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Research paper

Response growth using a low-frequency suppressor

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Abstract

Numerous psychophysical studies on two-tone suppression have been carried out. More recently, researchers have attempted to relate the magnitude of suppression to the level of suppressee. [Wojtczak, M., Viemeister, N.F., 2005. Psychophysical response growth under suppression. In: Pressnitzer, D., de Cheveigne, A., McAdams, S., Collet, L. (Eds.), Auditory Signal Processing: Physiology, Psychoacoustics, and Models. Springer, New York, pp. 67–74] demonstrated that the magnitude of suppression for a higher-frequency, fixed-level suppressor decreases with increasing level of the suppressee. This suggests a linearization of the basilar membrane response in presence of a high-frequency suppressor. The present study expands these results to a low-frequency suppressor of varying intensity levels. Detection of a 10-ms, 4.0-kHz probe was measured under different forward-masking conditions: one with a 200-ms, 4.0-kHz masker (suppressee) presented with no suppressor and another with the same masker paired with a 2.2-kHz, 200-ms suppressor. The 4.0-kHz masker level was varied adaptively and a range of probe levels was used to measure the growth of suppression. Results indicate that (1) the magnitude of suppression increases with increasing suppressor level and (2) generally, the probe level was not related to the magnitude of suppression.

Keywords: Suppression; Psychoacoustics; Psychophysics; Basilar membrane; Forward masking; Masking

1. Introduction

Two-tone suppression refers to the phenomenon of the reduction of a response to a tone in the presence of another tone. Although this occurrence has been demonstrated at various levels of the auditory system, it has been attributed to the interaction between the outer hair cells and the basilar membrane within the cochlea (Ruggero et al., 1992). Stoop and Kern (2004) used cochlear biophysics to provide qualitative and quantitative evidence for two-tone suppression, thereby demonstrating that the active elements of the cochlea are responsible. Since two-tone suppression results from the nonlinear processing of the basilar membrane, level effects on the magnitude of suppression have generated a great deal of interest among researchers. Numerous studies examining the relation between amount of suppression and level of suppressor and/or suppressee have been conducted (Duifhuis, 1980; Javel et al., 1978; Ruggero et al., 1992; Shannon, 1976; Wojtczak and Viemeister, 2005).

Physiologic studies have succeeded in relating the magnitude of suppression to suppressor and/or suppressee levels. (Javel et al., 1978) measured auditory-nerve data in cats in the presence of a suppressor higher than the characteristic frequency (CF). The suppressor was fixed in intensity while a second excitatory tone of variable intensity was introduced. Suppression was observed in the form of reduced response to the excitatory tone by a fixed amount irrespective of the intensity of the excitatory tone. Rate-intensity functions were obtained for excitatory tones of different frequencies with and without the suppressor. Results indicated

Abbreviations: CF, characteristic frequency; ERB, equivalent rectangular bandwidth; GMB, growth-of-maskability

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that the amount of suppression of the response to an excitatory tone caused by a suppressor is dependent on the intensity of the suppressor. Additionally, increased frequency separation between the suppressor and the excitatory tone produced a reduction in the amount of suppression. Their findings should be interpreted with caution, however, as they only used high-spontaneous rate fibers. These fibers have a low threshold and a small dynamic range which is generally limited to the linear response portion of the basilar membrane.

Ruggero et al., (1992) conducted a physiologic study and demonstrated two-tone suppression for the CF probe tones using suppressors with frequencies both higher and lower than the CF (herein: high-frequency suppressor and low-frequency suppressor, respectively). They found that suppression magnitude for a fixed level suppressor decreases as a function of increasing probe intensity. Also, the rate of growth of suppression magnitude with suppressor intensity was higher for low-frequency suppressors than for high-frequency suppressors.

