Pure tone plus bandlimited noise as Zwicker-tone-exciter

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INTRODUCTION

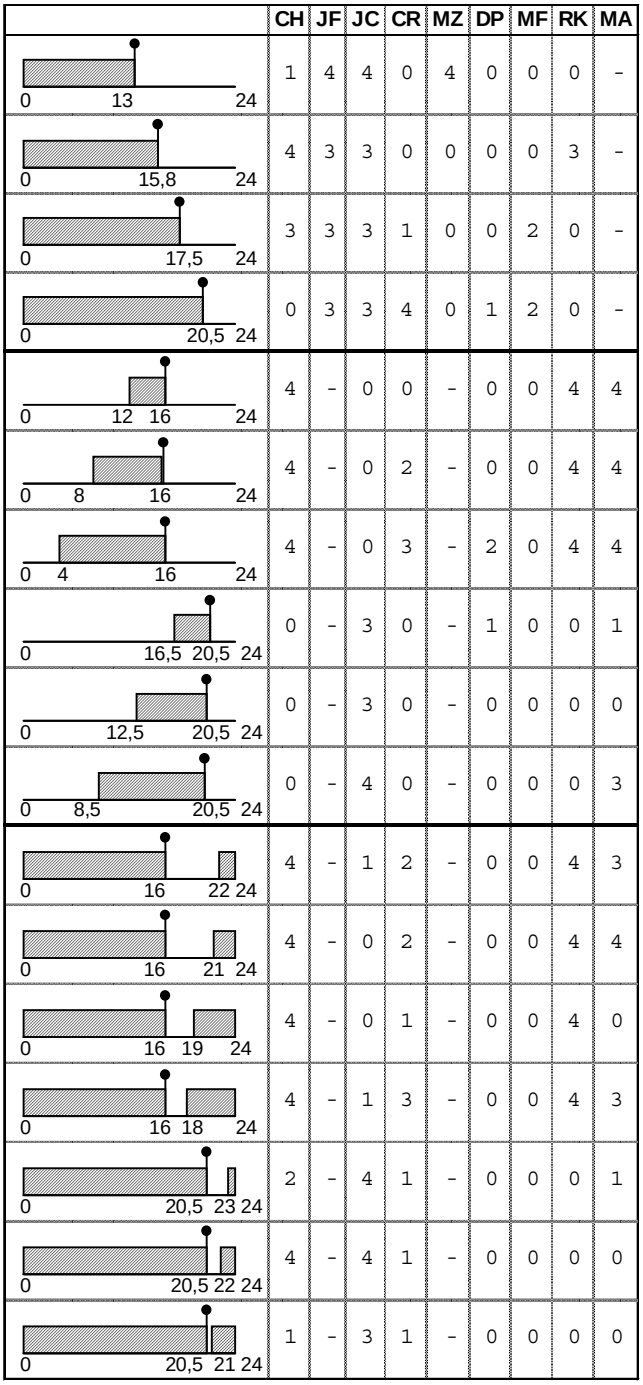
After switching off a broadband noise with a spectral gap, a faint pure tone can be heard which was named after its discoverer a Zwicker-tone (Zwicker 1964, Lummis and Guttman 1972).
The Zwicker-tone phenomenon was extensively studied (e.g. Fastl 1986, 1989). In addition, it was found (Krump 1994) that a broadband noise plus a pure tone can elicit a Zwicker-tone (Fastl and Krump 1995). Models of the Zwicker-tone were elaborated, which are based on masking patterns (Fastl and Krump 1995).
In the present paper, results of experiments are presented, in which the following questions were adressed: does there exist a Zwicker-tone for the combinations pure tone plus lowpass noise, pure tone plus bandpass noise, pure tone plus lowpass and highpass noise? If these sounds can elicit a Zwicker-tone, can it be predicted by current models?

