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Masking Patterns for Partially Masked Tinnitus

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Abstract: Tinnitus isomasking contours were determined for unmasked tinnitus and for tinnitus partially masked by high-pass noise. The noise was selected so that it masked all but the low frequency components of the tinnitus. As a control, the masking pattern of an external tone in the tinnitus region and in the presence of the high-pass noise was compared with that of the partially masked tinnitus. Frequency-specific masking was obtained for the external tone but not for the partially masked tinnitus. This suggests that even narrowband tinnitus is not masked in the cochlea. Thus, tinnitus maskers need not include the frequency region presumed to contain the tinnitus.

INTRODUCTION

Tinnitus is frequently described as tonal or as a narrowband stimulus (Reed, 1960; Kodama & Kitahara, 1990). However, the frequency of a pure tone which is adjusted to match the pitch of the tinnitus exhibits considerable variability (Burns, 1984; Norton, Schmidt & Stover, 1990; Penner, 1983; Tyler & Conrad-Armes, 1983). The inconsistent matches to tinnitus are not indicative of an inability to perceive pitch because subjects whose matches to tinnitus are labile may nonetheless make reliable matches to external tones in the tinnitus region (Burns, 1984; Penner, 1983). These observations suggest that tinnitus may be tonal but that its pitch is evanescent.

If the pitch of tinnitus is perceptibly changeable, then tinnitus might not even be a narrowband stimulus. Indeed, the broadband nature of tinnitus was demonstrated by permitting subjects to mimic the sensation of tinnitus with a complex sound pattern consisting of the sum of sine waves (Penner, 1993; 1995). For all the subjects so tested, the sensation of tinnitus was mimicked more accurately with a complex sound pattern than with a single sine wave and the complex spanned an average of 2.94 kHz (Penner, 1995).

If tinnitus were generally a fluctuant, broadband stimulus as the above data suggest, then, even if tinnitus were generated in the cochlea, it could not be masked by a single pure tone. However, tinnitus is often reported to be masked by an intense pure tone of any frequency (Feldmann, 1971). Such flat tinnitus isomasking contours suggest either that tinnitus is masked retrocochlearly (Burns, 1984; Feldmann, 1971; Penner, 1987; Tyler & Conrad-Armes, 1984) or that some other perceptual judgment was inadvertently made (Penner & Bilger, 1994).

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To understand what other perceptual judgment might have been made, consider a prominent model of the masking a single external pure tone. In this excitation model, masking is thought to be a "swamping" of neural activity elicited by the signal on the neural channels which respond to it (Moore & Glassberg, 1982). The neural activity pattern (Moore & Glassberg, 1982; Zwicker, 1958) evoked by a broadband fluctuant stimulus, such as tinnitus, would produce activity encompassing many neural channels, some sporadically. With the neural activity due to tinnitus changing noticeably over many channels, masking of tinnitus might be hard to distinguish from variation in the tinnitus itself. In these circumstances, the tinnitus "masker" might merely produce the same overall excitation as the tinnitus, but not necessarily in specific channels. Thus, overall excitation might be equated with masking. Because overall excitation is likely to be related to loudness (Zwicker, 1963), the masking contours could represent isoloudness contours with the tinnitus serving as the standard, as Penner and Bilger (1994) have argued. The link between "isoloudness contours" and tinnitus "isomasking contours" was further implicated by the close fit of the linear-correction power law describing isoloudness judgments to the tinnitus "isomasking" contours (Penner & Bilger, 1994).

An empirical demonstration enabling the separation of isomasking and isoloudness judgments might be possible if tinnitus were a narrowband stimulus. If the neural activity due to narrowband tinnitus encompassed a few channels, masking of tinnitus might be easy to distinguish from variation in the tinnitus itself. In these circumstances, the tinnitus "masker" might produce the same overall excitation as the tinnitus in the specific channels corresponding to the tinnitus. In this case, tinnitus masking patterns would be frequency-specific. In other words, it might be possible to better delineate the masking task for the subject if the tinnitus were narrowband or partially masked. It is this hypothesis which is tested here.

