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Transient elevations in the threshold of a signal presented within milliseconds of onset and just prior to the offset of a masker are called "overshoot." Overshoot was investigated by manipulating three independent variables: frequency of the signal, temporal delay of the signal, and mode of stimuli presentation (monaural or dichotic). The masker was always a 60 dB SPL, 250 msec, 1000 Hz pure tone, while the 10 msec signal was one of 8 pure tone frequencies centered around the masker from 400 to 1600 Hz. The signal onset was delayed by one of 4 temporal intervals: +2, +20, +125, and +238 msec. Thresholds were taken for both dichotic and monaural presentation of stimuli. A 2x4x8 Repeated Measures design was used, and an ANOVA provided the statistical analysis.

Significant main effects for all three independent variables were found, as well as a significant frequency by mode of presentation interaction. The results confirmed previous research on the effects of signal temporal delay and mode of presentation of stimuli. The absence of frequency selective characteristics of overshoot in the dichotic condition conflicted with research by Zwislocki et al. (1967, 1968). The results were discussed in terms of Scholl's neural sharpening hypothesis.

SIMULTANEOUS TONE ON TONE MASKING: AN INVESTIGATION OF MONAURAL AND DICHOTIC OVERSHOOT

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Auditory masking occurs when the detection of one sound, the signal, is impaired by the presence of another, the masker (Deatherage & Evans, 1969). The threshold for the signal in the presence of the masker is referred to as the masked threshold. This masked threshold has been shown to remain constant for masking periods of up to 25 minutes. The studies usually use a continuous masker stimulus, and thresholds are taken at regular intervals throughout (Burgeat & Hirsh, 1961; Egan, 1955). Although the masked threshold appears to be constant from masker onset to masker offset, a transient elevation in the masked signal threshold has been noted when thresholds are obtained within milliseconds of the onset or just prior to the masker offset. Such threshold shifts have been noted by Elliott (1965), Fastl (1976), Green (1969), Zwicker (1965a,b), Zwislocki, Damianopoulos, Buining and Glantz (1967), and Zwislocki, Buining and Glantz (1968). These temporary signal threshold elevations are called "overshoot" and are usually measured in dB relative to either (a) the absolute threshold of the signal or (b) the signal threshold within a continuous masker.

Parameters of Overshoot

Various investigations have examined the stimulus parameters which appear to be related to the magnitude of overshoot. Although there are instances of conflicting results, it is still possible to draw some general conclusions concerning several stimulus parameters affecting overshoot. The next few paragraphs sketch the general facts and briefly mention supporting research related to the particular parameter.

1) Overshoot increases as a function of decreasing signal duration. Fastil (1976) reported a 15 dB overshoot for a 5 msec, 8500 Hz tone masked by an 18,000 Hz critical bandwidth noise masker (1965a). The overshoot declines to 8 dB with a 20 msec signal. Zwicker (1965a) found a 13 dB overshoot for a 2 msec, 5000 Hz tone masked by a 600 msec white noise burst. This overshoot disappeared with a 10 msec signal duration. Both Fastil's and Zwicker's signals were delayed 2 msec relative to the masker onset.

2) Overshoot is greatest when the signal follows the masker within 2 to 3 milliseconds. The threshold elevation decays rapidly and approaches the continuous masker threshold with a 200 msec delay. Fastil (1976) noted a 25 dB threshold shift for an 8000 Hz tone delayed by 2 msec, and a 7 dB overshoot for the same tone delayed by 20 msec. Fastil used a uniform masking noise in this

study and a monaural presentation of stimuli. Green (1969) also noted threshold elevations at short signal delays in a study using pure tone maskers and signals presented dichotically. He noted a 22 dB overshoot at a 3 msec signal delay which declined to 5 dB with a 30 msec delay. Zwislocki et al. (1967), Zwicker (1965a), and Elliott (1965), all found similar results, although the amount of overshoot varied from study to study.

3) Overshoot increases as a function of increasing signal frequency. Fastil (1976) found a 5 dB overshoot for signals from 2000 to 4000 Hz masked by broadband noise, and an 8 to 12 dB overshoot for 7000 to 12,000 Hz signals. Both sets of signals were delayed by 2 msec and presented monaurally. A tone on tone study by Green (1971) showed a 17 dB overshoot for a 250 Hz signal delayed by 2 msec and masked by a 600 Hz tone, while a 26 dB overshoot was observed for a 1000 Hz signal masked by a 12,000 Hz masker. Elliott's 1965 study supports this effect.

4) Gated maskers produce more overshoot than maskers with durations over 500 msec. Fastil (1976), Green (1969), and Zwicker (1965) all found pulsed or gated maskers with durations up to 500 msec to be more effective maskers than maskers of longer duration. More specifically, Zwicker found that the signal threshold or overshoot increased as masker duration decreased to approximately 50 msec. Signal threshold decreased for masker durations less than 10 msec.

5) Overshoot increases linearly as a function of increased masker intensity for SPLs over 50 dB. Zwicker (1965a) and Fastil (1976) both observed a positive linear relationship between increases in overshoot and masker intensity for SPLs over 50 dB. Smiarowski and Carhart (1975) discuss Hawkins and Stevens' 1950 study investigating this relationship with pure tone and white noise simultaneous masking. In this latter study a positive linear relationship was found for SPLs from 10 to 80 dB and the threshold of pure tones. The signal and masker onset were simultaneous here, so overshoot per se was not studied.

6) Overshoot depends upon the relative spectral characteristics of the signal and masker. Investigations using different combinations of signal and masker spectra have yielded different results. An overview of these studies is given here.

Masking of pure tones by white noise. Zwicker's 1965 study showed a 12 dB overshoot using a 5kHz tone signal masked by white noise. However, no overshoot was seen for noise signals over two critical bandwidths wide, or for white noise signals, regardless of onset delay. Elliott (1965) found overshoot when tones were presented 5 msec after the onset of a wideband masker and noted that more overshoot occurred at signal frequencies above 1000 Hz than below it. Fastil (1976) also noted overshoot for pure tone signals masked by broad and wide band noise.

Masking of pure tones by narrow bands of noise. In studies using continuous masking conditions (which are not intended to investigate overshoot) narrowband maskers are found to be more effective than pure tones, when a pure tone signal is used. Richards (1976) presents the results from a 1950 study by Egan and Hake finding that the narrowband noise masker produced more masking within the band than did the tone masker at closely adjacent frequencies. Sherrick and Mangabeira-Albernaz (1961) support the effectiveness of a narrowband masker centered at 4000 Hz on a simultaneously presented 4000 Hz signal. A 28 dB threshold elevation was seen for this signal, but there was only a negligible effect on a 1000 Hz signal.

Elliott (1965) is the only investigator of overshoot that has been able to find overshoot using narrowband maskers and tone signals. She found that overshoot for brief tone signals increases for frequencies within and near the narrow masking band. Relatively small overshoot was noted for signal frequencies within a one critical bandwidth masker centered at 2550 Hz, while considerable overshoot appeared just outside the band. Wright (1964), however, found no overshoot using a 1000 Hz pure tone signal masked by narrowband noise. Zwicker (1965b), who discusses Wright's study, also was unable to find overshoot with a narrowband masker centered at 4700 Hz and 2 msec, 4800 Hz signals.

Masking of pure tones by pure tones. Pure tone masking is frequently characterized by the critical band phenomenon, viz., a critical band of frequencies surrounding a signal does the majority of the masking. Richards (1976) discusses this effect and notes that Ehmer (1959) extended the pioneer work of Wegel and Lane (1924) by investigating changes in the masked threshold with increasing masker intensity and signal frequency. Masking was symmetrical around the 1000 Hz masker at SPLs of 60 dB and below. Masking peaked around the masker frequency, falling sharply for frequencies further away. Additional peaks above the masker frequency were seen at SPLs of 80 and 100 dB. Sherrick and Mangabeira-Albernaz (1961) and Ingham (1959) both found peaks in masked thresholds for signals near the masker frequency.

Zwislocki et al. (1967) studied this critical band phenomenon in a dichotic overshoot paradigm, using a 250 msec, 1000 Hz masker and a 10 msec test tone delayed by 20 msec. A maximum overshoot of 15 dB was observed, with a 170 Hz wide peak appearing around the masker. The author cites Zwicker, Flottorp and Stevens' 1957 data indicating that the width of this peak is nearly identical to the calculated critical band at 1000 Hz. Green (1969) noted similar effects using both continuous and gated pure tone maskers and 10 msec signals in a monaural presentation.

In summary, overshoot is maximized under conditions of short signal duration, minimal signal onset delays, and high signal frequencies. Gated maskers and masker intensity levels over 50 dB SPL are most effective in producing overshoot. The amount of overshoot seen varies with the relative spectral characteristics of the signal and masker. Pure tones are, in most instances, effectively masked by white noise and other pure tones. However, narrowband noise maskers only infrequently produce overshoot. When both masker and signal are broad or narrowband noise, little or no overshoot is observed. White noise and pure tone masking studies of overshoot appear to show the critical band patterns in both monaural and dichotic situations.

Current Hypotheses

Studies of overshoot have been plagued by large differences among subjects (Fastl, 1976; Green, 1969; Zwicker, 1965a), causing some difficulty in replication. One source of the discrepancies among studies could be a function of the psychophysical methods used, since Elliott (1965) has shown that a two-alternative forced-choice procedure produces less overshoot than other techniques. Differences in the rise/decay times of the masker and signal may also be responsible for some confusion in interpretation. Brief rise/decay times for the signal in particular are assumed to increase threshold. The energy spreads to other frequencies when rise/decay is "instantaneous."

