Does Onset Enhancement Improve Availability of Envelope ITDs in Cochlear Implant Users?

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Introduction

Auditory scene analysis (ASA) is the process by which the auditory system detects, identifies and tracks sounds coming from a certain position in a mixture of different sounds (i.e. multiple talkers, noise, reverb). The auditory system makes use of location, pitch, temporal onset and common modulation cues. Cochlea implant (CI) users do not rely on pitch cues for segregation and therefore we propose that location cues are of greater importance. Reduced access to binaural cues (i.e., interaural time differences [ITD]) in the temporal fine structure (TFS) limits sound localization ability in CI users [4]. Kerber and Seeber (2013) [2] showed that localization performance in reverberation of CI users is correlated with their ability to make use of envelope ITDs (envITD). Monaghan et al. (2013) [3] showed that saliency of envITDs can be improved by increasing modulation depth, steepness of the rising slope and interaural coherence. Seeber and Monaghan (2013) [6] developed a stimulation strategy where selective enhancement of envITDs based on the direct-to-reverberant ratio (DRR) could improve localization performance in CI users in reverberant spaces. The aim of the present study was to analyse locations of envelope peaks (*envpeak*) and their relation to the direct-to-reverberant ratio (*max DRR*) for speech sounds in two different rooms to identify the favourable time points in the envelope that provide most information about the ITD of the direct sound and to test the respective outcomes in a lateralization and speech test.

Methods

Sinewave-vocoder & onset enhancement

Sentences from the Oldenburg sentence test (OLSA [7]) were used as test stimuli. Direct sound was generated by convolving each test sentence with head-related transfer functions belonging to the target direction. The reverb was generated by convolving OLSA test sentences with the binaural room impulse responses from a simulated room (4.7×6.0 m) and a real room (3.3×6.0 m; [1]) for respective sound-receiver distances (SRD): simulated room 0.5-2.0 m; real room 1.81-3.63 m. The direct sound and reverb were summed and subsequently vocoded separately for each ear in eight independent frequency channels. Onset enhancement was applied for each frequency channel after the envelopes were extracted (for details on the vocoding and the onset enhancement algorithm see Seeber and Monaghan [2013] [6]); envpeaks were selected based on the DRR; the envelope was set to zero between the preceding trough and the corresponding envpeak

Signal analysis

Max DRRs *re* envelope peaks were analysed as a function of: i) relative distribution across rooms, SRDs (simulated room: 0.5-2.0 m, real room 1.81-3.63 m) and frequency bands (broadband) (condition 1); ii) frequency band: low, medium, high (condition 2); iii) and SRD: simulated room 0.5 m, 1.0 m, and 2.0 m (condition 3). Max DRRs were normalized to the envpeak.

Lateralization & speech understanding

Four male subjects (20-29 years) with normal hearing (<25 dB HL) participated in this study. Onset enhancement based on three different DRR-strategies (*On Peak, Fixed Offset, Variable Offset*) was tested for six ITDs using the line-dissection paradigm of Seeber and Hafter (2011) [5]. Stimuli were 10 OLSA test sentences, which were sinewave-vocoded (8 band pass filters, 1.26 to 8 kHz) and onset enhanced. Continuous low pass noise (<1 kHz) was presented at 50 dB SPL to mask any information in the low frequencies that might introduce TFS ITDs. Sentences were presented from three SRDs (0.5, 1.0 and 2.0 m) in the simulated room.

50% Speech reception thresholds (SRT) were measured with OLSA test sentences (2 lists, 20 sentences) that were processed with the respective onset enhancement strategy to measure whether the different strategies affect speech understanding.

Results and Summary

Signal analysis

Most max DRR coincided with the envelope peaks when analysed across rooms, frequencies and SRDs (condition 1; fig. 1, upper plot). A smaller number of DRRs tended to be slightly preceding the envelope peaks for the highest frequency-band (blue lines and error bars, fig. 1, middle plot) and for larger distances (@2.0 m, blue lines and error bars, fig. 1, lower plot). Based on these results, a modified enhancement strategy was developed which sets the envelope to zero between preceding trough and time point of max DRR.

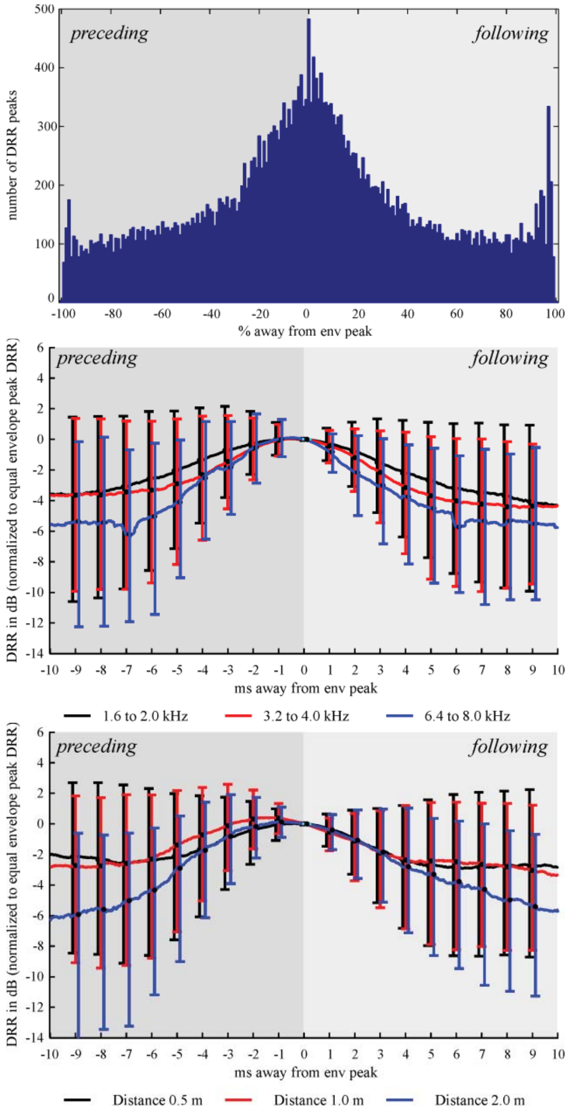

Figure 1. Median (errorbars depict interquartiles) max DRRs relative to envelope peaks. DRRs were normalized to envelope peaks. **Upper plot:** relative number of max DRR from condition 1 (across rooms, all SRDs and frequency bands). **Middle plot:** max DRR distribution for each frequency band across rooms from condition 2. Max DRRs tended to occur prior to envpeaks for higher frequency bands. **Lower plot:** max DRR distribution for each SRD from the simulated room analysed in condition 3. The asterisk and arrow point to the tendency of max DRRs to occur prior to envpeaks for greater distances

Lateralization & speech understanding

Performance depended on enhancement strategy and varied as a function of source-receiver distance. The preliminary data show that all enhancement strategies led to more lateralized responses at 0.5 m with similar slope magnitudes across strategies. At 1.0 m distance, the *OnPeak* strategy caused significantly steeper slopes. Enhancement strategies also tended to increase lateralization magnitude at 2.0 m.

Speech understanding did not differ across enhancement strategies, i.e. word recognition was not affected by the enhancement strategy. These results seem very promising in that such an onset enhancement could increase the availability of envITD cues in CI users.

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