METHOD

Subjects

Three male subjects with tinnitus participated in this experiment. Subject 1 had sensorineural hearing loss and had been a subject in this laboratory for 16 years, whereas Subjects 2 and 3 had nearly normal audiometric thresholds and were not experienced subjects.

Before the onset of the tasks which constitute the focus of this manuscript, the subjects were checked for spontaneous otoacoustic emissions, SOAEs (as in Penner, et al. 1993), and thresholds were measured at the audiometric frequencies (0.5, 1, 2, 4, 6, 8 kHz) using a two-interval forced-choice (2IFC) adaptive procedure (Levitt, 1971).

Apparatus

A computer (IBM 486) controlled a commercially available Tucker Davis Technologies (TDT) System II module (consisting of one digital signal processing board, two channels of digital-to-analog conversion, one antialiasing filter, two programmable attenuators and one headset buffer). All stimuli were played at a 40-kHz sampling rate and filtered using a 20-kHz low-pass filter. The filtered stimuli were passed through two programmable attenuators in series. The first attenuator was used to calibrate the sound pressure level. The second one was used to adjust the stimulus level. The attenuated stimuli served as the input to the headset buffer, and were then delivered to an insert phone (Etymotic ER-2). Measured harmonic distortion levels of the computer-generated pure tones were at least 90 below the primary level. The stimuli were all 1 sec in duration with a 10 msec cosine-shaped rise-decay time and the time between intervals in all tasks was 500 msec.

Each subject sat inside a double-walled Industrial Acoustics chamber (IAC model 1201A) which contained both a video display terminal (VDT) and a keyboard. The stimuli were played in synchrony with a visual display on the computer screen and the subject responded by pressing a key on the keyboard.

Procedure

Each experimental session lasted 2 hours, with intermittent rest periods spaced about 20 minutes apart. Four tasks were undertaken during the experiment. Details of each task are presented in the following paragraphs. In all tasks, the final step size for the stimulus level was 2 dB and, for the adjustment tasks, 10 adjustments were made. By agreement with the University of Maryland's Institutional Review Board, the maximum level of a pure tone was limited to 90 dB SPL.

Task 1

Task 1 was a modified forced-choice double staircase procedure (FCDS as in Penner & Bilger, 1992; Penner & Klafter, 1992; Penner & Saran, 1994) in which the subject matched an external tone to the frequency and level of the lowest pitch component of the subject's tinnitus.

The FCDS task is described in detail elsewhere (Penner & Saran, 1994). Briefly though, the procedure used two randomly interleaved forced-choice dependent sequences of trials with different decision rules. In one double staircase, the sequence began with comparison stimuli which were above the tinnitus pitch or loudness and one with the comparison stimuli which were below it.

In the FCDS procedure, the subject chose one of two clearly demarcated (1 sec) temporal intervals. All instructions to the subject appeared on the VDT. The first interval was marked with a flash of light, and the subject instructed to listen to the standard (an external tone or the tinnitus) during that flash. The second (1 sec) interval was also marked with a flash of light and an external comparison tone was presented.

The subject chose between two subjective labels in responding to each pair of stimuli. For example, the subject might have been instructed to pick the interval with the lower pitch tone, in which case the subject should pick the first interval if the standard seemed lower in pitch than the external tone, or the second if the converse were true. The rules for adjusting the stimuli in response to the subject's subjective choices are those of Levitt (1971). The data presented are based on 10 reversals per staircase, with at least the preceding 4 reversals discarded. The step size for the stimulus frequency was initially 32 Hz, changing to 2 Hz after 4 reversals. The step size for the stimulus level was initially 8 dB changing to 2 dB after 4 reversals.

Task 2

Task 2 was an adjustment task in which the subject adjusted a (1 sec) pure tone at the audiometric frequencies to mask the tinnitus. For the first adjustment, the level of the pure tone was set at 90 dB SPL (so that tinnitus was masked). Thereafter, the level of the pure tone was randomized.

Task 3

Task 3 was an adjustment task in which the subject adjusted the level of a pure tone to mask the lowest pitch component (as determined in Task 1) of the partially masked tinnitus.

