On the Effects of a Subharmonic Masker on the Loudness of a Pure Tone

Kenji Ozawa†, William Hellman‡*, Yoshinori Inoue†, Yoiti Suzuki† and Toshio Sone†

†Research Institute of Electrical Communication Tohoku University, Sendai 980-8577, Japan
‡Department of Physics and Hearing Research Center, Boston University, Boston, Massachusetts 02215
*This work was performed while the second author was a visiting researcher at the Res. Inst. of Elect.
Comm., Tohoku University

Abstract: Loudness matching functions between a 1kHz tone in quiet and in the presence of a 70dB SPL 500Hz subharmonic masker were measured for phase conditions corresponding to minimum and maximum thresholds. The shape and relative displacement of the loudness matching functions from each other as well as the threshold data were strongly determined by the systematics of the vector summation model (1), (2). The agreement between experiment and theory for the suprathreshold data demonstrates that loudness matching can reveal the effects of nonlinear processing in the auditory system.

INTRODUCTION

The interaction between a tone and a tonal masker can produce effects not present when tones are masked by bands of noise. The observed systematic variation of the masked threshold with the phase between masker and a stimulus whose frequency is twice that of the masker has been explained by the presumption of the generation of a harmonic of the masker at the stimulus frequency through the action of a quadratic nonlinearity in the transduction process(2), (3). Phase generated threshold shifts arising from subharmonic maskers should also produce alterations of loudness at suprathreshold levels.

In this study, loudness matching experiments between a partially masked 1kHz tone and an unmasked 1kHz comparison tone were carried out using the method of adjustment. Four normally hearing young adults were the subjects for the experiments. The frequency of the masker was 500Hz at a fixed level of 70dB SPL. The matching was obtained for phase conditions corresponding to maximum and minimum masked thresholds. The masked thresholds were measured as a function of the initial phase between the stimulus and the masker at 30° intervals in a separate set of experiments.

RESULTS

The dependence of the masked threshold on masker phase in the present experiments was described by the almost sinusoidal shape observed in previous studies (1). Figure 1 below shows this data for subject #2 by the filled circles. The predicted variation from the vector summation model is depicted by the continuous curve.

![Figure 1](image-url)  
**FIGURE 1.** The variation of the masked threshold with the phase between masker and the stimulus.

The explicit form of the equation for the curve in Fig. 1 is obtained from vector summation model thru the equation

\[
\text{Masked threshold in } \text{dB (SPL)} = \text{Threshold in } \text{dB (SPL)} + \text{Phase shift in degrees re lab} 
\]
\[ A_{\text{eff}}^2 = A_s^2 + A_{ah}^2 + 2A_s A_{ah} \cos \theta \]  

when the stimulus is adjusted for a threshold. The constants \( A_s \), \( A_{ah} \), and \( A_{\text{eff}} \) are the rms amplitudes of the stimulus, the aural harmonic, and their resultant respectively. The angle \( \theta \) is the phase between the stimulus signal and the aural harmonic. The minimum and maximum thresholds correspond to \( \theta \) equal to 0 and 180 degrees respectively. The square of the effective amplitude is assumed to be proportional to the total power available at the stimulus frequency for transduction into neural activity by the inner ear auditory mechanisms. In this case the measured \( A_s \)'s always satisfied the condition that \( A_{\text{eff}} \) equaled a constant corresponding to the true threshold under masking.

The good agreement of the data in Fig. 1 with previous experiments indicated that the subjects and the experimental procedures were operating satisfactorily. The results for the loudness matching experiments are shown in Fig. 2 below.

**Figure 2.** Panel A. The matching functions for low and high thresholds. Panel B: The effective matching functions.

Panel A of Fig. 2 depicts the matching functions measured for minimum and maximum thresholds. Assuming that the effective amplitude is unique for a given loudness match, it follows from Eq. (1) that

\[ (A_s-A_{ah})_{\text{max}} = (A_s+A_{ah})_{\text{min}} = A_{\text{eff}} \]  

for a matched loudness at any level. The subscripts refer to matching data from minimum and maximum thresholds. The aural harmonic amplitude can be calculated from the minimum and maximum threshold data. \( A_{\text{eff}} \) is the total amplitude generated at the cochlear in response to the signal plus the aural harmonic necessary to produce the same loudness match from minimum and maximum threshold matching functions.

By means of Eq. (2) we can construct two effective matching functions from the two matching functions in Panel A. If the data are described by the vector summation model, then the two effective matching functions should coincide. The results of this calculation shown in panel B of Fig. 2 support this prediction of the vector summation model.

**CONCLUSIONS**

The results of the loudness matching experiments with a tonal masker are in good agreement with the predictions of the vector summation model. In particular, the curves in panel B of Fig. 2 display that both the shape and relative displacement of the matching functions are dictated by the consequences of the interaction between the stimulus and the second harmonic generated by the masker. Since this interaction occurs through cochlear mechanisms, it is evident that the psychophysical loudness variable is able to exhibit consequences of nonlinear inner ear transduction processes.

**REFERENCES**