivalent stimulus events. This division removes the near chance performance with nonequivalent stimulus events and allows the demonstration of significant performance deficits as the result of time sharing. The use of highly different stimulus parameters provides observers with a release from the high degree of perceptual fusion and results in better-than-chance performance with nonequivalent stimulus events and a demonstration of time-sharing limitations in the performance data irrespective of contralateral stimulus/response events.

Ear Dominance

Some observers appear to have asymmetrical contributions from the two earphone channels to the overall perceptual array. This asymmetrical effect, called an ear dominance, is inferred from a large difference in performance between the two ears in dichotic conditions utilizing simultaneous stimulus presentation; and subjective reports of an

inability to "hear" a (non-dominant) channel, but is not the result of differential sensitivity to frequency changes in the two ears. The ear dominance causes changes in the shape of the psychometric functions in the selective-attention conditions which involve an increase (steepening) of the psychometric functions's slope in the dominant ear and a decrease (flattening) of the slope in the non-dominant ear. (These changes are relative to the psychometric functions of another observer who appears to have no ear dominance as described above.)

The ear dominance appears to be most evident when the observers experience a high degree of dichotic competition such as when the dichotic stimuli were presented simultaneously and were relatively close in frequency (Ahroon, 1976). The effects of an ear dominance also appear to be attenuated by the use of stimulus variables which increase the observer's ability to perceptually separate the stimuli from the two earphones and thus decrease the amount of dichotic competition.

Future Research

The present set of experiments has demonstrated what is believed to be a two-factor performance deficit in two-channel frequency difference limen tasks. The experiments have attempted to define the phenomena as well as empirically manipulate the factors involved. Future research should assess further the role of these factors on the ability to perform two-channel listening tasks. For instance, since Sorkin, Pastore, and Pohlmann (1972) have suggested that lateralization information may be used by observers to overcome performance deficits in two-channel signal detection tasks, can perceptual-separation variables be used to improve performance in two-channel tasks involving a meta-

thetic continuum [e.g., can the presence or absence of binaural fusion (Perrott & Barry, 1969) serve as additional information by which a two-channel frequency discrimination may be performed]? Are sensitivity (d') or criterion (β) variables primarily responsible for the effect termed an ear dominance in the present investigation? Generating receiver operating characteristic (ROC) curves may help to answer this question. The role of stimulus parameters (i.e., the direction of ipsilateral stimulus change) may be examined by additional systematic manipulation of this variable. The nature of the <u>perceptual masking</u> (Chapter IV) may be assessed through discrimination analogues to threshold-masking paradigms. The answers to such questions may further contribute to our knowledge on attentional processes and on binaural signal processing.

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Sorkin, R. D., Pohlmann, L. D., and Gilliom, J. D. Simultaneous two-channel signal detection. III. 630- and 1400 Hz signals. *The Journal of the Acoustical Society of America*, 1973, *53*, 1045-1050.

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Appendix

Data Summary

Observer J.W. Chapter II

Frequencies: Left = 1605 (11); Right = 1739 (11)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 17	0.936 (0.041)	0.041 (0.033)	3.476 (0.636)
Total (right) 8	0.931 (0.035)	0.069 (0.024)	3.096 (0.435)
	Selective Attention (left) 20		
Signal*	0.948 (0.032)	0.430 (0.119)	1.902 (0.481)
Non-Signal*	0.662 (0.068)	0.077 (0.050)	1.932 (0.424)
Equivalent	0.948 (0.032)	0.077 (0.050)	3.010 (0.952)
Non-equivalent	0.662 (0.068)	0.430 (0.119)	0.607 (0.432)
Total	0.807 (0.033)	o.250 (o.068)	1.561 (0.285)
	Selective Attention (right) 20		
Signal*	0.913 (0.080)	0.711 (0.082)	0.947 (0.483)
Non-Signal*	0.544 (0.107)	0.180 (0.073)	1.102 (0.373)
Equivalent	0.913 (0.080	0.180 (0.073)	2.510 (o.833)
Non-equivalent	0.544 (0.107)	0.711 (0.082)	-0.483 (0.277)
Total	0.729 (0.069)	0.447 (0.049)	0.756 (0.167)

* A "signal" event is defined as a trial on which there was a frequency difference between the standard and comparison stimuli.

Observer J.W. Chapter II

Divided Attention - Left Ear 20

Frequencies: Left = 1605 (11); Right = 1739 (11)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.802 (0.093)	0.347 (0.153)	1.335 (0.570)
False Alarm	0.926 (0.125)	0.357 (0.144)	2.397 (0.897)
Signal*	0.829 (0.071)	0.349 (0.119)	1.408 (0.413)
False Alarm	0.535 (0.157)	0.072 (0.108)	2.039 (0.892)
Correct Rejection	0.610 (0.134)	0.052 (0.049)	2.074 (0.645)
Non-Signal*	0.567 (0.102)	0.055 (0.047)	1.927 (0.550)
Correct	0.739 (0.080)	0.146 (0.057)	1.744 (0.345)
Incorrect	0.634 (0.133)	0.299 (0.123)	0.929 (0.504)
Answer "Signal"	0.684 (0.099)	0.274(0.119)	1.139 (0.393)
Answer "Non-Signal"	0.726 (0.098)	0.174 (0.079)	1.616 (0.436)
Equivalent	0.829 (0.071)	0.055 (0.047)	2.749 (0.488)
Non-Equivalent	0.567 (0.102)	0.349 (0.119)	0.584 (0.369)
Total	o.697 (0.072)	0.199 (0.074)	1.401 (0.291)

Observer J.W. Chapter II

Divided Attention - Right Ear 20

Frequencies: Left = 1605 (11); Right = 1739 (11)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.766 (0.115)	0.584 (0.145)	0.570 (0.613)
False Alarm	0.914 (0.155)	0.655 (0.134)	1.551 (0.968)
Signal*	0.791 (0.094)	0.621 (0.086)	0.559 (0.465)
False Alarm	0.416 (0.163)	0.153 (0.229)	1.474 (1.280)
Correct Rejection	0.427 (0.139)	0.136 (0.054)	0.941 (0.411)
Non-Signal*	0.424 (0.111)	0.142 (0.055)	0.908 (0.338)
Correct	0.616 (0.096)	0.304 (0.067)	0.832 (0.317)
Incorrect	0.574 (0.157)	0.599 (0.134)	-0.066 (0.398)
Answer "Signal"	0.658 (0.107)	0.546 (0.138)	0.306 (0.404)
Answer "Non-Signal"	0.527 (0.128)	0.299 (0.084)	0.616 (0.281)
Equivalent	0.791 (0.094)	0.142 (0.055)	1.979 (0.379)
Non-Equivalent	0.424 (0.111)	0.621 (0.086)	-0.511 (0.301)
Total	0.603 (0.088)	0.377 (0.064)	0.589 (0.214)

Observer R.B. Chapter II

Frequencies: Left = 1605 (23); Right = 1739 (23)

Monaural

Contralateral Event	P(Hit)	P(F.A.)	d'
Total (left)	0.879 (0.040)	0.094 (0.041)	2.555 (0.387)
Total (right)	0.897 (0.416)	0.069 (0.020)	2.804 (0.329)

Selective Attention (left)