To eliminate the tinnitus in one ear, a broadband white Gaussian noise was adjusted by the subject so that it masked the tinnitus in that ear. To restrict the subject to the lowest pitch component in the contralateral ear, white Gaussian noise was high-pass filtered with a cutoff frequency twice the frequency matching the lowest pitch tinnitus component as measured in Task 1. The roll-off rate of the filter skirt was 120 dB per octave. Because low-frequency noise could potentially mask high-frequency tinnitus components, only high-pass noise which did not affect the audibility of the low-frequency tinnitus components was employed.

Each subject adjusted the level of the high-pass noise so that only the lowest pitch component of the tinnitus remained audible. A simultaneous external tone was then added to the high-pass noise and the subject adjusted the level of that tone until it masked the lowest component of the tinnitus.

For all subjects, five tonal maskers were presented at 1% frequency intervals centered at the tinnitus frequency presented in Table 1.

Task 4

Task 4 is analogous to Task 3 except that the signal was an external tone rather than the tinnitus and therefor two psychophysical methods (method of adjustment and two-interval forced-choice) could be employed. The level of a pure tone required to mask the signal (whose level and the frequency were those that matched the tinnitus in Task 1) was determined in both a forced-choice and an adjustment task. As in Task 3, a broadband white Gaussian noise in one ear and a high-pass filtered noise in the contralateral ear were presented. These noises were identical to those used in Task 3.

For all subjects, five maskers were presented at 1% frequency intervals centered at the tinnitus frequency presented in Table 1.

RESULTS

The matches from Task 1 are presented in Table 1. As reported previously (Penner & Bilger, 1992; Penner & Klafter, 1992; Penner & Saran, 1994; Penner, 1995), the standard deviation (SD) of the matches to tinnitus does not greatly exceed the SD of matches to external tones when the FCDS procedure is employed. The scant variability of the matches to the lowest pitch component of the tinnitus raises the question of whether the tinnitus might be psychophysically equivalent to a low-frequency tone in certain psychophysical tasks.

Table 1: Pitch and loudness matching results using the forced-choice double staircase procedure for the three subjects. The entries are the mean frequency of the match (Hz), the standard deviation (SD) of these matches, the mean level of the match (dB SPL), and the SD of these matches.

Subject	Mean Frequency	SD	Mean Level	SD
1	944	10	20	3
2	867	3	23	1
3	4684	2	36	1

The data from the audiogram and from Task 2 are presented in Figure 1. For Subject 1, the audiogram and the isomasking contour converge. For Subjects 2 and 3, the audiogram and the isomasking contour remain nearly equidistant. Both of these patterns have been observed previously (Feldmann, 1971).

The data from Tasks 3 and 4 are presented in Figure 2. For all the subjects, the tinnitus isomasking contours are nearly flat despite the evident tuning for the frequency of the tone said to match the tinnitus in Task 1.

In each case, the tinnitus isomasking contour was obtained using the tinnitus as the signal. For the two-tone isomasking contours, the signal was 10 dB above the level of tinnitus (i.e., above the level of the matching tone from Task 1). The reason for this discrepancy is that the tone matching the tinnitus loudness in the FCDS task was quite near threshold and so it was easier for the subjects to perform the task at slightly higher signal levels.

