Effects of informational maskers within and across trials

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The across-trial effect of maskers in conditions of informational masking was evaluated from performance on occasional trials in which the signal was presented alone. For 6 of 12 listeners participating in the study, a significant number of errors were obtained on signal-alone trials; in some cases equivalent to that signal+masker trials. On immediately preceding trial blocks for which there were no intervening maskers, performance for these signals was perfect. The results indicate that informational maskers can have a significant effect on signal threshold, both within and across trials. © *2005 Acoustical Society of America.* [DOI: 10.1121/1.1923348]

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I. INTRODUCTION

Informational masking is the term often used to describe elevations in signal threshold that cannot be accounted for by traditional energy detection or auditory filter models of masking. It is a term typically reserved for cases where the maskers are highly uncertain and are far removed from the signal in frequency and/or time (Neff and Green, 1987; Watson and Kelly, 1981). Accounts vary, but generally focus on the immediate effect of maskers within each observation interval or trial. The focus on within-trial effects is explicit, for example, in the component-relative-entropy (CoRE) model, a model that has been shown to accurately predict many of the results from studies of informational masking (Lutfi, 1993; Oh and Lutfi, 1998). It is also evident in perceptual accounts of the effects of signal-masker similarity (Arbogast, Mason, and Kidd, 2002; Kidd *et al.*, 2001; Kidd, Mason, and Arbogast, 2002; Kidd *et al.*, 1994; Neff, 1995), and in molecular analyses intended to reveal aspects of the decision process from trial to trial (Lutfi, 1992; Richards, Tang, and Kidd, 2002; Tang and Richards, 2002; Wright and Saberi, 1999). In each of these cases the signal and masker components on a given trial are assumed to combine or interact somehow so as to influence the listener's decision only on that trial.

Predominant attention to the within-trial effects of maskers is understandable given that such effects seem likely to have the greatest impact on listener performance. Yet, the signature of informational masking is that maskers need not be in close spectral or temporal proximity to the signal to exert a significant effect (Watson and Kelly, 1981). This raises the question as to whether informational masking can occur across trials. The CoRE model predicts that maskers can have an across-trial effect by establishing listener expectations in the presence and absence of the signal regarding the sum of levels at the output of independent auditory filters (a criterion effect). Maskers may also have an across-trial effect by interfering with memory for the signal over the course of many trials (cf. Neff, 1985; Neff and Jesteadt, 1983). There is evidence, for example, that such interference may cause listeners to "confuse" the signal for a component of the masker even in cases where the signal is previewed before each trial (Lutfi *et al.*, 2003).

The goal of the present study was to evaluate the across-trial effects of informational maskers by examining performance on occasional trials in which the signal is presented alone. Where the signal is presented alone there can be no immediate effect of maskers within the trial; hence, errors can only reflect the effect of maskers across trials.

II. METHODS

A. Listeners

Twelve (1 male, 11 females) paid listeners between the ages of 18 and 20 years were recruited from the U.W.-Madison campus. Each listener used his or her right ear for the experiments. All listeners had normal hearing based on standard audiometric measurements of pure-tone air conduction thresholds at the octave frequencies between 250 and 8000 Hz (ANSI, 1996). None of the listeners had any prior experience on psychoacoustic tasks.

B. Stimuli

The signal and maskers were coincident pure tones gated with 5 ms, $\cos^2$ onset/offset ramps for a total duration of 100 ms. The frequency of the signal was 2000 Hz. Masker frequencies were selected at random on each trial with replacement from a uniform distribution of frequencies separated by 5 Hz from 1500 to 2500 Hz, excluding a protected region from 1940 to 2060 Hz. The levels of the masker tones were selected from a uniform distribution from 22 to 62 dB SPL, independent of each other and of masker frequency. The signal and maskers were computer generated and were played over a 16 bit sound card (Sound Blaster™ 16 MultiCD™ audio card; Creative Technology, Ltd.) at a 20 kHz sampling rate before being passed through a programmable attenuator (Tucker-Davis Technologies, PA4). All stimuli were presented monaurally through a Sennheiser HD 520 (II) headphone. A TDH-50 earphone with known trans-

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fer function was used to calibrate the Sennheiser headphones using a binaural loudness balancing procedure at the signal frequency (ANSI, 1996).

