CAEP measurement of sound discrimination of CI patients in noise

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key words

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Introduction

For non-cooperative patients such as infants or patients with multiple handicaps, evaluation of sound discrimination in noise with subjective audiological tests is difficult. Our project aims at establishing cortical auditory evoked potentials (CAEP), especially event-related potentials (ERP), as objective measures of auditory discrimination abilities of cochlear implant (CI) patients in noise. Therefore, we investigate ERPs and subjective responses in auditory discrimination tasks. The results of the study are intended to establish a basis for objective evaluation of discrimination abilities in noise of non-cooperative patients. In this paper, we present first results.

Methods

Subjects: Subjects were 6 adult normal hearing (NH) listeners and 6 CI patients with postlingual deafness or progredient hearing loss. All CIs worked in the monopolar stimulation modus (2 Nucleus Freedom CI24, 1 Nucleus CI24, 2 MedEl Pulsar, 1 MedEl C40+). For CI patients with bimodal fitting, the hearing aid was turned off.

Auditory stimuli: For discrimination experiments, pairs of speech sounds (/ada/, /ama/) or tonal stimuli (1 kHz, 2 kHz) were used. Speech sounds were spoken by a male speaker, digitized with a sampling rate of 48 kHz, and edited with the Software Praat (www.praat.org) for adjusting frequencies and intensities of the vocal parts and the duration of stimuli (350 ms). Tonal stimuli had a duration of 80 ms, including 5 ms rise and fall time.

Auditory stimulation and tasks: Subjects were sitting in a comfortable chair in a sound-attenuated room. Acoustic stimuli were presented with the software Presentation (Neurobehavioral Systems) and with custom-made Visual Basic programs via a loudspeaker in frontal position (distance approx. 1.60 m).

After subjective evaluation of the hearing threshold (sensation level, SL) for various stimuli, the subjects were asked to adjust the stimuli to a comfortable level. The discrimination experiments were conducted with the signal level adjusted to and constantly kept at the individual comfortable level, masked with white noise at variable signal-to-noise ratio (SNR).

For evaluation of the subjective discrimination threshold with an adaptive forced-choice test, the two stimuli of a pair were randomly presented and the subject had to indicate by mouse click after each presentation the stimulus he/she had heard. The noise level was continuously adapted, i.e. increase of the noise level by 1 dB and decrease by 2 dB after correct and false responses, respectively. With this method, the mean noise level corresponds to a hit rate of 67% after stabilization of the run.

For CAEP recordings, the stimuli were presented in an oddball paradigm (80% standard and 20% deviant stimuli in random order) with a fixed SNR within a series. The subjects had to respond to the deviant stimulus with a mouse click. Thus, these experiments simultaneously yielded the subjective discrimination ability (hit rate) in dependence on the SNR.

EEG acquisition and analysis: Continuous EEGs were recorded with a 32-channel Neuroscan 32 system (Neuroscan, Inc.) during the oddball discrimination tasks. Analysis was performed with the BrainVision Analyzer software (Brain Products GmbH). For CAEP analysis, data were digitally filtered to DC-30 Hz, and stimulus-related segments were extracted (100 ms prestimulus + 1000 ms poststimulus time, referring to the sound onset). The segmented data were visually analyzed for extraneous noise and abnormal activity (e.g. eye movements). Bad segments were manually marked and excluded from further analysis. The remaining segments were averaged for unresponded standard stimuli and correctly answered deviant stimuli, respectively. The averaged waveforms were baseline-corrected according to the prestimulus interval and rereferenced from the original reference (nose tip) to the right mastoid in NH listeners and to the mastoid contralateral to the CI in CI users. P300 latencies and amplitudes were determined from the difference curve (deviant – standard) by visual inspection.

The experiments have been approved by the ethic commission of the University of Cologne.

Results

For evaluation of the discrimination ability for speech sounds in noise, the stimulus pair /ada/ - /ama/ was presented at various signal-to-noise ratios, with the signal level kept at the individual comfortable level. Mean signal levels ± SD were 49.0 ± 5.8 dBA for NH (n=6) and 54.0 ± 2.8 dBA (=19.8 ± 5.5 dB SL) for CI listeners (n=6).