Signal*	0.800 (0.075)	0.429 (0.198)	1.050 (0.300)
Non-Signal*	0.502 (0.113)	0.113 (0.093)	1.376 (0.677)
Equivalent	0.800 (0.075)	0.113 (0.093)	2.236 (0.587)
Non-equivalent	0.502 (0.113)	0.429 (0.198)	0.190 (0.393)
Total	0.648 (0.066)	0.276 (0.069)	0.994 (0.264)

Selective Attention (right)

Signal*	0.856 (0.073)	0.484 (0.072)	1.171 (0.458)
Non-Signal*	0.484 (0.114)	0.105 (0.049)	1.247 (0.429)
Equivalent	0.856 (0.073)	0.105 (0.049)	2.425 (0.575)
Non-equivalent	0.484 (0.114)	0.484 (0.072)	-0.001 (0.406)
Total	0.658 (0.081)	0.293 (0.060)	0.973 (0.375)

Observer R.B. Chapter II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (23); Right = 1739 (23)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.691 (0.072)	0.360 (0.133)	0.886 (0.451)
False Alarm	0.692 (0.186)	0.454 (0.142)	0.753 (0.827)
Signal*	0.694 (0.081)	0.407 (0.099)	0.761 (0.316)
False Alarm	0.481 (0.135)	0.126 (0.160)	1.589 (1.104)
Correct Rejection	0.531 (0.139)	0.235 (0.087)	0.834 (0.459)
Non-Signal*	0.510 (0.106)	0.223 (0.077)	0.817 (0.382)
Correct	0.628 (0.077)	0.279 (0.088)	0.936 (0.329)
Incorrect	0.563 (0.090)	0.371 (0.120)	0.516 (0.354)
Answer "Signal"	0.616 (0.066)	0.299 (0.110)	0.850 (0.338)
Answer "Non-Signal"	0.587 (0.117)	0.313 (0.092)	0.737 (0.366)
Equivalent	0.694 (0.081)	0.223 (0.077)	1.050 (0.598)
Non-Equivalent	0.510 (0.106)	0.407 (0.099)	0.214 (0.317)
Total	0.607 (0.071)	0.311 (0.082)	0.783 (0.263)

Observer R.B. Chapter II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (23); Right = 1739 (23)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.769 (0.108)	0.459 (0.136)	0.901 (0.497)
False Alarm	0.786 (0.108)	0.504 (0.104)	0.886 (0.599)
Signal*	0.771 (0.092)	0.478 (0.085)	0.834 (0.391)
False Alarm	0.411 (0.129)	0.107 (0.146)	1.476 (1.055)
Correct Rejection	0.502 (0.122)	0.176 (0.063)	0.969 (0.353)
Non-Signal*	0.462 (0.074)	0.162 (0.066)	0.922 (0.266)
Correct	0.649 (0.082)	0.283 (0.073)	0.981 (0.085)
Incorrect	0.578 (0.073)	0.365 (0.103)	0.557 (0.354)
Answer "Signal"	0.642 (0.068)	0.343 (0.113)	0.789 (0.347)
Answer "Non-Signal"	0.607 (0.078)	0.294 (0.057)	0.824 (0.246)
Equivalent	0.771 (0.092)	0.162 (0.066)	1.437 (0.863)
Non-Equivalent	0.462 (0.074)	0.478 (0.085)	-0.032 (0.188)
Total	0.624 (0.053)	0.311 (0.062)	0.818 (0.230)

Observer W.A. Chapter II

Frequencies: Left = 1605 (15); Right = 1739 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 10	0.877 (0.048)	0.045 (0.028)	2.973 (0.415)
Total (right) 10	0.929 (0.039)	0.056 (0.028)	3.190 (0.459)
	Selective Attention (left) 16		
Signal*	0.944 (0.042)	0.666 (0.108)	1.266 (0.484)
Non-Signal*	0.456 (0.092)	0.063 (0.036)	1.499 (0.455)
Equivalent	0.944 (0.042)	0.063 (0.036)	3.328 (0.545)
Non-Equivalent	0.456 (0.092)	0.666 (0.108)	-0.564 (0.371)
Total	0.693 (0.052)	0.354 (0.037)	0.886 (0.189)
	Selective Attention (right) 16		
Signal*	0.924 (0.044)	0.486 (0.089)	1.556 (0.443)
Non-Signal*	0.588 (0.122)	0.064 (0.032)	1.801 (0.407)
Equivalent	0.924 (0.044)	0.064 (0.032)	2.906 (0.837)
Non-Equivalent	0.588 (0.122)	0.486 (0.089)	0.308 (0.368)
Total	0.759 (0.072)	0.273 (0.049)	1.332 (0.310)

Observer W.A. Chapter II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (15); Right = 1739 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.838 (0.048)	0.686 (0.084)	0.517 (0.366)
False Alarm	0.723 (0.309)	0.338 (0.189)	1.585 (1.792)
Signal*	0.830 (0.044)	0.568 (0.097)	0.792 (0.365)
False Alarm	0.760 (0.119)	0.407 (0.443)	1.425 (1.796)
Correct Rejection	0.319 (0.109)	0.077 (0.040)	0.984 (0.403)
Non-Signal*	0.496 (0.096)	0.097 (0.040)	1.332 (0.229)
Correct	0.637 (0.056)	0.312 (0.066)	0.854 (0.261)
Incorrect	0.751 (0.099)	0.379 (0.183)	1.103 (0.884)
Answer "Signal"	0.816 (0.060)	0.686 (0.089)	0.428 (0.320)
Answer "Non-Signal"	0.371 (0.118)	0.137 (0.047)	0.765 (0.415)
Equivalent	0.830 (0.044)	0.097 (0.040)	2.312 (0.339)
Non-Equivalent	0.496 (0.096)	0.568 (0.097)	-0.188 (0.310)
Total	0.664 (0.061)	0.321 (0.057)	0.900 (0.266)

Observer W.A. Chapter II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (15); Right = 1739 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.865 (0.236)	0.616 (0.132)	1.251 (0.578)
False Alarm	0.881 (0.145)	0.189 (0.106)	2.644 (0.412)
Signal*	0.920 (0.048)	0.401 (0.095)	1.729 (0.412)
False Alarm	0.802 (0.013)	0.224 (0.270)	2.357 (1.133)
Correct Rejection	0.492 (0.147)	0.013 (0.015)	2.248 (0.525)
Non-Signal*	0.662 (0.097)	0.034 (0.030)	2.396 (0.445)
Correct	0.781 (0.058)	0.217 (0.062)	1.587 (0.227)
Incorrect	0.823 (0.083)	0.201 (0.062)	1.882 (0.610)
Answer "Signal"	0.877 (0.051)	0.551 (0.108)	1.064 (0.296)
Answer "Non-Signal"	0.604 (0.127)	0.077 (0.044)	1.814 (0.454)
Equivalent	0.920 (0.048)	0.034 (0.030)	3.441 (0.624)
Non-Eqivelent	0.662 (0.097)	0.401 (0.095)	0.691 (0.273)
Total	0.794 (0.053)	0.212 (0.052)	1.645 (0.200)