C. Procedure

Thresholds in all experimental conditions were measured using an adaptive, two-down-one-up, single-interval, yes–no procedure with feedback (Levitt, 1971). The use of the single-interval procedure, which is subject to response bias, was dictated by the need to measure responses to the signal that could not in any way be influenced by maskers that occurred within the same trial. Response bias, analyzed as the sum of the z-scores for hits and false alarms (Macmillan and Creelman, 1991), showed listener S08 to have a significant negative bias on SMM tracks (see below) which was largely responsible for the lower than chance performance on SMM trials. For the remaining listeners the magnitude of the bias was never so great as to be identified as a significant factor contributing to the large amounts of informational masking obtained. Listeners were informed that the signal frequency would remain the same throughout the experiment and that it would be presented on about half of the trials at random. To familiarize listeners with the task at least one 40-trial block of each experimental condition was run prior to data collection. Starting levels for the signal on subsequent trial blocks were 10 dB above the running average of threshold estimated from all previous blocks, beginning with the practice block. Step size for the adaptive track was 3 dB. Threshold for a block was defined as the average level of the points making up each track, excluding the first 4 trials of each type. Mean threshold is reported as the average of 5 such estimates.

D. Experimental design

Our goal was to measure performance on signal-alone trials in conditions known to produce large amounts of informational masking from past studies (cf. Neff and Green, 1987). The challenge was to include enough signal-alone trials to obtain meaningful estimates of performance, but not so many as to change the fundamental nature of the task. The level of the signal was adjusted independently for three different pairings of signal and nonsignal trials, i.e., three types of tracks. For SQ tracks signal-alone trials were randomly mixed with trials of quiet, each type of trial having an equal probability of occurrence within the trial block. For SMM tracks signal-plus-masker trials were randomly mixed with masker-alone trials that always included a two-tone masker. Note, a two-tone masker was used so that the listener could not simply base judgments on qualitative differences associated with one (masker) and two (signal-plus-masker) tones. Finally, for SM tracks signal-alone trials were randomly mixed with masker-alone trials that always included a single-tone masker. SMM and SM tracks differed from SQ tracks in that they were interleaved within a single block of 80 trials, 40 trials each track. This was done to increase the similarity to conditions of past informational masking studies by increasing the number of possible masker and signal-plus-masker combinations and by decreasing the proportion of signal-alone trials. Before the start of each block, the listeners were informed of which type of block they would be listening to (SQ or SM+SMM blocks). For SM+SMM blocks, listeners were also informed of the exact nature of the two independent tracks. SQ blocks were alternated with the SM+SMM blocks for the purpose of aiding memory for the signal.

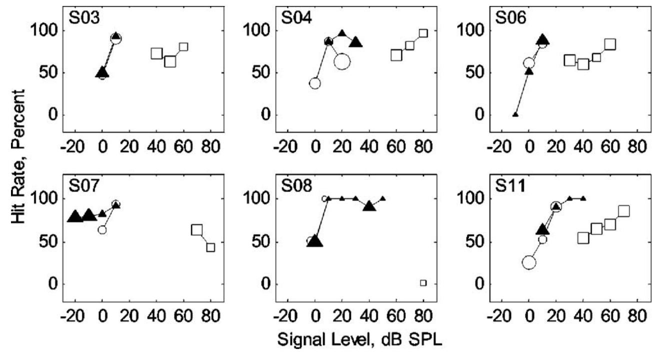

FIG. 1. Psychometric functions (hit rate) for SQ (open circles), SM (closed triangles), and SMM (open squares) trials. Vertical extent of each symbol is approximately equal to the square-root of the binomial variance associated with each point. Data are from six listeners whose results indicate little or no across-trial effect of maskers.