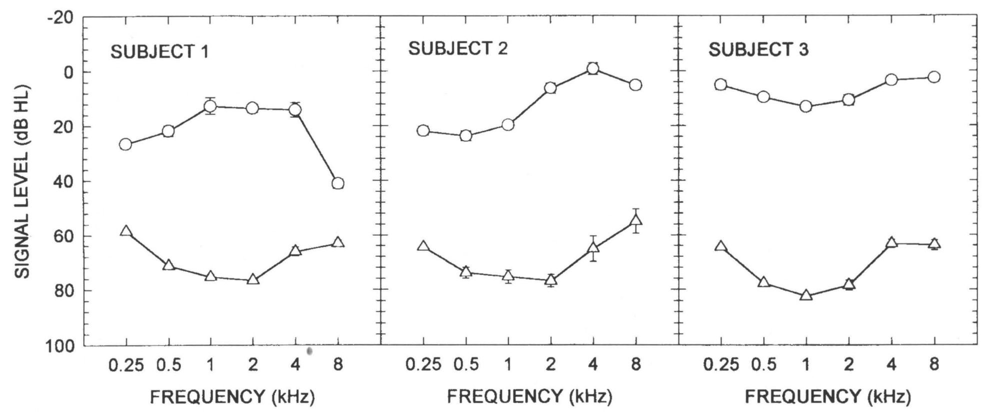

Figure 1. Audiogram (circles) and tinnitus isomasking contour (triangles) at the audiometric frequencies using the adjustment procedure. Each subject's data appears in a separate panel. The standard error of the mean is shown whenever its width exceeded the width of the data point used in the graph.

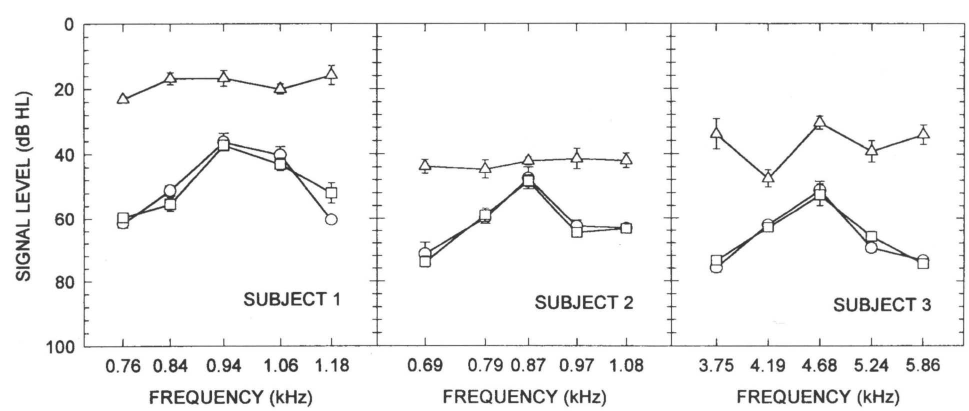

Figure 2. Isomasking contours for tinnitus and for pure tones in the presence of broadband contralateral and high-pass ipsilateral noise. Each subject's data appears in a separate panel. The triangles represent the data for the tinnitus isomasking contour and the squares (adjustment) and circles (forced-choice) represent the data for the isomasking contour of an external tone.

DISCUSSION

Masking in psychoacoustic experiments means that the perception of an acoustic signal is "swamped" (Moore, 1989) by that of the masker. Signals and maskers compete with each other in well-recognized ways, as first documented by Wegel and Lane (1924). The interaction of the masker and the signal is thought to reflect the mechanics of the cochlea. As seen in Figure 1, tinnitus isomasking contours do not mimic those of external tones. Instead, they are flat when the tinnitus is not restricted to a specific narrow frequency region. However, it is unlikely that broadband external stimuli can be masked in the cochlea, raising the possibility that some other psychophysical judgment is inadvertently made at least for broadband tinnitus (Penner & Bilger, 1994).

In an attempt to better delineate the tinnitus, tinnitus isomasking contours were determined when all but a portion of the tinnitus was masked. As seen in Figure 2, tinnitus isomasking contours again fail to exhibit frequency specific masking even when the tinnitus itself is a relatively narrow band stimulus, as it was for Subjects 1 and 2. Because even narrowband tinnitus isomasking contours are not frequency-specific, it is likely that the masking of tinnitus involves perceptual or neural mechanisms of inhibition above the site of the origin of the tinnitus, as Feldmann (1971) has argued.

If tinnitus cannot be masked by swamping, then why might tinnitus "maskers" (Vernon, 1977) nonetheless be used successfully by some patients? The answer to this question may involve many factors. First, it may be that the maskers obscure the fluctuation in the tinnitus, as Penner (1986) as argued. It may also be that the maskers provide another perceptual focus for the subject so that concentration on the tinnitus is minimized, as Jastreboff and Hazell (1993) have argued. In any event, the impact of the data presented in Figure 2 is that even narrowband tinnitus is unlikely to be masked in the cochlea so palliatives for tinnitus are likely to be those that affect retrocochlear events.

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