Observer W.A. Chapter II

Frequencies: Left = 1305 (13); Right = 2039 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 15	0.938 (0.044)	0.090 (0.041)	3.000 (0.370)
Total (right) 15	0.960 (0.020)	0.134 (0.062)	3.025 (0.500)
	Selective Attention (left) 16		
Signal*	0.934 (0.050)	0.443 (0.131)	1.823 (0.678)
Non-Signal*	0.604 (0.089)	0.051 (0.037)	2.037 (0.447)
Equivalent	0.934 (0.050)	0.051 (0.037)	3.448 (0.678)
Non-Equivalent	0.604 (0.089)	0.443 (0.131)	0.429 (0.386)
Total	0.769 (0.045)	0.241 (0.079)	1.470 (0.276)
	Selective Attention (right) 16		
Signal*	0.934 (0.053)	0.681 (0.113)	1.148 (0.517)
Non-Signal*	0.561 (0.113)	0.109 (0.051)	1.430 (0.244)
Equivalent	0.934 (0.053)	0.109 (0.051)	2.906 (0.527)
Non-Equivalent	0.561 (0.113)	0.681 (0.113)	-0.330 (0.500)
Total	0.745 (0.069)	0.399 (0.064)	0.934 (0.297)

Observer W.A. Chapter II

Divided Attention - Left Ear 16

Frequencies: Left = 1305 (13); Right = 2039 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.929 (0.053)	0.887 (0.082)	0.174 (0.781)
False Alarm	0.696 (0.263)	0.184 (0.100)	1.714 (1.265)
Signal*	0.899 (0.046)	0.507 (0.093)	1.305 (0.345)
False Alarm	0.916 (0.071)	0.639 (0.323)	0.966 (1.890)
Correct Rejection	0.314 (0.154)	0.058 (0.059)	1.244 (0.616)
Non-Signal*	0.693 (0.134)	0.109 (0.068)	1.859 (0.384)
Correct	0.751 (0.078)	0.347 (0.058)	1.096 (0.052)
Incorrect	0.871 (0.081)	0.248 (0.100)	1.923 (0.498)
Answer "Signal"	0.923 (0.043)	0.854 (0.084)	0.301 (0.608)
Answer "Non-Signal"	0.409 (0.147)	0.104 (0.062)	1.108 (0.411)
Equivalent	0.899 (0.046)	0.109 (0.068)	2.569 (0.532)
Non-Equivelent	0.693 (0.134)	0.507 (0.093)	0.513 (0.429)
Total	0.796 (0.065)	0.314 (0.053)	1.337 (0.216)

Observer W.A. Chapter II

Divided Attention - Right Ear 16

Frequecies: Left = 1305 (13); Right = 2039 (15)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.909 (0.048)	0.845 (0.085)	0.333 (0.595)
False Alarm	0.609 (0.305)	0.196 (0.181)	1.669 (1.380)
Signal*	0.879 (0.054)	0.644 (0.152)	0.806 (0.462)
False Alarm	0.802 (0.104)	0.569 (0.359)	0.591 (1.424)
Correct Rejection	0.124 (0.104)	0.031 (0.029)	0.627 (0.753)
Non-Signal*	0.464 (0.124)	0.085 (0.053)	1.391 (0.566)
Correct	0.619 (0.088)	0.392 (0.094)	0.597 (0.332)
Incorrect	0.773 (0.085)	0.274 (0.159)	1.522 (0.728)
Answer "Signal"	0.869 (0.061)	0.798 (0.092)	0.303 (0.427)
Answer "Non-Signal"	0.201 (0.091)	0.071 (0.049)	0.669 (0.471)
Equivalent	0.879 (0.054)	0.085 (0.053)	2.600 (0.456)
Non-Equivalent	0.464 (0.124)	0.644 (0.152)	-0.477 (0.482)
Total	0.666 (0.075)	0.367 (0.102)	0.791 (0.304)

Observer J.J. Chapter III Experiment I

Frequencies: Left = 1305 (9); Right = 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.948 (0.028)	0.062 (0.024)	3.257 (0.425)
Total (right) 16	0.942 (0.049)	0.079 (0.038)	3.170 (0.677)
	Selective Attention (left) 16		
Signal*	0.937 (0.053)	0.222 (0.070)	2.467 (0.628)
Non-Signal*	0.823 (0.075)	0.038 (0.051)	2.959 (0.660)
Equivalent	0.937 (0.053)	0.038 (0.051)	3.669 (0.892)
Non-Equivalent	0.823 (0.075)	0.222 (0.070)	1.757 (0.395)
Total	0.883 (0.055)	0.126 (0.041)	2.404 (0.425)
	Selective Attention (right) 16		
Signal*	0.888 (0.090)	0.431 (0.111)	1.554 (0.569)
Non-Signal*	0.719 (0.107)	0.136 (0.089)	1.830 (0.501)
Equivalent	0.888 (0.090)	0.136 (0.089)	2.587 (0.744)
Non-Equivalent	0.719 (0.107)	0.431 (0.111)	0.797 (0.553)
Total	0.801 (0.081)	0.287 (0.074)	1.460 (0.383)

Observer J.J. Chapter III Experiment I

Divided Attention - Left Ear 16

Frequencies: Left = 1305 (9); Right 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.766 (0.102)	0.407 (0.106)	1.018 (0.568)
False Alarm	0.820 (0.151)	0.292 (0.090)	1.785 (0.916)
Signal*	0.781 (0.083)	0.353 (0.066)	1.194 (0.422)
False Alarm	0.687 (0.129)	0.123 (0.169)	2.233 (1.185)
Correct Rejection	0.516 (0.160)	0.109 (0.063)	1.341 (0.670)
Non-Signal*	0.607 (0.085)	0.111 (0.062)	1.564 (0.507)
Correct	0.681 (0.091)	0.223 (0.053)	1.266 (0.399)
Incorrect	0.737 (0.069)	0.243 (0.093)	1.369 (0.472)
Answer "Signal"	0.741 (0.069)	0.223 (0.053)	1.266 (0.399)
Answer "Non-Signal"	0.617 (0.145)	0.172 (0.056)	1.280 (0.500)
Equivalent	0.781 (0.083)	0.111 (0.062)	2.109 (0.488)
Non-Equivalent	0.607 (0.085)	0.353 (0.066)	0.657 (0.282)
Total	0.699 (0.062)	0.231 (0.049)	0.657 (0.310)

Observer J.J. Chapter III Experiment I

Divided Attention - Right Ear 16

Frequencies: Left = 1305 (9); Right = 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.740 (0.098)	0.582 (0.170)	0.449 (0.339)
False Alarm	0.787 (0.159)	0.401 (0.155)	1.361 (1.055)
Signal*	0.753 (0.076)	0.506 (0.144)	0.691 (0.328)
False Alarm	0.629 (0.130)	0.149 (0.228)	2.002 (1.119)
Correct Rejection	0.504 (0.108)	0.166 (0.085)	1.039 (0.416)
Non-Signal*	0.547 (0.083)	0.169 (0.076)	1.136 (0.329)
Correct	0.631 (0.083)	0.329 (0.082)	0.081 (0.305)
Incorrect	0.687 (0.084)	0.353 (0.137)	0.899 (0.464)
Answer "Signal"	0.706 (0.071)	0.516 (0.133)	0.509 (0.307)
Answer "Non-Signal"	0.579 (0.091)	0.238 (0.065)	0.930 (0.330)
Equivalent	0.753 (0,076)	0.169 (0.076)	1.720 (0.452)
Non-Equivalent	0.547 (0.083)	0.506 (0.114)	0.102 (0.413)
Total	0.651 (0.059)	0.334 (0.067)	0.829 (0.239)

