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Backward detection and discrimination unmasking: Suppression or cueing?

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BACKWARD DETECTION AND DISCRIMINATION UNMASKING:

SUPPRESSION OR CUEING?

by

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Previous research has shown the threshold for a masked signal may decrease if another auditory stimulus, a suppressor, is added to the masker. This improvement in signal threshold is called unmasking. The experiments outlined in this paper were designed to examine possible underlying mechanisms responsible for unmasking. In particular, the experiments attempted to eliminate cueing effects which have plagued previous detection unmasking experiments. The rationale was that if cueing effects could be eliminated, the presence or absence of underlying physiological suppressive mechanisms could be inferred. Because the same set of cues exists in each observation interval of a discrimination task, it was reasoned that a backward **discrimination** unmasking task would not be susceptible to the cueing effects found in **detection** unmasking experiments. Backward discrimination unmasking was measured separately for both pitch and intensity discrimination. There were no observed unmasking effects in the backward pitch discrimination unmasking experiment. The magnitude of the unmasking effects observed in the backward intensity discrimination unmasking experiment were far less than in the corresponding detection unmasking study. The intensity discrimination experiment yielded a maximum unmasking value of approximately 5 dB as compared to the 26 dB observed in the detection experiment. A flat unmasking response as a

function of suppressor frequency suggested that cueing was the mechanism responsible for unmasking in the intensity discrimination study. The pattern of results suggested the possibility that these cues arose through processes similar, if not identical, to profile analysis (Green, 1983). There was no evidence in the current study to suggest that physiological suppression mechanisms were responsible for unmasking effects.

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CHAPTER I

INTRODUCTION

In temporal auditory masking experiments, it has been shown that the detectiblity of a signal may be reduced by a masking stimulus presented either before or after the signal. In forward masking experiments, the masker precedes the signal. In backward masking experiments, the signal precedes the masker. According to classical masking theory, masking occurs if the frequency of the signal and masker are located within the same frequency region, i.e. within the same hypothesized auditory filter. The frequency region responsible for the masking effect is known as the critical band (Fletcher, 1940). However, Houtgast (1973, 1974) demonstrated that signal detectibility improved when a third stimulus, with a frequency slightly above the critical band of the masker, was presented simultaneously with the masker. This third stimulus was called a "suppressor." Using a sinusoidal suppressor and masker, significant improvements in signal detectibility occurred when the suppressor was 20 dB more intense and 200 Hz higher than the masker (Houtgast, 1974). Counter-intuitively, the signal became easier to detect when the more intense component was added to the masker. This increase in signal detectibility is referred to as "unmasking".

The typical unmasking experiment obtains a detection threshold for a 3 to 20 msec sinusoidal signal in the presence of either a sinusoidal or narrowband noise masker. The masker duration is typically 300 to 500 msec. A detection threshold is also obtained after adding a sinusoidal suppressor or narrowband noise to the masking stimulus. The signal threshold in the suppressed-masker (SM) condition is then subtracted from the signal threshold in the masker-alone condition to obtain the amount of unmasking attributable to the suppressor. Unmasking has been observed in forward masking (Duifhuis, 1980; Moore, 1980; Shannon, 1976; Terry & Moore, 1977), backward masking (Tyler & Small, 1977; Weber & Green, 1978, 1979), and occasionally simultaneous masking experiments (Carterette, Friedman & Lovell, 1969; Fastl & Bechly, 1983). The presence of unmasking in simultaneous conditions, however, remains controversial (Houtgast, 1972; Rainbolt & Small, 1972). In simultaneous masking, the suppressor is presented simultaneously with both the masker and the signal. It is generally believed that, in simultaneous masking, the suppressor exerts its effect on both the signal and masker equally, thus negating the effect of the suppressor (Houtgast, 1972). In temporal masking, the suppressor exerts its influence on the masker, but has little influence on the signal. Although Carterette et al.'s (1969) observation of unmasking in simultaneous conditions failed to be replicated (Rainbolt & Small, 1972), Fastl and Bechly (1983) reported a small amount of unmasking in a simultaneous masking situation. Although Fastl and Bechly (1983) reported less of an unmasking effect for simultaneous masking than for forward masking, the study suggested that the explanation underlying unmasking may not be a simple attenuation of the signal and/or masker. Thus, further study is warranted.

There are two hypotheses which address auditory unmasking, suppression and cueing. Researchers advocating auditory suppression as a means of unmasking claim that the reduction in masking is due to hydromechanical processes in the inner ear. The addition of a suppressor reduces the masker activity due to intrinsic nonlinear response properties within the cochlea. Those advocating the cueing hypothesis claim that subjects are using perceptual cues to enhance their judgment. In particular, subjects use either pitch difference cues and/or timing cues elicited by the suppressor and the signal to enhance their performance (Moore, 1980). In short, suppression is due to a physical mechanism in the cochlea, while cueing is a higher level perceptual process. To understand the conceptual thread underlying these two viewpoints, a brief historical overview is in order.

CHAPTER II

SUPPRESSION HYPOTHESIS

Auditory suppression was first proposed by Georg von Békésy in an attempt to find an auditory analogue to lateral suppression in the visual and tactile modalities (von Békésy, 1963). Researchers were trying to reconcile the troublesome belief that the cochlea possessed widely tuned filter characteristics while central auditory nuclei were very sharply tuned. A mechanism was needed whereby the outputs of the broadly tuned filters in the cochlea were sharpened prior to further processing. This hypothetical processing stage, located between the cochlea and the cochlear nucleus, became known as the "second filter". A lateral suppression mechanism similar to that found in the visual system would have provided an ideal mechanism for the second filter. In such a mechanism, the presentation of an auditory stimulus would have produced maximal activation of neurons with best frequencies close to the stimulus frequency. Because the basilar membrane was assumed to be broadly tuned, it was believed that neurons with response frequencies both above and below the signal frequency would also show activation. If neural suppression existed, the neuron showing maximal response to the stimulus would suppress the response characteristics of neurons with slightly lower and slightly higher critical frequencies, thus sharpening the filter characteristic of the cochlear output. Unfortunately, although lateral suppression mechanisms have been observed in the cochlear nucleus and other central auditory areas, no such neural suppressive mechanisms exist in the peripheral auditory system. However, psychophysical studies conducted in the late 1960's and early 1970's indicated that suppressive mechanisms might exist in the auditory periphery (Carterette et al., 1969; Houtgast, 1972). Thus, another mechanism was needed which accounted for these apparent psychophysical suppression effects without relying on peripheral neural interactions. A possible solution was found in the hydromechanical action and nonlinear properties of the cochlea. It was well established that the cochlea responds nonlinearly to the simultaneous presentation of two tones, in certain cases by producing the perception of a third "difference" tone (Wegel & Lane, 1924). A logical assumption was that the addition of a suppressing stimulus to a masker acts to reduce the response of the basilar membrane in the area corresponding to the frequency region of the masker. Theoretically, the traveling wave associated with the suppressor interferes with the traveling wave associated with the masker. Thus, the basilar membrane response to the suppressor displaces the response to the masker. This hypothesis is supported by the bulk of unmasking literature which shows that the suppressor is most effective when presented at least 20 dB greater than the masker (Houtgast, 1972; Moore, 1980; Shannon, 1976; Terry & Moore, 1977). In short, the more intense suppressor creates a greater overall disturbance on the basilar membrane which effectively reduces the effect of the masker.

Theoretically, suppression should not occur if the masker and suppressor are activating widely disparate portions of the basilar membrane. In order for a suppressor to be effective, the frequency of the suppressor must be fairly close to the masker frequency. Both physiological and psychophysical studies suggest that suppression effects should not be demonstrated when the suppressor is more than an octave higher than the masker (Sachs & Kiang, 1968; Shannon, 1976).

CHAPTER III

CUEING HYPOTHESIS

Cueing was first posited by Terry and Moore (1977) to explain unmasking observed in forward masking when masker and signal frequencies were equal. When the suppressor was absent and the masker and signal frequencies were the same, detection was thought to be difficult because there was little fluctuation in the stimulus envelope separating the offset of the masker and the onset of the signal. The addition of a "suppressor" to the masker gave the listener both a frequency cue and a timing cue. The frequency cue was believed to be a perceptual pitch difference between the suppressor and signal. The timing cue arose because the suppressor and masker offsets were simultaneous and highlighted the fluctuation in the stimulus envelope at the onset of the signal. This hypothesis was later supported by Moore & Glasberg's (1982) finding that the presentation of a suppressor in the ear contralateral to the masker could produce as much unmasking as a suppressor presented ipsilaterally. In their study, Moore and Glasberg used a 53 dB/Hz spectrum level, 975-1025 Hz narrowband masker and an approximately 2000 Hz wide, 20 dB/Hz spectrum level noiseband cue (suppressor). A 20 msec, sinusoidal signal with a frequency equal to the center frequency of the masker was chosen so that there would be uncertainty between the offset of the masker and the onset of the signal. If suppression was a byproduct of cochlear mechanics, as the suppression hypothesis implied, a contralateral suppressor should have had no effect on the detection of the signal. Not only was the suppressor shown to be effective when presented contralateral to the masker, it was also shown to be effective at 20 dB/Hz spectrum level, a far less intense value than would be predicted by the traditional two-tone suppression hypothesis. Since signal detectibility improved in both contralateral and ipsilateral conditions, it was assumed that the improvement was due to cueing and not suppression. However, when the 2000 Hz wide band suppressor was replaced with a 1.2 kHz, 90 dB SPL sinusoid, an additional 10 dB of unmasking was observed in the ipsilateral condition. No additional unmasking was observed in the contralateral condition. The additional amount of unmasking in the ipsilateral condition was, therefore, attributed to the effects of suppression. Thus, it was believed that when a more intense sinusoid was used as a suppressor ipsilateral to the masker, both suppression and cueing were at work. Presumably, suppression effects were separated from cueing effects by subtracting the contralateral condition, which was assumed to be a "pure cueing" effect, from the ipsilateral condition which was assumed to be cueing plus suppression. The validity, however, of isolating suppression effects by subtracting the ipsilateral from contralateral threshold rests on the questionable assumption that cueing effects are equal in both conditions.