This energy spread across the spectrum is assumed to increase the threshold. Investigators do not always report the rise/decay values of the signal and masker, so interpretation is difficult (Lankford, 1969; Smiarowski, 1975).

Several other hypotheses have been suggested as partial explanations for the overshoot phenomenon. Elliott (1965), for example, proposed that neural on-and-off effects account for threshold shifts occurring at masker onset and offset. The heavier barrage of neural firings from the masker onset presumably either lowers the transmission of the neural response to the signal or interferes with information processing at higher neural levels to obstruct the subject's "attention" to the tone. Elliott concedes however that this hypothesis alone can not account for the frequency dependent characteristics of overshoot.

Elliott (1965) and Green (1969) discuss another hypothesis by Scholl (1962) where it is assumed that the critical band "sharpens" and requires some time to develop. In this hypothesis the masker is thought to produce an initial widespread excitation on the basilar membrane, which quickly sharpens into the critical band through activation of inhibitory processes. The decreasing critical bandwidth makes signal detection easier by improving the signal-to-noise ratio. Evidence of parallel neural sharpening mechanisms in vision and touch are cited by Green (1969) and Elliott (1965) to support this hypothesis (Battersky

& Wagman, 1964; Novak & Sperling, 1963; Ratliff, 1965).

It should be noted, however, that Zwislocki et al. (1967, 1968) have collected dichotic data which do not support Scholl's hypothesis. That is, the critical band has been shown to be narrow (170 Hz) when the signal is delayed only 20 msec. Under Scholl's hypothesis, the critical band should be relatively wide, have a low S/N ratio, and be in the process of "sharpening." Hence, the measure of the critical band and short signal delay should be difficult. Nevertheless, Zwislocki et al.'s data clearly reveal the masking required to support the notion of no critical band sharpening. The conflict in the data has not been resolved.

Zwicker has attempted to explain the frequency dependent nature of overshoot in terms of the relative bandwidths of signal and masker. Noting little or no overshoot for wideband signals masked by wideband stimuli, but increasing overshoot with decreasing signal bandwidth, Zwicker maintains that overshoot would not occur when both signals have similar critical band spectra. This hypothesis is supported by some data on wide and narrowband stimuli, but is in conflict with the appearance of overshoot in tone-on-tone masking (Green, 1969; Zwislocki et al., 1967).

Green (1969) discusses an "energy splatter" hypothesis, designed to account for differences in gated and continuous masker conditions. Gated maskers may be assumed to elevate the threshold of a signal because energy of short duration maskers is "splattered" and enters functional auditory filters (critical bands) near the signal. Hence this splattering of energy tends to mask the signal and raise its threshold. The energy splatter here is inherent in the presentation of sinusoids of very brief duration. Continuous pure tone maskers, however, have their energy "centralized" at the masker frequency and therefore produce less interference with signal detection and less overshoot.

Smiarowski and Carhart (1975) suggest that simultaneous and forward masking are both related to auditory persistence. Although their study did not directly explore overshoot, by expanding their hypothesis, onset overshoot could logically be explained in terms of the limits of temporal resolution. They cite studies showing that masking effects remain at a high level for a few milliseconds following termination of a burst of masking noise. The effect declines progressively over time and dies out within 250 msec. Smiarowski and Carhart replicated these results, and then compared the relationship between amount of masking and level of the masker for simultaneous and forward masking conditions. The functions were in close agreement, supporting their idea that the processes involved in simultaneous and forward masking are similar. The minimum perceptible separation time for two noise bursts in their study was 2.8 msec, which closely agrees with a study the authors cite by Plomp's (1964) and Green's (1971) data. In addition, Penner and Cudahy (1973) have suggested a critical masking interval which is similar to Plomp's and Green's values. Overshoot is typically found by other investigators to peak within a few milliseconds after masker onset and to decay in the same fashion as forward masking. The similarities in the temporal characteristics of simultaneous and forward masking are impressive, but this hypothesis can not alone account for the frequency dependent characteristics of overshoot.

Central and Peripheral Masking

Central masking may occur when the masking sound is presented to one ear and the test tone to the other. Central processes are assumed to be activated and are invoked to explain the resulting threshold shift for the test stimuli. This is because the ears are, to a large extent, acoustically insulated from each other but not neurologically isolated. An interaction between the masker and signal somewhere within the central nervous system, beyond the VIIIth auditory nerve, is often hypothesized to be responsible for central masking effects.

In contrast, peripheral masking is investigated by presenting both masker and signal to the same ear, and masking is assumed to occur within the peripheral mechanism. There are a few differences between peripheral and central overshoot effects, though studies comparing the two are infrequent. Studies by Elliott (1965) and Lankford (1969) provide a comparison of peripheral and central masking offset overshoot. Elliott (1965) consistently observed peripheral overshoot for a tone presented just prior to the offset of a noise masker, though the amount of offset overshoot was smaller than onset overshoot. Lankford (1969) found the same effect for his monaurally presented tones, but found no significant offset overshoot for dichotically presented tones. Relatively few simultaneous masking studies have investigated offset overshoot, but these researchers describe it as a process similar to backward masking.

For most other parameters, overshoot appears in central masking presentations under the same conditions that it does in monaural or peripheral masking experiments. However, the threshold shift is much smaller than that seen in monaural masking, and rarely exceeds 10 dB (Zwislocki, 1971). The central effect is maximized, as it is in monaural masking, when both stimuli are gated and the brief signal is presented near the onset of the masker (Elliott, 1965; Green, 1969). In both central and peripheral masking overshoot peaks for stimuli in the frequency region of the masker (Zwicker, 1965b; Zwislocki et al., 1967).

Ingham (1959) proposes three hypotheses to explain central masking in general. The Mutual Inhibition theory assumes two separate groups of neurons which are activated at the same time, as in simultaneous masking procedures, one group may inhibit the other group of neurons and produce masking.

The second proposal involves a variation on the mutual inhibition notion, and is called "Overlapping Patterns." The two groups of neurons may have neurons in common, depending on how close in frequency the masker and test tone are. Simultaneous activation of the groups would cause a level of masking related to the number of common neurons through a mutual inhibition process.

The third hypothesis discusses a statistical model for central masking. Assuming random spontaneous firing rates for both groups of neurons in the absence of external stimulation, the onset of a signal would result in an increase in the variability of firing, making the signal more difficult to detect. The firing rate of the signal then must exceed the masker firing rate by a margin wide enough to "convince" the system of external stimulation.

The processes involved in central masking overshoot have not been determined. Zwislocki et al. (1967) have proposed that excitatory-inhibitory interactions in the auditory central nervous system are involved. Zwislocki observed a critical band effect in his tone-on-tone masking study and noted maxima and minima threshold points around the masker frequency; these points were offered as evidence for his excitatory-inhibitory notion.

In summary, the hypotheses proposed to account for central masking rest on some neurological interaction between the signal and masker impulses. Mutual inhibition of simultaneously presented stimuli, overlapping patterns of neurons close in frequency, and increased variability in the firing rate of the masker and signal have been offered by Ingham (1959) as possible explanation for central masking effects. Zwislocki et al. (1967) assumes that excitatory-inhibitory processes are involved in central masking overshoot even though investigators are still in an early speculation stage in regard to this phenomenon.

It should be noted that, with few exceptions, for every study showing a particular effect and for every proposed hypothesis, there is at least one study offering conflicting results, and one investigator to discount the particular hypothesis. This study, as part of a larger project combining backward, simultaneous, and forward masking, investigated the critical band effect in tone-on-tone masking, offering additional evidence on the relative spectral characteristics of overshoot (see parameter no. 6). Relatively long rise/decay times for the signal and masker were used to minimize possible transients, which may have exaggerated the overshoot effect in previous studies. The signal was delayed by four intervals relative to the masker onset in order to investigate onset overshoot and its decay, as well as offset overshoot. Measurements were taken for both the monaural and dichotic presentation of stimuli to provide a contrast of peripheral and central overshoot effects.

CHAPTER II

METHOD

Subjects

Three unpaid subjects participated in the investigation, one male and two females. Their mean age was 30 and each had normal hearing in the frequency spectrum used in the study.

Procedure

The Double Random Staircase technique (Cornsweet, 1962) was used as the psychophysical method to obtain both the absolute and the masked thresholds. Figures 1 and 2 illustrate the technique and include a flow diagram of the experimental apparatus. Each subject completed three phases of the experiment: Introduction and audiometric screening, Training, and Experimental data collection.

