Directional Perception of Multiple Sound Sources Based on Envelope Cues

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1 Introduction

In recent years, cochlear implants (CIs) have been successful in restoring the ability in many patients to understand speech in quiet and in acoustically dry environments. However, patients still encounter great difficulties in situations of speech-in-noise or in reverberation. The impact of reflections on perception can be studied in the precedence-effect paradigm which shows the suppression of the influence of a lagging sound on localization of a leading sound. Previous studies have shown that CI-patients rely on interaural level cues (ILDs) for localization while ignoring interaural temporal cues (ITDs) [7]. Since ITDs at low frequencies play an important role for precedence as well as for localization in normal hearing, the goal was to see if the altered cues with CIs carry enough information for precedence. Results with CI-patients show no precedence and two different outcomes: An immediate breakup into two images for short lead-lag delays or the localization of a single image even for longer delays [8]. The purpose of the present study was to investigate the failure of CI-patients to show the precedence effect with a noise-vocoder CI-simulation and normal hearing subjects.

2 Methods

Precedence was investigated in terms of localization dominance. The lead and lag sounds were played randomly from ±30°, and the lead-lag delay was varied within 0-48 ms, with the upper limit depending on the stimulus. Subjects localized the sound image(s) using the *ProDePo*-light pointer method by adjusting a light point to the perceived image location with a turn of a trackball [5]. If subjects perceived more than a single sound image, they were instructed to localize the left/right/dominant/least dominant of the images heard. Four experiments were done: (1) Precedence was studied in the free field with two loudspeakers of the Simulated Open Field Environment placed at ±30° [4]. (2) Using identical methods precedence was studied with virtual acoustics based on subjectively selected non-individual HRTFs [9]. (3) The precedence effect stimuli were convolved with HRTFs as before, but processed through a noise-band vocoder which simulates CI-processing. A 16-channel vocoder with logarithmically spaced filters in 300 Hz-8 kHz was used. The channel envelopes were computed independently for both ears and applied to noise bands (carriers, synthetization noise) of varying interaural correlation. Since stimuli were perceived inside the head, lateralization was measured with a line-dissection method. The line was projected in front of the listener similar to the dot used in the localization method, and it's position was also adjusted with the trackball. (4) In order to reduce the impact of ITDs in the envelope, the channel envelopes were quantized in 1.5 ms steps before being applied to the noise.

3 Subjects and Stimuli

Five normal hearing subjects (< 20 dB HL in 300 Hz-10 kHz) participated in the study, but results are shown for only one subject (fem., age 29 yrs). Stimuli were a burst of white noise (10 ms duration, 300 Hz-10 kHz), a low-pass noise (10 ms, cut-off at 770 Hz, but playback/vocoder high-pass at 300 Hz), and the CVC "shape". Level was roved in 2 dB-steps within ±6 dB from a base level of 60 dB(A) (55 dB(A) for the CVC). 10 trials were taken each for the lead at −30° and +30°.

4 Results and Discussion

The results for virtual acoustics in experiment 2 are similar to the free-field results in experiment 1 and both show the well known localization dominance of the lead [1].

Selected results with CI-simulation from experiment 3 are shown for a single subject in Figures 1-4. Two images are heard within the head for the processed low-pass noise with uncorrelated carrier noise and no delay between lead and lag (Fig. 1). For short delays of 0.5 ms, anomalous localization produces a combined image localized towards the lag [3]. This is surprising, since the noise covers several frequency bands (300 Hz-770 Hz) and ITDs are still present in the envelope. For longer delays two images are heard, one dominant image at the lead location and one weaker image at the lag. A correlation of one in the carrier noise (Fig. 2) centralizes and combines the images for delays up to 30 ms. The centralization is based on the ITD=0 ms present in the carrier noise. For high correlations anomalous localization is still present at around 0.5 ms delay, but there is some precedence, i.e. the localization towards the lead, for delays 2-6 ms.

Precedence for the CVC "shape" is not existent at any delay and for any correlation of the carrier noise (Figures 3 and 4). It appears that for ongoing sounds the lag image is always heard, although subjects report it to be weaker. The reasons for this breakdown of precedence are unclear at present. Apparently, the breakdown occurs only for ongoing sounds which suggests a change in auditory scene analysis. Two hypotheses can be stated: (1) The incorrect ITDs from the carrier noise at low frequencies and natural ILDs at high frequencies point to different locations and thus suggest two images. However, for single sound sources across-channel grouping is functioning and a single image is heard [6]. (2) The missing pitch in-