The contention has been made that the Moore and Glasberg (1982) study is not typical of the bulk of suppression literature because the signal was too long (20 msec signal with a 10 msec rise/fall and no steady state) (Weber, 1984). Prior research using contralateral suppressors had failed to demonstrate an unmasking effect (Weber & Green, 1979). It was concluded by Weber and Green (1979) that the use of shorter duration signals precluded the possibility of cueing and that any observed unmasking, using short duration signals, was due to suppression. Weber & Green (1979), for example, failed to demonstrate contralateral cueing in forward masking, although they demonstrated a large contralateral effect for backward masking. The signal used in this series of experiments was a 2 kHz sinusoid between 2 and 9 msec in duration. The masker was a 500 msec, 40 dB/Hz spectrum level, 200 Hz wide noiseband centered at 2 kHz. Their study incorporated both noiseband and sinusoidal suppressors. In addition to the lack of a contralateral effect in forward masking, significantly more unmasking in backward than forward masking was observed. Moore and Glasberg (1985) countered Weber's (1984) claim that a short duration tone could not produce cueing by demonstrating that the detection threshold of a 10 msec signal could be reduced by providing a subject with detection cues. In addition, they further concluded that Weber's (1979, 1984) studies which reported suppression effects were actually contaminated by cueing effects. Moore and Glasberg (1985) used the same stimulus configurations used by Weber (1984), but also added a variety of suppressors which should not have had an suppression effect on the masker. For example, they added a 4 kHz sinusoid to the 950 - 1050 Hz narrowband masker. Hypothetically, suppression effects should be negligible when the suppressor frequency is an octave or more above that of the masker. It was demonstrated, however, that the 4 kHz suppressor produced comparable amounts of unmasking to the suppressors used by Weber (1984). It was concluded that the suppressor was acting as a cue to reduce the ambiguity between the masker and signal. Even though suppression effects could have been present in the Weber (1984) study, it was likely that the observed unmasking was due to cueing and not suppression.

CHAPTER IV

RESEARCH GOALS

Given the evidence presented by Moore & Glasberg (1982), it is plausible that much of the psychophysical "suppression" data collected prior to 1982 may be contaminated by cueing effects. Especially susceptible would be experiments which used similar signal and masker frequencies. The extent or presence of this contamination is still uncertain. The goal of the present set of experiments is to ascertain the extent of both suppression and cueing effects in the context of backward temporal masking. The challenge will be to eliminate as many extraneous perceptual cues as possible so that any observed unmasking will be due to suppression and not cueing. The elimination of extraneous cues can be achieved in a variety of ways. For example, the traditional detection task can be replaced with a discrimination task.

Backward Discrimination Masking

Since it is hypothesized that, in forward masking, subjects obtain detection cues from timing information available at suppressor offset and signal onset, it is plausible that signal offset and suppressor onset cues are available in backward masking. One way to eliminate these cues would be to perform a Backward Discrimination Masking

(BDM) task. In a forced choice detection experiment, subjects are aided in their decision process because the target interval, containing the signal, has an offset/onset cue which is not available in the other intervals. A BDM task, on the other hand, would provide the same set of cues in each observation interval by placing a suprathreshold signal and a suppressor-masker complex in <u>each</u> interval. Because each interval would contain the same set of offset/onset cues, the subject would be unable to use these particular cues to choose the target interval. The subject's task would be to make intensity or pitch discriminations. For example, in a pitch discrimination task, two intervals might contain a suppressor-masker complex preceded by a 1000 Hz signal (the Standard), while the third interval would contain a suppressor-masker complex preceded by a 850 Hz signal (the Target). The inter-stimulus-interval (ISI) and stimulus intensities would remain constant. The measure of discrimination would be the minimum signal frequency difference (Δf) necessary for subjects to make a correct discrimination 71% of the time. The problem with pitch discrimination tasks of this sort is that the narrowband masker has the potential for masking one signal frequency more than another. In the example given above, it is probable that a 950-1050 Hz narrowband masker would mask the 1000 Hz Standard more than the 850 Hz Target. The result of this differential masking would be that the

850 Hz Target could seem perceptually louder than the 1000 Hz Standard, because it is masked less. At large Δf's, subject's would have access to a very salient intensity cue which could be used to enhance their performance. However, as the Δf approaches pitch discrimination threshold, the intensity cue should be far less salient and subjects should be forced to rely on the available pitch cues to make their judgments.

If subjects perform an intensity discrimination task, rather than a pitch discrimination task, one could eliminate the dual cue problem found in the pitch discrimination task. In the intensity discrimination task, the signal in each interval would maintain the same frequency, but one interval would differ with respect to signal intensity. For example, two intervals might contain a suppressor-masker complex preceded by a 50 dB SPL Standard, while the third interval would contain a suppressor-masker complex preceded by a 60 dB SPL Target. Since Target and Standard stimuli are the same frequency, each will receive the same amount of masking.

If unmasking is due to offset/onset cues, unmasking should disappear in a discrimination task. Although there would be a slight possibility in the **pitch** discrimination task that subjects could also utilize a pitch difference cue between the signal and suppressor, this possibility could be rendered negligible by using a noiseband as the suppressor.

The use of noisebands for both the masker and the suppressor would make the comparison of the signal to the suppressor/masker more difficult. The energy associated with the suppressor would be spread across a band of frequencies, making the pitch of the suppressor more diffuse. For example, the overall intensity of a 100 Hz wide narrowband suppressor might be 80 dB SPL, but each individual frequency within that noiseband would be 60 dB SPL. If, on the other hand, a 60 dB SPL sinusoidal suppressor were used, all of the stimulus energy would be concentrated near the sinusoidal frequency, making a comparison of the signal frequency and the suppressor frequency easier. Using a narrowband suppressor should make the use of these pitch cues more difficult. Although the Moore and Glassberg (1982) study demonstrated less unmasking using a 20 dB/Hz spectrum level, 2000 Hz wide noiseband suppressor, the use of a 60 dB/Hz spectrum level, 100 Hz wide narrowband noise should be more effective. The use of a narrower band of noise will reduce the possibility that the suppressor itself will exert a masking influence on the signal. Finally, since both the suppressor and the masker would be independently generated noisebands, both would be fluctuating independently. The stimulus envelope associated with the masker/suppressor would be more variable and less predictable than with an intense sinusoidal suppressor. Thus, the fluctuations in the envelope due to the offset of the signal would be less obvious.

Although discrimination tasks involve central processes, predictions can be made regarding the suppression hypothesis. The suppression hypothesis would predict that the suppressor would cause a reduction in masker efficacy due to peripheral processes. If unmasking is due to suppression, the suppressor will exert its influence in the cochlea by equally degrading the masker in each listening interval. Thus, if suppression is occurring, pitch discrimination should be better in the SM conditions than in the masker-alone conditions. It can also be predicted that suppression, should it occur, will be greatest for suppressor frequencies relatively close to the masker frequency. Previous backward masking experiments using pure tone suppressors and maskers have shown that unmasking is greatest when the suppressor is approximately 400 Hz above the masker frequency. When the suppressor is less than 400 Hz above the signal, it also exerts a masking influence on the signal (Tyler & Small, 1977). It can be conservatively predicted that, if suppression occurs, unmasking should start to decrease when the suppressor noise band frequencies are approximately 1000 Hz above the masker. When the suppressor noise band is increased to an octave above the masker band, the suppression effect should be minimal. It can also be predicted that the signal will be masked more when the suppressor frequency is less than 400 Hz above the signal frequency.

Ipsilateral and Contralateral Suppressors

Initially, the signal and suppressor-masker in the discrimination tasks should be presented ipsilaterally. If no unmasking occurs then the conclusion can be made that unmasking effects reported in the literature were due to cueing and not suppression. This conclusion would be drawn because the unmasking cues plaguing previous experiments were successfully eliminated from the present discrimination unmasking tasks. If, however, unmasking is exhibited, one of two conclusions is possible. First, it is possible that unmasking is due to the hypothesized suppression mechanism. It is also plausible, however, that subjects are still obtaining unforeseen cues from the experimental stimuli, especially if the values of Δf and ΔI do not change as a function of suppressor frequency. To address this problem it will be necessary to perform an experiment where the suppressor is presented contralaterally to the masker. If either the suppressor or masker is still offering an uncontrolled cue, then subjects should be able to use these cues contralaterally as well as ipsilaterally. In addition, any unmasking observed in the contralateral condition should be entirely due to cueing because suppression is hypothesized to be a peripheral process (Moore & Glasberg, 1982). If there is no unmasking in the contralateral condition and there is unmasking in the ipsilateral condition, it can be concluded that the unmasking, revealed by changes in Δf and ΔI across suppressor frequencies, is due to physiological suppressive mechanisms and not cueing.

Backward Detection Masking

In addition to the backward discrimination studies, it will be necessary to conduct a backward detection masking experiment using the same signal, masker, and suppressor values as in the discrimination experiments. The reasons for doing a detection experiment are three-fold. First, it is necessary to establish whether the stimulus parameters chosen for the discrimination tasks are valid and will produce unmasking in a standard unmasking procedure. Second, although detection and discrimination tasks are fundamentally different, an informal comparison of the amount of unmasking found using each technique should prove to be interesting. Finally, performing a backward detection masking study would provide a useful replication of prior research into backward detection masking and unmasking (Weber & Green, 1978, 1979). The expectation is that there should be 10 to 15 dB improvement in the detection threshold when a suppressor is added to the masker. However, past backward detection unmasking experiments may have been contaminated by cueing effects (Weber & Green, 1978, 1979). It is possible that the stimulus configuration chosen for the present experiment, using a noiseband for both the suppressor and masker, will reduce the overall amount of unmasking due to cueing. As in the discrimination experiment, the detection task will also include both ipsilateral and contralateral suppressors in order to separate suppression from possible cueing effects.

As noted previously, the pitch discrimination task requires subjects to discriminate between high and low frequency signals. A possible confound could occur if the suppressor itself had the effect of a masker. If the suppressor had a masking effect, it would have more influence on the signal closest in frequency to the suppressor. Thus, the higher frequency signal could be masked more than the lower frequency signal. If this differential masking were to occur, subjects could derive an intensity or loudness difference cue in the SM condition which would not be present in the masker-alone condition. To assess the amount of masking which is attributable to the suppressor, it will be necessary to perform a detection task with a suppressor, but no masker. The detection threshold for both the lower frequency Target (e.g., 850 Hz) and the higher frequency Standard (e.g., 1000 Hz) used in the discrimination task must be measured for selected values of the suppressor. The masked detection thresholds for the Target and Standard can then be assessed for differential masking by the suppressor. Because the frequency difference between 850 and 1000 Hz is small, it is not anticipated that the suppressor will have a differential impact.

Furthermore, in the event that there is a differential masking effect, it should only occur for the lowest frequency values of the suppressor, e.g. suppressors less than 200 Hz above the signal. Above 200 Hz the critical bands of the signal and the suppressor do not overlap and little or no masking should occur. It is, nevertheless, important that the possibility of differential masking effects is assessed.

The problem arises that some or all of the proposed experiments, or individual components therein, may demonstrate no unmasking, thus, failing to reject the null hypothesis. Obviously, no conclusions can be drawn from a situation where an individual experiment or series of experiments fails to reject the null hypothesis. Therefore, conclusions derived from the outcomes of the proposed experiments will be based on the overall pattern of results and **not** on individual outcomes. For example, the suppression hypothesis would only be supported if there were null results in the contralateral suppressor condition **and** unmasking was demonstrated in the ipsilateral suppressor conditions closest in frequency to the masker. If there is no unmasking in either the ipsilateral or contralateral suppressor condition, no conclusions may be drawn about either the suppression or cueing hypothesis.

CHAPTER V

METHODS

Subjects

The present study used eight normal hearing adult subjects. Five subjects participated in the pitch discrimination study and five participated in the intensity discrimination study. Two subjects, RS and DS, participated in both studies. Subjects were volunteers from the faculty and graduate students at The University of North Carolina at Greensboro.

