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Towards quantifying cochlear implant localisation performance in complex acoustic environments

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Introduction

Many users of bilateral cochlear implants (CIs) can discriminate the side of sound incidence and some even show good localisation ability in quiet (e.g., Seeber and Fastl, 2008). Informally, however, patients report great difficulty in complex acoustic environments characterized by background noise and reverberation. Localisation of sounds is mainly based on the differences in time-of-arrival (ITD) and level (ILD) at both ears. This cue redundancy helps making auditory localisation robust against interfering noises, but CI users base their localisation mainly on ILDs (e.g., Seeber and Fastl, 2008), likely contributing to problems in noisy environments.

Despite the informal reports by CI users, only few studies have addressed the problems in complex acoustic environments directly. Seeber (2007) showed that localisation in simulated rooms as well as the precedence effect are severely impaired with CIs. The present study aims to quantify localisation performance of a CI user in diffuse background noise, which is, unlike reverberation, unrelated to the direct sound and of constant intensity over time. Localisation performance of the CI user in background noise is then compared to that of normal-hearing people. The data will add weight to informal reports and will help us understand the contributions of different localisation cues in reverberant and noisy situations, a prerequisite for effectively encoding them in tomorrow's cochlear implants.

Methods

Participants

This short paper will show data for one bilateral cochlear implant user and compare it with average results of six normal hearing participants. Normal hearing participants were aged between 22 and 34 years (Median: 28 years) and their hearing was tested using pure tone audiometry. Thresholds lower than 25 dB HL were considered normal.

The cochlear implant user was 68 years old, male, and used a Cochlear Nucleus Freedom device. He had suffered from a progressive, hereditary hearing loss and was using his left and right implants for 11 and 10 years, respectively. His speech reception threshold for 50% sentence understanding was +6 dB when speech and interferer originated from the front (IHR sentence list which is based closely on BKB sentences).

Experimental Methods

Experiments were done in the “Simulated Open Field Environment” (Seeber et al. 2010). The participants were sitting in an anechoic chamber surrounded by 36 loudspeakers arranged horizontally on ear height in 10° steps. Acoustically transparent projection screens were mounted frontal, left and right of the participant, visually hiding the loudspeakers. Loudspeakers were equalized to ± 1.5 dB between 200-12000 Hz, and visual pointing was possible with a theoretical accuracy of at least 0.06° .

During our experiments participants were presented with target sounds from one of the loudspeakers at 0° , $\pm 10^\circ$, $\pm 20^\circ$, $\pm 40^\circ$, $\pm 60^\circ$, $\pm 80^\circ$ whilst they were sitting in a chair with their head supported by a headrest. After each presentation a light spot appeared to their front which they had to move by means of a trackball to the perceived direction of the sound. During the presentation of the target sounds uncorrelated uniform exciting noise was played synchronously from all 36 loudspeakers, acting as an interferer. Presentation of the interferer started 500 ms prior to the target to settle the compressors in the hearing devices and ended 340 ms after the target. Interferer on- and offsets were faded using 20 ms Gaussian ramps.

Target stimuli were pulse-trains consisting of six pulses, gated on for 10 ms and followed by a 120 ms gap. Each pulse was faded in and out using 2 ms Gaussian ramps. The pulses were cut out of uniform exciting noise of 60 dB SPL. All levels given in this report refer to the level at the middle of the listener’s head without the listener present. At the ears, levels and SNRs thus vary depending on the direction of an actual sound source.

For the data presented here the interferer was either switched off or presented at a level of 60 dB SPL, leading to a signal-to-noise ratio (SNR) of 0 dB. This SNR is representative for the SNR encountered in common cocktail-party situations (Plomp, 1977). The overall level of target plus interferer was roved simultaneously in ± 6 dB in 3 dB steps. Each of the five roving levels was applied twice to each of the eleven test directions. Participant completed a total of 550 trials (11 directions $\times$ 5 SNRs $\times$ 5 roving levels $\times$ 2 trials per roving level), but only results at an SNR of 0 dB and in quiet are presented here.

In a subsequent experimental run participants were asked to report on every trial by pressing a button if the target stimulus was audible in addition to giving a localisation response. Procedures were otherwise similar to the main experiment. Stimulus audibility was assessed at 0 dB SNR with the present patient.

Prior to the experiment participants received training until they felt confident with the task. Before the training both cochlear implant devices were adjusted for equal loudness with a person speaking in front of the participant. This adjustment was further refined during the training sessions until a centred localisation percept was achieved.

Results and Discussion

Localisation performance of the normal hearing participants in quiet, anechoic conditions was similar to that reported in the literature (Blauert, 1997). At a signal-to-noise ratio of 0 dB, normal hearing people only showed minimal degradation of localisation performance, with an increase of absolute error by 1.8° on average.

The localisation performance in quiet of the cochlear implant user is reported in Fig. 1 (left). Despite the fact that median localisation responses (filled diamonds) were close to the target, there was considerably more variance in the data than for normal hearing people. The absolute error averaged over all test directions was 22.2° . A line fit to the localisation data

had a steepness of 0.86, slightly below 1.0 which would denote optimum performance. For source angles beyond $\pm 40^\circ$ the localisation percept stopped to change monotonically with source direction, particularly for sources on the left. This can be attributed to the fact that ILDs in CI-processors increase less for lateral positions beyond about 50° (c.f. Seeber and Fastl, 2008, Fig. 9).

Localisation performance of the same bilateral CI user in background noise at 0 dB SNR is shown in Fig. 1 (right). Generally, localisation performance declined considerably but side discrimination ability was preserved and was significant at a 0.1% level (Wilcoxon ranksum test between the pooled data from 40° , 60° and 80° degrees on either side). The absolute localisation error averaged over all directions increased in the presence of background noise to 30.9° , and the steepness of the line fit decreased to 0.36. Most sounds from directions within $\pm 20^\circ$ were localised at the front (0°). However, this might not reflect the perceived sound location but rather the fact that at 0 dB SNR stimuli were inaudible in a large percentage of trials. In a separate run the percentage of target sounds detected at 0 dB SNR was determined for each source direction. It is given in the top of the right diagram. The target sounds were generally better audible at the sides than in the front. Simulations using head related transfer functions showed that the SNR was approximately 3 dB higher at the ear towards a lateral sound source than if the sound came from the front. This “better ear effect” helped detecting these sounds and it underlay the preserved localisation ability at the sides.

Conclusions

The disturbing impact of background noise on localisation performance reported by cochlear implant users was confirmed by quantitative measurements in our experiments. At a signal-to-noise ratio of 0 dB, which is representative of typical cocktail party settings, localisation ability of a cochlear implant user was degraded and only limited localisation ability was preserved for sources well off the median plane. With normal hearing, instead, localisation ability hardly declined at the same SNR. The robustness against background noise seen in normal hearing people is not available to cochlear implant users, most likely because they are missing relevant cues which help them to segregate and localise target sounds and interferers. Our ongoing research also shows that the performance seen in this cochlear implant user is representative for most bilateral CI users we tested. These findings underpin the problems reported with group conversation and in classroom settings. Especially in the latter, SNRs below 0 dB are frequently encountered and problems might even be exacerbated because children experience greater disruption with speech understanding than adults at similar SNRs (Neuman et al., 2010).

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Figure 1.

Source direction versus localised direction for a bilateral CI user in quiet (left) and at a SNR of 0 dB. Filled diamonds connected by solid lines represent medians and interquartiles. Unfilled circles show individual responses. The top numbers in the right graph give the percentage of audible sounds for the corresponding direction.