Prosody perception in cochlear implant recipients wearing a hearing aid in the contralateral ear.

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Introduction

Patients who are implanted with a cochlear implant (CI) are mostly able to understand speech in quiet and improve their quality of life in many aspects. However CI-recipients with residual hearing on their non-implanted ear are recommended to continue to wear their hearing aid (HA) referred to as bimodal fitting. Bimodal fitting promises to improve performance in several occurrences, such as speech understanding in quiet (Mok et al., 2006) and in noisy environments (Luntz et al., 2005), the ability to localize sound (Dunn et al., 2005), and provides improvement to the functional performance in everyday life (Ching et al., 2004).

CI-patients are mostly able to recognize temporal changes but have difficulties to discriminate spectral changes, especially the contours of the fundamental frequency (f0). HAs can additionally transmit low-frequency information such as f0 and their harmonics to improve the recognition of spectral changes. Thus bimodal fitting utilizes residual acoustic hearing in the low frequencies for better place coding and might improve the perception of speech, music, and prosodic cues.

Prosody describes the rhythmic and melodic phenomena of speech like stress, duration, rhythm, and intonation. For many of those aspects, the most important parameter is the fundamental frequency (McDermott, 2004; Clark, 2003). Early investigations on prosody perception by means of control of contrastive stress (control of its own speech) on CI-patients using a single-channel CI have been conducted by Leder et al. (1986). The study revealed that the CI-patients, who were not able to produce contrastive stress correctly prior to cochlear implantation, were able to use f0 to significantly differentiate contrastive stress for both initial and final syllables after implantation. Further work on prosodic and segmental aspects of speech was done by Rosen et al. (1989) on the House/3M single-channel implant. They conducted a question and statement labelling test and found that the CIs were able to successfully convey the question/statement distinction to the subject. Rosen and colleagues found evidence that temporal fine-structure in the stimulating waveform can be important in determining the nature of auditory precepts experienced by the subjects.

Kong et al. (2005) examined speech and melody recognition of bimodally fitted CI-patients to clarify the role of temporal fine structure at low frequencies. The study revealed that for the melody recognition experiment low-frequency acoustic hearing (HA alone) produced significantly better performance than CI alone.

To our knowledge, no other study has investigated the interaction between the three conditions (CI alone, HA alone and CI plus HA) on prosody perception. The present experiments aim to examine the perception of prosodic cues in bimodally fitted CI-recipients by employing a testbattery with focus on the identification of question and statement as well as stress in a sentence. It is hypothesised that with the help of the hearing aid that conveys low-frequency information in the non-implanted ear prosody perception is improved.

Methods and Subjects

Five postlingually deafened adult CI-recipients with an average age of 65 years (50-73 years) and German as their 1st. language participated in the study. All participants have had at least 6 months CI-experience and have been wearing their HA in the non-implanted ear after implantation. Five conditions were tested; CI alone, HA alone, CI plus HA (CIHA), CIHA with filtered stimuli where f0 has been removed (CIHA-f0) and CIHA with filtered stimuli where frequencies up to the third harmonic have been removed (CIHA-3f0). The prosody-testbattery includes a sentence stress procedure (experiment 1) and a question vs. statement paradigm (experiment 2).

Experiment 1 contains out of 6 modifications for the phrase „Die Katze jagt.“. Therefore a natural utterance was modified with the software package “Praat”. F0 was increased within 3 steps to produce stress either on the word “Katze” or on the word “jagt” (Figure 1, left panel). Experiment 2 contains out of 6 modifications for the sentence „Der Opa fährt ein blaues Fahrrad.“

With gradually increasing f0 on the last syllable of the word “Fahrrad” the statement was transformed into a question within 6 steps (Figure 1, right panel). Further, in order to examine the influence of the low-frequency cues on the prosody perception, the stimuli of experiment 1 and 2 were filtered using a highpass filter (18. Order) with the software “CoolEdit” to remove f0 and all frequencies up to the 3rd. harmonic. Within each experiment, stimuli were presented in random order to the subjects. Their task was to assign the stimuli to stress on the word “Katze” or “jagt” and to question or statement, respectively. Moreover a categorical loudness scaling was conducted with a speech-shaped noise to estimate the hearing thresholds for each subject with CI alone and HA alone.