Apparatus

Each subject was seated in a double-walled IAC chamber in front of a VGA color monitor. Auditory stimuli were presented via matched earphones (TDH-49, with circumaural cushions). The video game was produced using Borland Turbo Pascal 5.0 and Electronic Arts' Deluxe Paint Animation 1.0. The experiment was controlled using a Northgate 20 MHz 80386 computer. Subject responses were recorded via an Elographics Touchscreen and controller. Sinusoidal stimuli were generated digitally at a sampling rate of 25 kHz and converted by a Data Translations 2801-A D/A converter. Analog noise stimuli were produced using a Hewlett-Packard 8057-A precision noise generator bandpassed through a 90 dB/oct Stewart VBF 8 adjustable filter. A 950-1050 Hz narrowband masker was recorded and reproduced at a sampling frequency of 48 kHz using a Sony Digital Audio Tape Deck (DTC-700) and Sony Digital Audio Tape (DT-60). Stimuli were mixed, amplified and controlled using Coulbourn Instruments mixer/amplifiers (S82-24), Coulbourn Instruments programmable attenuators (S85-08), and a Crown (D-75) amplifier.

Procedure

Backward Detection Masking and Unmasking

In order to assure that the stimulus parameters used in this study were amicable to unmasking, it was necessary to verify the presence of unmasking in a traditional backward detection masking paradigm. The study used a three-alternative forced choice adaptive procedure (3AFC) embedded in a computer generated video game (Appendix). Each interval contained a 300 msec, 950 - 1050 Hz narrowband noise masker with a spectrum level of 40 dB (Figure 1A). In suppressed-masker (SM) conditions a 60 dB/Hz spectrum level, 100 Hz wide narrowband noise (suppressor) was added to the masker (Figure 1B). The 100 Hz wide noiseband suppressor frequencies were centered at 1250, 1550, 1950, and 2450 Hz. The suppressor stimulus remained constant during a block of trials. A 20 msec, signal was randomly presented prior to one of the three noise bursts in each trial. For subjects participating in the pitch discrimination study, the signal for the detection task was a 1000 Hz sinusoid

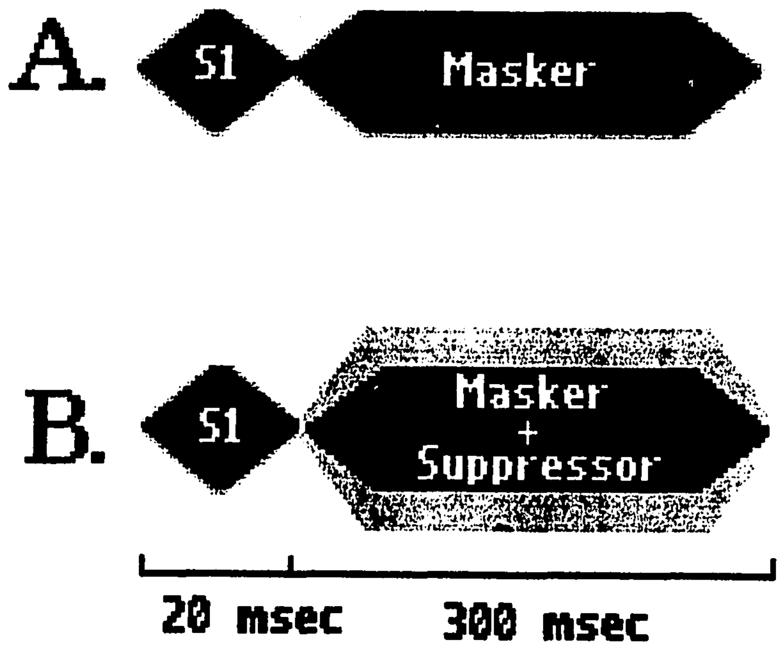

FIGURE 1. Stimulus configuration for backward masking and unmasking experiments. A 20 msec signal (S1) is followed by either a 40 dB spectrum level masker (A) or a 40 dB spectrum level masker plus a 60 dB spectrum level suppressor (B).

(Experiment 1a). For subjects participating in the intensity discrimination study, the signal in the detection task was a 950-1050 Hz bandpass noise (Experiment 1b). In both detection experiments, the ISI between the offset of the signal and the onset of the masker was approximately 3.0 msec. In order to measure the amount of unmasking attributable to the suppressor, one condition in each experiment had no suppressor added to the masker (masker-alone). The amount of masking in the SM condition was then subtracted from the masker-alone condition to obtain the amount of unmasking due to each suppressor value. All stimuli had 10 msec rise/falls. In the ipsilateral condition, all stimuli were presented to the right ear. In the contralateral condition, the suppressor was presented to the left ear, while the signal and masker were presented to the right ear. The subjects' task was to detect the signal in one of the three intervals. The intensity of the signal was manipulated using a 2-down, 1-up algorithm (Levitt, 1971). Thus, if a subject made two correct responses consecutively, the signal intensity decreased. The signal intensity increased, however, for each incorrect response. A reversal occurred whenever the direction of the signal intensity changed from increasing to decreasing, or vice versa. A block of trials consisted of 10 reversals. The stepsize for the signal intensity was 3 dB SPL for the first three reversals and 1 dB SPL for the final 7 reversals. The threshold estimate was based on the average (mean) value of the stimulus intensity for each of the last 7 reversals. In this manner, the 71% threshold for correctly detecting the signal was obtained. Final thresholds were obtained by averaging (mean) across three blocks of trials. Prior to the experimental block of trials, each subject was given a practice block. The practice block was not averaged into the final threshold estimate. As noted earlier, for subjects participating in the pitch discrimination experiment, it was also necessary to measure the amount of **detection** masking attributable to the suppressor centered at 1250 Hz. Since it was possible that the suppressor would mask the 1000 Hz Standards more than the lower frequency Target, it was necessary to measure the difference in threshold between a 1000 Hz sinusoid and a sinusoid with a frequency set significantly below the critical band of the suppressor. Detection thresholds were measured separately for 850 Hz and 1000 Hz sinusoidal signals in the presence of a 1200 - 1300 Hz suppressor. There was no masker in this case.

Pitch Discrimination: Ipsilateral Suppressor

The pitch discrimination experiment was similar to the detection experiment (Experiment 1a) except that a signal was presented within each listening interval. In addition, the signal frequency was different in one of the three intervals, the Target interval. Whereas the goal in the backward detection masking experiment (Experiment 1a) was to detect the presence of a signal, the goal of the backward pitch discrimination masking task was to determine which interval contained a different signal frequency. Note, that the subjects' goal was not to make a judgment concerning the exact pitch of the signal, but to make a same/different judgment. The dependent variable was the minimum difference in signal frequency (Δf) required to discriminate the 20 msec sinusoidal Target from the two 20 msec sinusoidal Standards. The value of Δf was obtained for two different signal intensities. Discrimination was measured for fixed signal intensities 0.0 dB SL (above detection threshold) and 10.0 dB SL. The Standard frequency was fixed at 1000 Hz. At the beginning of each block of trials, the Target frequency was set to an easily discriminable value between 75 and 250 Hz below the 1000 Hz frequency of the Standards. Using the same Levitt 3AFC procedure described in Experiment 1a, the signal frequency was manipulated in a 2-up, 1-down procedure until the 71% discrimination threshold was determined. The fixed intensity for the signal and Standards was determined for each subject by using the threshold value obtained in the masker-only condition of the detection experiment (Experiment 1a). The stepsize for signal frequency was 4 Hz for the first three reversals and 2 Hz for the final 7 reversals. As in the detection experiments, the 100 Hz wide noiseband suppressors were centered at 1250, 1550, 1950, and 2450 Hz. Also, the intensities and durations for the suppressor and masker remained the same as in the detection experiments (40 and 60 dB SPL, 300 msec). To determine the amount of improvement attributable to the suppressor, the discrimination thresholds obtained in the SM conditions were subtracted from the masker-alone condition. All stimuli were presented to the right ear.

Intensity Discrimination: Ipsilateral Suppressor

In the intensity discrimination experiment, the center frequency of the 20 msec, 950-1050 Hz narrowband noise signal remained constant in each of the three intervals, but the signal intensity was greater in one interval. As in the pitch discrimination experiment, the fixed intensity of the Standards was determined by performance in the masker-alone condition obtained from Experiment 1b. The Standard intensity was set at 0 dB SL or 20 dB SL below detection threshold. The rationale for these settings was as follows. If the suppressor were acting as a cue, then the discrimination level, in dB, in the -20 dB condition should approximate the detection threshold. That is, the Standards should be inaudible, and discrimination will take place when the subjects can detect the signal. The suppressor, masker, and ISI values remained the same as in the pitch discrimination and detection experiments. The stepsize for the Target intensity was 3 dB for the first three reversals and 1 dB for the final 7 reversals. The dependent variable was ΔI, the difference in dB between the Target and the Standards.

Discrimination Unmasking: Contralateral Suppressor

To eliminate the possibility that cues were responsible for any unmasking effects exhibited in the ipsilateral pitch and intensity discrimination experiments, it was necessary to present the suppressor contralateral to the masker. If unmasking were exhibited in a contralateral suppressor condition, it would be concluded that cueing was at least partially responsible for the unmasking exhibited in the ipsilateral suppressor condition. These experiments, therefore, were conducted exactly as the ipsilateral discrimination experiments except that the 60 dB/Hz spectrum level suppressor was presented to the left ear, while the masker and signals were presented to the right ear. As in the previous experiments, the masker and suppressor were presented simultaneously.

Discrimination Masking by the Suppressor

To measure the amount of **discrimination** masking attributable to the suppressor, the ipsilateral discrimination experiments were repeated in the absence of the 950 - 1050 Hz masker. Procedures and stimulus parameters remained the same, except that only the 1250 Hz and 2450 Hz centered noiseband suppressor conditions were examined. Finally, discrimination thresholds were also measured in the absence of both the suppressor and the masker (signal-alone). In this experiment, the signal-alone condition was subtracted from the suppressor-alone condition to obtain the total amount of discrimination masking attributable to the suppressor.

CHAPTER VI

RESULTS

In both the detection and discrimination experiments, the amount of unmasking measured in the 1250, 1550, 1950, 2450, and masker-alone conditions were analyzed using repeated measures ANOVA. The amount of unmasking in the masker-alone condition was, by definition, 0.0 dB. Contrasts were calculated to determine whether the masker-alone condition differed significantly from any of the four SM conditions ($\alpha <= .05$). If the results of the contrasts indicated unmasking, the data were further analyzed without the masker-alone condition. This latter analysis was used to determine if there were effects associated with signal level, suppressor location (ipsi vs contra) and/or suppressor frequency. Throughout this paper, unmasking is represented as a positive value. Negative values, conversely, represent an increase in masking. All data were analyzed using BMDP statistical software on a VAX mainframe computer. BMDP unit 4V was used for performing contrasts and repeated measures analyses. The Greenhouse-Geisser correction for degrees of freedom was applied where appropriate and is designated as GGDF.

