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Perceptual grouping of tone sequences in cochlear implant stimulation

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ABSTRACT

The perceptual grouping of alternating tone sequences, also known as auditory stream segregation, has already been studied for normal hearing [1] and sensorineurally impaired listeners [2]. If the frequency separation between two tones A and B is less than a critical value, called the fission boundary, the two streams can not be heard as separate patterns any more. For normal hearing listeners, the frequency separation at the fission boundary amounts to about 100 cents (1/12 of one octave). Listeners with cochlear hearing loss, expected to exhibit generally larger frequency separations at the fission boundary because of broader auditory filters, showed either normal or very large values. This paper reports on preliminary measurements of the fission boundary in postlingually deafened subjects wearing multichannel cochlear implants. This kind of stimulation by-passes the peripheral hearing mechanisms by direct electrical stimulation of the auditory nerve. The present results indicate that fission in electrical stimulation occurs at about the same frequency distance between tones A and B as in normal hearing.

INTRODUCTION

Perceptual grouping of sound sources is an essential ability of the normal auditory system. It enables the listener to separate different sounds and to concentrate on one of them, e. g. on a speaker in a noisy environment. The grouping of individual elements in rapid sound sequences depends on a number of acoustical cues. One important cue is the frequency separation. If the frequency separation between two alternating tone sequences A and B is large, they can be heard as separate patterns, which has been called “fission” [1]. Alternatively, if the frequency separation is less than a critical value, called the fission boundary, the two streams can not be separated and perceptual “fusion” occurs. It is believed that perceptual grouping depends on the degree of overlap between the cochlear excitation patterns evoked by the sounds. A high degree of overlap causes fusion and a low degree results in “fission”.

This preliminary experimental study investigates perceptual grouping of alternating tone sequences in electrical stimulation and in normal hearing. The main question are: (1) Does the frequency-to-place transformation as performed by multichannel cochlear implants (CIs) lead to a similar dependency on frequency separation as found in normal hearing. (2) Is the fission boundary as independent of the tone repetition time as in normal hearing. The second question arises from the observation that phase locking of neural spikes is more precise in electrical stimulation than in acoustical stimulation [3]. It might be expected that this leads to a higher dependency on the tone repetition time.

Modern multichannel CIs filter the microphone signal into a number of frequency channels. The temporal envelope of each channel signal is used to modulate trains of electrical pulses, which are delivered to the tonotopically positioned electrodes. A frequency-sweeping sinusoid therefore either activates one single electrode mainly (when the signal frequency coincides with the center frequency of a filter channel) or two electrodes mainly (when the sinusoid falls in-between two filter channels). In this study two conditions are tested: In condition I, the tones A and B are always centered at one of the filterbank’s channels, stimulating single electrodes mainly. In condition II, the variable tone B can be located at any frequency position. This represents a more realistic situation like environmental sound-sources with arbitrary frequency contents.

METHOD

Subjects and stimulus generation

2 postlingually deafened subjects participated in the experiment. Both received the *Med-El Combi40+* implant system, supplied with 12 monopolar electrodes. For testing, the *CIS PRO+* speech processor was used, programmed with the *CIS*-strategy (stimulation-rate/channel: 1515 pps, pulse-duration: 40µs). Both subjects can understand conversational speech without lip-reading. Additionally, one normal hearing control subject was tested.

The stimuli were generated and controlled digitally by custom-made software-routines (ST^X-system) and delivered via an external D/A-converter into the auxiliary input of the speech processor. Sinusoidal test tones - centered at the filterbank channels - were equated in loudness at about 80 % of the subject’s dynamic ranges. The presentation levels of test tones with intermediate frequency values were interpolated.

Measurement of the fission boundary

Two conditions were applied to measure the fission boundary for the sequence ABA−ABA−… . In condition I, each trial consisted of 8 repetitions of an ABA− group.

Both the frequencies of stimuli A and B were centered at filter-bands of the CI-processor's filterbank. After each sequence, the subject had to indicate if he heard fission or not. If he could hear fission, the frequency of tone B was set one filter channel closer to the frequency of tone A. Otherwise, if the subject could not hear the tone B as a separate pattern, the current frequency of tone B was defined as the fission boundary. In condition II, a frequency sweep procedure was applied which also had been used by Rose et al. [2]. As in condition I, the frequency of tone A was kept constant at a filter channel's center frequency. However, the frequency of tone B progressed towards the frequency of tone A in an exponential manner, starting with a large frequency distance. So, at the beginning of each sweep, the frequency interval between the tone B in the *i*th and the (*i*+1)th ABA-group was large, and decreased with decreasing frequency distance between tones A and B. The subject had to press a button as soon as he could not perceive the variable tone B as a separate pattern any more. The frequency of tone B at this moment was defined as the fission boundary.