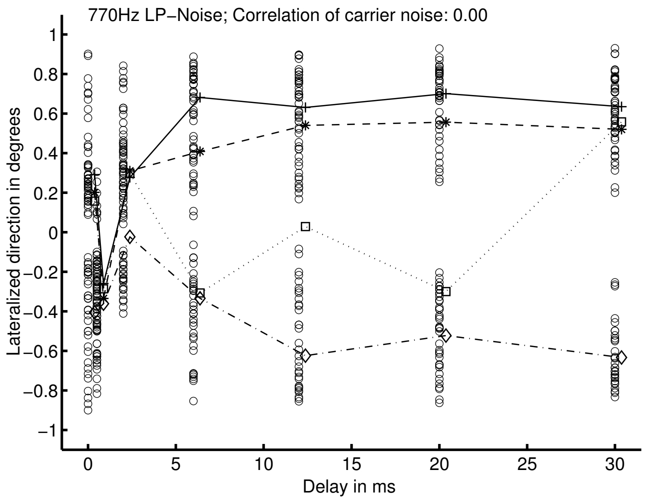

Figure 1: Lateralization of 300 Hz-770 Hz low-pass noise processed with a noise-band vocoder in a precedence situation in dependence of lead-lag delay. Uncorrelated carrier noise. Ordinate values of ±1 depict the lead/lag ears. Legend in Fig. 2.

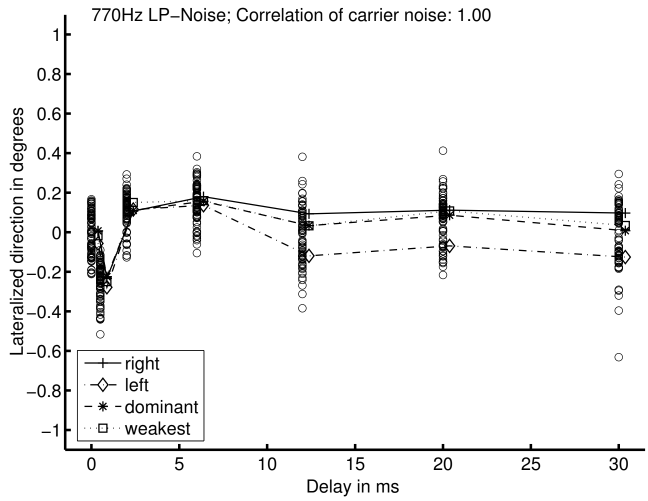

Figure 2: As Fig. 1 (low-pass noise), but correlation of carrier noise equals 1. Legend shows instruction of which image to point to if several images are heard.

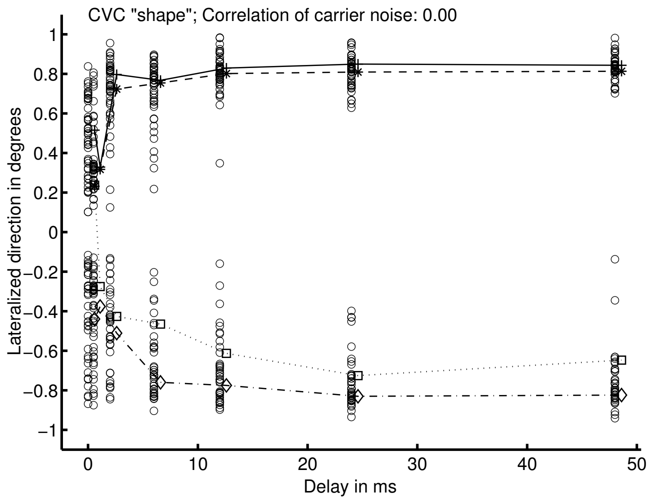

Figure 3: As Fig. 1, but CVC "shape" used, correlation = 0.

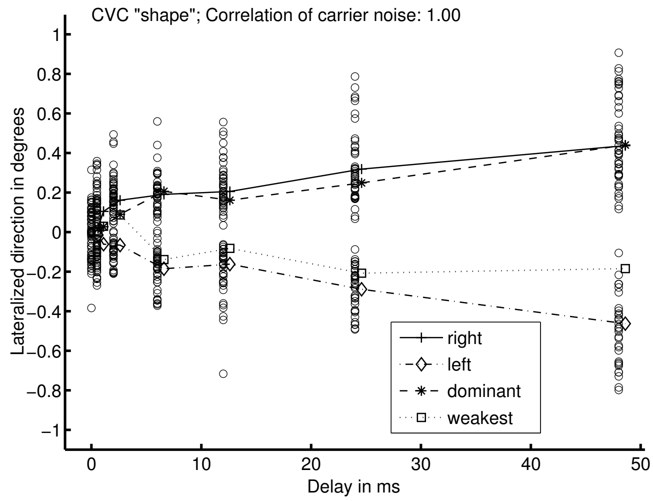

Figure 4: As Fig. 1, but CVC "shape", correlation = 1.

formation prevents across-channel grouping which leads to the split into two images. Pitch and harmonicity information serve as the strongest cues to combine auditory objects, but they are not well represented in CI-listeners [2]. Experiment 4 served to assess the impact of ITDs in the envelope on precedence. Despite the temporal envelope quantization no changes in localization occurred which suggests a restricted influence of high-frequency ITDs.

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