<u>Backward Detection Masking and Unmasking</u>

Individual and mean data for sinusoidal signal detection are summarized in Table 1 and shown in Figure 2. The data, plotted in Figure 2, were obtained by subtracting the SM threshold from the masked threshold. As can be seen, the between subject variability was rather large for both the ipsilateral suppressor condition (A) and the contralateral suppressor condition (B). Contrasts failed to show significant unmasking in any of the four suppressor frequency conditions in either the ipsilateral or contralateral conditions ($p>.05$).

Table 1. Individual and mean thresholds for the detection of a 20 msec 1000 Hz sinusoid.

SUBJECT		AK		AO		DS		RS		BF		CUMULATIVE	
		MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
	No Supp	41.00	0.71	56.10	4.22	67.52	1.69	62.76	0.38	41.52	1.25	53.78	6.06
IPSI	1250 Hz	40.52	1.24	41.43	2.38	48.81	1.76	30.05	0.21	36.29	1.69	39.42	3.46
	1550 Hz	42.19	0.67	35.33	0.33	38.62	4.12	29.24	0.25	40.29	0.68	37.13	2.54
	1950 Hz	40.57	1.36	34.24	1.10	37.52	0.42	29.43	0.83	37.86	0.54	35.92	2.13
	2450 Hz	41.62	2.24	44.10	2.05	41.76	2.27	34.86	0.60	38.62	0.31	40.19	1.78
CONTRA	1250 Hz	45.00	2.03	46.38	3.59	39.76	4.12	48.67	1.57	41.24	0.97	44.21	1.83
	1550 Hz	44.62	1.41	44.86	0.33	39.48	1.18	48.76	1.82	41.29	1.49	43.80	1.79
	1950 Hz	47.48	0.39	50.71	1.05	45.95	2.56	49.33	0.72	42.43	0.60	47.18	1.61
	2450 Hz	49.90	1.61	54.05	2.55	62.19	1.33	59.00	2.57	42.29	2.00	53.49	3.91

As noted in the methods section, the participants in the pitch discrimination study also had thresholds measured for 850 Hz and 1000 Hz sinusoidal signals followed by a

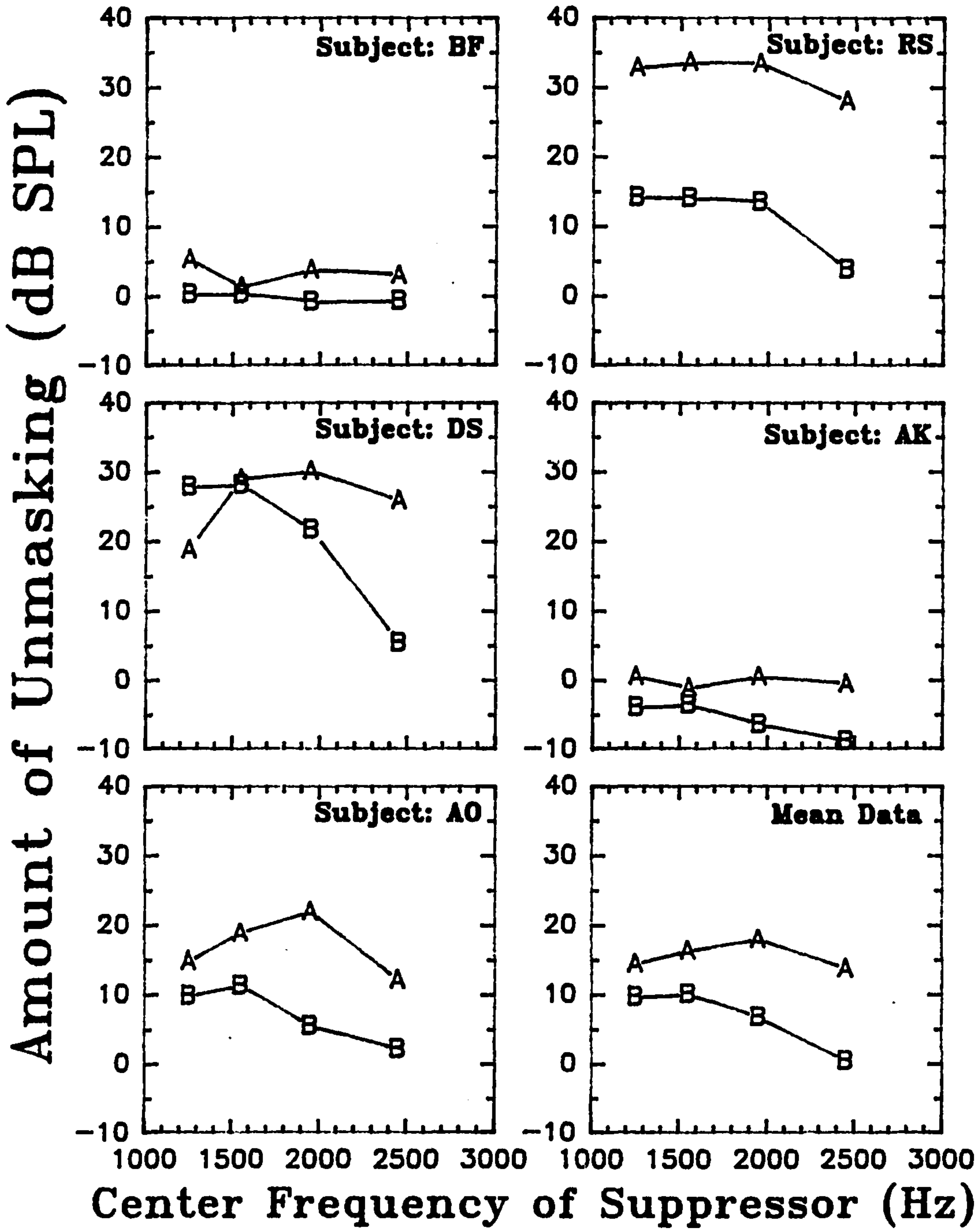

Figure 2. Individual and mean detection unmasking: 1000 Hz sinusoid. Parameters are ipsilateral (A) and contralateral (B) suppressors centered at 1250, 1550, 1950, and 2450 Hz.

1200-1300 Hz bandpass noise suppressor. There was no masker in this task. The mean thresholds for the two signals were 30.00 dB SPL and 32.15 dB SPL, respectively. The difference between the 850 Hz and 1000 Hz thresholds was not significant (F=2.79, p=.1703).

Individual and mean thresholds for the detection of a 950-1050 Hz narrowband noise signal are summarized in Table 2 and shown in Figure 3. Contrasts indicated a significant amount of unmasking in the 1250 Hz (F=42.92, p=.0028), 1550 Hz (F=103.32, p=.0005), 1950 Hz (F=186.12, p=.0002) and 2450 Hz (F=136.21, p=.0003) ipsilateral suppressor conditions.

Table 2. Individual and mean backward detection unmasking thresholds for the 950-1050 Hz narrowband noise signal.

SUBJECTS		CC		TJ		DS		CH		RS		CUMULATIVE	
		MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
	No Supp	67.05	0.63	65.76	0.83	67.43	0.17	65.81	0.48	64.52	0.74	66.11	0.58
IPSI	1250 Hz	43.19	2.06	54.00	0.31	44.57	2.40	45.29	2.64	31.33	0.80	43.68	4.05
	1550 Hz	41.62	1.06	47.95	0.67	38.38	0.55	42.14	1.58	31.76	0.37	40.37	2.96
	1950 Hz	35.33	4.01	41.81	1.82	40.00	0.29	43.67	0.88	32.33	0.42	38.63	2.34
	2450 Hz	36.13	0.88	45.33	0.86	41.81	3.50	43.67	0.62	33.14	1.36	40.02	2.58
CONTRA	1250 Hz	36.43	2.48	39.43	2.16	33.86	2.30	36.48	0.94	37.52	2.32	36.74	1.01
	1550 Hz	39.43	2.60	43.71	1.43	48.14	2.81	42.52	2.68	36.29	1.57	42.02	2.24
	1950 Hz	44.19	1.14	44.24	3.42	53.43	2.29	55.95	2.04	40.90	2.62	47.74	3.27
	2450 Hz	48.62	1.84	52.10	2.15	66.29	1.29	65.00	1.03	57.24	0.58	57.85	3.88

In the contralateral condition, a significant amount of unmasking was demonstrated in the 1250 (F=500.41, p=.0000), 1550 (F=199.78, p=.0001), and 1950 Hz (F=45.50, p=.0025)

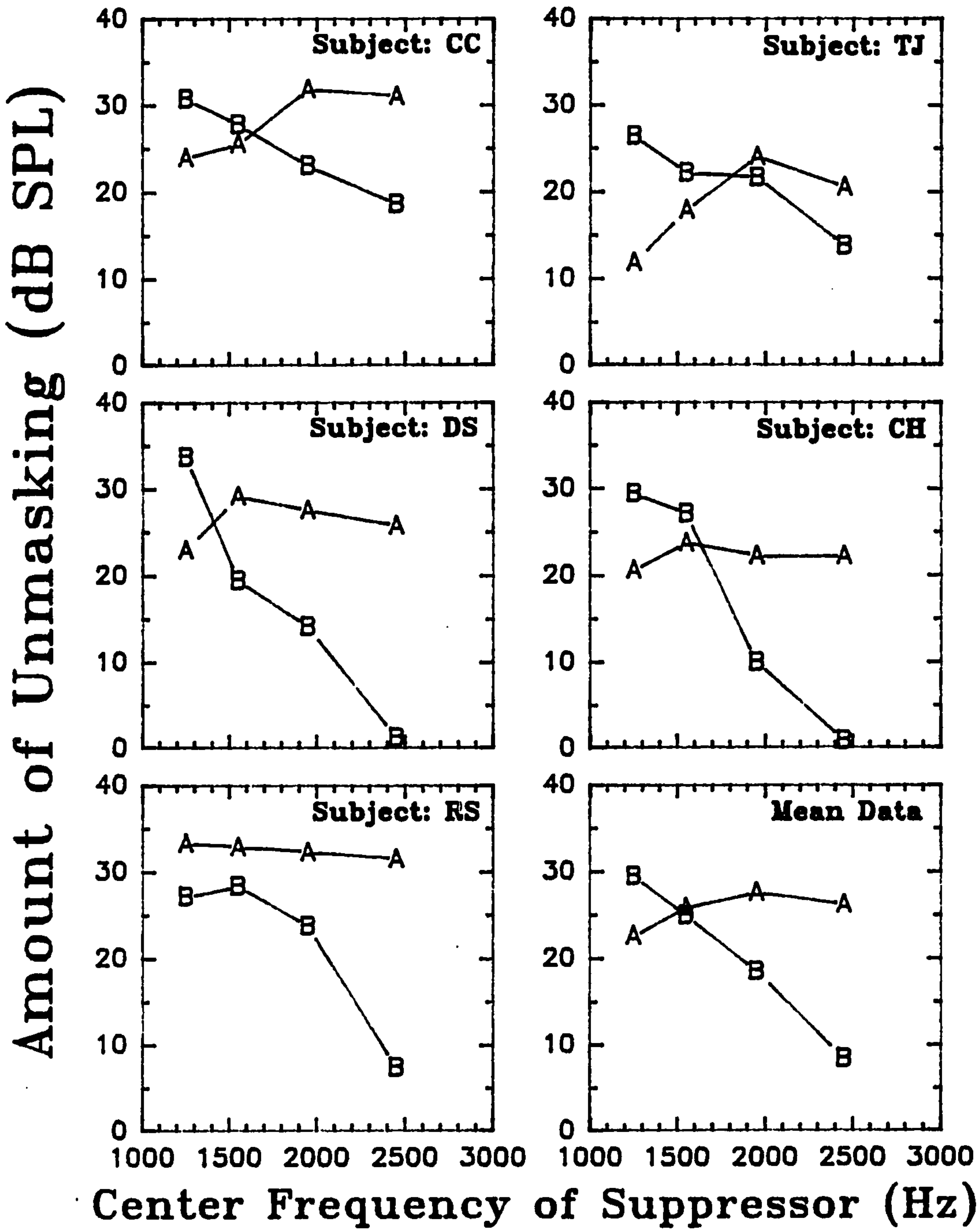

Figure 3. Individual and mean detection unmasking: 950-1050 Hz narrowband noise signal. Parameters are ipsilateral (A) and contralateral (B) suppressors centered at 1250, 1550, 1950, and 2450 Hz.