Observer M.R. Chapter III Experiment I

Frequencies: Left = 1305 (18); Right = 3339 (60)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 10	0.858 (0.043)	0.100 (0.093)	2.578 (0.771)
Total (right) 10	0.920 (0.033)	0.062 (0.032)	3.083 (0.478)
	Selective Attention (left) 16		
Signal*	0.877 (0.078)	0.349 (0.053)	1.646 (0.405)
Non-Signal*	0.577 (0.096)	0.048 (0.025)	1.902 (0.357)
Equivalent	0.877 (0.078)	0.048 (0.025)	2.961 (0.579)
Non-Equivalent	0.577 (0.096)	0.349 (0.053)	0.587 (0.316)
Total	0.729 (0.077)	0.196 (0.022)	1.492 (0.241)
	Selective Attention (right) 16		
Signal*	0.873 (0.073)	0.366 (0.114)	1.597 (0.427)
Non-Signal*	0.766 (0.105)	0.102 (0.050)	2.079 (0.549)
Equivalent	0.873 (0.073)	0.102 (0.505)	2.549 (0.540)
Non-Equivalent	0.766 (0.105)	0.366 (0.114)	1.126 (0.566)
Total	0.822 (0.067)	0.233 (0.066)	1.694 (0.404)

Observer M.R. Chapter III Experiment I

Divided Attention - Left Ear 16

Frequencies: Left = 1305 (18); Right = 3339 (60)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.792 (0.087)	0.701 (0.156)	0.222 (0.600)
False Alarm	0.291 (0.352)	0.105 (0.188)	0.724 (2.212)
Signal*	0.767 (0.081)	0.560 (0.131)	0.600 (0.399)
False Alarm	0.778 (0.082)	0.399 (0.298)	1.307 (1.350)
Correct Rejection	0.048 (0.060)	0.002 (0.008)	0.536 (0.638)
Non-Signal*	0.524 (0.086)	0.058 (0.057)	1.836 (0.498)
Correct	0.585 (0.076)	0.356 (0.139)	0.598 (0.374)
Incorrect	0.744 (0.085)	0.196 (0.156)	1.715 (0.700)
Answer "Signal"	0.789 (0.073)	0.686 (0.145)	0.242 (0.518)
Answer "Non-Signal"	0.090 (0.094)	0.024 (0.030)	0.451 (0.853)
Equivalent	0.767 (0.081)	0.058 (0.057)	2.531 (0.598)
Non-Equivalent	0.524 (0.086)	0.560 (0.131)	-0.095 (0.371)
Total	0.644 (0.061)	9,560 (0.131)	-0.095 (0.371)

Observer M.R. Chapter III Experiment I

Divided Attention - Right Ear 16

Frequencies: Left = 1305 (18); Right = 3339 (60)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.974 (0.030)	0.969 (0.042)	0.011 (0.597)
False Alarm	0.833 (0.179)	0.307 (0.124)	1.824 (0.871)
Signal*	0.944 (0.038)	0.654 (0.091)	1.296 (0.514)
False Alarm	0.963 (0.049)	0.729 (0.442)	0.882 (2.345)
Correct Rejection	0.507 (0.212)	0.063 (0.060)	1.654 (0.786)
Non-Signal*	0.771 (0.075)	0.112 (0.097)	2.149 (0.634)
Correct	0.808 (0.062)	0.414 (0.137)	1.103 (0.453)
Incorrect	0.927 (0.050)	0.365 (0.127)	1.984 (0.623)
Answer "Signal"	0.968 (0.026)	0.968 (0.047)	-0.151 (0.463)
Answer "Non-Signal"	0.613 (0.171)	0.143 (0.050)	1.409 (0.418)
Equivalent	0.944 (0.038)	0.112 (0.097)	3.086 (0.745)
Non-Equivalent	0.771 (0.075)	0.654 (0.091)	0.359 (0.328)
Total	0.856 (0.035)	0.401 (0.104)	0.331 (0.308)

Observer R.E. Chapter III Experiment I

Frequencies: Left = 1305 (10); Right = 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.942 (0.020)	0.092 (0.015)	2.944 (0.245)
Total (right) 16	0.941 (0.001)	0.104 (0.026)	2.887 (0.330)
	Selective Attention (left) 14		
Signal*	0.973 (0.020)	0.193 (0.070)	2.907 (0.456)
Non-Signal*	0.846 (0.063)	0.067 (0.035)	2.606 (0.385)
Equivalent	0.973 (0.028)	0.067 (0.035)	3.581 (0.486)
Non-Equivalent	0.846 (0.063)	0.193 (0.070)	1.932 (0.259)
Total	0.909 (0.031)	0.125 (0.032)	2.510 (0.170)
	Selective Attention (right) 14		
Signal*	0.874 (0.070)	0.421 (0.073)	1.419 (0.406)
Non-Signal	0.731 (0.092)	0.153 (0.077)	1.711 (0.278)
Equivalent	0.874 (0.070)	0.153 (0.077)	2.304 (0.438)
Non-Equivalent	0.731 (0.092)	0.421 (0.073)	0.826 (0.373)
Total	0.806 (0.064)	0.284 (0.052)	1.463 (0.231)

Observer R.E. Chapter III Experiment I

Divided Attention - Left Ear 10

Frequencies: Left = 1305 (10); Right = 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.936 (0.038)	0.083 (0.034)	3.010 (0.428)
False Alarm	0.989 (0.043)	0.269 (0.124)	3.180 (0.320)
Signal*	0.947 (0.031)	0.129 (0.045)	2.832 (0.368)
False Alarm	0.750 (0.122)	0.001 (0.003)	3.401 (0.716)
Correct Rejection	0.997 (0.010)	0.003 (0.009)	5.002 (0.404)
Non-Signal*	0.894 (0.050)	0.003 (0.009)	3.827 (0.406)
Correct	0.961 (0.024)	0.042 (0.016)	3.564 (0.355)
Incorrect	0.852 (0.071)	0.174 (0.082)	2.201 (0.802)
Answer "Signal"	0.876 (0.043)	0.072 (0.028)	2.701 (0.493)
Answer "Non-Signal"	0.996 (0.012)	0.061 (0.028)	4.053 (0.282)
Equivalent	0.947 (0.031)	0.003 (0.009)	3.011 (0.285)
Non-Equivalent	0.894 (0.050)	0.129 (0.045)	2.004 (0.257)
Total	0.925 (0.025)	0.065 (0.022)	3.010 (0.388)

Observer R.E. Chapter III Experiment I

Divided Attention - Right Ear 10

Frequencies: Left = 1305 (10); Right 3339 (35)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.761 (0.080)	0.306 (0.082)	1.274 (0.571)
False Alarm	0.979 (0.083)	0.875 (0.342)	0.509 (1.884)
Signal*	0.772 (0.075)	0.372 (0.107)	1.136 (0.636)
False Alarm	0.508 (0.229)	0.001 (0.003)	2.593 (1.006)
Correct Rejection	0.821 (0.037)	0.133 (0.032)	2.059 (0.269)
Non-Signal*	0.782 (0.048)	0.132 (0.032)	1.922 (0.287)
Correct	0.790 (0.050)	0.204 (0.047)	1.667 (0.382)
Incorrect	0.647 (0.120)	0.854 (0.343)	-1.395 (1.915)
Answer "Signal"	0.731 (0.086)	0.305 (0.082)	1.182 (0.573)
Answer "Non-Signal"	0.829 (0.034)	0.199 (0.051)	1.824 (0.319)
Equivalent	0.772 (0.075)	0.132 (0.032)	0.860 (0.204)
Non-Equivalent	0.782 (0.048)	0.372 (0.107)	-0.026 (0.146)
Total	0.777 (0.053)	0.241 (0.059)	1.502 (0.429)

