Minimum Audible Angles with Dynamic Binaural Synthesis and Bilateral Noise Vocoder: Effects of the Channel Distribution

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Introduction

The ability of normal hearing subjects to differentiate directional information extracted from vocoder stimuli may be used as indication for discriminative directional information potentially present in cochlear implant listening. In this contribution, the angle formed with respect to the listener's head by two sound sources perceptually just differentiable in position when sounded in succession, the minimum audible angle is measured for normal hearing subjects with dynamic binaural synthesis playback. The synthesized signals are passed through symmetric but inter-aurally uncorrelated vocoder systems before being presented to the listeners. The results indicate considerable effects of the channel distribution.

Binaural Synthesis and Vocoder

Non-individual dynamic binaural synthesis implemented with blocked auditory canal recording and average magnitude equalization according to Völk (2011) is selected as playback method for the experiments presented in this paper due to its ability to approximate the dynamically varying ear signals of a real reference scene by means of headphones. The system is set up with an RME Multiface II audio interface, a Polhemus 3 Space Fastrack tracking system, and Sennheiser HD 800 headphones selected based on Völk (2010). The binaural impulse response pairs are recorded according to Völk et al. (2009) in the anechoic chamber of the former Institute of Electroacoustics at Technische Universität München with a subject whose recordings allowed for good average localization in earlier studies. The binaural synthesis is limited to the horizontal plane in that binaural impulse response pairs are recorded for a full rotation of the listener around a fixed center in 6° steps with a Klein + Hummel Studio Monitor Loudspeaker O 200 at 2 m distance and ear height. For the experiment, the horizontal angular resolution is increased to 1° by interpolating the time aligned impulse responses and the delay separately and reintroducing the interpolated delays.

The signal analysis of cochlear implant speech processors can be efficiently implemented based on discrete Fourier transform (DFT) analysis (cf. Verschuur 2009). A comparable approach is used here to generate vocoder-like stimuli in modifying the binaurally synthesized discrete left and right ear signal spectra independently. Taking into account the Hermitian properties of the DFT of a real valued sequence, the bins are set to the spectral DFT magnitude average in their channels, combined with uniformly distributed random phase values. Bins outside the channel distribution are set to zero. The number of channels and their bandwidths are varied for the experiments presented here. The first set of channel distributions is based on the critical band concept (Fastl and Zwicker 2007, sec. 6) so that the audible critical-band rate range is covered by a given number of channels equally wide on an auditory adapted frequency scale (upper panel of figure 1). The second set of channel distributions is selected to resemble the spectral analysis of current cochlear implant speech processors (upper panel of figure 2, cf. Fu et al. 2005, Verschuur 2009, Mühler and Ziese 2010).

Psychoacoustic Procedure

Following Perrott and Pacheco (1989), a two-alternative forced choice 2-down/1-up procedure is used for assessing the minimum audible angles in the different conditions, combined with Parameter Estimation by Sequential Testing for the step size adaption. The subjects are asked to indicate whether the second hearing sensation occurred to the left of the first by pushing one of two buttons while the presentation sequence is chosen randomly. This procedure is repeated until both, the deviation between the last two minimum and the deviation between the last two maximum values remains smaller than 1°. Since this procedure converges towards the 70.7% point of the psychometric function, the minimum audible angle is defined here as the angular threshold where about 71% of all judgments of the relative positions of the sound sources are correct. As sound stimuli, uniform exciting noise impulses according to Fastl and Zwicker (2007, fig. 6.16) are selected for providing equal intensity in all critical bands and thus being assumed to provide all spectral localization cues at the same perceptual weight. Two impulses are successively presented to the listeners by two sources binaurally synthesized symmetrically to the left and right of the median plane. The impulse duration of 700 ms with 20 ms Gaussian gating and 300 ms pause between the stimuli is assumed to provide dynamic cues. The experiments are conducted with the subject seated in a darkened laboratory, aiming at applying the visual stimulus darkness and therefore providing a controlled situation with regard to audio-visual interactions.