suppressor conditions. However, the 2450 Hz suppressor condition failed to show unmasking ($F=5.68$, $p=.0757$). A 2 (ipsi vs contra) X 4 (suppressor frequencies) repeated measures ANOVA revealed a significant main effect for suppressor frequency ($F=7.64$, $p=.033$ GGDF), but no significant effect of suppressor location ($F=4.95$, $p=.09$). However, there was a highly significant interaction between suppressor frequency and suppressor location ($F=24.98$, $p=.0002$ GGDF). Thus, for a narrowband signal, unmasking was relatively stable across suppressor frequencies (approximately 20 dB) in the ipsilateral condition, but decreased steadily as suppressor frequency increased in the contralateral condition until unmasking approached 0 dB.

Pitch Discrimination Unmasking

Individual and mean thresholds for the pitch discrimination experiment are summarized in Table 3 and shown in Figures 4 and 5. Statistical contrasts between the masker-alone condition and each suppressor condition (1250, 1550, 1950, and 2450) did not indicate significant unmasking in either suppressor location condition or in either signal level condition (see Table 4). The one exception was the 1250 Hz contralateral suppressor condition when the signal level was +10 dB SL ($F=8.23$, $p=.0455$).

Table 3 Individual pitch discrimination unmasking data.

Signal Level = 0 dB above detection threshold

SUBJECTS	AO		AK		DS		RS		BF		CUMULATIVE	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
IPSI												
No Supp	747.95	2.87	915.81	5.58	897.00	4.46	932.67	10.6	783.57	6.73	855.40	41.87
1250 Hz	750.24	2.85	901.05	12.5	912.38	7.17	900.95	5.24	787.71	5.04	850.47	37.85
1550 Hz	785.48	6.85	901.67	2.66	929.24	4.43	928.67	7.29	791.52	6.55	867.32	36.42
1950 Hz	767.24	2.96	906.81	0.89	916.76	2.83	941.33	4.17	791.00	5.10	864.63	39.75
2450 Hz	778.81	8.92	895.14	9.70	905.29	9.42	934.67	9.42	809.24	5.88	864.63	33.47
CONTRA												
1250 Hz	756.05	5.47	907.57	3.68	903.52	2.91	907.52	4.74	852.00	13.2	865.33	32.73
1550 Hz	744.71	5.56	923.86	6.29	936.00	3.99	920.29	5.93	839.19	4.41	872.81	40.62
1950 Hz	746.76	11.5	923.86	5.03	923.95	6.98	942.48	5.12	833.48	1.12	874.11	41.46
2450 Hz	728.95	2.77	918.57	4.64	919.86	5.57	930.48	5.90	833.43	0.46	866.26	43.06

Signal Level = 10 dB above detection threshold

SUBJECTS	AO		AK		DS		RS		BF		CUMULATIVE	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
IPSI												
No Supp	873.95	4.82	937.19	3.72	878.86	2.79	936.33	5.46	846.24	10.4	894.51	20.26
1250 Hz	886.95	4.05	896.48	5.21	966.38	2.95	952.29	5.98	898.62	2.29	920.14	18.19
1550 Hz	888.38	0.94	908.67	4.83	936.24	6.85	963.90	5.67	914.38	2.23	922.31	14.41
1950 Hz	911.29	3.51	890.57	8.59	932.95	7.73	952.19	3.55	915.62	6.56	920.52	23.26
2450 Hz	905.38	3.77	892.33	10.9	934.57	5.55	957.86	3.84	905.24	10.1	919.08	13.32
CONTRA												
1250 Hz	894.24	5.69	946.24	1.56	931.24	5.94	953.62	0.24	917.52	2.37	928.57	11.85
1550 Hz	898.43	3.27	950.52	1.56	914.95	8.87	940.38	7.97	941.43	6.78	929.10	10.87
1950 Hz	890.19	3.49	929.86	5.44	909.05	5.78	965.14	2.82	917.00	0.44	922.25	13.98
2450 Hz	843.62	10.4	944.19	2.56	918.76	5.37	932.19	1.06	931.10	6.27	913.97	20.17

Ipsilateral suppressor with no masker
Signal = 0 dB above detection threshold

SUBJECTS	AO		AK		DS		RS		BF		CUMULATIVE	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
No Supp	959.62	7.06	978.90	3.29	969.38	1.94	985.95	1.74	981.38	5.87	975.05	5.27
1250 Hz	891.95	3.69	920.14	3.35	949.81	1.57	931.14	2.56	914.48	4.96	921.50	10.66
2500 Hz	945.52	8.95	952.95	5.16	948.33	4.44	977.67	2.65	973.71	4.25	959.64	7.48

Signal = 10 dB above detection threshold

No Supp	965.86	2.86	973.29	4.99	968.00	4.67	981.33	1.36	982.48	0.67	974.19	3.78
1250 Hz	931.43	1.70	921.62	6.72	949.76	7.32	954.00	5.12	953.10	6.07	941.98	7.30
2500 Hz	941.62	7.09	963.43	1.06	912.24	4.21	976.43	1.00	975.48	1.62	953.84	13.58

Table 4. Statistical contrasts for pitch discrimination experiment. Contrasts are between the masker-alone condition and each of the suppressor conditions.

SIGNAL LEVEL = 0 dB SL

IPSI

	MEAN	SE	F	DF	P
1250 Hz	-4.93	8.25	0.36	1,4	0.5820
1550 Hz	10.92	9.56	1.30	1,4	0.3179
1950 Hz	9.23	5.23	3.11	1,4	0.1527
2450 Hz	9.23	9.18	1.01	1,4	0.3715
CONTRA					
1250 Hz	9.93	15.81	0.39	1,4	0.5639
1550 Hz	17.41	12.90	1.82	1,4	0.2484
1950 Hz	18.71	9.03	4.29	1,4	0.1070
2450 Hz	10.86	11.82	0.84	1,4	0.4101

SIGNAL LEVEL = 10 dB SL

IPSI

	MEAN	SE	F	DF	P
1250 Hz	25.63	21.45	1.43	1,4	0.2981
1550 Hz	27.80	17.11	2.64	1,4	0.1795
1950 Hz	26.01	20.22	1.65	1,4	0.2677
2450 Hz	24.57	18.76	1.71	1,4	0.2606
CONTRA					
1250 Hz	34.06	11.87	8.23	1,4	0.0455
1550 Hz	34.63	16.06	4.65	1,4	0.0974
1950 Hz	27.73	12.69	4.78	1,4	0.0941
2450 Hz	19.46	19.86	0.96	1,4	0.3826

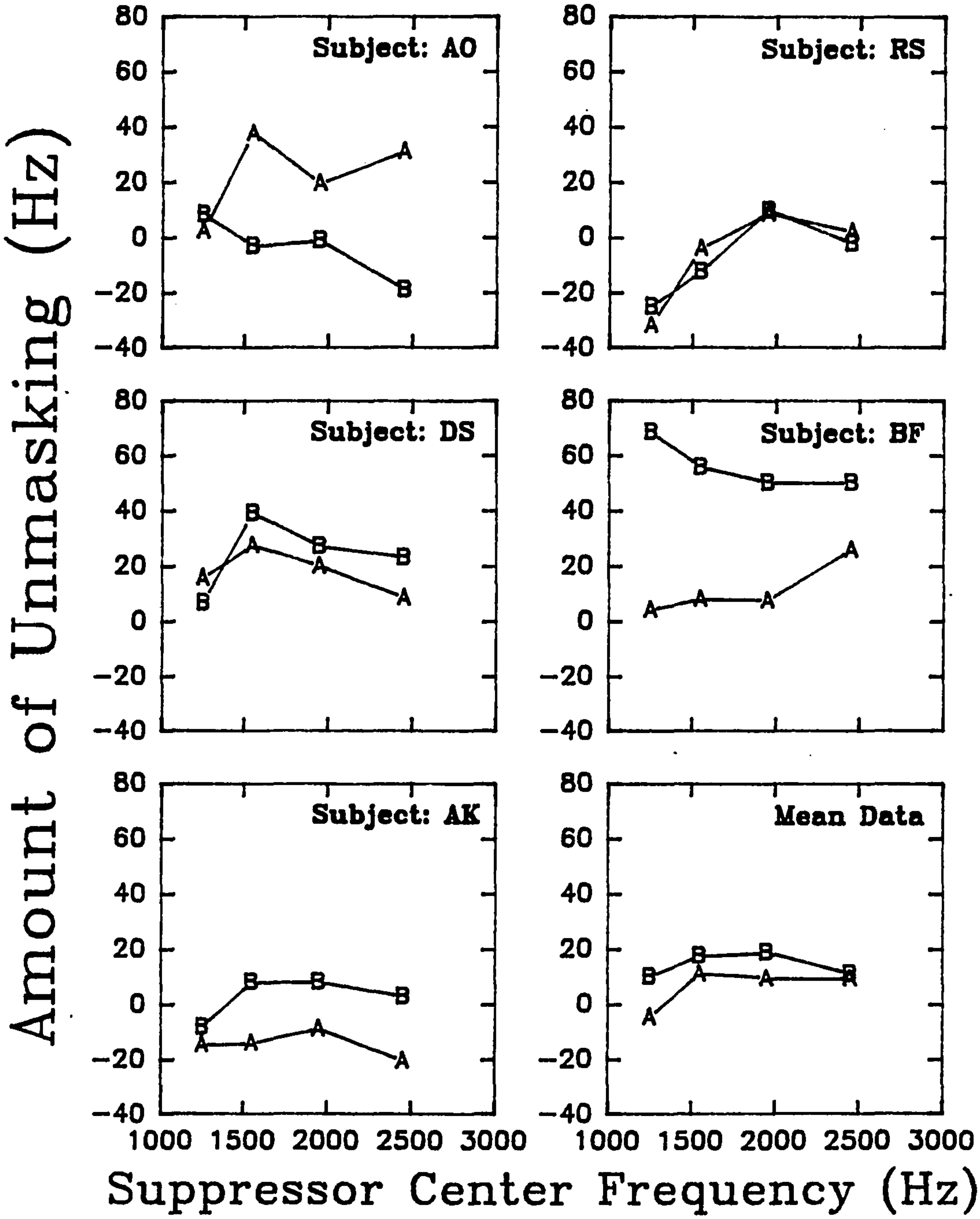

Figure 4. Individual and mean pitch discrimination for 0 dB SL signals using ipsilateral (A) and contralateral (B) suppressors.