Introduction and Audiometric Screening. At the onset of the investigation each subject was instructed in the basic procedures and rationale of the experimental sessions. Since two of the subjects acted as both experimenter and subject, a criticism concerning biased data may be raised. However, knowledge concerning the goals of the experiment is not critical for three reasons: First, the psychophysical technique used to collect the data eliminated

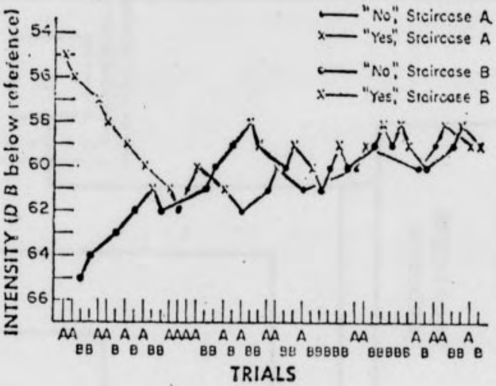

Figure 1. Typical example of the double random staircase psychophysical technique. Threshold is determined by the average of the two signal intensities on the last 3 trials. (Cornsweet, 1962)

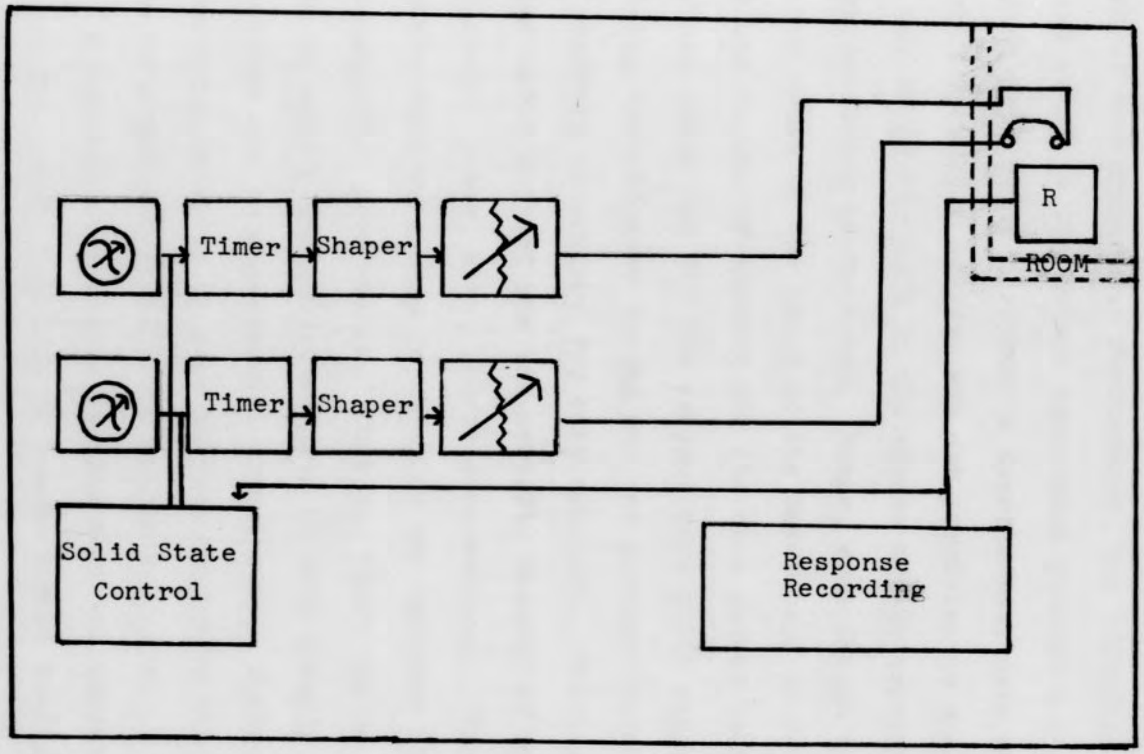

Figure 2. Block diagram of the experimental apparatus.

the possibility of malingering or spuriously high or low thresholds. This is true because any such malingering tends to be revealed in the variability of the individual threshold measurements. Furthermore, the training of the subject prior to the actual experiment yielded a stable baseline from which a subject's experimental data may be judged. Second, a subject was not permitted to view the data nor to participate in the choice of the experimental parameters being manipulated. Hence, even though the subject was aware of the range of the parameters to be used there was no way of knowing how the data should look in the final stage nor did the subject know which parameter was being investigated during any one session (parameters were randomly determined for each session). Finally, there was one naive subject who was entirely unaware of the experimental goals, aims, and/or expectations. This last subject's data were used to check on the validity of the other subjects' performance. That is, there was no a priori reason to expect the subjects' data to vary greatly (between variability due to experimental parameters). Furthermore, the training received by each subject tended by its very nature to eliminate variability within subjects.

A typical audiometric hearing test was administered prior to the actual training to insure normal hearing of subjects. A Tracor Quik-Check (Model No. 1292) portable audiometer was used.

Training. Training entailed approximately two hours of experience in listening to stimuli, both dichotic and monaural, in the frequency range of the stimuli used in the experiment per se. Instructions concerning headphone adjustment, modes of listening, and actual practice were emphasized. Training was completed when the subject showed a consistent and reliable threshold to several training stimuli and when a minimum of two hours practice was completed (approximately 1000 trials). Threshold data were considered reliable when they varied no more than 2 dB on the last three measurements during training.

Experimental Sessions. The experimental sessions consisted of three parts: First there was an absolute threshold obtained for each of the particular stimulus frequencies used. Second, the actual masked thresholds were obtained. Finally, a measurement of the absolute threshold was once again ascertained to determine if any change occurred throughout the experimental sessions.

Each session, of approximately 500 trials, began with the stimulus parameters preset according to a randomization procedure for each subject. The signal frequency varied for each block of approximately 100 trials, while the signal temporal delay remained constant for all frequencies within a session. Thus the subject's task was simply to enter the sound attenuated chamber and prepare for the stimulus presentations. The first block of trials was used to "settle-in" to the task. Each block of trials thereafter was the actual data for the experiment. At the end of each block of trials the subject was required to remove the headphones and leave the experimental chamber. This prevented fatigue and insured that the "fit" of the headphones on each block was determined individually and prevented a "bad fit" from occurring throughout a complete session of four of five blocks. The subject's knowledge of the results per block was reported only in general terms, i.e., "You are in the ball park," or "The data are still consistent." Each session lasted approximately one hour.

Figure 3 diagrams the sequence of events within a single trial. The left-hand light on the response apparatus flashed at the beginning of each trial to signal the approaching onset of the masker and signal. Five hundred msec after the presentation of the masker and signal the middle light flashed. This light flash marked the beginning of the response interval. The subject responded by pushing one of two buttons to indicate whether or not the signal was detected. The third light flashed at the end of the response interval to mark the end of the trial. A brief pause followed before the sequence began for the next trial.

Independent Variables. Three independent variables were manipulated in this study: the monaural and dichotic presentation of stimuli, temporal delay of the signal, and signal frequency. The signal frequencies were: 400, 800, 900, 950, 1050, 1100, 1200 and 1600 Hz. The signal was delayed by one of the following intervals: +2, +20,

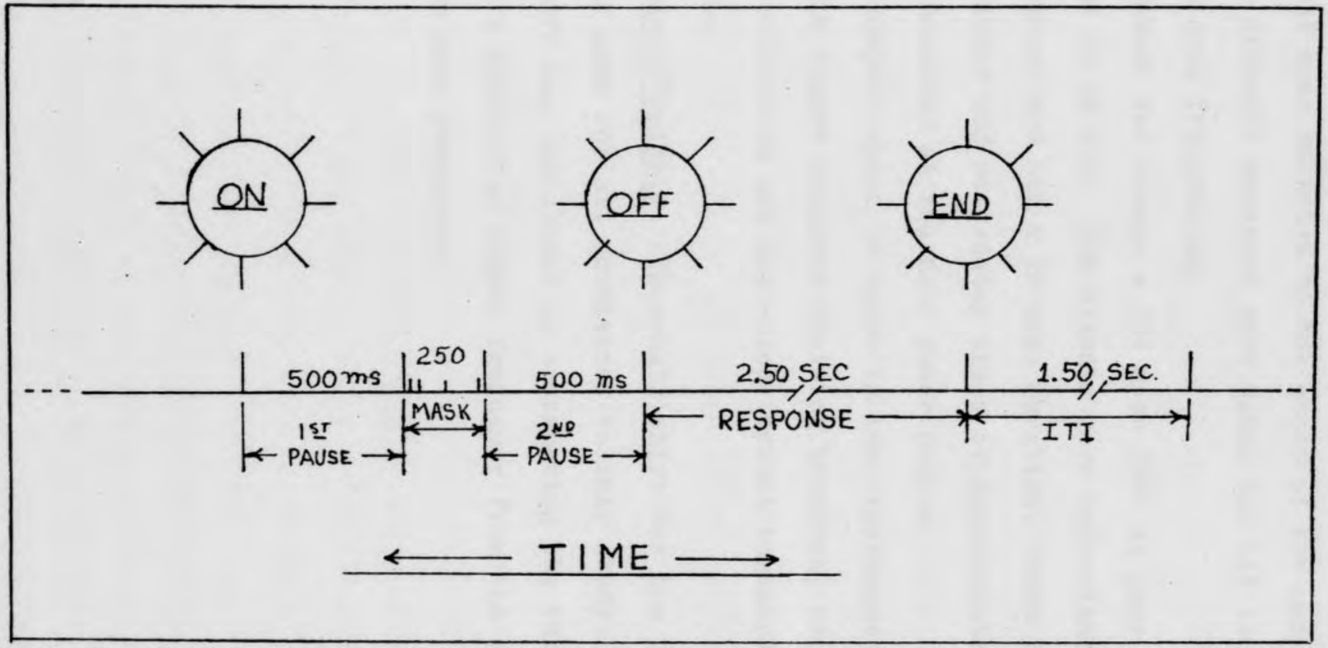

Figure 3. Representation of the sequence of events within a single trial. Masker is always 250 msec in duration at 60 dB SPL. Short vertical lines represent the 10 msec signal. Signal presentation is measured from masker onset. Light flashes (.1 msec) are used to demarcate signal presentation, Response interval and Inter-trial interval.