Although physiologic studies have provided ample data relating the magnitude of suppression to suppressee levels (Javel et al., 1978; Ruggero et al., 1992), psychophysical studies have not. Historically, psychophysical studies have either examined suppression by using a constant suppressee and varying suppressor levels or by varying both levels while keeping the difference between them constant (Duifhuis, 1980; Shannon, 1976).

Shannon (1976) studied two-tone suppression using forward masking where the probe consisted of a single sinusoid and the suppressor was gated with a masker of the same frequency as the probe. The amount of suppression, or 'unmasking' as Shannon referred to it, is the difference between the masked threshold of the probe with and without the suppressor. The probe was a 1.0-kHz tone while the suppressors ranged in frequency from 0.3 to 4.5 kHz. Intensity levels of the suppressor and the suppressee were varied with the difference between them fixed at 20 dB. Results suggested that for low-frequency suppressors the magnitude of suppression was dependent only on the level of the suppressor. However, for high-frequency suppressors, suppression was dependent on the difference between the suppressor and the suppressee levels.

In contrast, Duifhuis (1980) measured level effects in psychophysical suppression using the pulsation threshold for a probe of 1.0 kHz and suppressors ranging in frequencies from 0.2 to 1.4 kHz. Suppression was observed for both low-frequency and high-frequency suppressors with the magnitude of suppression being dependent on both the level of both the suppressor and the suppressee. Therefore, when the overall level was higher, more suppression was observed. In contrast to Shannon (1976), Duifhuis found that magnitude of suppression was neither exclusively dependent on level of the suppressor nor was it consistent for a constant suppressor/suppressee amplitude ratio. Duifhuis postulated that Shannon's conclusions were too simplistic in nature and needed significant modifications.

In an attempt to relate the magnitude of suppression to suppressee levels, Wojtczak and Viemeister (2005) conducted a psychophysical study using a fixed-level suppressor. They tested the hypothesis that the response to a CF is less compressive in the presence of a fixed-level suppressor than it is in quiet. They obtained growth-of-maskability (GMB) functions for five different suppressor levels across several probe levels with a high-frequency suppressor. The results suggested that the magnitude of suppression for a fixed-level suppressor decreases with increasing suppressee levels as found by Ruggero et al. (1992), i.e. the response to a tone becomes less compressive in the presence of a higher frequency suppressor. No inference could be drawn regarding low-frequency suppressors.

The purpose of the present study is to expand the findings of Wojtczak and Viemeister (2005) for a low-frequency suppressor. For a high-frequency suppressor, it is the nonlinear growth of the high-frequency side of the suppressee excitation pattern that interacts with the suppressor. For a low-frequency suppressor, it is the linear growth of the low-frequency side of the suppressee tone excitation pattern that interacts with the suppressor. Given this fundamental difference in suppressor/suppressee interaction for low- and high-frequency suppressors, an investigation of a low-frequency suppressor is warranted. There are two hypotheses: (1) the amount of suppression will increase with suppressor level and (2) the low-frequency suppressor will manifest differently than a high-frequency suppressor in that suppression will be observed with increasing probe levels. This experiment studies two-tone suppression using forward masking to investigate whether the linearization of the basilar membrane at CF measured in the presence of a fixed-level suppressor is also observed for low-frequency suppressors.

2. Materials and methods

2.1. Participants

Three normal-hearing listeners were recruited as participants. The ages of participants were 25, 25, and 22 years, respectively. Informed consent was obtained from all participants and they were paid for participation. All participants had audiometric thresholds of 15 dB HL or better from 0.25 to 8.0 kHz and a negative report of auditory pathology.

2.2. Stimuli

The stimuli were generated digitally at a sampling rate of 24.414 kHz using a computer (Dell Dimension, DIM 4550). The computer controlled a signal processor (Tucker-Davis Technologies, RP2.1) with a 24-bit digital to analog converter. After filtering and attenuation (Tucker-Davis Technologies, PA-5), sounds were presented to the listener through insert earphones (Etymotic Research Labs, ER-2). Stimuli were generated using the