Measurement of temporal interaction due to neural dynamics with cochlear implants

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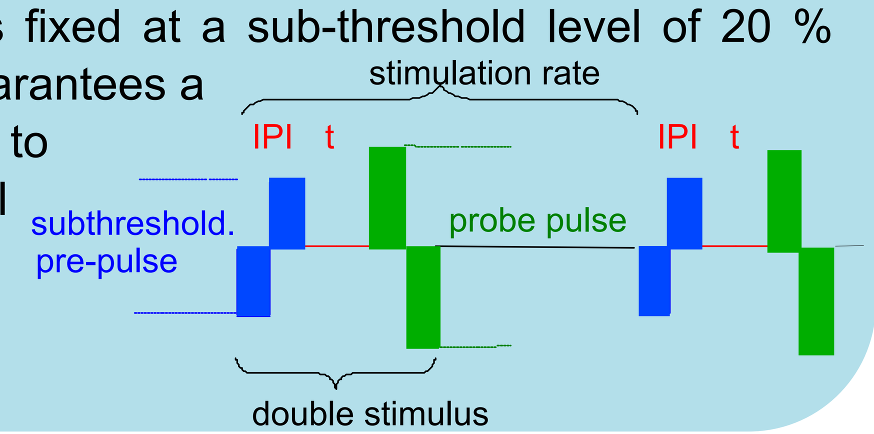
ABSTRACT

In cochlear implants (neuroprosthesis for deaf) the auditory nerve is stimulated directly by electrical pulses. The general shortcoming of electrical stimulation is field spread and results in channel interaction. The independent information transmission to the brain is limited as the channels are not well separated which leads to poor frequency resolution and impaired speech understanding in noise. In this context the trend to encode auditory signals by low numbers of frequency channels but high stimulation pulse-rates arises the question: how good is the temporal resolution?

Stimuli

Double stimuli were given at a stimulation rate of 4 Hz. Biphasic pulse parameters are: phase 40 µs, gap 30 µs. The IPD was varied in the range of 20 µs to 20480 µs. Polarity conditions are the four possible combination: anodic cathodic AC, cathodic anodic CA, anodic anodic AA and cathodic cathodic CC. The pre-pulse stimulus level was fixed at a sub-threshold level of 20 % below threshold. This guarantees a certain amount of charge to precondition the neuronal response of the second probe stimuli.



Method

In this study we tested 11 subjects (age ± std: 50,1 ± 13,9), 14 implanted ears, with MED-EL PulsarCI100 device implanted for more than 1 year. We measured at two electrodes, one middle (6) and one apical (1). The probe amplitude was varied to adjust the stimulus at hearing threshold. Each measurement consists of 5 repetitions.

We applied the stimuli directly to the implant by the research interface RIB II for MED-EL implants.

The experiment was in accordance with the ethical Declaration of Helsinki 1975 (clinic rechts der Isar vote no. 2126/08).

Conclusion

In summary, our measurements revealed significant temporal interaction effects from sub-threshold pulses. Neuronal single fibre and cortex measurements show similar temporal interaction effects (Dynes 1996, Bierer & Middlebrooks 2004). Concluding, we can say that significant temporal interaction on sub-threshold pulses occurs up to 600 µs, which is relevant in actual coding strategies because the inter pulse distances are often shorter. For CIS strategies the effects of field spread and channel interaction lead to even shorter IPIs between channels.

Our results show that it is important in coding strategies to predict and correct not only simultaneous interactions but also temporal interactions.