Condition I was tested with subject BD only and over a broad range of conditions to find configurations, where interaction percepts occurred (including the sensation of a gallop-like rhythm [1]. Condition II, however, was investigated more systematically: for subject BD, the fixed tone A was positioned at the 5th electrode (≅ 893 Hz), for subject KR at the 6th electrode (≅ 1138 Hz). The initial frequency of tone B was chosen randomly either below (upwards movement) or above (downwards movement) the frequency of tone A, with a minimum distance of 3 filter channels. All conditions were tested at the two tone repetition times 110 ms and 220 ms. The tone duration (including 10-ms raised-cosine ramps) was always 10/11 of the tone repetition time. Each condition (2 directions, 2 tone repetition times) was presented 10 times to the subjects. The last 6 repetitions of each condition were incorporated into the data collection.

Rep. time (ms)	Freq. A (Hz)	Direction	Freq. B (Hz)	Perception
66	339	down	432	fusion
66	3824	up	3000	gallop
110	3824	up	3000	gallop
110	339	down	432	gallop
286	339	down	432	fusion
286	1138	down	1450	gallop

TABLE 1. Interaction percepts occurring in condition I.

RESULTS

Table 1 shows those configurations of condition I, for which interaction percepts occurred. Fusion occurred only for electrode 1 (lowest frequency), both at a low and at a high tone repetition time, and was accompanied by a gallop-sensation. Figure 1 shows the fission boundaries of condition II for the CI-subjects BD (left side, frequency of tone A: 893 Hz) and KR (right side, frequency of tone A: 1138 Hz), each with the corresponding results for the NH-subject. The tone repetition times are given by numbers. The fission boundaries for subject NH correspond well with the results of Rose et al. [2] for a tone repetition time of 110 ms. Overally, the fission boundaries for subject BD resemble those of subject NH. Subject KR has higher thresholds than subject NH for the condition fA > fB, and similar thresholds for the condition fA < fB. In accordance with the results of van Noorden [1], there is no effect of tone repetition time for the normal hearing subject. For the CI-subject KR, the fission boundary increases with increasing tone repetition time, for the CI-subject BD there is no effect of repetition time.

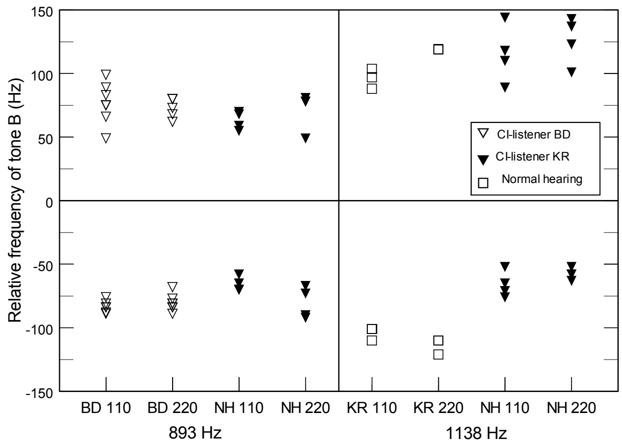

FIGURE 1. Fission boundaries for conditions II. Left side: CI-subject BD and subject NH (fA = 893 Hz); right side: CI-subject KR and subject NH (fA = 1138 Hz).

DISCUSSION

The results indicate that ABA-sequences, presented to CI-listeners with a CIS-processor, produce similar sensations as in normal hearing. When the frequency separation between tones A and B approached that of neighbouring filter channels (420 cents), gallop-like rhythms were perceived in some cases. The fission boundary was reached when fB crossed the lower or upper filter cutoff-frequency (of tone A) by more than about 50 cents. It may be concluded from this that channel interactions (neural-population interactions) had no effect on the fission boundary. It rather seems that the transition from fission to fusion was evoked solely by level differences between the streams A and B in a single electrode signal: van Noorden [4] found that level differences only between pure tones with identical frequencies can cause fission in normal hearing subjects. Regarding the dependency of the fission boundary on the tone repetition time, the limited data do not allow conclusions. Future studies will investigate this point in more detail.

REFERENCES

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