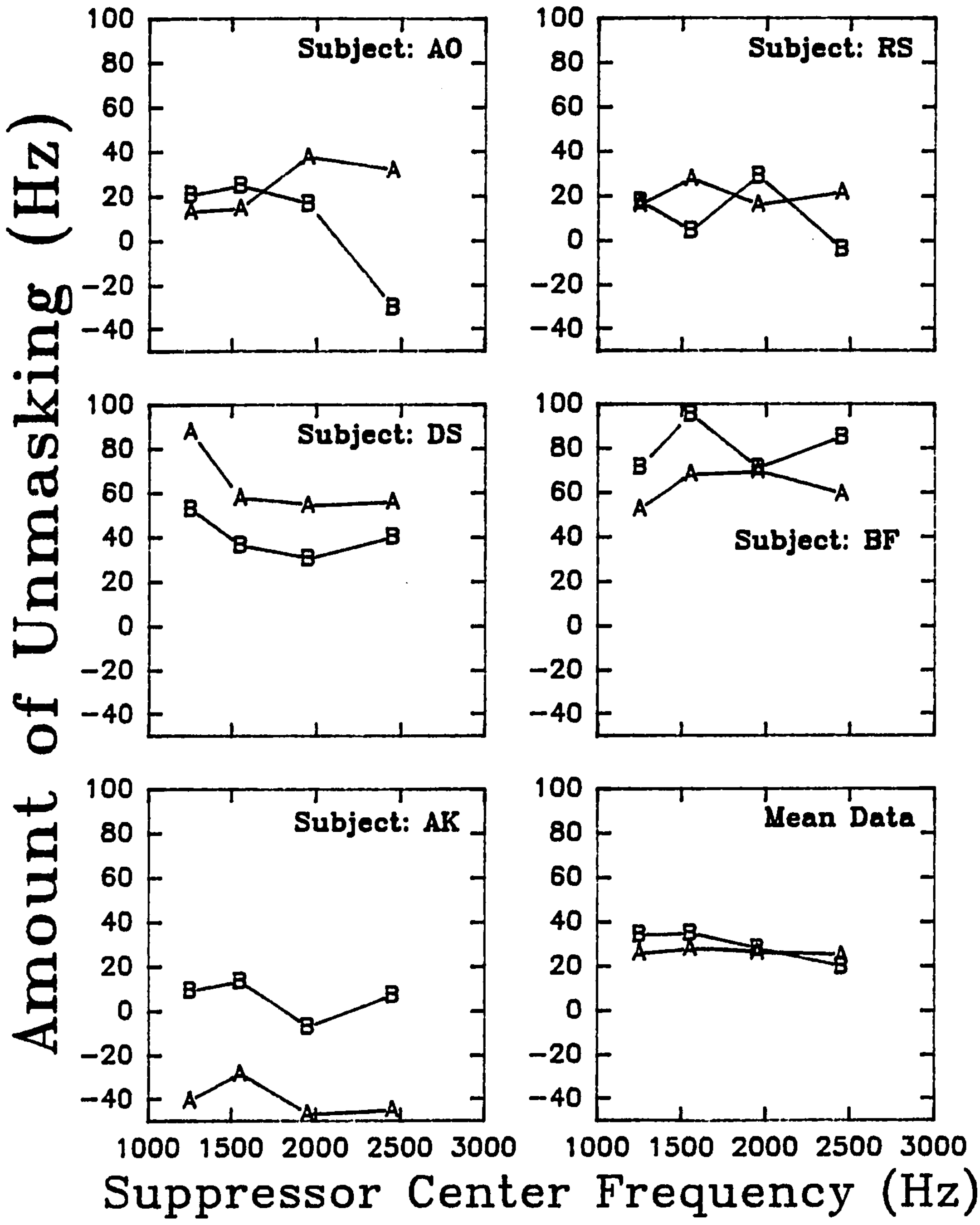

Figure 5. Individual and mean pitch discrimination for 10 dB SL signals using ipsilateral (A) and contralateral (B) suppressors.

Intensity Discrimination Unmasking

Individual and mean thresholds for the intensity discrimination experiment are summarized in Table 5 and shown in Figure 6. Results of the statistical contrasts are summarized in Table 6. Contrasts performed on the ipsilateral suppressor condition indicated significant amounts of unmasking for the 1550 Hz, 1950 Hz, and 2450 Hz suppressor conditions when the signal level was -20 dB SL; however, **masking** increased significantly in the 1250 Hz condition (see Figure 6, Mean Data, A). Also, masking increased significantly in the ipsilateral condition when the signal level was 0 dB SL. Additionally, in the 0 dB SL, contralateral condition, a small, but significant **increase** in **masking** was demonstrated for the 1550 Hz and 1950 Hz suppressor conditions, but not for the 1250 or 2450 Hz suppressor conditions. When the signal level was -20 dB SL, no unmasking was exhibited in any of the contralateral suppressor conditions. A 2 (signal intensity) X 2 (suppressor location) X 4 (suppressor frequencies) repeated measures ANOVA indicated significant main effects for signal intensity (F=10.06, p=.034) and suppressor frequency (F=29.32, p=.0003 GGDF), but not for suppressor location (F=2.79, p=.17). There was a significant interaction effect between signal intensity and suppressor frequency (F=5.02, p=.040 GGDF) as well as between suppressor frequency and suppressor location (F=31.4, p=.0002 GGDF). There was no

Table 5. Individual data for intensity discrimination experiment. Signal was a 950-1050 Hz wide noiseband.

Signal Level = 20 dB below detection threshold

	CC		TJ		DS		CH		RS		CUMULATIVE	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
IPSI												
No Supp	61.95	0.19	65.81	0.47	62.52	0.34	58.86	0.58	54.43	0.73	60.71	2.15
1250 Hz	65.86	1.86	73.76	3.46	65.24	2.39	61.05	1.45	64.86	1.19	66.15	2.32
1550 Hz	58.90	0.39	61.81	0.42	57.05	1.58	54.19	0.50	55.43	1.00	57.48	1.50
1950 Hz	56.76	0.93	56.76	0.64	55.58	1.00	54.81	1.34	54.67	0.98	55.72	0.51
2450 Hz	55.95	0.45	60.52	1.27	55.24	1.16	53.81	0.33	53.10	0.80	55.72	1.45
CONTRA												
1250 Hz	59.19	1.20	57.05	1.40	64.24	0.83	55.10	0.33	57.19	1.53	58.55	1.75
1550 Hz	59.38	0.63	57.95	1.14	62.67	0.91	57.52	1.24	61.48	1.32	59.80	1.11
1950 Hz	57.00	1.61	61.05	1.83	62.86	0.22	55.81	1.61	55.38	0.98	58.42	1.67
2450 Hz	57.67	1.41	58.43	0.89	64.48	1.41	59.67	0.91	54.95	1.59	59.04	1.75

Signal Level = 0 dB below detection threshold

IPSI												
No Supp	74.00	1.34	71.14	0.43	72.48	0.62	70.81	0.25	67.86	0.68	71.26	1.14
1250 Hz	83.38	0.13	78.71	0.58	79.62	0.87	77.67	0.83	71.62	1.60	78.20	2.13
1550 Hz	79.76	0.29	77.48	1.69	77.95	0.98	74.81	0.41	70.24	1.33	76.05	1.85
1950 Hz	78.52	2.41	80.10	0.63	75.05	0.81	75.00	0.60	69.24	0.27	75.58	2.09
2450 Hz	75.38	0.24	74.10	2.33	74.95	1.65	73.00	0.52	71.29	1.62	73.74	1.65
CONTRA												
1250 Hz	75.19	0.78	70.76	1.22	72.48	0.34	71.62	0.24	69.57	0.68	71.92	1.06
1550 Hz	74.81	0.55	72.52	0.66	72.86	0.58	73.38	0.05	69.10	0.45	72.53	1.05
1950 Hz	74.33	1.41	73.48	0.27	73.33	0.13	72.76	0.31	70.48	0.52	72.71	0.86
2450 Hz	72.29	0.72	72.24	0.62	73.29	1.03	70.90	0.79	69.90	0.05	71.72	0.66

Ipsilateral suppressor with no masker
Signal = 20 dB below detection threshold

No Supp	58.00	1.00	52.90	1.24	55.71	1.29	52.24	0.47	49.67	0.39	53.70	1.61
1250 Hz	67.67	1.45	69.24	0.47	67.52	1.19	60.67	1.90	61.57	2.08	65.33	1.96
2500 Hz	57.62	0.58	52.90	1.34	54.62	2.47	52.57	0.46	48.95	1.62	53.33	1.58

Ipsilateral suppressor with no masker
Signal = 0 dB below detection threshold

No Supp	74.14	0.44	71.67	0.47	74.76	0.99	72.33	0.33	72.90	2.24	73.16	1.27
1250 Hz	79.48	0.95	76.24	0.50	78.90	0.39	75.19	1.03	73.05	0.88	76.57	1.33
2500 Hz	76.76	1.14	74.52	1.06	74.29	0.22	72.29	0.71	72.19	1.00	74.01	0.94

Table 6. Statistical contrasts for intensity discrimination experiment. Contrasts are between the masker-alone condition and each of the suppressor conditions.