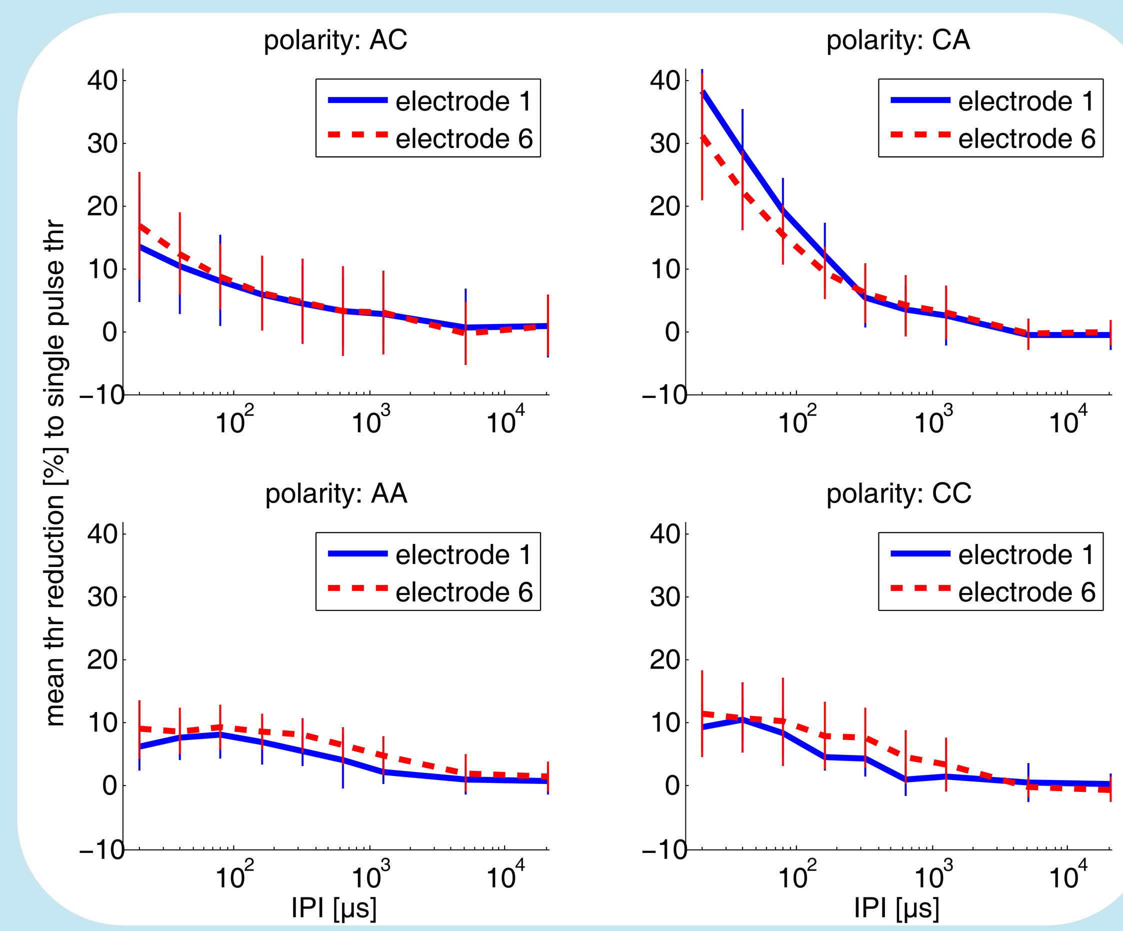
Introduction

Most patients with cochlear implants are again able to participate in normal life. Their rehabilitated ability of hearing leads in most cases to good speech understaning, telephone usage and return to working environment. The ability to understand speech in noise or to perceive tonal features is though limited. The reason is, that the information transmission encoded by electrical stimuli is reduced by electrical field spread. The trend is to stimulate with high rates. Several studies about speech recognition could not correlate high stimulation rates with better performance (Fu & Shannon 2002). In speech recognition the detection of amplitude modulation is essential. The higher the rate the better the encoding of temporal variations like amplitude modulation but Galvin et al. 2005 showed that with rising encoding quality which means high rates the detection of amplitude modulation worsens. Why is the detection peformance with high rates reduced though the content of temporal information is enlarged with higher stimulation rates? This leads to the question of our study: how good is temporal resolution?

Results

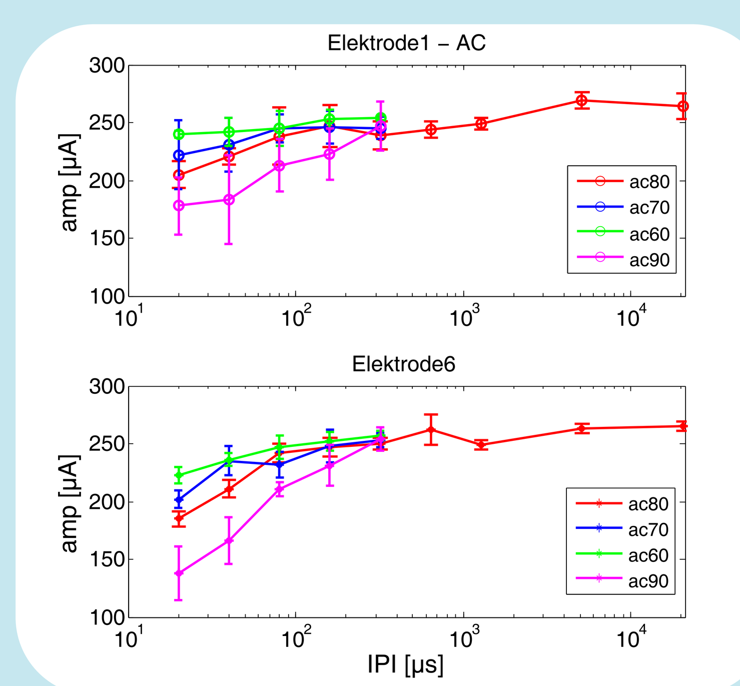
The result of our measurements is that the temporal interaction leads to a threshold reduction of the probe pulse in all cases. This threshold reduction effect was significant up to 600 µs and in some subjects even interaction effects up to 1 ms were seen. The interaction effect was largest for small IPIs. Here it reaches up to 35 % ± 6% threshold reduction in relation to the single pulse threshold. The threshold reduction effect size depended on the polarity of pre-pulse and probe pulse. When both pulses had the same polarity the effect was smaller than if the pulses have different polarities.