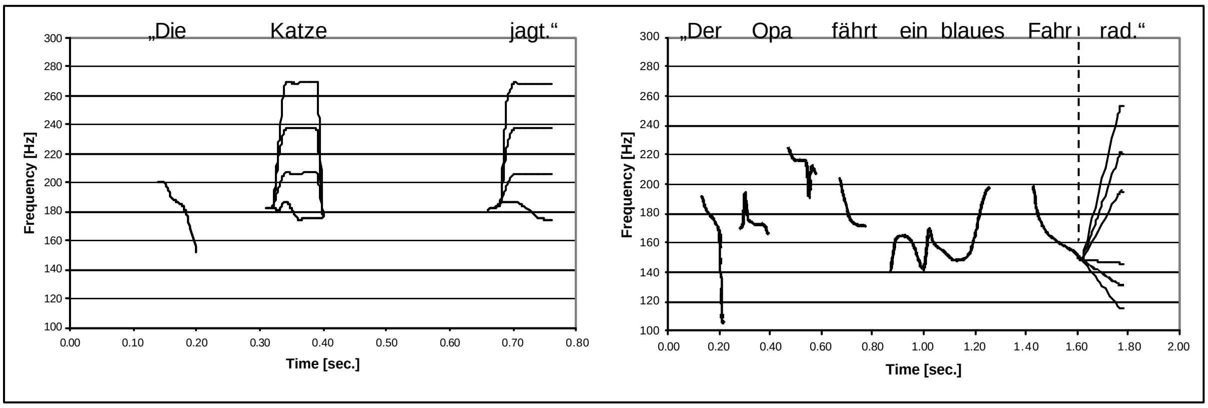

Figure 1: Distribution of f0 over time for the stimuli of experiment 1 (left panel) and experiment 2 (right panel).

Results

Figure 2 shows percent correct scores of the mean of both experiments and all responses as a function of condition for subject S1 to S5. Data of both experiments were collapsed since similar response patterns were found for the question/statement paradigm and the sentence stress procedure. Conditions are grouped for clarity, the three bars on the left panels present the conditions combination (CIHA), CI alone, and HA alone. The bars on the right panels show the influence of removing f0 and frequencies up to 3 times f0, respectively for the condition CIHA.

Basically, three different patterns (S1 and S5, S3, S2 and S4) can be observed with the data (Figure 2, left panels). A McNemar’s test for matched pairs indicates significant differences for subject S1 and S5 between the conditions CIHA and HA ($p < 0.0001$). Subject S3 revealed significant differences between CIHA and CI ($p < 0.0001$). Subject S2 and S4 indicate significant differences between CIHA and CI (S2: $p = 0.05$, S4: $p < 0.0001$) as well as CIHA and HA ($p < 0.0001$). Measurements with the filtered stimuli (Figure 2, right panels) indicate no or marginal differences for subject S1 and S5 ($p = 0.019$). Subject S3 revealed significant differences between CIHA and CIHA-f0 ($p < 0.0001$) and CIHA vs. CIHA-3f0 ($p < 0.0001$). A significant difference between CIHA and CIHA-3f0 can be observed with subject S2 ($p = 0.0014$) and S4 ($p = 0.016$).