Observer W.A. Chapter III Experiment II

Frequencies: Left = 1605 (17); Right = 1605 (17) Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.946 (0.028)	0.118 (0.036)	2.879 (0.317)
Total (right) 16	0.923 (0.029)	0.080 (0.035)	2.903 (0.370)
	Selective Attention (left) 16		
Signal*	0.915 (0.067)	0.815 (0.102)	0.527 (0.423)
Non-Signal*	0.338 (0.111)	0.146 (0.069)	0.650 (0.372)
Equivalent	0.915 (0.067)	0.146 (0.069)	2.577 (0.537)
Non-Equivalent	0.338 (0.111)	0.815 (0.102)	-1.400 (0.423)
Total	0.653 (0.070)	0.498 (0.063)	0.404 (0.263)
	Selective Attention (right) 16		
Signal*	0.982 (0.071)	0.222 (0.066)	2.935 (0.406)
Non-Signal*	0.993 (0.032)	0.105 (0.085)	3.007 (0.768)
Equivalent	0.982 (0.017)	0.105 (0.085)	3.636 (0.692)
Non-Equivalent	0.993 (0.032)	0.222 (0.066)	2.306 (0.347)
Total	0.957 (0.016)	0.165 (0.056)	2.725 (0.276)

Observer W.A. Chapter III Experiment II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (17); Right = 1739 (17)

Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.901 (0.069)	0.819 (0.145)	0.269 (0.711)
False Alarm	0.802 (0.193)	0.477 (0.115)	1.212 (0.808)
Signal*	0.881 (0.076)	0.662 (0.095)	0.952 (0.275)
False Alarm	0.877 (0.114)	0.438 (0.496)	1.760 (2.667)
Correct Rejection	0.447 (0.149)	0.092 (0.071)	1.350 (0.458)
Non-Signal*	0.641 (0.137)	0.105 (0.071)	1.742 (0.418)
Correct	0.767 (0.096)	0.385 (0.069)	1.067 (0.235)
Incorrect	0.840 (0.098)	0.472 (0.103)	1.119 (0.447)
Answer "Signal"	0.891 (0.052)	0.794 (0.128)	0.317 (0.790)
Answer "Non-Signal"	0.560 (0.121)	0.274 (0.082)	0.762 (0.337)
Equivalent	0.881 (0.076)	0.105 (0.071)	2.632 (0.469)
Non-Equivalent	0.641 (0.137)	0.662 (0.095)	0.062 (0.430)
Total	0.787 (0.086)	0.415 (0.071)	1.046 (0.285)

Observer W.A. Chapter III Experiment II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (17); Right 1739 (17)

Left prededes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.855 (0.068)	0.641 (0.053)	0.759 (0.440)
False Alarm	0.711 (0.263)	0.149 (0.114)	2.190 (1.167)
Signal*	0.835 (0.072)	0.466 (0.086)	1.129 (0.396)
False Alarm	0.574 (0.096)	0.204 (0.343)	1.470 (1.816)
Correct Rejection	0.211 (0.144)	0.026 (0.030)	1.124 (0.919)
Non-Signal*	0.441 (0.086)	0.040 (0.021)	1.659 (0.442)
Correct	0.666 (0.066)	0.264 (0.104)	1.427 (0.764)
Incorrect	0.595 (0.097)	0.152 (0.104)	1.427 (0.764)
Answer "Signal"	0.736 (0.073)	0.565 (0.087)	0.476 (0.334)
Answer "Non-Signal"	0.315 (0.145)	0.067 (0.054)	1.160 (0.933)
Equivalent	0.835 (0.072)	0.040 (0.021)	2.852 (0.404)
Non-Eqivalent	0.441 (0.086)	0.466 (0.086)	-0.065 (0.290)
Total	0.636 (0.070)	0.242 (0.058)	1.065 (0.316)

Observer W.A. Chapter III Experiment II

Frequencies: Left = 1605 (17); Right = 1739 (17) Right precedes Left

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.946 (0.028)	0.118 (0.036)	2.879 (0.317)
Total (right) 16	0.923 (0.029)	0.080 (0.035)	2.903 (0.370)
	Selective Attention (left) 16		
Signal*	0.915 (0.049)	0.359 (0.123)	1.829 (0.422)
Non-Signal*	0.643 (0.071)	0.069 (0.048)	1.986 (0.503)
Equivalent	0.915 (0.049)	0.069 (0.048)	3.056 (0.600)
Non-Equivalent	0.643 (0.071)	0.359 (0.123)	0.759 (0.391)
Total	0.787 (0.045)	0.204 (0.067)	1.649 (0.286)
	Selective Attention (right) 16		
Signal*	0.919 (0.024)	0.344 (0.075)	1.821 (0.249)
Non-Signal*	0.685 (0.064)	0.148 (0.083)	1.570 (0.375)
Equivalent	0.919 (0.024)	0.148 (0.083)	2.497 (0.400)
Non-Equivalent	0.685 (0.064)	0.344 (0.075)	0.894 (0.327)
Total	0.798 (0.030)	0.256 (0.059)	1.512 (0.248)

Observer W.A. Chapter III Experiment II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (17); Right = 1739 (17)

Right precedes Left

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.872 (0.037)	0.782 (0.084)	0.344 (0.296)
False Alarm	0.787 (0.364)	0.659 (0.181)	0.944 (1.716)
Signal*	0.881 (0.046)	0.755 (0.099)	0.491 (0.280)
False Alarm	0.760 (0.151)	0.584 (0.334)	0.527 (1.461)
Correct Rejection	0.481 (0.086)	0.127 (0.086)	1.156 (0.255)
Non-Signal*	0.599 (0.115)	0.165 (0.093)	1.290 (0.476)
Correct	0.709 (0.066)	0.399 (0.094)	0.821 (0.296)
Incorrect	0.792 (0.143)	0.647 (0.165)	0.605 (0.597)
Answer "Signal"	0.830 (0.077)	0.774 (0.094)	0.217 (0.314)
Answer "Non-Signal"	0.550 (0.103)	0.226 (0.116)	0.920 (0.234)
Equivalent	0.881 (0.046)	0.165 (0.093)	2.236 (0.494)
Non-Equivalent	0.599 (0.115)	0.755 (0.099)	-0.459 (0.139)
Total	0.731 (0.081)	0.441 (0.098)	0.794 (0.314)

Observer W.A. Chapter III Experiment II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (17); Right = 1739 (17)

Right precedes Left

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.859 (0.137)	0.522 (0.116)	1.267 (0.691)
False Alarm	0.965 (0.065)	0.224 (0.132)	3.116 (1.062)
Signal*	0.866 (0.126)	0.412 (0.111)	0.567(0.606)
False Alarm	0.761 (0.093)	0.277 (0.180)	1.610 (0.919)
Correct Rejection	0.677 (0.129)	0.027 (0.025)	2.530 (0.324)
Non-Signal*	0.760 (0.092)	0.067 (0.051)	2.365 (0.530)
Correct	0.809 (0.116)	0.222 (0.061)	1.730 (0.358)
Incorrect	0.807 (0.083)	0.237 (0.115)	1.665 (0.428)
Answer "Signal"	0.826 (0.114)	0.475 (0.119)	1.087 (0.409)
Amswer "Non-Signal"	0.760 (0.087)	0.094 (0.057)	2.170 (0.561)
Equivalent	0.866 (0.126)	0.067 (0.051)	2.979 (1.020)
Non-Equivalent	0.760 (0.092)	0.412 (0.111)	0.964 (0.308)
Total	0.811 (0.102)	0.234 (0.061)	1.679 (0.311)

