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Auditory evoked potentials from deaf individuals using cochlear implants

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Abstract

Auditory evoked potentials (AEPs) provide an objective measure of auditory cortical function. However AEPs from cochlear implant (CI) users are contaminated by the electrical artefact produced by the device. Independent component analysis (ICA) has been reported to attenuate the CI artefact and recover the AEPs. Here the effects of CI artefact attenuation on the quality of the AEPs were systematically investigated. Electroencephalogram data were recorded from 18 adult CI users presented with auditory and visual stimuli. The CI artefact attenuation rate was calculated to investigate ICA sensitivity and AEP quality was determined based on a signal to noise ratio (SNR) measure. ICA specificity was evaluated with a hybrid simulation approach and by comparing visual evoked potentials (VEPs) from CI users with and without CI artefact attenuation. The results showed that AEPs could be recovered from all CI users, indicating high sensitivity. Moreover, AEP amplitudes were highly correlated with age, demonstrating that individual differences were well preserved. CI users with a high AEP SNR were characterised by a significantly shorter duration of deafness compared to low AEP SNR individuals. The results confirm that ICA is a valid tool to attenuate CI artefacts, allowing the objective, non-invasive study of auditory cortex rehabilitation in CI users.

Method

Eighteen post lingually deafened cochlear implant (CI) users (10 females, mean age 59.89±13.06 years) and 18 age and gender matched normal hearing (NH) participants (10 females, mean age 55.17± 12.31 years) took part in the study . All CI users were implanted unilaterally except one. All participants were right-handed and had no history of neurological or psychiatric disorders and normal or corrected to normal vision.

Stimuli

Auditory stimuli were taken from a pool of 270 environmental sounds of natural objects previously rated in a norming study (Schneider, Engel, & Debener, 2008). Sounds (22 kHz, 16-bit) were played for 800 ms via loudspeakers positioned at an azimuth of 45° in front of the participant. Sounds were presented at a comfortable level. Visual stimuli were taken from a pool of 320 degraded pictures of natural objects from the same norming study. The stimuli were presented centrally for 800 ms, with the visual stimuli covering an angle of 8.6° vertically and horizontally. In visual blocks (see Experimental design and Task) trials included a grey square which was presented centrally for 800 ms subtending a visual angle of 1.9° . Stimuli were presented using a 23 inch monitor and screen background was black at all times. All stimuli were presented using Presentation 10.0 software (Neurobehavioral Systems).

Experimental design and Task

An audio-visual semantic priming paradigm (Schneider, Debener, Oostenveld, & Engel, 2008; Schneider, Engel, et al., 2008) was adapted. Eighty environmental sounds (auditory primes) and 160 degraded pictures of natural objects (visual targets) from eight different categories (animals, computer & communicative devices, kitchen utensils, musical instruments, vehicles, sport equipment, tools, everyday objects) were included (freely available at www.multimost.com).

EEG Recording

Participants were seated in an electrically shielded, sound attenuated and dimly lit booth. EEG data were recorded from 68 channels using a high-input impedance amplifier system (Neuroscan, Compumedics, El Paso, USA) and a customized electrode cap (Easycap, Herrsching, Germany) (Hine & Debener, 2007; Hine, Thornton, Davis, & Debener, 2008). The cap was fitted with 66 Ag/AgCl electrodes in an equidistant layout. Two additional electrodes were placed below the eyes. EEGs from some electrodes (mean 3.94±0.94 electrodes, range 2–6 electrodes) could not be recorded due to the location of parts of the CI device (i.e., transmitter-receiver coil, cable to processor, processor). Data were recorded with a sampling rate of 1000 Hz using the nose-tip as reference, and were analogue filtered between 0.1 and 200 Hz. Electrode impedances were maintained below 20 kΩ prior to data acquisition.

Data Processing

EEG data were processed using custom scripts and EEGLAB (Delorme & Makeig, 2004) running in the MATLAB (Mathworks, Natick, MA) environment. Independent components (ICs) representing eye-blinks and electrocardiograph (ECG) artefacts were semi-automatically identified using CORRMAP (Viola, et al., 2009) and were removed by back projection of the remaining ICs. These ICs are labelled as conventional artefacts. The properties of the remaining ICs were visually inspected to identify those representing the CI artefact.