+125, and +238 msec relative to the onset of the masker. Monaural and dichotic measures were taken for all temporal delays and signal frequencies.

The masker was always a 250 msec 1000 Hz pure tone maintained at 60 dB SPL. The signals were approximately Guassian in shape and had a 10 msec duration. Both the signal and masker had rise/decay times of approximately 4.2 msec as measured at the half power points.

Each subject spent 30 hours in the experimental setting. This figure includes training sessions, experimental data collection and post-experimental threshold determinations.

Dependent Variable. Threshold shift was the dependent variable used for all conditions in this study. Threshold shift was calculated by subtracting the threshold in quiet for a particular signal frequency from the masked threshold for that frequency.

CHAPTER III

RESULTS

Figure 4 shows the 2x4x8 non-additive Repeated Measure design used in this study. All factors were assumed to be fixed effects. Factor A was the signal Mode of Presentation. The monaural and dichotic presentation of stimuli were the two levels of this main effect. Factor B was the Temporal Delay of the signal. The four levels of factor B included 2, 20, 125, and 238 msec delays. The eight levels of factor C were the Signal Frequencies: 400, 800, 900, 950, 1050, 1100, 1200, and 1600 Hz. The data were analyzed with an ANOVA and Tukey HSD post-hoc tests.

Table 1 shows the ANOVA summary table. Table 2 shows the mean overshoot obtained in the experiment. The analysis yielded the three expected significant main effects ($p < .001$). Tables 3, 4, and 5 present the masked thresholds in dB SPL for each subject, and Tables 6, 7, and 8 present overshoot results for each subject. Figures 5, 6, and 7 display the individual overshoot effects graphically. Figure 8 depicts the mean performance of all subjects. The individual data were consistent across all three subjects. Mode of Presentation, Temporal Delay and Signal Frequency were each effective in the production

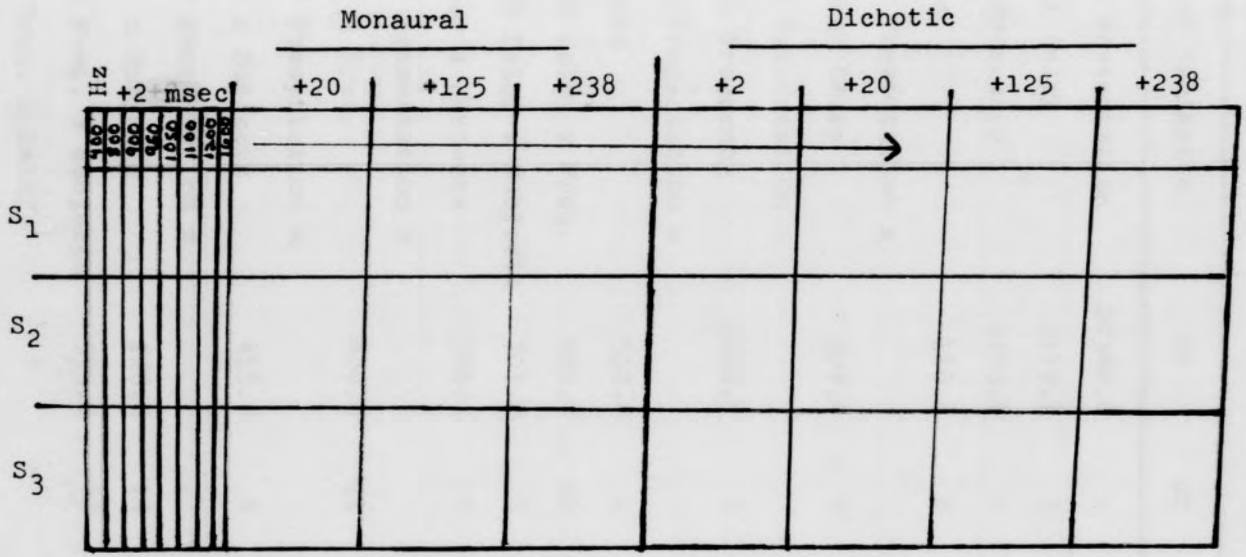

Figure 4. 2 x 4 x 8 Repeated Measures Design, Fixed Effects, Non-additive model.

Table 1

Summary of Analysis of Variance

Source of Variation	SS	df	MS	F
Mode of Presentation	20348.6	1	20348.6	*79.4
Temporal Delay	3779.7	3	1259.9	*10.7
Signal Frequency	3743.7	7	534.8	*19.7
Subjects	120.8	2	60.4	
Mode of Presentation x Temporal Delay	397.4	3	132.5	1.9
Mode of Presentation x Signal Frequency	3428.1	7	489.7	*30.0
Mode of Presentation x Subjects	512.4	2	256.2	
Temporal Delay x Freq.	409.6	21	19.5	1.4
Temporal Delay x Subjects	707.8	6	118.0	
Frequency x Subjects	380.2	14	27.2	
Mode of Presentation x Delay x Freq.	470.5	21	22.4	1.4
Mode of Presentation x Delay x Subjects	415.8	6	69.3	
Mode of Presentation x Freq. x Subjects	228.8	14	16.3	
Delay x Freq. x Subjects	595.2	42	14.2	
Mode x Freq. x Delay x Subjects	691.9	42	16.5	

* Significant at $p < .001$

Table 2

Mean Overshoot Data for All Subjects in dB SPL

Delay		Dichotic				Monaural			
		2	20	125	238	2	20	125	238
Freq.	Thresh-old								
1600	26.2	5.6	6.5	-.4	-.9	25.3	8.6	4.6	13.5
1200	24.0	8.5	1.8	-.2	-.3	36.2	30.3	16.5	16.7
1100	24.6	9.2	1.9	-1.3	1.6	35.1	28.2	21.7	27.7
1050	23.5	8.7	6.5	.2	2.7	39.8	38.3	23.8	32.0
950	22.8	10.9	3.4	0.0	4.4	41.	37.4	27.2	29.2
900	23.1	8.6	2.7	-1.4	1.7	38.2	30.9	19.2	26.2
800	23.6	8.7	.9	.2	-.8	32.4	20.9	13.4	20.2
400	27.4	5.8	6.8	2.1	3.3	12.9	7.6	6.3	7.1

Table 3

Masked Thresholds for Subject JC in dB SPL

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-hold								
1600	26.8	34	41.5	26	29	50.5	38	31.5	37.5
1200	28.7	39	31	27.5	28.5	63.5	56	41	46.5
1100	30.5	40.5	35	29	30	62.5	56	45	54
1050	29.1	37.5	42	29	32	62	58.5	47.5	57
950	27	39	32	26	31	64.5	61.5	49.5	52
900	25.3	33	28.5	26	28	61	59.5	41.5	53.5
800	24.7	34	26	26	26	62	47	37	44.0
400	26	30	28	29.5	27.5	33	32	27	22.5

Table 4

Masked Thresholds for Subject DRS in dB SPL

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-hold								
1600	25.7	32	32	28	24.5	49	37	30.5	33
1200	19.7	32.5	24.5	23	21.5	64.5	60.8	36	26.5
1100	20.0	33.3	23	22	22.5	58	51	45	38.5
1050	19.6	33	22.5	22.5	20	65	65	43	45
950	19.8	35	22.5	21.5	25	63.5	68	47	44.5
900	21.7	33.5	24	18	23	62	55.5	38.5	40
800	24.1	35	26.5	23.5	24.5	49	47	35	36
400	25.0	34.5	33.5	27.5	26.5	35.5	35	30.5	46.5

Table 5

Masked Thresholds for Subject HF in dB SPL

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-hold								
1600	26	29.5	24.5	23.5	22.5	55	29.5	30.5	48.5
1200	23.7	26	22	21	21	52.5	46	44.5	49
1100	23.4	27.5	21.5	19	26	58.5	51.5	49	64.5
1050	21.8	26	25.5	19.5	26.5	63	62	51.5	64.5
950	21.5	27	24	21	25.5	63.5	51	53.5	59.5
900	22.4	28.5	25	21	23.5	61	47	47	54.5
800	22	28	21	22	18	57	39.5	39	51.5
400	31.2	35	41	31.5	38	52.5	38	43.5	34.5

Table 6

Overshoot (Masked Threshold Minus Threshold in Quiet) for Subject JC

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-old								
1600	26.8	7.2	14.7	-.8	2.2	23.7	11.2	4.7	10.7
1200	28.7	10.3	2.3	-1.2	-.2	34.8	27.3	12.3	17.8
1100	30.5	10.0	4.5	-1.5	-.5	32.0	25.5	14.5	23.5
1050	29.1	8.4	12.9	-.1	2.9	32.9	29.4	18.4	27.9
950	27.0	12.0	5.0	-1.0	4.0	37.5	34.5	22.5	25.0
900	25.3	7.7	3.2	.7	2.7	35.7	34.2	16.2	28.2
800	24.7	9.3	1.3	1.3	1.3	37.3	22.3	12.3	19.3
400	26.0	4.0	2.0	3.5	1.5	7.0	6.0	1.0	-3.5