Observer M.M. Chapter III Experiment II

Frequencies: Left = 1605 (18); Right = 1739 (20) Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.879 (0.056)	0.063 (0.021)	2.767 (0.309)
Total (right) 16	0.56 (0.057)	0.045 (0.020)	2.838 (0.323)
	Selective Attention (left) 16		
Signal*	0.884 (0.094)	0.829 (0.120)	0.313 (0.514)
Non-Signal*	0.486 (0.143)	0.418 (0.142)	0.183 (0.447)
Equivalent	0.884 (0.094)	o.418 (0.142)	1.579 (0.516)
Non-Equivalent	0.486 (0.143)	0.829 (0.120)	-1.083 (0.669)
Total	0.677 (0.092)	0.582 (0.098)	0.257 (0.249)
	Selective Attention (right) 16		
Signal*	0.759 (0.113)	0.134 (0.065)	1.928 (0.483)
Non-Signal*	0.691 (0.086)	0.128 (0.066)	1.701 (0.367)
Equivalent	0.759 (0.113)	0.128 (0.066)	1.944 (0.388)
Non-Equivalent	0.691 (0.086)	0.134 (0.065)	1.686 (0.480)
Total	0.730 (0.083)	0.131 (0.054)	1.786 (0.292)

Observer M.M. Chapter III Experiment II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (18); Right = 1739 (20)

Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.480 (0.210)	0.462 (0.253)	0.108 (0.536)
False Alarm	0.103 (0.113)	0.062 (0.101)	0.348 (0.932)
Signal*	0.421 (0.192)	0.350 (0.204)	0.268 (0.406)
False Alarm	0.439 (0.212)	0.459 (0.228)	--.072 (0.855)
Correct Rejection	0.029 (0.039)	0.008 (0.024)	0.332 (0.435)
Non-Signal*	0.177 (0.104)	0.125 (0.068)	0.207 (0.591)
Correct	0.278 (0.131)	0.185 (0.110)	0.381 (0.331)
Incorrect	0.341 (0.180)	0.393 (0.151)	0.127 (0.687)
Answer "Signal"	0.468 (0.201)	0.464 (0.217)	0.027 (0.408)
Answer "Non-Signal"	0.040 (0.038)	0.019 (0.038)	0.375 (0.408)
Equivalent	0.421 (0.192)	0.125 (0.068)	1.022 (0.586)
Non-Equivalent	0.177 (0.104)	0.350 (0.204)	-0.550 (0.432)
Total	0.293 (0.137)	0.215 (0.113)	0.270 (0.318)

Observer M.M. Chapter III Experiment II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (18); Right = 1739 (20)

Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.462 (0.045)	0.835 (0.269)	0.567 (1.701)
False Alarm	0.722 (0.118)	0.235 (0.084)	1.364 (0.376)
Signal*	0.831 (0.068)	0.355 (0.087)	1.369 (0.280)
False Alarm	0.970 (0.055)	0.895 (0.269)	0.218 (1.465)
Correct Rejection	0.564 (0.134)	0.154 (0.069)	1.243 (0.460)
Non-Signal*	0.710 (0.082)	0.254 (0.071)	1.247 (0.381)
Correct	0.757 (0.077)	0.276 (0.059)	1.325 (0.357)
Incorrect	0.801 (0.077)	0.333 (0.093)	1.323 (0.342)
Answer "Signal"	0.963 (0.043)	0.912 (0.136)	0.152 (1.014)
Answer "Non-Signal"	0.658 (0.051)	0.192 (0.072)	1.311 (0.342)
Equivalent	0.831 (0.051)	0.254 (0.071)	1.669 (0.331)
Non-Equivalent	0.710 (0.082)	0.355 (0.087)	0.949 (0.407)
Total	0.780 (0.049)	0.305 (0.070)	1.303 (0.265)

Observer J.V. Chapter III Experiment II

Frequencies: Left = 1605 (20); Right = 1739 (20) Left precedes Right

Contralateral Event	Monaural P(Hit)	P(F.A.)	d'
Total (left) 16	0.908 (0.053)	0.096 (0.032)	2.748 (0.574)
Total (right) 16	0.911 (0.054)	0.084 (0.050)	2.903 (0.622)
	Selective Attention (left) 16		
Signal*	0.829 (0.056)	0.801 (0.111)	0.057 (0.486)
Non-Signal	0.366 (0.093)	0.297 (0.065)	0.189 (0.195)
Equivalent	0.829 (0.056)	0.297 (0.065)	1.512 (0.316)
Non-Equivalent	0.366 (0.093)	0.801 (0.111)	-1.265 (0.488)
Total	0.590 (0.061)	0.496 (0.052)	0.247 (0.168)
	Selective Attention (right) 16		
Signal*	0.812 (0.067	0.241 (0.111)	1.665 (0.487)
Non-Signal*	0.794 (0.096)	0.147 (0.070)	1.993 (0.602)
Equivalent	0.812 (0.067)	0.147 (0.070)	2.017 (0.442)
Non-Equivalent	0.794 (0.096)	0.241 (0.111)	1.641 (0.655)
Total	0.805 (0.063)	0.193 (0.062)	1.781 (0.473)

Observer J.V. Chapter III Experiment II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (20)

Left precedes Right

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.284 (0.151)	0.337 (0.128)	-0.188 (0.669)
False Alarm	0.388 (0.112)	0.225 (0.172)	0.596 (0.820)
Signal*	0.320 (0.087)	0.312 (0.100)	0.596 (0.820)
False Alarm	0.185 (0.087)	0.156 (0.121)	0.166 (1.051)
Correct Rejection	0.215 (0.098)	0.180 (0.096)	0.155 (0.579)
Non-Signal*	0.206 (0.076)	0.172 (0.072)	0.145 (0.425)
Correct	0.250 (0.095)	0.242 (0.053)	0.006 (0.289)
Incorrect	0.286 (0.063)	0.197 (0.092)	0.318 (0.332)
Answer "Signal"	0.256 (0.114)	0.268 (0.089)	-0.053 (0.476)
Answer "Non-Signal"	0.263 (0.093)	0.198 (0.095)	0.245 (0.470)
Equivalent	0.320 (0.087)	0.172 (0.172)	0.505 (0.334)
Non-Equivalent	0.206 (0.076)	0.312 (0.100)	-0.335 (0.333)
Total	0.263 (0.073)	0.227 (0.051)	0.109 (0.231)

Observer J.V. Chapter III Experiment II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (20)

Left precedes Right

Contralateral Event	p(Hit)	P(F.A.)	d'
Hit	0.592 (0.237)	0.275 (0.150)	1.005 (0.856)
False Alarm	0.727 (0.126)	0.296 (0.047)	1.171 (0.457)
Signal*	0.698 (0.112)	0.289 (0.048)	1.105 (0.427)
False Alarm	0.739 (0.197)	0.267 (0.191)	1.656 (1.006)
Correct Rejection	0.663 (0.160)	0.295 (0.106)	1.028 (0.689)
Non-Signal*	0.689 (0.144)	0.287 (0.086)	1.117 (0.649)
Correct	0.644 (0.163)	0.291 (0.099)	0.982 (0.665)
Incorrect	0.727 (0.131)	0.289 (0.050)	1.198 (0.452)
Answer "Signal"	0.666 (0.181)	0.263 (0.066)	1.135 (0.563)
Answer "Non-Signal"	0.702 (0.127)	0.296 (0.073)	1.107 (0.533)
Equivalent	0.698 (0.112)	0.287 (0.086)	1/131 (0.580)
Non-Equivalent	0.689 (0.144)	0.289 (0.048)	1.095 (0.487)
Total	0.693 (0.122)	0.288 (0.060)	1.102 (0.507)