The AEPs were obtained by time-domain averaging. AEP amplitude and latency analyses were performed for a frontal central electrode where the grand average amplitudes were largest for both groups (approximately FCz). AEP peak amplitudes and latencies were determined using a semi-automatic procedure as implemented in peakdet.m (www.billauer.co.il/peakdet.html).

Results

ICA sensitivity- there was not a single CI user dataset where AEPs were not buried by large electrical CI artefact.

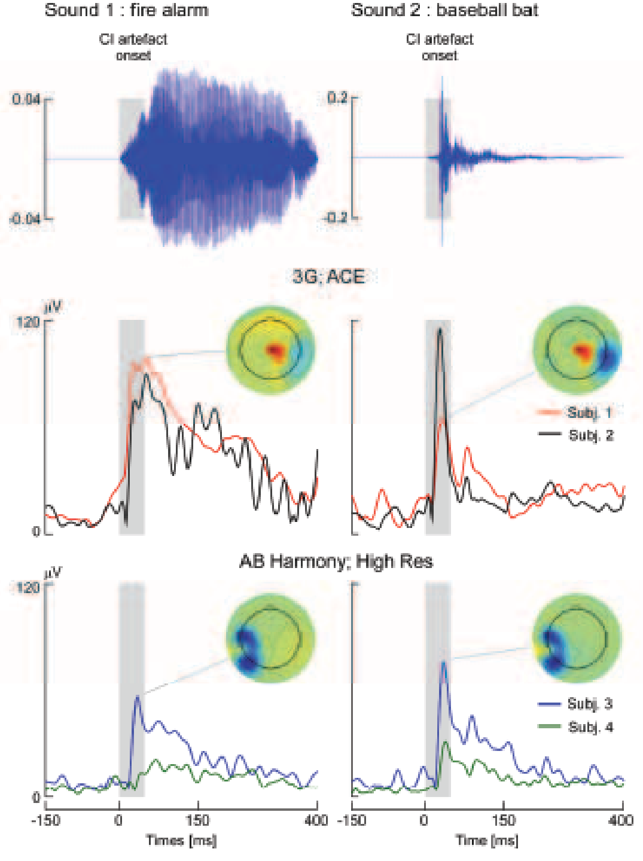

Figure 1 – Cochlear implant (CI) artefact evoked by different environmental sounds. Panels in the top row show the sound profile of two stimuli used in the experiment, on the left side a "sheep" sound, on the right side a "hitting baseball bat" sound. The panels in the middle row show the root mean square (RMS) of the EEG activity of two CI users when stimulated with the two sounds, respectively. Both implantees used a Nucleus CI system on the right side with the ESPrit G processor and the ACE speech processing strategy. The topography at the latency of maximum amplitude is illustrated for the same subject on both panels. The panels in the bottom row show RMS activity for another two CI users and the respective topography at the latency of maximum amplitude for one of them. Both implantees used the Advanced Bionics CI system on the left side with the AB Harmony processor and the HiRes-S with Fidelity 120 speech processing strategy. Grey shadow represents the average time window of CI artefact onset.

ICA Specificity: CI artefact attenuation rate - substantial individual differences were observed in the amount of attenuation, largely reflecting strong individual differences in the magnitude of the artefact.