SIGNAL LEVEL = 0 dB SL

IPSI

	MEAN	SE	F	DF	P
1250 Hz	-6.98	0.90	59.53	1,4	0.0015
1550 Hz	-4.86	0.71	46.53	1,4	0.0024
1950 Hz	-4.32	1.29	11.18	1,4	0.0287
2450 Hz	-2.52	0.34	55.03	1,4	0.0018

CONTRA

	MEAN	SE	F	DF	P
1250 Hz	-0.70	0.39	3.22	1,4	0.1470
1550 Hz	-1.30	0.39	11.12	1,4	0.0290
1950 Hz	-1.64	0.44	13.75	1,4	0.0207
2450 Hz	-0.48	0.62	0.60	1,4	0.4804

SIGNAL LEVEL = -20 dB SL

IPSI

	MEAN	SE	F	DF	P
1250 Hz	-5.44	1.61	11.49	1,4	0.0276
1550 Hz	3.26	1.14	8.23	1,4	0.0455
1950 Hz	5.04	1.56	10.43	1,4	0.0320
2450 Hz	5.00	1.00	24.90	1,4	0.0075

CONTRA

	MEAN	SE	F	DF	P
1250 Hz	2.18	2.08	1.10	1,4	0.3541
1550 Hz	0.92	2.44	0.14	1,4	0.7248
1950 Hz	2.32	1.26	3.38	1,4	0.1397
2450 Hz	1.68	1.79	0.88	1,4	0.4009

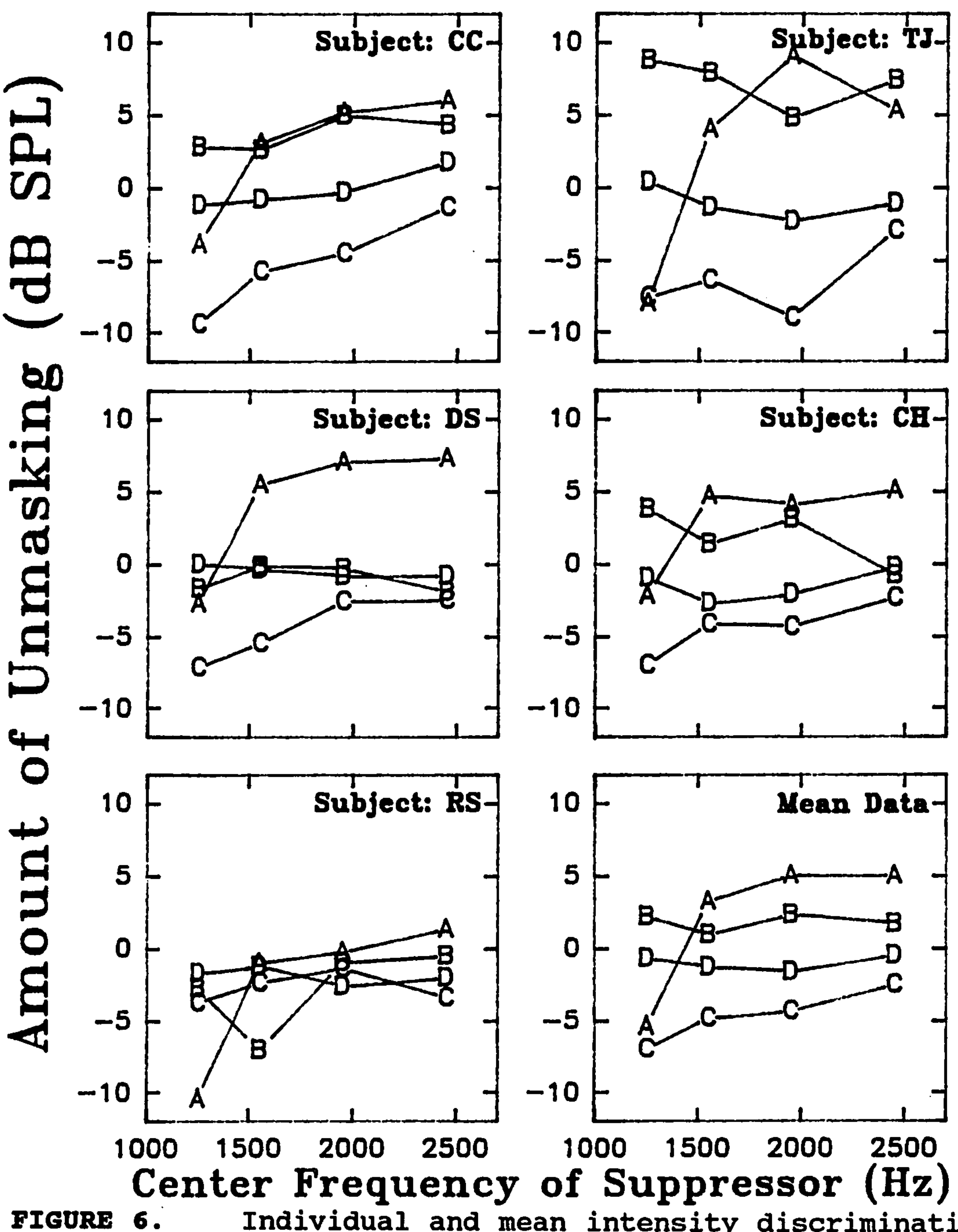

FIGURE 6. Individual and mean intensity discrimination data. "A" and "B" are the ipsilateral and contralateral suppressor conditions for -20 dB SL signals, respectively. "C" and "D" are the ipsilateral and contralateral conditions for 0 dB SL signals, respectively.

triple interaction between signal intensity, suppressor frequency, and suppressor location (F=4.35, p=.073 GGDF).

Discrimination Masking by the Suppressor

Mean thresholds and statistical contrasts for the suppressor-alone pitch and intensity discrimination masking experiments are summarized in Table 7 and shown in Figure 7. In both the pitch and intensity discrimination masking experiments, there was a significant **masking** effect in the 1250 Hz noiseband suppressor condition at all signal levels (p<.02). In the pitch experiment (Figure 7a), there was also a significant amount of masking by the suppressor centered at 2450 Hz when the signal level was 0 dB SL (p=.0125), but not 10 dB SL (p=.0982). In the intensity discrimination experiment (Figure 7b), however, the 2450 Hz narrowband suppressor condition did not cause significant masking at either signal level. In summary, the 1250 Hz suppressor condition exerted its own masking effect in all conditions. The 2450 Hz narrowband suppressor acted as a masker only in the pitch discrimination experiment when the signal level was 0 dB SL.

Table 7. Statistical contrasts for suppressor-only discrimination masking experiment. Contrasts are between the masker-alone condition and two of the suppressor conditions (1250 Hz and 1550 Hz).

Pitch Discrimination Unmasking (Suppressor only)

SIGNAL LEVEL = 0 dB SL

	MEAN	SE	F	DF	P
1250 Hz	-53.54	8.83	36.73	1,4	0.0037
2450 Hz	-15.41	3.57	18.60	1,4	0.0125

SIGNAL LEVEL = +10 dB SL

	MEAN	SE	F	DF	P
1250 Hz	-32.21	5.53	33.98	1,4	0.0043
2450 Hz	-20.35	9.48	4.61	1,4	0.0982

Intensity Discrimination Unmasking (Suppressor only)

SIGNAL LEVEL = 0 dB SL

	MEAN	SE	F	DF	P
1250 Hz	-4.81	1.26	14.49	1,4	0.0190
2450 Hz	-0.67	0.64	1.12	1,4	0.3503

SIGNAL LEVEL = -20 dB SL

	MEAN	SE	F	DF	P
1250 Hz	-10.43	1.83	32.58	1,4	0.0047
2450 Hz	-0.64	0.63	1.03	1,4	0.3673

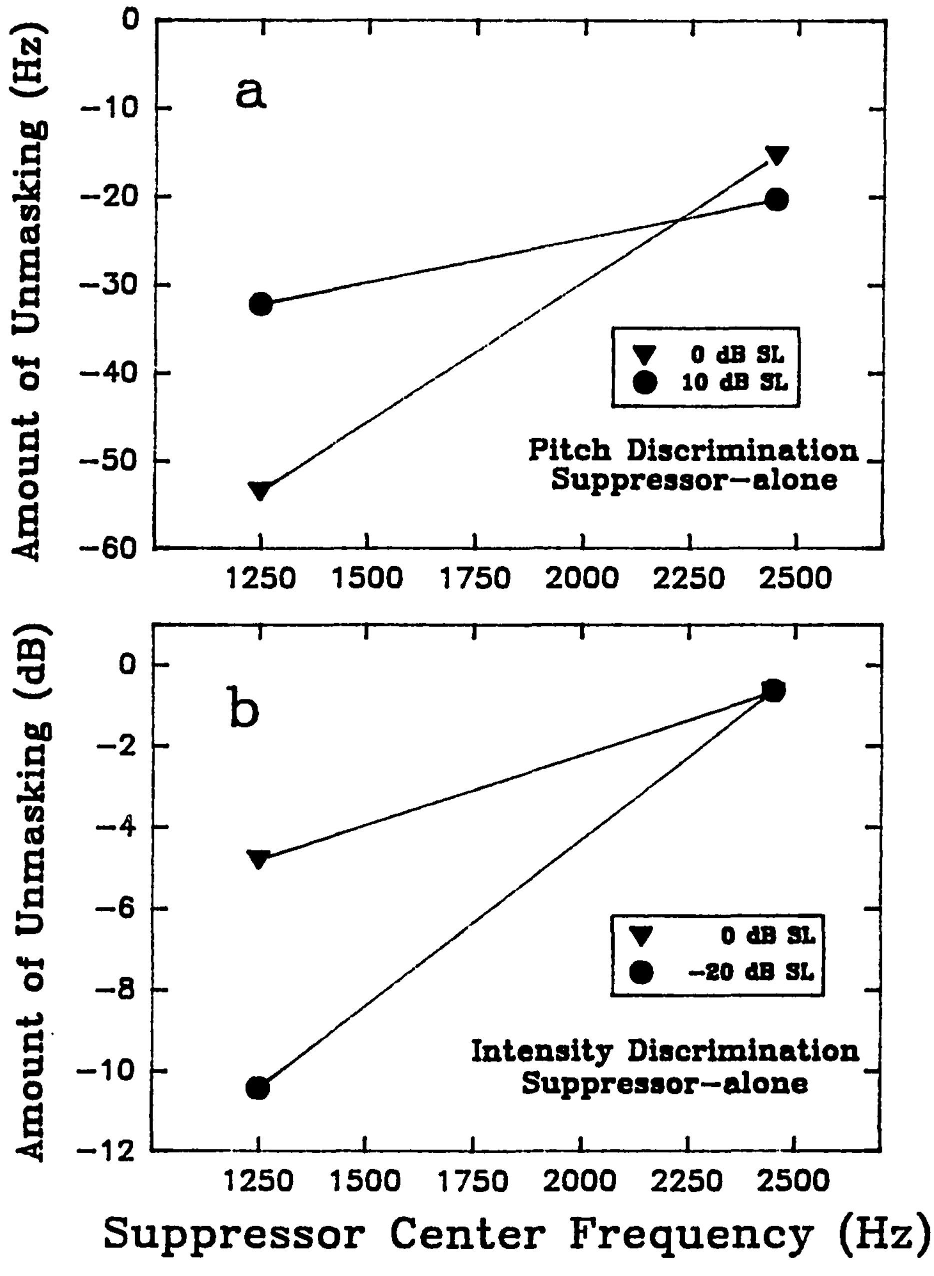

Figure 7. Mean pitch and intensity discrimination masking data for suppressor-alone condition.