Observer J.V. Chapter III Experiment II

Frequencies: Left = 1605 (20); Right = 1739 (20) Right precedes Left

Contralateral Events	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 16	0.908 (0.053)	0.096 (0.032)	2.748 (0.574)
Total (right) 16	0.911 (0.054)	0.084 (0.050)	2.903 (0.622)
	Selective Attention (left) 16		
Signal*	0.806 (0.085)	0.708 (0.087)	0.364 (0.477)
Non-Signal*	0.573 (0.082)	0.298 (0.055)	0.722 (0.189)
Equivalent	0.806 (0.085)	0.298 (0.055)	1.462 (0.519)
Non-Equivalent	0.573 (0.082)	0.708 (0.087)	-0.376 (0.336)
Total	0.685 (0.042)	0.456 (0.042)	0.603 (0.154)
	Selective Attention (right) 16		
Signal*	0.748 (0.039)	0.354 (0.089)	1.056 (0.279)
Non-Signal*	0.674 (0.126)	0.147 (0.039)	1.543 (0.299)
Equivalent	0.748 (0.039)	0.147 (0.039)	1.744 (0.160)
Non-Equivalent	0.674 (0.126)	0.354 (0.089)	0.854 (0.546)
Total	0.716 (0.060)	0.250 (0.041)	1.256 (0.243)

Observer J.V. Chapter III Experiment II

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (20)

Right precedes Left

Contralateral Event	p(Hit)	p(F.A.)	d'
Hit	0.815 (0.125)	0.161 (0.133)	0.144 (0.764)
False Alarm	0.372 (0.119)	0.239 (0.133)	0.352 (0.507)
Signal*	0.242 (0.101)	0.191 (0.127)	0.271 (0.463)
False Alarm	0.105 (0.141)	0.113 (0.150)	-0.036 (1.322)
Correct Rejection	0.153 (0.103)	0.114 (0.062)	0.167 (0.270)
Non-Signal*	0.139 (0.088)	0.112 (0.064)	0.155 (0.270)
Correct	0.166 (0.090)	0.131 (0.075)	0.202 (0.335)
Incorrect	0.225 (0.108)	0.174 (0.120)	0.280 (0.554)
Answer "Signal"	0.156 (0.120)	0.140 (0.125)	0.111 (0.708)
Answer "Non-Signal"	0.216 (0.095)	0.145 (0.065)	0.315 (0.294)
Equivalent	0.242 (0.101)	0.112 (0.064)	0.507 (0.309)
Non-Equivalent	0.139 (0.088)	0.191 (0.127)	-0.166 (0.504)
Total	0.187 (0.087)	0.142 (0.081)	0.241 (0.309)

Observer J.V. Chapter III Experiment II

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (20)

Right precedes Left

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.440 (0.165)	0.262 (0.337)	0.890 (1.509)
False Alarm	0.644 (0.106)	0.346 (0.076)	0.790 (0.375)
Signal*	0.599 (0.099)	0.334 (0.073)	0.696 (0.362)
False Alarm	0.419 (0.205)	0.231 (0.235)	0.899 (1.218)
Correct Rejection	0.603 (0.106)	0.300 (0.097)	0.813 (0.441)
Non-Signal*	0.581 (0.099)	0.299 (0.084)	0.751 (0.379)
Correct	0.559 (0.094)	0.336 (0.073)	0.697 (0.439)
Incorrect	0.624 (0.094)	0.336 (0.073)	0.754 (0.363)
Answer "Signal"	0.456 (0.128)	0.288 (0.251)	0.565 (1.118)
Answer "Non-Signal"	0.625 (0.079)	0.322 (0.064)	0.799 (0.316)
Equivalent	0.599 (0.099)	0.299 (0.084)	0.802 (0.415)
Non-Equivalent	0.581 (0.099)	0.334 (0.073)	0.646 (0.334)
Total	0.592 (0.079)	0.317 (0.053)	0.720 (0.298)

Observer E.B. Chapter II Ahroon (1976)

Frequencies: Left = 1605 (20); Right = 1739 (27)

Monaural

Contralateral Event	P(Hit)	P(F.A.)	d'
Total (left) 16	0.892 (0.054)	0.081 (0.038)	2.762 (0.353)
Total (right) 16	0.944 (0.052)	0.082 (0.035)	3.126 (0.459)
	Selective Attention (left) 15		
Signal*	0.949 (0.059)	0.529 (0.126)	1.776 (0.518)
Non-Signal*	0.533 (0.097)	0.069 (0.059)	1.738 (0.535)
Equivalent	0.949 (0.059)	0.069 (0.059)	3.509 (0.650)
Non-Equivalent	0.533 (0.097)	0.529 (0.126)	0.005 (0.353)
Total	0.737 (0.048)	0.298 (0.074)	1.183 (0.189)
	Selective Attention (right) 16		
Signal*	0.922 (0.041)	0.519 (0.119)	1.438 (0.313)
Non-Signal*	0.586 (0.094)	0.066 (0.049)	1.869 (0.455)
Equivalent	0.922 (0.041)	0.066 (0.049)	3.131 (0.668)
Non-Equivalent	0.586 (0.094)	0.519 (0.119)	0.176 (0.399)
Total	0.756 (0.055)	0.294 (0.068)	1.254 (0.272)

Observer E.B. Chapter III Ahroon (1976)

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (27)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.951 (0.046)	0.855 (0.134)	0.444 (0.904)
False Alarm	0.830 (0.120)	0.532 (0.120)	1.045 (0.807)
Signal*	0.911 (0.050)	0.681 (0.117)	0.908 (0.424)
False Alarm	0.881 (0.120)	0.411 (0.422)	1.891 (2.199)
Correct Rejection	0.617 (0.128)	0.087 (0.065)	1.829 (0.665)
Non-Signal*	0.717 (0.081)	0.109 (0.068)	1.932 (0.532)
Correct	0.787 (0.060)	0.302 (0.088)	1.345 (0.314)
Incorrect	0.857 (0.087)	0.532 (0.124)	1.069 (0.459)
Answer "Signal"	0.926 (0.062)	0.811 (0.153)	0.454 (0.868)
Answer "Non-Signal"	0.681 (0.095)	0.239 (0.065)	1.210 (0.267)
Equivalent	0.911 (0.050)	0.109 (0.068)	2.763 (0.514)
Non-Equivalent	0.717 (0.081)	0.618 (0.117)	0.088 (0.425)
Total	0.810 (0.050)	0.374 (0.069)	1.222 (0.244)

Observer E.B. Chapter III Ahroon (1976)