EXPERIMENTS

Nine subjects with normal hearing ability and an age between 25 and 33 (median 29 years) took part in the experiments. At least seven out of the nine subjects participated in a session. Sounds were presented diotically in a soundproof booth by electrodynamic headphones (Beyer DT48) with freefield equalizer (Zwicker and Fastl 1999, p.7).
Pure tones with 60 dB SPL were combined with noises of -3 dB spectrum level. Sounds were digitally synthesized with 1 Hz line spacing and random phase. For further detail about the sounds and the procedure see Fastl and Krump (1995).

RESULTS AND DISCUSSION

In figure 1, the Zwicker-tone-exciter sounds are schematically displayed. For each of the nine subjects (CH through MA) it is indicated how often they could perceive a Zwicker-tone when the sounds were presented four times in random order. This means that the number 4 indicates that the subject could perceive a Zwicker-tone for all presentations, the number 0 that no Zwicker-tone was perceived, and a dash that the subject did not participate in the specific session of the experiment.
For pure tone plus lowpass noise subject DP can hear only one out of 16 possible Zwicker-tones, whereas subject JF hears 13 out of 16 possible Zwicker-tones.
For pure tone plus bandpass noise, five out of seven subjects can hear a Zwicker-tone for a bandpass between 4 and 16 Bark, whereas only one out of seven subjects can perceive a Zwicker-tone for bandpass noise between 12.5 and 20.5 Bark. While subjects CH and RK hear Zwicker-tones for combinations with pure tones at 16 Bark and no Zwicker-tones for combinations with the pure tone at 20.5 Bark, for subject JC the situation is quite opposite.
For pure tone plus lowpass and highpass noise, a maximum of five out of seven subjects or at least three out of seven subjects can perceive a Zwicker-tone. Two of the subjects (DP, MF) never can hear a Zwicker-tone for this stimulus configuration.



	CH	JF	JC	CR	MZ	DP	MF	RK	MA
0 13 24	1	4	4	0	4	0	0	0	-
0 15,8 24	4	3	3	0	0	0	0	3	-
0 17,5 24	3	3	3	1	0	0	2	0	-
0 20,5 24	0	3	3	4	0	1	2	0	-
0 12 16 24	4	-	0	0	-	0	0	4	4
0 8 16 24	4	-	0	2	-	0	0	4	4
0 4 16 24	4	-	0	3	-	2	0	4	4
0 16,5 20,5 24	0	-	3	0	-	1	0	0	1
0 12,5 20,5 24	0	-	3	0	-	0	0	0	0
0 8,5 20,5 24	0	-	4	0	-	0	0	0	3
0 16 22 24	4	-	1	2	-	0	0	4	3
0 16 21 24	4	-	0	2	-	0	0	4	4
0 16 19 24	4	-	0	1	-	0	0	4	0
0 16 18 24	4	-	1	3	-	0	0	4	3
0 20,5 23 24	2	-	4	1	-	0	0	0	1
0 20,5 22 24	4	-	4	1	-	0	0	0	0
0 20,5 21 24	1	-	3	1	-	0	0	0	0

Fig. 1: *Overview of the audibility of Zwicker-tones for pure tone plus band limited noise.*

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Figure 2 shows the results for the combination of pure tone plus lowpass noise. In this situation four out of seven subjects can perceive a Zwicker-tone. The pitch and the loudness of the Zwicker-tone are rather similar for the combination of pure tone plus broadband noise (cf. Fastl and Krump 1995) versus pure tone plus lowpass noise.

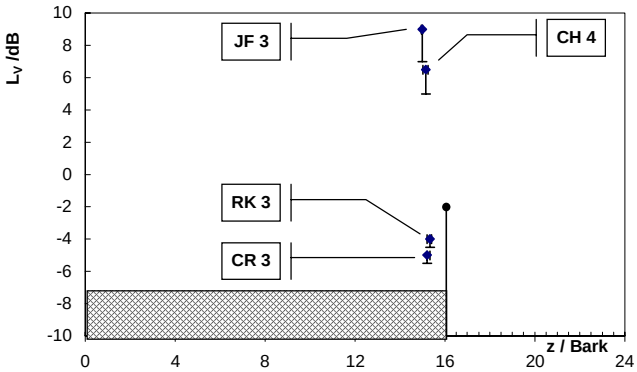

Fig. 2: *Pitch z in Bark and level L_V in dB of comparison tones matched to Zwicker-tones for pure tone plus lowpass noise exciter.*

Figure 3 shows the results for the combination of pure tone plus lowpass and highpass noise. For subject CH, RK, and CR the pitch of the Zwicker-tone is below the pitch of the pure tone, whereas for subject MA the comparison tone has a significantly higher level and lies around 18 Bark which suggests that this might be an otoacoustic emission (see e.g. Fastl and Krump 1995).