Table 7

Overshoot (Masked Threshold Minus Threshold in Quiet) for Subject DRS

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-old								
1600	25.7	6.3	6.3	2.3	-1.2	23.3	11.3	4.8	7.3
1200	19.7	12.8	4.8	3.3	1.8	44.8	41.2	16.3	6.8
1100	20.0	13.3	3.0	2.0	2.5	38	31	25	18.5
1050	19.6	13.4	3.0	2.9	.4	45.4	45.4	23.4	25.4
950	19.8	15.2	2.7	1.7	5.2	43.7	48.2	27.2	24.7
900	21.7	11.8	2.3	3.7	1.3	40.3	33.8	16.8	18.3
800	24.1	10.9	2.4	-.6	.4	24.9	22.9	10.9	11.9
400	25.0	9.5	8.5	2.5	1.5	10.5	10.0	5.5	21.5

Table 8

Overshoot (Masked Threshold Minus Threshold in Quiet)

for Subject HF

		Dichotic				Monaural			
Delay		2	20	125	238	2	20	125	238
Freq.	Thresh-old								
1600	26	3.5	-1.5	-2.5	-3.5	29	35	4.5	22.5
1200	23.7	2.3	-1.7	-2.7	28.8	22.3	20.8	25.3	
1100	23.4	4.1	-1.9	-4.4	2.6	35.1	28.1	25.6	41.1
1050	21.8	4.2	3.7	-2.3	4.7	41.2	40.2	29.7	42.7
950	21.5	5.5	2.5	-.5	4.0	42.0	29.5	32.0	38.0
900	22.4	6.1	2.6	-1.4	1.1	38.6	24.6	24.6	32.1
800	22	6.0	-1.0	0.0	-4.0	35.0	17.5	17.0	29.5
400	31.2	3.8	9.8	.3	6.8	21.3	6.8	12.3	3.3

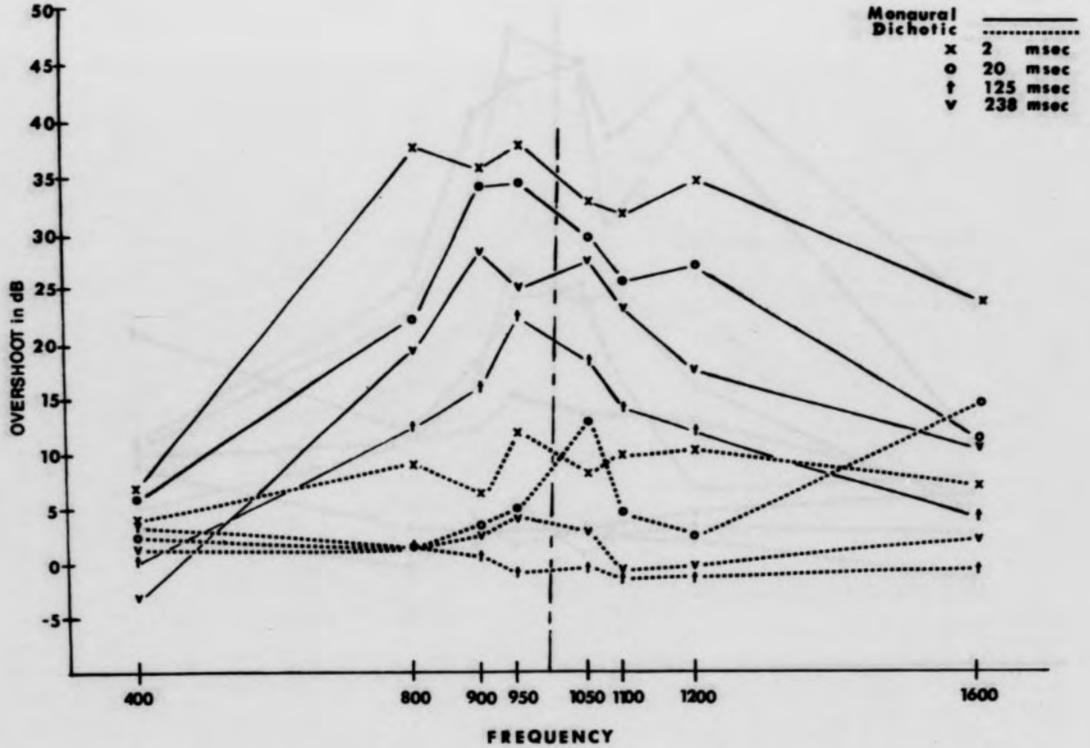

Figure 5. Graph of the overshoot for subject JC in dB SPL. The vertical line represents the 1000 Hz masker. Signal frequency is on the abscissa. Parameter is signal delay in msec.

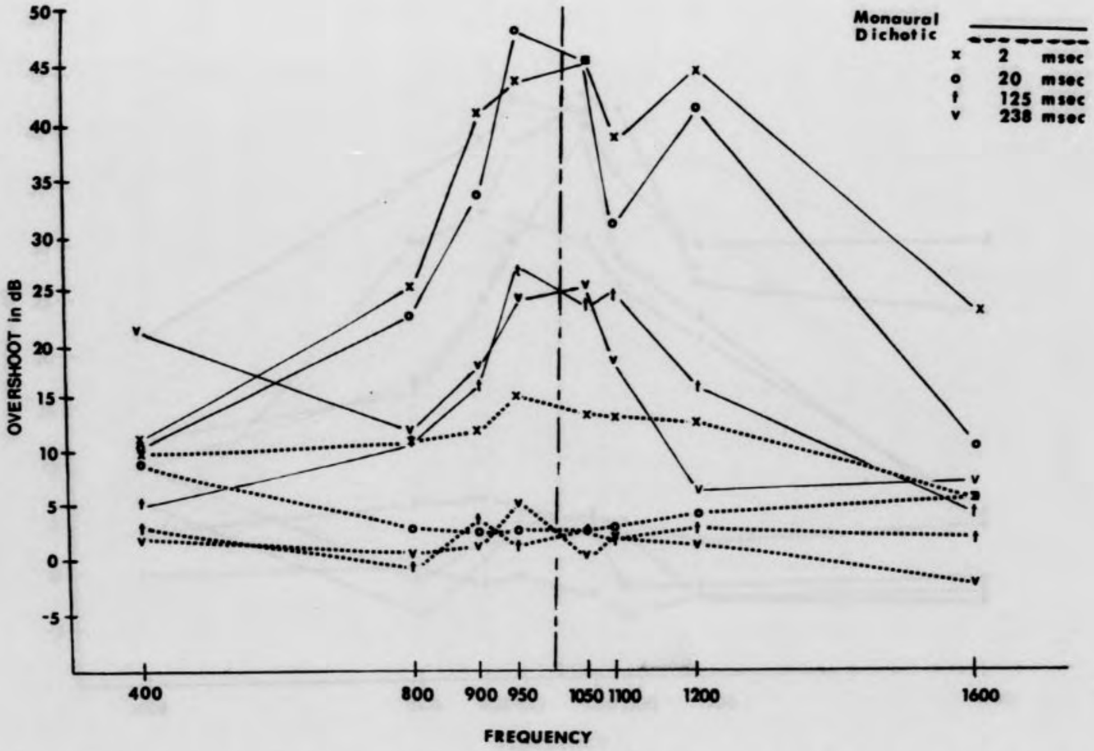

Figure 6. Graph of the overshoot for subject DRS in dB SPL. The vertical line represents the 1000 Hz masker. Signal frequency is on the abscissa. Parameter is signal delay in msec.

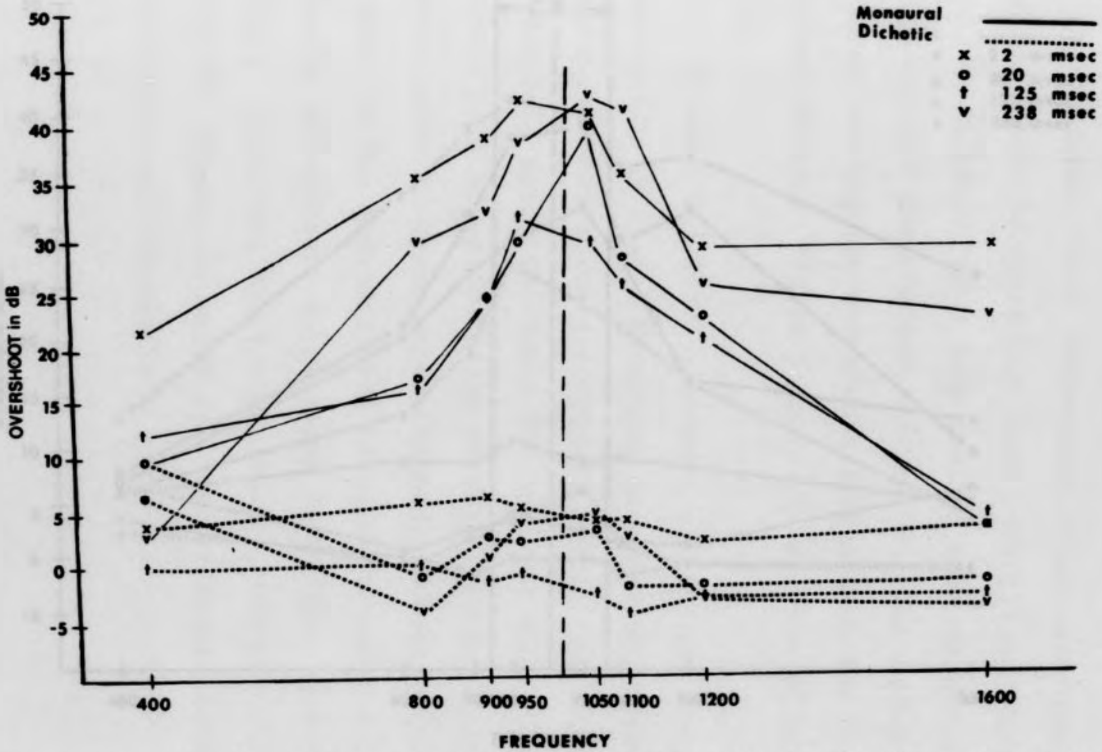

Figure 7. Graph of the overshoot for subject HF in dB SPL. The vertical line represents the 1000 Hz masker. Signal frequency is on the abscissa. Parameter is signal delay in msec.

