THE RELATION BETWEEN PSYCHOACOUSTIC COMBINATION TONE GENERATION AND TWO-TONE SUPPRESSION IN AN AUDITORY MODEL

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INTRODUCTION

This paper reports on the computational modelling of the 2f1-f2 psychoacoustic combination tone (CT) elicited by two closely-spaced primary tones f1 and f2. Previous research indicated that the amplitude of the perceived CT depends on the method of measurement [1,2]. Typically, a cancellation-tone or a loudness-matching experiment is used. The latter method gives consistently lower estimates of the CT amplitude. It was suggested that the difference between methods could be attributed to suppression effects by the primary tone f1 [1,2]. Computer simulations carried out with a model of the auditory periphery support this hypothesis [3,4]. These results are summarized in this paper.

COMBINATION TONES

In the cancellation-tone experiment, a probe tone at the frequency of the CT to be measured, i.e. 2f1-f2, is presented externally and *simultaneously* with the primary tones f1 and f2. The task of the subject is to adjust the amplitude and phase of the probe until the pitch sensation of the CT becomes inaudible. In the model, this experiment is simulated by adjusting the amplitude and phase of the probe until the peak in the basilar membrane excitation pattern at the corresponding CT frequency disappears completely [3].

In the loudness-matching experiment, the probe tone 2f1-f2 is presented externally but *non-simultaneously* with the primary tones f1 and f2, e.g. by alternating successively between probe tone and primary tones. The task of the subject is to adjust the amplitude of the probe until it matches the loudness of the CT during presentation of the two primaries. In the model, this is simulated by adjusting the amplitude of the probe until the peak of its excitation pattern equals that of the CT during presentation of the primaries [3].

The results from both psychoacoustic experiments [1,2] and model simulations [3,4] give consistently lower estimates of the CT when measured with a loudness-matching rather than a cancellation-tone method. The difference between methods increases with primary level for L1=L2. When measured as a function of L2 for L1 = constant, the difference between methods is essentially constant, so that L1 seems to be the controlling factor. The experimental and model data agree well as shown in Table I for typical stimulus conditions.

TWO-TONE SUPPRESSION

Under certain conditions, the loudness of a stimulus tone decreases when presented simultaneously with a second stronger tone. Thus, the probe in the cancellation-tone experiment could be subjected to suppression effects by the primaries, especially by f1.

Table I: Comparison of estimates of the 2f1-f2 CT level from two different methods for three subjects [1] and for the model. Stimulus: f1 = 1400 Hz, f2 = 1680 Hz, L1 = L2 = 50 dB SL (for subjects) or 50 dB SPL (for model).

Subject	Cancellation-tone	Loudness-matching	Diff (dB)
GS	24.2 dB SL	17.3 dB SL	6.9
FW	20.4 dB SL	15.2 dB SL	5.2
TH	28.4 dB SL	16.4 dB SL	12.0
Model	22.4 dB SPL	15.0 dB SPL	7.4

To test this hypothesis, the suppression of a stimulus tone 2f1-f2 by a tone f1 in absence of f2 was studied in the model for the stimulus conditions corresponding to the data presented in Table I. It was found that a stimulus tone 2f1-f2 of 22.4 dB SPL presented simultaneously with a tone f1 of 50 dB SPL would be suppressed to the level of a 15.0 dB SPL tone when presented alone. This and other simulations carried out with the model suggest that the probe is subjected to suppression effects in the cancellation-tone experiment. Moreover, the amount of suppression is exactly equal to the difference between the two main methods of measuring the CT level (Table I). Further simulations also revealed that, as a result of suppression by f1, the phase of the probe in the cancellation-tone experiment becomes exactly out-of-phase with the internally-generated CT. These conditions guarantee cancellation.

In summary, this modelling study supports the hypothesis that the difference between methods of measuring the CT amplitude is due to suppression effects, and that the generation of auditory distortion products and the effects of two-tone suppression have a common origin in the nonlinearity of the cochlea.

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