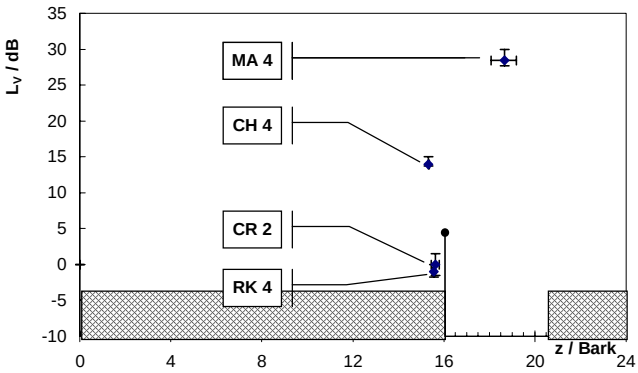

Fig. 3: *Same as Fig. 2, but for pure tone plus lowpass and highpass noise exciter.*

Figure 4 shows schematic masking patterns for the combinations of pure tone plus noises adapted from Zwicker and Fastl (1999). The excitaton level L_E is given as a function of the Bark scale z. The dashed line indicates the absolute threshold, the masking pattern of a pure tone at 16 Bark with 60 dB SPL is illustrated by the solid line. Different types of hatching indicate the different Zwicker-tone-exciter sounds, i.e. pure tone plus lowpass noise, narrowband noise as well as lowpass and highpass noise. According to the model proposed by Krump (Krump 1995, Fastl and Krump 1995) the pitch of the Zwicker-tone is determined by the first crossing of the masking pattern of the noise and the pure tone which is highlighted in figure 4 by a circle. For all the situations illustrated in figure 4, a pitch of the Zwicker-tone around 15 Bark is predicted. This prediction is at least qualitatively in line with the pitches of the Zwicker-tones indicated by the subjects.

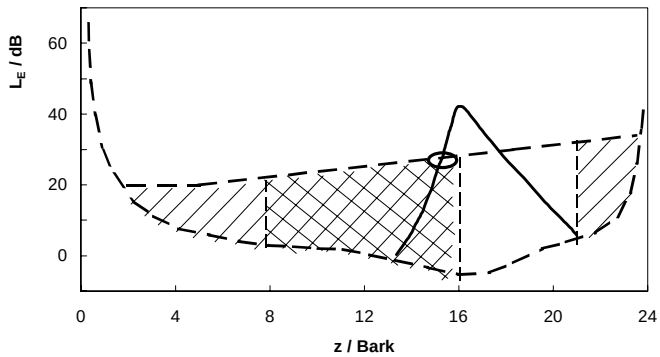

Fig. 4: *Schematic representation of excitation patterns for pure tone (solid) plus bandlimited noise (hatched). Pitch of the Zwicker-tone illustrated by circle.*

In summary it can be stated that the combinations of pure tone plus lowpass noise, bandpass noise as well as lowpass and highpass noise can elicit Zwicker-tones. However, usually only some subjects can hear the Zwicker-tone with some preference in pitch height: while some subjects can hear Zwicker-tones for pure tones at 16 Bark plus noises, others more often hear Zwicker-tones for pure tones at 20.5 Bark plus noise. The reasons for the fact that some persons do not hear Zwicker-tones for combinations of pure tones plus bandpass noise, and that persons who can hear Zwicker-tones have some preferences with respect to height are not clear so far. However, for those persons who can hear Zwicker-tones for combinations of pure tone plus bandlimited noise, the pitch of the Zwicker-tone can be predicted by a simple model based on masking patterns.

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