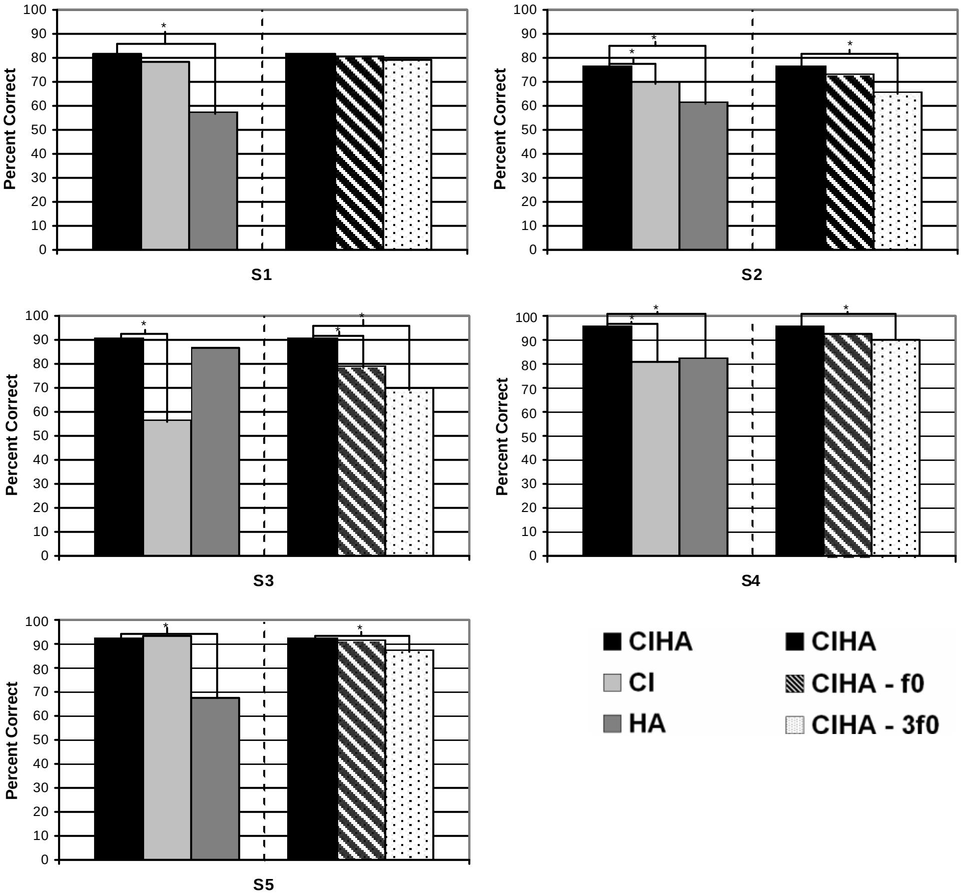

Figure 2: Percent correct scores collapsed across both experiments for each subject and condition. CIHA = the combination of CI and HA, CI = CI alone, HA = HA alone, CIHA-f0 = stimuli filtered at f0 for the condition CIHA, CIHA-3f0 = stimuli filtered at 3 f0 for CIHA. Significant differences between the conditions are marked with brackets and asterisks (p < 0.05).

Discussion

The results shown in figure 2 revealed that participant S1 and S5 mainly utilize the CI for perception of prosodic cues. Measurements with the filtered stimuli showed, that subjects who are mainly using the CI don't use the low-frequency information transmitted via HA. In contrast, they might use the higher frequencies in the signal or unresolved harmonics that are conveyed in the envelopes of the filters of the speech processors.

Subject S3's perception indicates a strong dependency on the low-frequency information. Obviously this participant utilizes mainly the HA to recognize the prosodic cues. This pattern was also found in a study by Kong et al. (2005). Their study revealed that for the melody recognition experiment low-frequency acoustic hearing (HA alone) produced significantly better performance than CI alone. The relatively good residual hearing in the non-implanted ear of subject S3 seems to be another explanation for the results. Four out of 5 subjects who participated in the study by Kong et al. (2005) showed also relatively good residual hearing in the low frequencies especially at 125 Hz and 250 Hz on their pure-tone audiogram and revealed significant better results for HA alone than CI alone.

Subject S2 and S4 showed significant lower results for HA and CI than for the combination. This can be referred to an addition effect whereas CI and HA add up to a better perception when using both devices. An addition effect has also been found by Blamey et al. (2000) when they investigated monaural and binaural loudness measures in bimodally fitted patients.

The explanation, why we found three different patterns in the perception of prosodic cues can be given with the results of the additionally conducted loudness scaling. When looking at the differences of the thresholds between CI and HA for a speech-shaped noise, a certain correlation ($r = 0.93$) could be found regarding the results of the prosody-tests. S1 and S5 showed clearly lower thresholds for the CI than with the HA. In S3, the opposite held true. Only S2 and S4, who revealed an addition effect with respect to the perception of prosodic cues, had relatively similar hearing thresholds for CI and HA.

This indicates that if both devices are not matched it is more likely that no addition effect occurs and the patients don't receive the entire possible information for prosody perception. As could be assimilated on the results of the present paper as well as other studies addressing the importance of low-frequency information for prosody perception and speech understanding, bimodal fitting should be recommended for cochlear implant users (Ching et al., 2004).

Acknowledgments

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