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (20); Right = 1739 (27)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.701 (0.117)	0.446 (0.173)	0.696 (0.377)
False Alarm	0.334 (0.328)	0.154 (0.162)	0.711 (1.656)
Signal*	0.673 (0.114)	0.364 (0.140)	0.840 (0.380)
False Alarm	0.540 (0.172)	0.272 (0.289)	1.113 (0.396)
Correct Rejection	0.143 (0.145)	0.035 (0.037)	0.581 (0.876)
Non-Signal*	0.432 (0.142)	0.054 (0.043)	1.544 (0.533)
Correct	0.569 (0.095)	0.207 (0.071)	1.024 (0.284)
Incorrect	0.520 (0.163)	0.186 (0.152)	0.195 (0.779)
Answer "Signal"	0.637 (0.127)	0.417 (0.161)	0.586 (0.332)
Answer "Non-Signal"	0.181 (0.129)	0.062 (0.055)	0.654 (0.855)
Equivalent	0.673 (0.114)	0.054 (0.043)	2.211 (0.573)
Non-Equivalent	0.432 (0.142)	0.364 (0.140)	0.188 (0.382)
Total	0.554 (0.111)	0.202 (0.070)	0.999 (0.256)

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (62); Right = 1739 (67)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.871 (0.103)	0.192 (0.159)	2.298 (0.720)
False Alarm	0.994 (0.023)	0.723 (0.321)	1.526 (1.130)
Signal*	0.895 (0.080)	0.294 (0.171)	1.977 (0.523)
False Alarm	0.535 (0.204)	0.011 (0.043)	2.351 (0.889)
Correct Rejection	0.951 (0.059)	0.017 (0.017)	4.086 (0.679)
Non-Signal*	0.833 (0.106)	0.021 (0.028)	3.192 (0.535)
Correct	0.916 (0.044)	0.091 (0.064)	2.904 (0.466)
Incorrect	0.712 (0.143)	0.549 (0.198)	0.469 (0.522)
Answer "Signal"	0.779 (0.123)	0.185 (0.159)	1.902 (0.626)
Answer "Non-Signal"	0.926 (0.043)	0.136 (0.072)	3.131 (0.512)
Equivalent	0.895 (0.080)	0.021 (0.028)	3.530 (0.496)
Non-Equivalent	0.833 (0.106)	0.294 (0.171)	1.649 (0.414)
Total	0.869 (0.067)	0.154 (0.092)	2.285 (0.323)

Observer E.B. Chapter III Ahroon (1976)

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (62); Right = 1739 (67)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.777 (0.103)	0.192 (0.091)	1.751 (0.585)
False Alarm	0.925 (0.252)	0.852 (0.156)	0.632 (1.938)
Signal*	0.799 (0.094)	0.294 (0.105)	1.424 (0.539)
False Alarm	0.466 (0.217)	0.067 (0.200)	2.067 (1.231)
Correct Rejection	0.925 (0.068)	0.054 (0.039)	3.356 (0.642)
Non-Signal*	0.797 (0.108)	0.059 (0.042)	2.557 (-.544)
Correct	0.843 (0.053)	0.116 (0.043)	2.262 (0.388)
Incorrect	0.616 (0.164)	0.756 (0.151)	-0.539 (0.968)
Answer "Signal"	0.710 (0.096)	0.194 (0.093)	1.514 (0.580)
Answer "Non-Signal"	0.931 (0.060)	0.161 (0.077)	2.725 (0.641)
Equivalent	0.799 (0.094)	0.059 (0.042)	2.551 (0.513)
Non-Equivalent	0.797 (0.108)	0.294 (0.105)	1.460 (0.545)
Total	0.799 (0.073)	0.175 (0.059)	1.824 (0.376)

Frequencies: Left = 1605 (17); Right = 1739 (25)

Contralateral Event	P(Hit)	P(F.A.)	d'
	Monaural		
Total (left) 12	0.899 (0.036)	0.080 (0.032)	2.738 (0.281)
Total (right) 16	0.922 (0.040)	0.072 (0.033)	2.981 (0.461)
	Selective Attention (left) 16		
Signal*	0.733 (0.082)	0.701 (0.076)	0.116 (0.286)
Non-Signal*	0.429 (0.115)	0.285 (0.090)	0.409 (0.352)
Equivalent	0.733 (0.082)	0.285 (0.090)	1.244 (0.518)
Non-Equivalent	0.429 (0.115)	0.701 (0.076)	-0.728 (0.396)
Total	0.578 (0.051)	0.496 (0.046)	0.212 (0.179)
	Selective Attention (right) 16		
Signal*	0.809 (0.056)	0.408 (0.087)	1.139 (0.371)
Non-Signal*	0.696 (0.076)	0.211 (0.077)	1.399 (0.522)
Equivalent	0.809 (0.056)	0.211 (0.077)	1.777 (0.570)
Non-Equivalent	0.696 (0.076)	0.408 (0.087)	0.761 (0.308)
Total	0.752 (0.052)	0.313 (0.068)	1.191 (0.261)

Observer J.V. Chapter III Ahroon (1976)

Divided Attention - Left Ear 16

Frequencies: Left = 1605 (17); Right = 1739 (25)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.380 (0.127)	0.391 (0.149)	-0.023 (0.489)
False Alarm	0.411 (0.263)	0.621 (0.315	-1.097 (1.290)
Signal*	0.387 (0.114)	0.412 (0.130)	-0.065 (0.456)
False Alarm	0.321 (0.141)	0.321 (0.119)	0.037 (0.405)
Correct Rejection	0.349 (0.146)	0.407 (0.120)	-0.183 (0.510)
Non-Signal*	0.332 (0.097)	0.367 (0.061)	-0.106 (0.325)
Correct	0.368 (0.091)	0.401 (0.108)	-0.088 (0.373)
Incorrect	0.344 (0.116)	0.347 (0.096)	-0.007 (0.327)
Answer "Signal"	0.357 (0.108)	0.354 (0.113)	0.006 (0.316)
Answer "Non-Signal"	0.367 (0.138)	0.428 (0.108)	-0.177 (0.418)
Equivalent	0.387 (0.114)	0.367 (0.061)	0.927 (0.364)
Non-Equivalent	0.332 (0.097)	0.412 (0.130)	-0.753 (0.600)
Total	0.360 (0.082)	0.386 (0.078)	-0.071 (0.280)

Divided Attention - Right Ear 16

Frequencies: Left = 1605 (17); Right = 1739 (25)

Contralateral Event	P(Hit)	P(F.A.)	d'
Hit	0.877 (0.102)	0.504 (0.180)	1.357 (0.767)
False Alarm	0.905 (0.052)	0.538 (0.168)	1.253 (0.513)
Signal*	0.899 (0.043)	0.526 (0.140)	1.227 (0.441)
False Alarm	0.828 (0.117)	0.389 (0.163)	1.401 (0.584)
Correct Rejection	0.915 (0.108)	0.490 (0.120)	1.738 (0.777)
Non-Signal*	0.887 (0.079)	0.452 (0.092)	1.459 (0.440)
Correct	0.899 (0.064)	0.496 (0.105)	1.396 (0.481)
Incorrect	0.886 (0.042)	0.486 (0.124)	1.272 (0.304)
Answer "Signal"	0.857 (0.065)	0.440 (0.139)	1.366 (0.451)
Answer "Non-Signal"	0.909 (0.065)	0.511 (0.130)	1.371 (0.426)
Equivalent	0.899 (0.043)	0.452 (0.092)	1.134 (0.299)
Non-Equivalent	0.887 (0.079)	0.526 (0.140)	1.062 (0.428)
Total	0.892 (0.046)	0.487 (0.103)	1.307 (0.272)