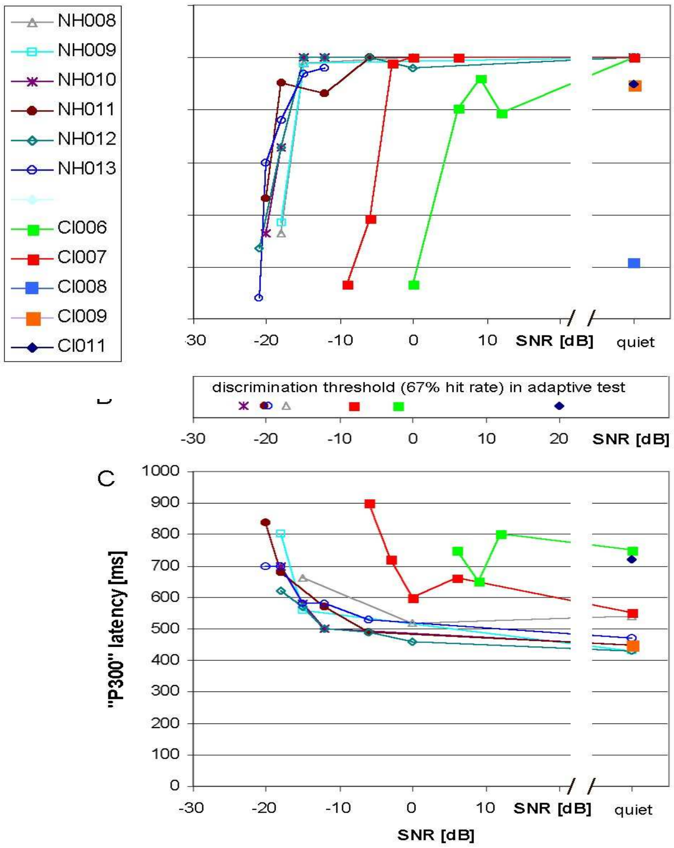

Fig. 1: /ada/ - /ama/ discrimination of normal hearing (NH) and CI listeners in noise.A+C: Numbers of correct responses to the deviant stimulus (A) and latency of the P300 wave (C) in oddball experiments. B: Discrimination threshold as revealed from adaptive measurements of the SNR producing a hit rate of 67%.

The subjective results of the oddball experiments are shown in Fig. 1A. The data obtained from NH subjects (n=6) yielded a homogeneous population of waveforms showing (nearly) 100% correct discrimination of /ada/ - /ama/ down to SNR = -15 dB and a steep decline at lower SNR. The data fit well to the subjective discrimination thresholds obtained with the adaptive forced-choice discrimination test which indicate the SNR producing a hit rate of 67% (Fig. 1B; mean value for NH listeners: -19.8 ± 2.1 dB).

The /ada/ - /ama/ oddball experiment was performed with 5 CI patients. Two of them achieved 100% correct responses in quiet conditions. With lowering the SNR, the steep decline occurred at considerably higher SNR as compared to the NH listeners (Fig. 1, CI006 and CI007). For the other 3 subjects, this experiment was only performed without masking noise for different reasons. Subject IC008, a poor performer, was not able to discriminate the sounds: the hit rate (Fig. 1A) as well as the rate of false alarms (not shown) were at 21%. With a hit rate of 90%, subject CI009 seemed to discriminate well. However, the number of false alarms was also very high (42%, not shown), indicating a poor discrimination. For subject CI011, the measurement had to be stopped for technical reasons.

CAEP recordings

CAEP recordings from CI patients are at risk to be contaminated by electrical artefacts resulting from the activity of the implant which are time-locked to the stimulus and, thus, appear in the averaged responses. The artefacts can outlast the stimulus and mask the biological response in recordings from electrodes near the device. With multi-electrode recordings, the spatial dispersion of the artefacts can be determined and the analysis of the CAEPs can be performed from selected, non-contaminated channels (Igelmund et al. 2007).

In our recordings, the amplitude of the artefacts and the spatial distribution of contaminated electrodes varied between subjects in dependence on the position and the type of the device. In all subjects, the artefacts were restricted to ipsilateral electrodes, in one case including central electrodes (Cz, Pz). The data shown in Figs. 1 and 2 are from electrodes P3 and P4, respectively, contralateral to the CI