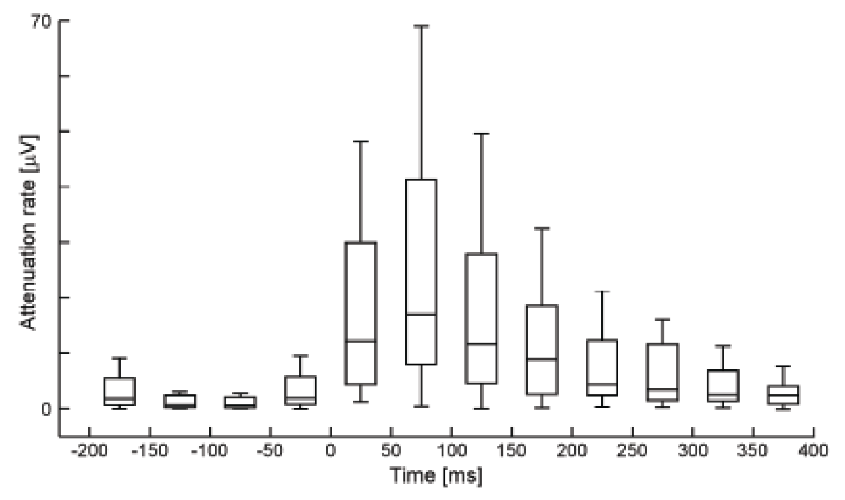

Figure 2 – Box plots showing median cochlear artefact (CI) attenuation rate (horizontal line in the middle) across 18 CI users for bins of 50 ms (range: -200–400 ms). Top and bottom of each "box" are the 25th and 75th percentiles of the samples, respectively. Whiskers are drawn from the end of the interquartile range to the furthest observation. Attenuation rate was calculated as the difference between mean RMS for original data and mean RMS for corrected data for each bin.

AEPs: correlation between N1-P2 peak-to-peak latency and age - A significant negative correlation between age and peak-to-peak amplitude was found for the NH participants (r=-0.56, p=.015). For the CI users a very similar pattern was found (r=-0.67, p=.003), indicating that individual differences were preserved after CI artefact attenuation. It was found that the CI users with low SNR values had been deaf for a significantly longer period (HIGH: mean 244.78±50.18 months, LOW: mean 532.44±34.16 months; t(16)=-4.74, p<.001)

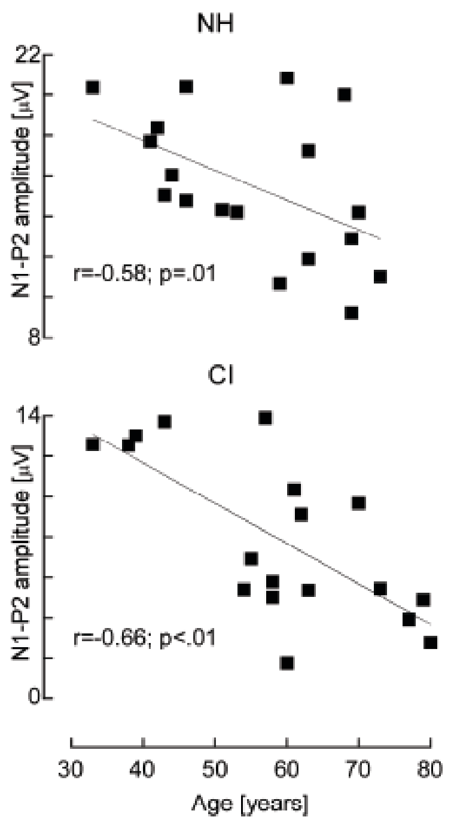

Figure 4 – Correlation between N1-P2 peak to peak latency at electrode of maximum amplitude and subject age. Top: normal hearing (NH) participants, Bottom: cochlear implant (CI) users.

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This study has been submitted to Psychophysiology

CI users comparison of clinical profiles - It was found that the CI users with low SNR values had been deaf for a significantly longer period (HIGH: mean 244.78±50.18 months, LOW: mean 532.44±34.16 months; t(16)=-4.74, p<.001)