Results

The results presented here are based on the data of ten normal hearing subjects in the age between 22 and 31 years (mean 25 years). Each subject carried out the adjustment procedure three times per condition, resulting in 9.6 minutes average duration per channel distribution. The data are represented by the inter-individual quartiles of the intra-individual medians (open symbols) and inter-quartile ranges (filled symbols). The lower panel of figure 1 shows the results corresponding to the set of channel configurations indicated by the upper panel. Analysis

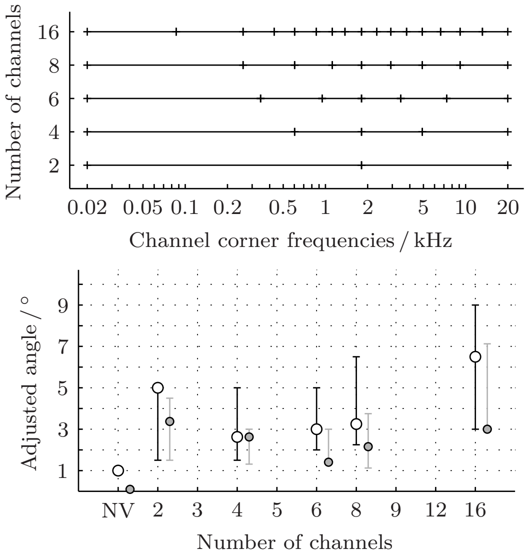

Figure 1: Horizontal plane free field minimum audible angles with dynamic binaural synthesis and bilateral noise vocoder. Number of channels equally distributed over the audible critical-band rate range (NV – no vocoder).

of variance (ANOVA) indicates significant influence of the channel configuration [$F(5,45) = 2.49$; $p = 0.0447$]. Figure 2 shows the configurations and results for the second set of conditions studied here. Again, ANOVA indicates a significant main effect of the channel configuration [$F(7,63) = 2.51$; $p = 0.0243$]. Informal subject and empir-

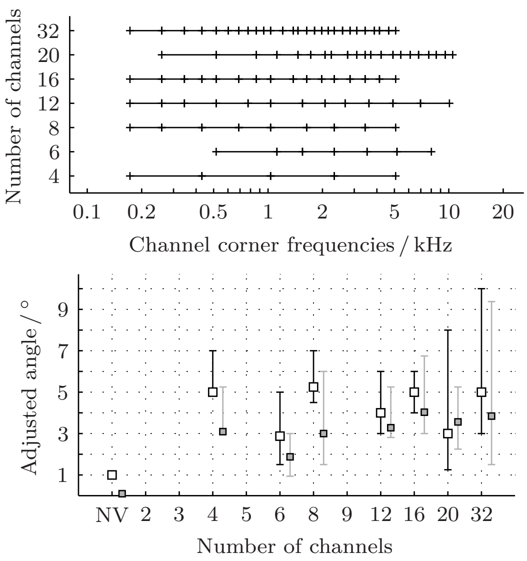

Figure 2: Free field minimum audible angles with noise vocoder. Channel configurations approximating the spectral analysis of typical cochlear implant processors.

ical listening indicate a tendency for up to three hearing sensations to arise simultaneously during this experiment, one at the intended position and two at the subject's ears.

Discussion

The minimum audible angles in general appear plausible compared to the situation without vocoder and to the angles between 3 and 8° reported for cochlear implant patients by Senn et al. (2005), but none of the vocoder conditions allows for angles comparable to normal hearing here. Results of Shannon et al. (1995) and Wilson and Dorman (2008, figure 13) indicate the speech reception score of vocoder stimuli to increase with the channel number up to six channels, while no further increase occurs for ten and 20 channels. Fu et al. (2005) show the voice gender identification to increase with channel numbers between four and 32. The results reported here indicate no clear dependency of the minimum audible angle on the number of channels, at which a tendency is visible of slightly increasing angles for more than six channels. The similarity of the data for both six channel conditions suggests little influence of the spectral components below 500 Hz and above 8 kHz not contained in the six channel condition in figure 2. The multiple hearing sensation effect may arise due to insufficient interaural correlation.

Based on the results, optimal channel distributions with regard to minimum audible angles are currently derived and evaluated at our lab.

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