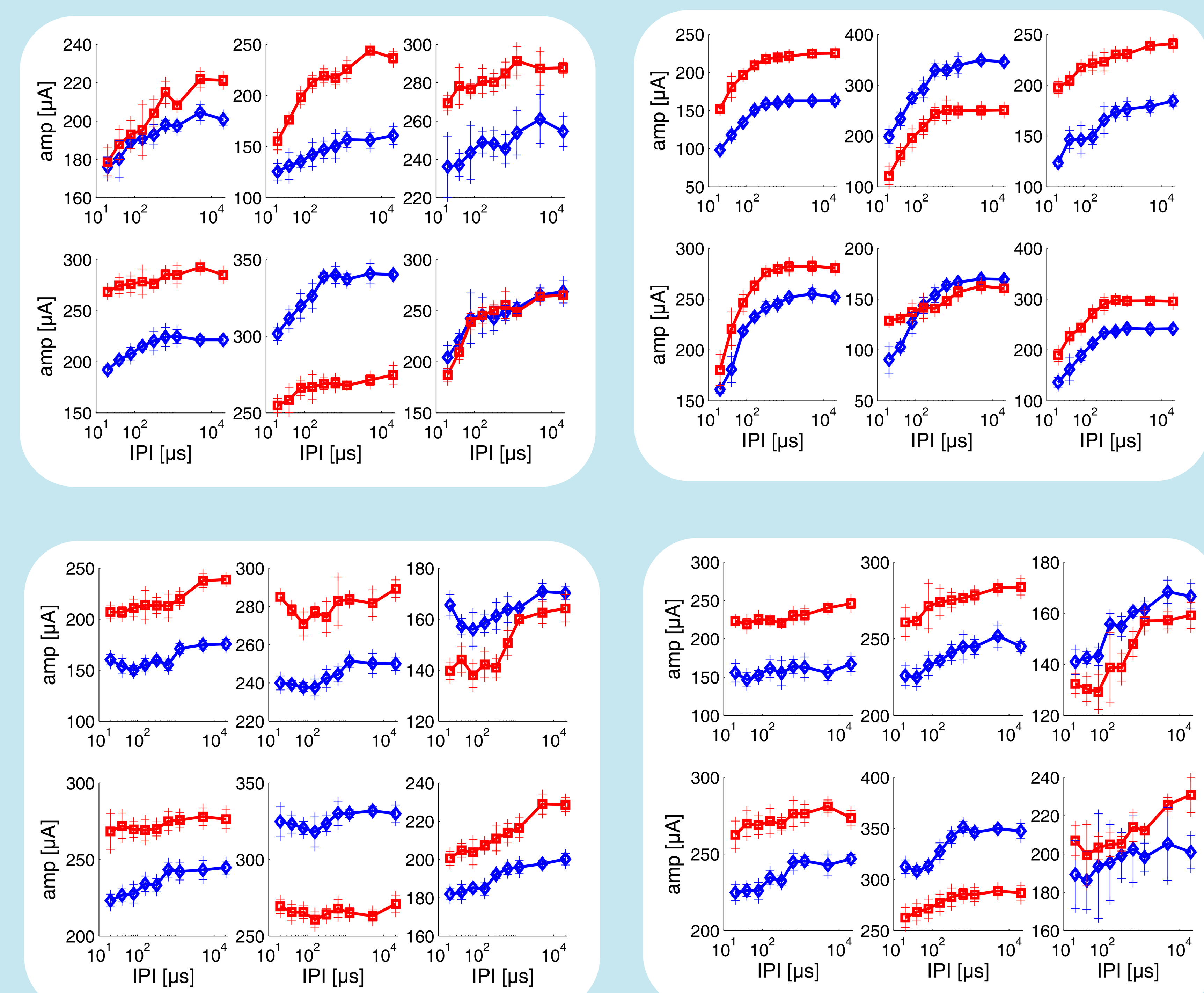
We suggest that this temporal interaction effect results from neuronal dynamics. The sub-threshold stimulation shifts the potential of the spiral ganglions. This shift out of resting state ,which depends on the polarity of the stimulation pulse influences the activation of the ion channels. The shift from the resting state is nonlinear, relaxation reaches long durations and causes temporal interactions.



The four polarities show different effect size for threshold reduction. And the shape of the threshold reduction curve is different for equal AA and CC and for non-equal polarity AC and CA conditions.

A varied pre-pulse level shows different influence on the temporal interaction. This indicates a level dependent interaction.





Polarity condition AC, CA (upper line) and AA, CC (lower line). The four figures show always 6 subjects measured on two electrodes. We measured the threshold (amp) of the probe pulse for 9 different IPIs. The absolute threshold level varies inbetween subjects and electrodes. The clearest effect over all subjects and electrodes is seen in the equal polarity conditions AC and CA.

Acknowledgement

This work was funded by a grant within the Munich Bernstein Center for Computational Neuroscience by the German Federal Ministry of Education and Research (reference numbers 01GQ0441 and 01GQ0443) and from MED-EL Innsbruck.

The clinicum Rechts der Isar, supported the experimental work with patients, thanks to J. Steinhoff.

Many thanks to all patients which participated in this study.

Bernstein Center for Computational Neuroscience Munich