III. RESULTS

The focus of our analysis is on the comparison between signal-alone trials for SQ, SM tracks. Across-trial effects of maskers should be evidenced as substantial number of errors on SM trials for signal levels well above quiet threshold. In other words, the prediction is that data from SM and SQ trials belong to very different psychometric functions. Psychometric functions (hit rate versus signal level) for each type of trial for each listener are given in Figs. 1–3; SQ trials are denoted by open circles, SM trials by closed triangles, and SMM trials by open squares. Each point gives the hit rate based on at least 5 responses within ±5 dB of the signal level indicated; each function is based on a total of approximately 90 trials. Symbol size gives an indication of the reliability of each point; vertical extent being very nearly equal to the square-root of the binomial variance associated with each point.

In the three figures listeners are roughly grouped according to their overall pattern of results. Figure 1 gives the data from listeners whose results indicate no across-trial effects of maskers. For SM trials there is no evidence of errors beyond that of SQ trials. At signal levels for which the SM and SQ functions overlap the hit rate for these listeners is never measurably poorer on SM trials, and at higher signal levels hit

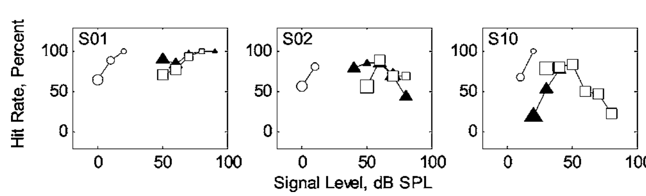

FIG. 2. Same as Fig. 1 except the data are from 3 listeners whose results indicate a significant across-trial effect of maskers.

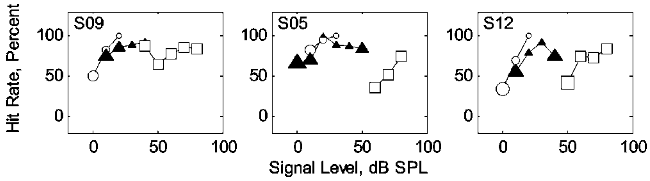

FIG. 3. Same as Fig. 2 except the data are from 3 listeners who showed intermediate results between the listeners of Figs. 1 and 2.

rate on SM trials is equal to or very nearly equal to 100%. All listeners in Fig. 1 also show a far rightward shift of the psychometric functions for SMM trials indicating substantial amounts of within-trial informational masking. These results stand in stark contrast to those of Fig. 2 where the three listeners show a clear across-trial effect of maskers. Here large numbers of errors are observed on SM trials of the same order of magnitude as on SMM trials.[1] There is also clear evidence of psychometric functions with negative slopes. Listener S02 shows a negative slope for SM trials while listener S10 shows a negative slope for SMM trials. The negative slopes appear to provide further evidence of confusion inasmuch as they occur in the region where the signal is likely to be clearly audible; that is where the signal level typically exceeds that of the masker. In this regard the functions are reminiscent of those of Brungart (2001) where plateaus attributed to confusion have been observed when the signal level roughly equals that of the masker. Finally, Fig. 3 gives the results of three listeners who show results intermediate between Figs. 1 and 2. These listeners show many fewer errors on SM trials than on SMM trials, but they nonetheless make large numbers of errors on SM trials at signal levels well above their quiet threshold.

IV. DISCUSSION

The results of this study make clear that informational maskers have the potential to exert significant across-trial effects on detection. To what extent these effects generalize to other studies remains an open question. In order to test for across-trial effects the conditions of this study needed to differ in fundamental ways from those of past informational masking studies. Moreover, the listeners of this study were not highly practiced. Practice is known to reduce the amount of informational masking and would likely have also reduced errors on signal-alone trials (Leek and Watson, 1984; Neff, 1995). Typically more practice has been given in past studies but the exact amount has varied greatly from one study to the next. Though it is unclear to what extent these results generalize to other studies, they at least suggest that greater consideration be given to the potential of informational maskers to exert effects that extend across trials.

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[1]Note that because the range of signal levels visited on the SM+SMM tracks was generally greater than that for the SQ tracks, there is a degree of uncertainty regarding signal level on the SM+SMM tracks that was not present on SQ tracks. Such level uncertainty could be both a contributor to and product of the across-trial criterion effect predicted by the CoRE model. The model would predict no errors if the same levels had been visited at random on SQ tracks.

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