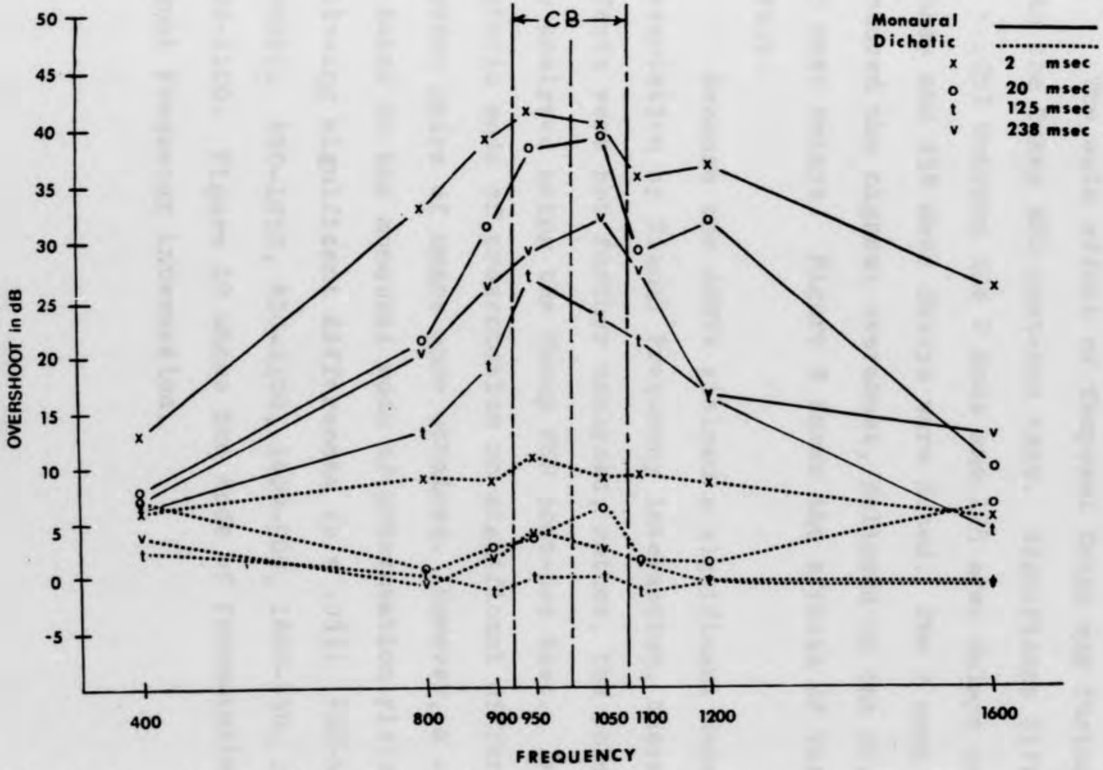

Figure 8. Graph of the overshoot for all subjects in dB SPL. The vertical line represents the 1000 Hz masker. Signal frequency is on the abscissa. Parameter is signal delay in msec. The vertical lines on either side of the masker frequency indicate the CB as calculated by Zwicker, Flottorp and Stevens (1957).

of overshoot. The Mode of Presentation by Signal Frequency interaction was the only interaction reaching statistical significance ($p < .001$).

The main effect of Temporal Delay was further analyzed with the Tukey HSD post-hoc test. Significant differences ($p < .05$) between the 2 msec and 125 msec delays and the 2 msec and 238 msec delays were noted. The 2 msec delay produced the highest overshoot, followed by the 20, 238, and 125 msec delays. Figure 9 shows the effects of this main effect.

Because the ANOVA yielded a significant Mode of Presentation by Signal Frequency interaction, these main effects were not further analyzed; rather, the interaction was analyzed using the Tukey HSD post-hoc test. In the dichotic mode of presentation no significant differences between pairs of means were obtained. However, a comparison of means in the monaural mode of presentation yielded the following significant differences ($p < .05$): 400-900. 400-950. 400-1050, 400-1100, 1600-900, 1600-950, 1600-1050, 1600-1100. Figure 10 shows the Mode of Presentation by Signal Frequency interaction.

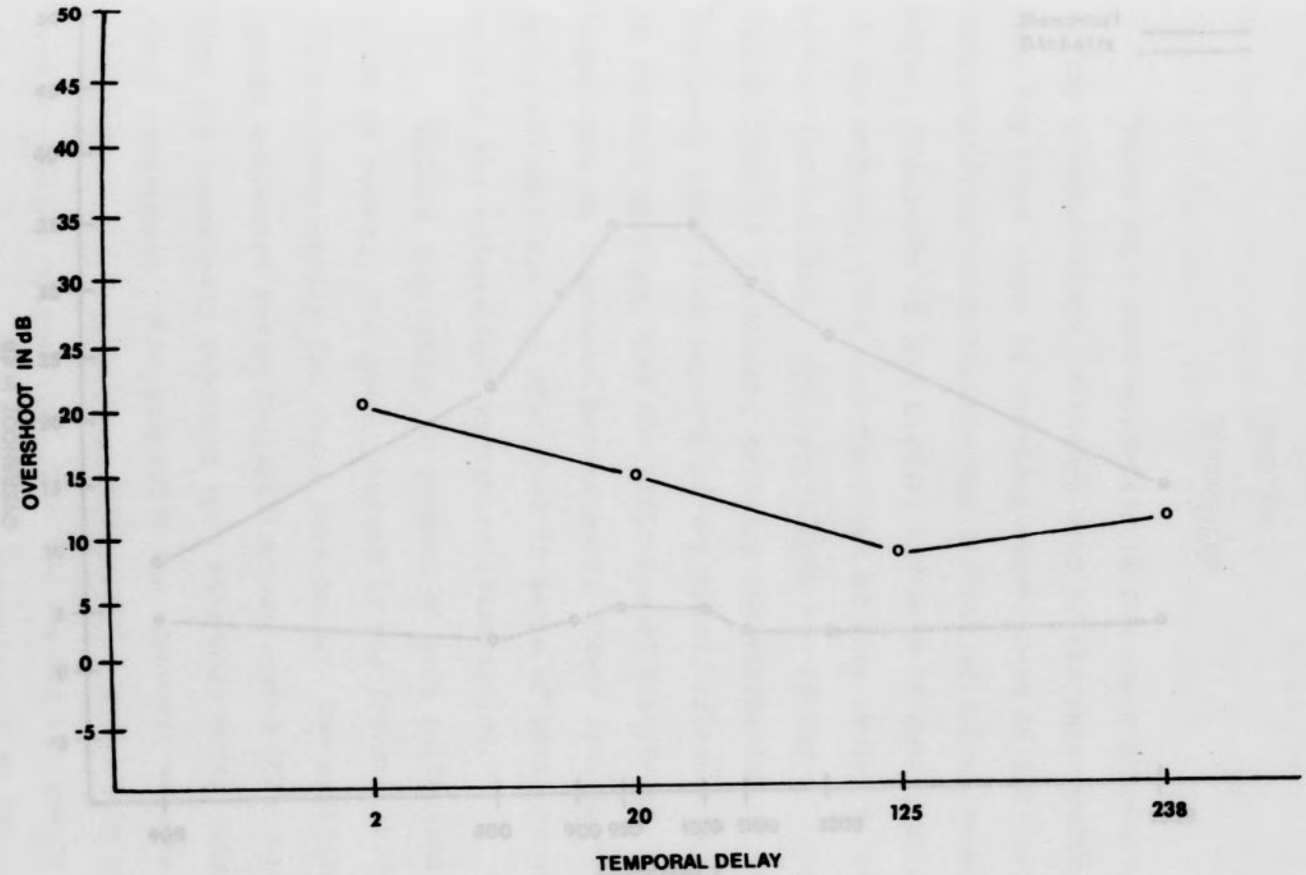

Figure 9. Graph of the mean overshoot found for each temporal delay.