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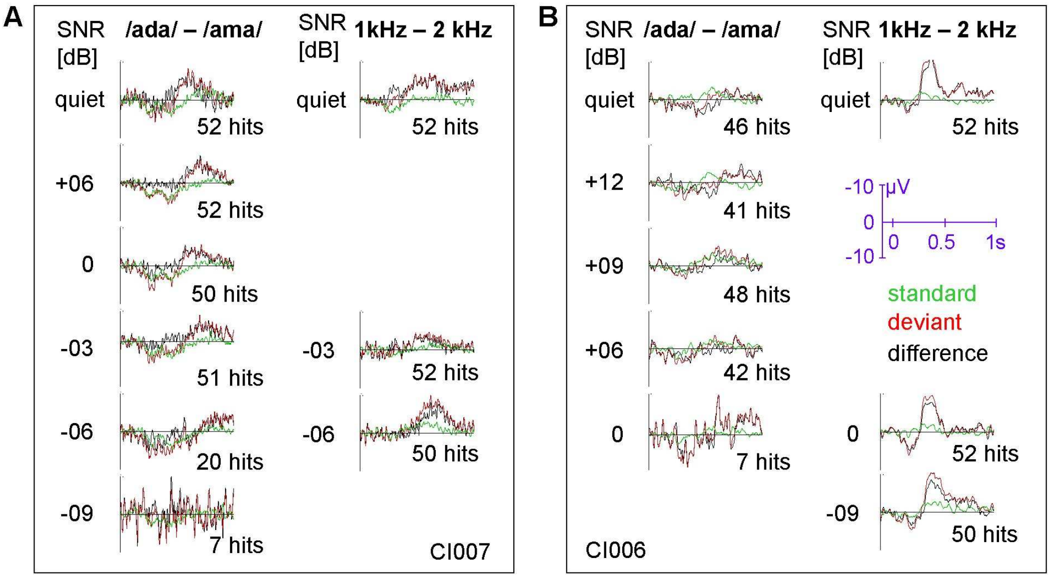

Fig. 2: CAEP recordings from two CI users in response to speech sounds and tonal sounds masked with white noise. Oddball paradigm (204 standard, 52 deviant stimuli). Signal level was kept constant, noise level was varied. Hit numbers indicate the number of deviant stimuli correctly identified by mouse click. Green and red waveforms represent the corresponding

CAEPs could be recorded from all NH subjects (n=6) and from 5 out of 6 CI users. In response to easily discriminable tonal stimuli (1 kHz – 2 kHz, duration 80 ms), all these subjects displayed robust ERPs which were present at all signal-to-noise ratios which allowed subjective discrimination of the sounds (Fig. 2). In quiet, the latency of the "P300" wave was 370 ± 27 ms and 430 ± 96 ms for NH and CI listeners, respectively.

With speech stimuli, NH subjects produced ERPs of comparable amplitude (not shown). For CI users, the ERPs in quiet were of equal size as compared to tonal stimulation (Fig. 2A) in 2 out of 5 subjects, considerably smaller (1/3) in 2 subjects (Fig. 2B), and completely absent in one subject (CI008, with poor discrimination ability, compare Fig. 1A). In quiet, the latency of the "P300" of NH (n=6) and CI listeners (n=4) was 462 ± 41 ms and 618 ± 142 ms, respectively (mean ± SD), which is about 100 and 160 ms longer as compared to tonal stimulation. In part, the longer latency for the speech stimuli is due to the initial vocal which delays the main difference given by the consonant by approximately 100 ms relative to the event marker.

Decrease of the SNR provoked prolongation of the P300 latency (Fig. 1C). As can be seen from the NH results, the increase of the slope of the curves is smoother and starts at higher SNRs as compared to the steep decay of the subjective discrimination ability (Fig. 1A). The results from subject CI007 (Fig. 1A) and the ERPs from subjects CI009 and CI011 to tonal stimuli (not shown) suggest a similar correlation for CI users.

Discussion and Summary

Our study aims at establishing cortical auditory potentials, especially event-related potentials (ERP) as objective measures for auditory discrimination abilities of CI patients in noise.

Several studies have shown that with easily discriminable tonal stimuli (e.g. 1 kHz, 2 kHz), event-related potentials comparable to those from normal hearing subjects can be reliably evoked in CI users. With reduction of the frequency difference, the latency of the P300 increases (Okusa et al. 1999). The latency of the P300 in response to speech stimuli is longer as compared to tonal stimuli (e.g. Beynon et al. 2002), and the latency of the P300 in response to tonal stimuli seems to correlate with the consonant recognition score (Kubo et al. 2001). Generally, the latency of the P300 seems to depend on the discrimination difficulty.

Here, we have studied CAEPs from NH and CI listeners in dependence on the level of a masking noise. The results show that the appearance and latency of the P300 correlates with the psychometrically evaluated discrimination ability in noise. The prolongation of the

P300 latency with decreasing SNR reflects a longer time for sound processing and, thus, a greater discrimination effort even at signal-to-noise ratios where subjective discrimination performance is still unambiguous.

For objective evaluation of discrimination abilities of non-cooperative patients, the study has to be extended to ERPs like MMN and P3a which do not depend on attentional listening.

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