CHAPTER VII

DISCUSSION

Pitch Discrimination Unmasking

Since the pitch discrimination unmasking experiment failed to reject the null hypothesis in either the ipsilateral or contralateral suppressor conditions, no conclusions can be made about either the suppression or cueing hypothesis. Nevertheless, it is important to identify possible factors which may have been responsible for the lack of an unmasking effect. The failure to observe unmasking in the backward pitch discrimination masking experiment could be due to a variety of factors. First, it is possible that the backward pitch discrimination masking experiment succeeded in its goal to deny subjects useful cues to enhance their judgment. However, the large between and within subject variability shown in Table 3, suggests that subjects were having a difficult time performing the task. Comments made by the subjects who participated in the pitch discrimination study indicated that the task was extremely difficult and sometimes confusing. There is a possibility that this confusion arose because subjects had access to an **intensity** difference cue in addition to the pitch cue. As discussed earlier, the 950-1050 Hz narrowband masker would have masked the 1000 Hz Standard more than the

Target, resulting in the Target sounding louder than the Standards. If the Target were presented at 850 Hz, the intensity cue may have been as salient as the pitch cue. However, as the Target frequency was adjusted closer to the 1000 Hz Standards, both the intensity and pitch cues would have been progressively less salient. Some subjects may have been tracking the intensity cue and others the pitch cue. In fact, some subjects may have used both cues. Regardless of which strategy subjects employed, it is important to realize that the initial premise of this experiment is still valid, i.e. the same set of pitch cues was available in all three intervals. Since the confounding intensity cue was present in the masker-alone condition and in each of the four suppressor conditions, the effect of intensity on unmasking should have been negligible. The intensity cue confound could be rectified in future research by performing a loudness matching experiment prior to the discrimination masking experiment. For example, loudness matching data could be obtained for a range of backward masked signals between 800 Hz and 1000 Hz. During the discrimination masking experiment, the intensity of the Target could be adjusted by a computer program to perceptually match the loudness of the Target with the Standards. Thus, the intensity cues would be eliminated and only the desired pitch cues would be available. In short, the backward pitch discrimination masking study failed to support either the cueing hypothesis or the suppression hypothesis probably due to the unexpected introduction of an intensity cue.

Intensity Discrimination Unmasking

The results of the backward intensity discrimination masking study support the cueing hypothesis. Although contralateral unmasking effects were not demonstrated in this experiment, the amount of unmasking in the -20 dB SL ipsilateral condition remained fairly constant as suppressor frequency was increased (Figure 6). If suppression were the underlying mechanism responsible for this unmasking, the effect should have decreased as suppressor frequency increased. The source of the perceptual cue is not readily obvious. One possible interpretation is that subjects were able to compare the outputs of multiple frequency channels to help make their judgments. In the SM conditions and the masker-alone condition, the signal and masker were identical in frequency and bandwidth. The signal and masker were, therefore, processed through the same frequency channel (e.g., Channel A). In the SM conditions, the suppressor was processed through a separate channel depending on the suppressor frequency (e.g., Channels B-E). In the masker-alone condition, the output of Channel A was the only channel evaluated. However, in the SM condition, the suppressor offered an additional fixed comparison point. In this process, somewhat like triangulation, the intensity of the signal could be determined more accurately by comparing the signal, masker and suppressor channel outputs. It is important to note that, in isolation, the suppressor did not offer any cues which improved intensity discrimination. The lack of unmasking in the suppressor-alone condition precludes the possibility that the suppressor acted as the sole cue for the unmasking effect. Thus, it is the combination of the masker and suppressor that improves signal intensity discrimination. The concept that frequency channels distant from the signal and masker may improve signal detectibility and discrimination is not new. For example, using modulated noise maskers, it has been shown that signal detectibility may improve due to the presence of masker components which are outside the critical band of the signal (Hall, 1984). Green (1983, 1988) also postulates that intensity discrimination tasks may be positively influenced by frequency components which are distant from both the frequencies of the signal and masker. The hypothesized process by which this improvement occurs is called profile analysis. For intensity discrimination, profile analysis involves a simultaneous comparison of multiple frequency regions in order to detect an increment or decrement in the frequency region of interest. It is not a specific frequency region which is being processed, rather it is the spectral shape, or profile, of the stimulus. When one frequency region of a complex stimulus is increased in intensity, the overall profile of the stimulus changes. The traditional view, on the other hand, states that intensity discrimination is performed by focusing on the frequency regions which are most likely to contain an intensity difference. The energy level for each signal to be discriminated is stored in memory. Intensity discrimination involves comparing these stored representations in memory. Green (1988) believed that for sinusoidal signals, the traditional approach was valid, because a change in intensity does not result in an overall change in the spectral profile. The discrimination tasks in the present series of experiments would seem to combine aspects of both profile analysis and the traditional model. Unlike Green's (1983) experiments, the signal in the present study did not have multiple frequency regions, i.e., the signal was a 950-1050 Hz noiseband which was separated temporally from the SM. The suppressor/masker complex, however, did have multiple frequency regions. The representation of the signal in each interval was stored in memory, but it was the addition of the suppressor to the masker which added to the amount of information available for making a discrimination judgment by creating a richer profile. The close temporal relationship of the signal to the SM may have enabled the signal to become integrated or associated with the SM. Thus discrimination benefitted from the hypothesized simultaneous processing in profile analysis, although the signal and SM were temporally separated.

It is not immediately clear why masking increased in the 0 dB SL ipsilateral suppressor condition relative to the masker-alone condition. It is possible that the 0 dB SL signal was more easily discriminable than the -20 dB SL signal and did not benefit from the across channel comparisons offered by the SM conditions. If the intensity discrimination task were easy in the masker-alone condition, the suppressor would not be as helpful in the decision making process. Performance may have been asymptotic. In fact, it might be expected that discrimination masking would increase due to the distraction of adding the 60 dB suppressor to the masker. In the -20 dB signal condition, this confusion would have been counteracted by the cueing effect.

Detection Unmasking

Probably, the most interesting outcome of this study was the result of the 950-1050 Hz noiseband detection experiment. In the original suppression hypothesis, it was expected that the effects of suppression would be greatest for suppressor frequencies closest to the masker. Suppression should have disappeared when the suppressor frequency was an octave above the masker frequency. It was most disconcerting to see this pattern of results occur in the contralateral condition, but not the ipsilateral condition, since suppression is considered to be a peripheral event. Notice, in Figure 3 (page 33), that the amount of unmasking in the contralateral 1250 Hz condition was approximately 29 dB SPL while the contralateral 2450 condition was not significantly different from 0 dB. The amount of unmasking in the ipsilateral suppressor conditions remained fairly constant around 26 dB SPL.

It is possible that this unusual outcome may be explained in terms of a perceptual grouping of the masker and contralateral suppressor. When the suppressor was centered at 1250 Hz, subjects reported that the suppressor and masker seemed to "fuse" into a single percept. More specifically, the fused image sounded similar to an antiphasic dichotic presentation of a narrowband noise. As the suppressor center frequency was increased, this "unitary" and "fused" perception decreased. When the suppressor frequency was centered at 2450 Hz, the suppressor and masker sounded entirely distinct, one at each ear. In the ipsilateral conditions, the suppressor and masker seemed to be a single fused image regardless of suppressor frequency. It is possible that when the masker and suppressor sound distinct, subjects are able to focus more attention on the ear receiving the signal and masker and disregard the information coming from the unattended contralateral ear. In this latter case, the subjects were not using the cues supplied by the contralateral suppressor. It is hypothesized that if subjects were forced to use the contralateral suppressor cue, unmasking would have increased. In fact, the flat unmasking response observed in the ipsilateral suppressor condition can best be explained in terms of the suppressor and masker being perceptually fused. Subjects were forced to use the suppressor cues in the ipsilateral condition, because the suppressor was indistinguishable from the masker at all suppressor frequencies.

It should also be possible to force the suppressor and masker to fuse in the contralateral suppressor condition. One way of examining this possibility uses a phenomenon related to the law of proximity in Gestalt psychology. It is possible to cause disparate auditory stimuli to group into a single percept by rapidly and simultaneously pulsing them on and off (Bregman, 1978). In this view, the pulsed suppressor and masker stimuli should group together, because they share a series of simultaneous onsets and offsets. A brief attempt was made to try to force the grouping of the suppressor and masker and possibly make the contralateral cue effective. This was done by trying to get the suppressor and masker to "group" into a single percept when the suppressor was centered at 2450 Hz. Instead of presenting a 300 msec SM condition, the SM was pulsed in seven, 50 msec parcels separated by 15 msec gaps. The results of this pilot study (N=1) were unsuccessful indicating the same reduction in unmasking due to increased suppressor frequency. Other SM configurations may yield a more powerful grouping effect at higher suppressor frequencies. Clearly, more research needs to be done to explore this grouping hypothesis. The lack of a similar contralateral effect in the 1000 Hz sinusoid detection experiment could have been due to the same confusion effects discussed earlier.

CHAPTER VIII

SUMMARY

The experiments outlined in this paper were designed to examine possible underlying mechanisms associated with unmasking in a backward discrimination masking paradigm. In particular, the experiments attempted to eliminate the cueing effects which have plagued detection unmasking experiments. The rationale was that if cueing effects could be removed from unmasking tasks, the presence or absence of underlying physiological suppression mechanisms would be revealed. It was reasoned that a backward discrimination unmasking task would not be susceptible to the cueing effects found in previous detection experiments because the same set of cues exists in each observation interval. Backward discrimination masking was measured separately for both pitch and intensity discrimination. There were no observed unmasking effects in the backward pitch discrimination masking experiment. The magnitude of the unmasking effects observed in the backward intensity discrimination masking experiment were far less than in the corresponding backward detection masking study. The intensity discrimination experiment yielded a maximum unmasking value of approximately 5 dB as compared to the 26 dB observed in the detection experiment. The amount of unmasking in the detection experiment was comparable to that found in previous backward unmasking studies (Weber & Green, 1978, 1979). A flat unmasking response across suppressor frequencies suggested that cueing was the mechanism responsible for unmasking in the intensity discrimination unmasking study. The pattern of results suggested the possibility that these cues arose through processes similar, if not identical, to profile analysis (Green, 1983). There was no evidence in the current study to suggest that physiological suppression mechanisms were responsible for the unmasking effects.

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Appendix

The Video Game

A video game format was used which was originally designed to obtain psychoacoustical information from children. In research involving children, the video game approach helps to maintain a child's attention to the psychophysical task. The technique seems to work equally well in adults and makes the large number of trials necessary to complete the experiment more palatable to the subjects. Subjects were told that an ogre had magically disguised himself as a gallant knight. The subject was instructed that he/she should pretend to be a wizard casting a spell on all three knights to discover which was really an ogre. As the "spell" was cast, each of the three knights glowed briefly and beeped. In the detection task the subject was told that the knight who beeped twice (signal interval) was really an ogre. In the discrimination task, the subject was told that the knight who made a sound different from the other two was really an ogre. The subject identified the proper interval by touching the appropriate knight. If the response was correct, the image of the knight was struck by a bolt of lightening and slowly transformed into the image of a burly ogre who showed his displeasure by waving his arms and his stone pike. If an incorrect response was made, the correct knight (ogre) simply raised his sword above his head. The game concluded by displaying the subject's "score" for the session. The "score" was based on the number of correct responses made during the session. The subject received more points based on the number of consecutively correct responses they made. Thus, if a subject made two correct responses in a row, they received two points. Three in a row scored three points, etc. The largest reward for consecutively correct responses was five points. The conclusion of the game was indicated by a continuous fireworks display and the subject was allowed to leave the IAC chamber.