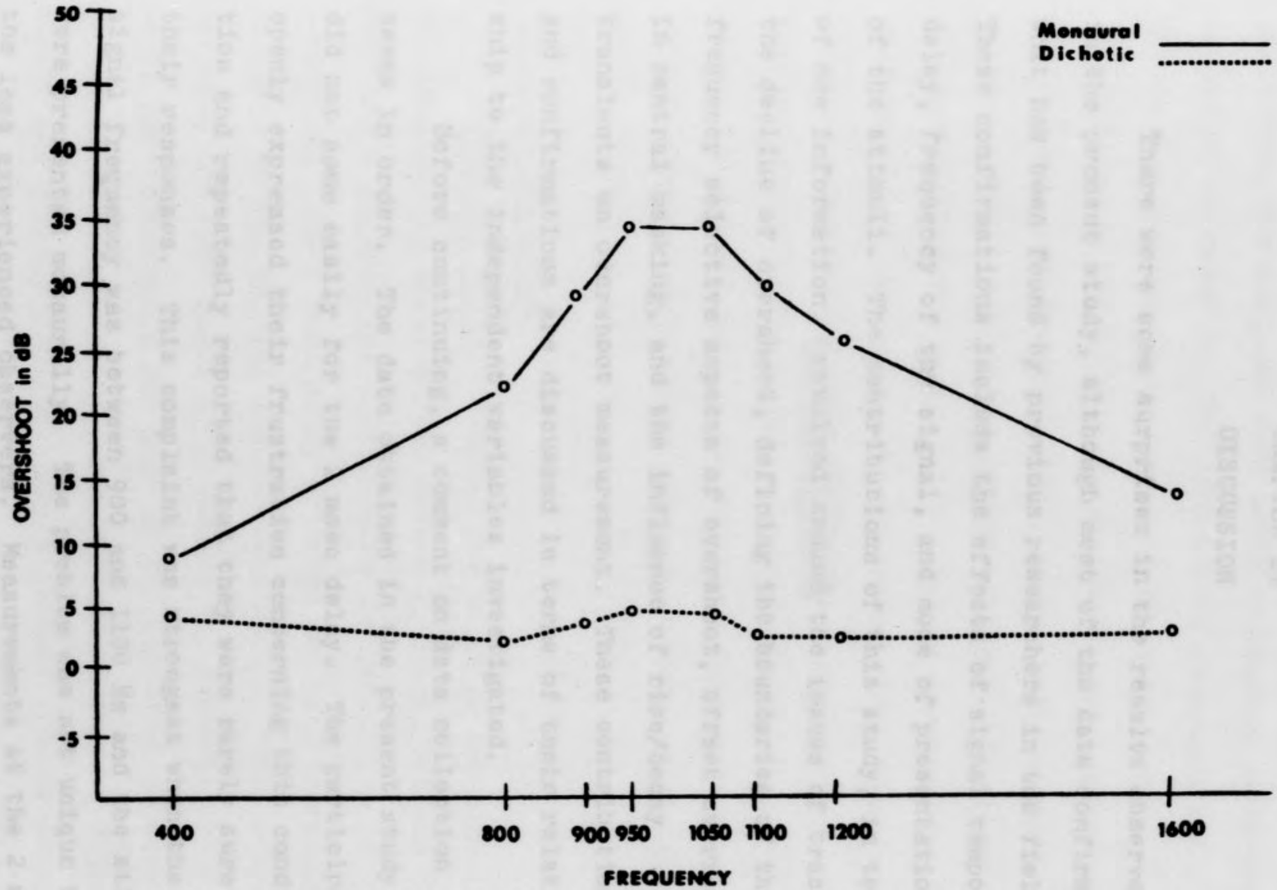

Figure 10. Graph of the mean overshoot found for the monaural and dichotic presentations.

CHAPTER IV

DISCUSSION

There were some surprises in the results observed in the present study, although most of the data confirms what has been found by previous researchers in the field. These confirmations include the effects of signal temporal delay, frequency of the signal, and mode of presentation of the stimuli. The contributions of this study, in terms of new information, revolved around the issues of tracing the decline of overshoot, defining the boundaries of the frequency selective aspects of overshoot, offset overshoot in central masking, and the influence of rise/decay transients on overshoot measurement. These contributions and confirmations are discussed in terms of their relationship to the independent variables investigated.

Before continuing, a comment on data collection seems in order. The data obtained in the present study did not come easily for the 2 msec delay. The participants openly expressed their frustration concerning this condition and repeatedly reported that they were rarely sure of their responses. This complaint was strongest when the signal frequency was between 900 and 1100 Hz and the stimuli were presented monaurally. The problem was not unique to the less experienced observers. Measurements at the 2 msec delay were taken repeatedly with the double random staircase method but reliable data simply could not be obtained. Therefore, the subjects were asked to respond using the method of adjustment. The mean of the ascending and descending staircases was accepted as reliable data. Although Green (1969) reports that this delay condition yielded the greatest variability among subjects, the problem was not specifically noted within subjects. It is possible, of course, that the variability noted by Green may be due to some extent by within subject variability. The present results, however, are consistent with other measurements in this investigation and were painstakingly obtained. The values are as reliable as we could make them. In some cases several hundred trials were used to verify a single data point.

Stimulus Parameters

Temporal delay. Varying the onset of the signal relative to the onset of the masker by 2, 20, 125 and 238 msec had a significant influence on the production of overshoot. The 2 msec delay produced the most overshoot, followed by the 20, 238 and 125 msec delays. This pattern was true for both modes of presentation, although the 2 msec delay was responsible for most of the overshoot obtained in the dichotic situation. These findings support Elliott (1965) and Zwicker's (1965) investigations. These data can also be compared with Zwislocki et al.'s (1967, 1968) investigations on central masking in which the masker and signal were both 1000 Hz pure tones of 250 and 10 msec durations, respectively. It should be noted however that there is some question regarding the signal duration for the 1968 investigation. It is possible that the signal duration was 20 msec rather than 10. The confusion lies in the manner in which Zwislocki described the signal duration. The Zwislocki et al. (1967, 1968) studies found a decline in overshoot from 11 dB to 4 dB when the onset of the signal was systematically varied at intervals from 0 through 160 msec delays. In the present study, the central masking declined from 10 dB in the 2 msec delay to 2 dB with a 125 msec delay. Given the differences in masker intensity (60 dB SPL in the present study and 60 dB SL in the Zwislocki studies) and slight differences in signal frequency and delay, the results in terms of the amplitude of overshoot are remarkably similar.

The 125 msec signal delay was included in the present study to allow the tracing of overshoot decline. It was expected to produce little or no overshoot in both the monaural and dichotic conditions. This delay did produce the least amount of overshoot for both modes of presentation, but substantial overshoot at this delay in the monaural presentation was observed (see Figure 8). The mean overpresentation was observed (see Figure 8). The mean overshoot for the 125 msec delay in the dichotic condition was .85 dB, compared to 16.6 dB in the monaural condition. The presence of overshoot at this delay in the monaural condition is consistent with Elliott's (1965) observation that minimum masking doesn't appear unless 250-300 msec delays are used (disregarding offset overshoot). Zwislocki et al. (1967, 1968), as noted, also observed slight overshoot at 160 msec delays. The 125 msec delay used in the present investigation then provides an additional point between the 20 msec and 160 msec delays useful in tracing the decline of overshoot.

Elliott (1965) and Lankford (1969) are the only previous studies providing data on offset overshoot. Elliott noted the effect peripherally, and found it to be of a smaller magnitude than onset overshoot. Lankford confirmed this, and found no significant offset overshoot in his central masking condition, although there was an increase of 1 to 2 dB. In the present investigation, an interaction between temporal delay and mode of presentation was expected, based on previously published findings. This interaction was not obtained because of the appearance of the overshoot in the 238 msec, or offset, condition in the dichotic presentation of stimuli. Four dB of dichotic overshoot was the highest amount found in the present study for this 238 delay, compared to as much as 40 dB in one subject (HF) for the monaural condition. Even though a small offset overshoot was observed in the central masking condition, it certainly appears to have a minimal effect when contrasted with the monaural offset overshoot.

In summary, when the magnitude of the overshoot is considered, the pattern of results for the temporal delay of the signal confirms results found in previous investigations. The appearance of a small offset overshoot in the dichotic condition was noted, also confirming results reported by Lankford (1969). The presence of overshoot in both central and peripheral conditions at the 125 msec delay further describes the decline of overshoot with increasing temporal delay of the signal.

Frequency of the signal. The signal and masker frequencies and durations chosen for the present study were within the same range as those used by Zwislocki et al. (1967, 1968). This allowed a comparison between the studies, and a test of Zwislocki et al.'s described "frequency selective" characteristics of overshoot in the dichotic condition. In review, Zwislocki et al. (1967, 1968) concluded that overshoot peaks at or near the masker frequency, and decays rapidly for surrounding frequencies on both sides of the masker. The range of frequencies affected by the masker was within a narrow frequency band of approximately 170 Hz surrounding the masker. This bandwidth is very close to the 160 Hz bandwidth calculated for the critical band (CB) by Zwicker, Flothorp and Stevens (1957). The overshoot effects were described as being symmetrical about the 1000 Hz masker in the Zwislocki investigation. In contrast with Zwislocki's data, the dichotic condition in the present study shows no obvious peaks within 160-170 Hz of the masker (see Figure 8). Close inspection of the data, however, reveals a slight elevation for the 20 msec delay. A peak of 6.5 dB overshoot can be seen at a signal frequency of 1050 Hz, surrounded by a decline in overshoot for frequencies 200 Hz away in either direction. Frequencies 600 Hz away on either side however (400 and 1600 Hz), show elevations equaling that of the 1050 Hz signals. An examination of individual subject data makes an explanation of these latter elevations more difficult. Only one subject (DRS) showed symmetrical elevations, and this subject had no near-the-masker peak. The other subjects had this middle peak, but only had outlying elevations in either the higher or lower frequencies. It should be noted that we are not describing significant elevations here; there were no significant differences among frequencies in the dichotic condition. The magnitude of overshoot in Zwislocki et al.'s (1967) study is greater than in the present study (15 dB at peak compared to 6 dB at peak), possibly due to the slightly higher masker intensity level used in the former investigation, and the use of insert earphones.