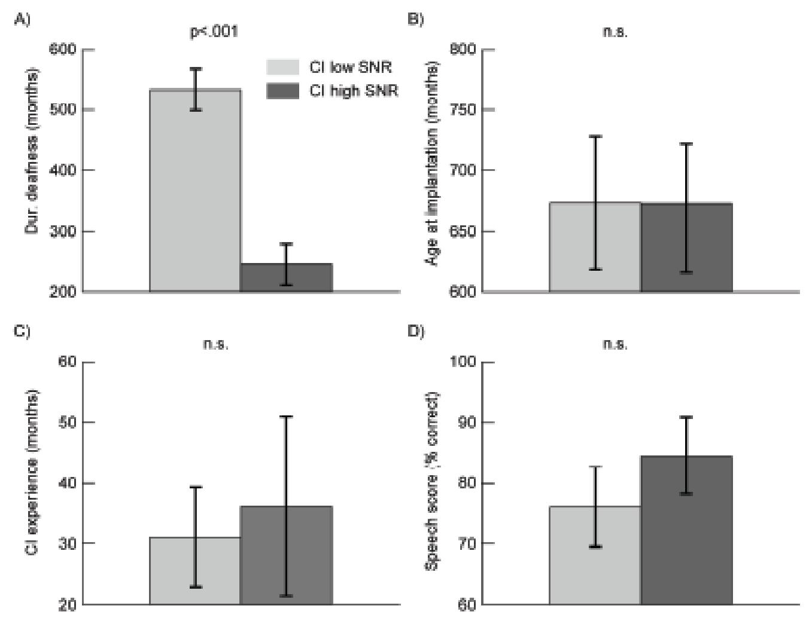

Figure 5 – Comparison of clinical profiles from cochlear implant (CI) users with low (light grey) and high (dark grey) SNR AEPs. All panels show mean ± SEM values. A) Self-reported duration of deafness in months. B) Age at implantation in months, i.e. age when the CI device was switched on. C) Experience with the CI device in months. D) Speech scores: percentage correct on the Bamford-Kowal-Bench (BKB) speech recognition test in quiet.

ICA specificity: CI users VEPs evaluation
CI-corrected VEPs were minimal.

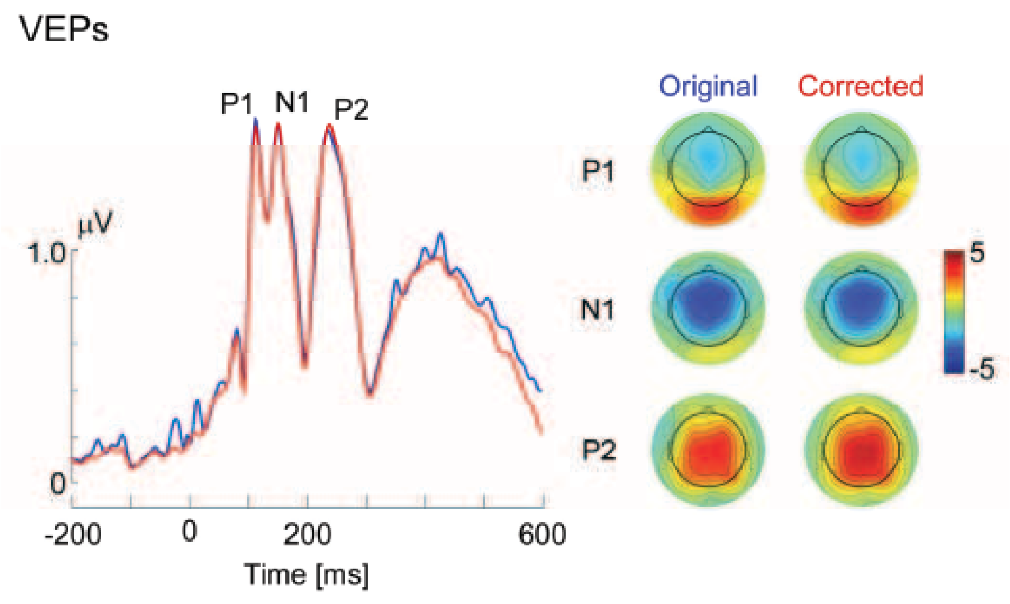

Figure 7 – Evaluation of ICA specificity by comparing visual evoked potentials (VEPs) from cochlear implant (CI) users with and without ICA based CI artefact attenuation. Root mean square (RMS) amplitudes for original (blue) and for corrected (red) VEPs after ICA based CI artefact attenuation. Topographies at mean P1, N1 and P2 peak latencies are shown for the original and corrected data, respectively.

Conclusion

These results complement previous studies showing that ICA can successfully attenuate the electrical CI artefact in EEG data from CI users, thus allowing the recovery of reliable AEPs. ICA has demonstrated good sensitivity and specificity. In addition, the recovered AEPs from CI users reflected the expected correlations with aging and clinical parameters. The development of tools to automatically identify and select components representing electrical artefact remains an important goal for the future. Overcoming this limitation would help to establish multi-channel AEPs in response to speech and musical sounds for the objective monitoring of auditory cortical rehabilitation after implantation. The complementary use of objective measurements of auditory cortex function may help to shape rehabilitation programs and thus improve the quality of life from CI users.

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