The frequency selective characteristic described by Zwislocki et al. (1967, 1968), however, can be seen in the present study's monaural data. Overshoot does indeed peak at frequencies closest to the masker and decline fairly rapidly for frequencies further removed from the masker in both directions.

The frequencies 400 and 1600 Hz were included in this study as a means of defining the limits of the frequency selective aspects of overshoot. Little or no overshoot was expected to appear at these frequencies regardless of delay or mode of presentation. In contrast, considerable amounts of overshoot at these frequencies were observed (approximately 8 dB for 400 Hz and 15 dB for 1600 Hz in the monaural condition, and 4 dB for both frequencies in the dichotic condition). While the amplitude of overshoot seen at these frequencies in the dichotic condition is fairly consistent with Zwislocki et al.'s (1967, 1968) data, the amount of overshoot seen for these frequencies in the monaural condition was somewhat surprising. In spite of these elevations the overshoot seen for the 400 and 1600 Hz signals is still significantly smaller than that observed for the signals near the masker frequency. Most likely, frequencies beyond 400 and 1600 Hz (possibly 100 and 1900 Hz) would be necessary to completely eliminate any overshoot.

The signal frequency by mode of presentation interaction was also significant in this study. As mentioned earlier, there were no significant differences among frequencies in the dichotic mode of presentation; the overshoot results were similar regardless of the signal frequency. Zwislocki et al. (1968) investigated the frequency distribution of central masking in detail. They found frequency selective characteristics present in central masking, although no statistical analyses were done. At first glance the graphs presented in their study appear to indicate much greater amounts of overshoot than in the present study. However, a closer examination of actual data points reveals strikingly similar results, roughly within 2-3 dB for comparable frequencies and delays. There are large differences, however, for some of the other frequencies and delays. It should be stressed again that the similarities appear in comparisons of the amplitude of overshoot, not in its frequency selective characteristics.

The frequency selective characteristics of overshoot described in the present study support Scholl's hypothesis that the critical band becomes more highly tuned shortly after the onset of stimulation. Scholl's hypothesis assumes that the frequency analyzing process may be like a filter whose bandwidth increases the signal-to-noise ratio and detection thereby improves. According to this formulation, with the shortest delay of 2 msec, the plotted data would be expected to be flat and wide relative to the critical band values calculated by Zwicker, Flottorp and Stevens (1957). As time passes, the critical band should sharpen, so that curves for the longer delays should have sharper skirts and be more peaked around the masker frequency.

This does indeed appear to be the observed trend in the monaural data collected. That is, the monaural data having the shortest delay clearly yield the most overshoot and are broadly shaped. The systematic decrease in monaural overshoot as a function on increased signal delay implies an improved S/N ratio. However, if these data were used to estimate the CB around the 1000 Hz masker, the estimate would be closer to 400 Hz than the usually accepted value of 160 Hz. Therefore, it is somewhat problematic whether or not the longer delays are actually producing sharper and more peaked forms as delay increases.

In conclusion, it is clear that the dichotic data fail to show any trend toward a peak within the usually accepted values of the CB, regardless of the delay time. This latter conclusion is in direct conflict with Zwislocki's central masking data. Reasons for the discrepancy are elusive.

Mode of presentation. The monaural presentation of stimuli produced substantially more overshoot than the dichotic presentation, regardless of temporal delay and signal frequency. This finding is in agreement with previous investigations (Elliott, 1965; Sherrick & Mangabeira-Albernaz, 1961; Lankford, 1969). While the exact magnitude of overshoot typically varies from study to study, the figures obtained in the present investigation for the monaural presentation are consistent with values reported previously in the literature. The highest amount of overshoot observed for any one subject was 45 dB (DRS), compared to a group average for the same frequency of 36 dB. Green (1969) also reports overshoot of from 30 to 40 dB for his subjects. The magnitude of the dichotic overshoot reported in this study is, if anything, smaller than that reported by Zwislocki et al. (1967, 1968), but is probably, consistent, considering differences in methodology.

Additional Considerations

As noted previously, it has been proposed that the use of rapid rise-decay times for the signal and masker may elevate the masking phenomenon. It was thought that by using gradual rise-decay times, the overshoot values in this study might be smaller than those reported previously, since many investigators have not systematically varied this parameter. The use of a gradual rise-decay time in this study, however, did not produce smaller overshoot values. Apparently these transients have a relatively minor influence on the magnitude of overshoot observed.

Two hypotheses mentioned earlier should now be discussed in light of the present findings. Zwicker (1965) has suggested that the relative bandwidths of the signal and masker have a direct influence on the production of overshoot. He noted no overshoot when both signal and masker had similar bandwidths; hence, overshoot would not be expected with tone-on-tone masking. This notion was challenged earlier by investigators who found overshoot with pure tone signals (Green, 1969; Ingham, 1959; Lankford, 1969; Zwislocki et al., 1967, 1968). The present investigation substantiates these latter investigations.

Zwislocki et al. (1967) spoke of excitatory-inhibitory processes in his explanation of the frequency selective aspects of central masking overshoot. Their proposal was based on the observation of maxima and minima points of masker effectiveness for signal frequencies distant from the masker frequency in both directions. Since no significant frequency effect in the dichotic presentation of stimuli was noted in the present study, the Zwislocki et al. proposal was not confirmed.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the frequency selective characteristics of overshoot in a paradigm which controlled for transients and provided data on offset overshoot. Both dichotic and monaural presentations of stimuli were included to provide a basis for comparison of central and peripheral simultaneous masking. It was anticipated that this study would provide confirmation of the frequency selective aspects of central overshoot. The basic design of this investigation was modeled after Zwislocki et al.'s (1967) approach to this problem, in hopes of replicating their findings.

The results of this study both confirm much of the previous research, and conflict with important features of the literature. The areas of confirmation include the effects of the temporal delay of the signal, the frequency selective aspects of overshoot in the monaural presentation of stimuli, and the influence of the mode of presentation of stimuli on the characteristic of overshoot. The areas of conflict are confined to the frequency selective aspects of overshoot in the dichotic presentation of stimuli.

Manipulating the temporal delay of the signal relative to the onset of the masker produced significant differences in the magnitude of overshoot observed in both the monaural and dichotic conditions. The 2 msec delay produced the greatest amplitude of overshoot, followed by the 20, 238 and 125 msec delays. In terms of overshoot magnitude the pattern of results was similar for both monaural and dichotic conditions, although the 2 msec delay was responsible for most of the overshoot observed in the dichotic presentation of stimuli. Post-hoc analysis showed the 2 msec delay to be significantly different from the 125 and 238 msec delays. These findings confirm previous research on the effects of temporal delay of the signal.

Offset overshoot (the 238 msec delay) was observed in both monaural and dichotic conditions. The overshoot values in the monaural condition were as high as 40 dB for one subject (HF) but peaked at 4 dB in the dichotic condition. The presence of offset overshoot in the dichotic condition was not statistically significant, which supports Lankford's (1969) findings. The offset overshoot observed in the monaural condition confirms Elliott's (1965) observations.

The frequency selective characteristics of overshoot were quite apparent in the monaural condition, but conspicuously absent in the dichotic condition. There were no significant differences in the magnitude of overshoot observed among frequencies in the dichotic condition, while the monaural data show the expected peaks around the masker frequency. This pattern of results produced a significant frequency by mode of presentation interaction. The absence of frequency selectivity in the dichotic presentation of stimuli is in direct conflict with the Zwislocki et al. (1967, 1968) studies which show obvious frequency effects. The minor methodological differences between the studies are not considered to be an adequate explanation for this discrepancy. An alternate explanation, however, is not available.

The two modes of presentation of stimuli produced significantly different results both in terms of the magnitude of overshoot seen, and the frequency selective aspects of the data. The monaural condition produced overshoot figures between 35 and 45 dB for frequencies surrounding the masker frequency, compared to 6 dB for comparable frequencies in the dichotic condition. The monaural data are consistent with previous research, but the dichotic figures are lower than those reported by Zwislocki et al. (1967, 1968). As noted earlier, there were no frequency selective characteristics of overshoot observed in the dichotic condition.

The signal and masker were both presented with slow rise-decay times in an attempt to control for possible transients. Given the magnitude of overshoot observed in the monaural condition, transients apparently have little influence on the production of overshoot.

The frequency selective characteristics of overshoot observed in the monaural condition were discussed in terms of Scholl's hypothesis that the critical band takes time to sharpen. Scholl's hypothesis predicts that the CB sharpens with time, and is reflected in a tightening of the range of frequencies effected by the masker. This hypothesis is partially supported by the data in the present study, where the shortest temporal delay yields the greatest magnitude of overshoot over a larger range of frequencies when compared to the data for longer temporal delays. However, the CB "peaks" were considerably larger in width than the usually reported values (Zwicker, Flothorp, & Stevens, 1957).

The results of the present study were also discussed as findings in conflict with Zwicker's "relative bandwidths" hypothesis, and Zwislocki et al.'s (1967) "excitatory-inhibitory" explanation of overshoot. Zwicker's formulation predicts no overshoot when the bandwidth of the signal and masker are similar, which is clearly countered by the presence of overshoot in this and other tone-on-tone studies. Zwislocki et al. propose that maxima and minima points of masker effectiveness for frequencies distant from the masker frequency indicate excitatory and inhibitory processes. The failure in the present study to find any frequency selective aspects of overshoot in the dichotic condition makes confirmation of this hypothesis difficult.

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