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Summary

The Dutch population counts about 12,000 adults and children with a severe to profound hearing loss. Cochlear implantation is an established technique to improve the ability to understand speech, and therefore nowadays a paramount opportunity of rehabilitation. Since the 1980's, manufacturers develop multi-channel cochlear implants with even more advanced speech coding strategies, in conjunction with the continuous evolution of the electrode arrays, which improved the speech perception scores significantly over the years. The newest developments on speech coding strategies are based on spectral and temporal fine structures cues, which potentially result in better speech perception in background noise and better appreciation of music. Fidelity 120 is one of these strategies based on simultaneous dual electrode stimulation (DES), the subject of the translational study in this thesis. The mechanism of DES is investigated both psychophysically and in a computational model of the cochlea, followed by a clinical implementation of DES, which aims to correct for defective electrode contracts.

Chapter 1 presents the basic principles of a cochlear implant and a short historical overview of the development of this device. Next, a historical overview of the development of the speech coding strategies is given from the basic principles to the currently used strategies and strategies under development. This chapter ends with an outline of this thesis.

Objective of **Chapter 2** was to establish how DES can be optimized and whether it has the same qualities as single electrode stimulation (SES), enabling its use in a CIS (Continuous Interleave Sampling) like strategy. The comparison of DES with SES was investigated with respect to the site of stimulation in the cochlea, the spread of excitation (SOE) and sequential channel interactions. Because it is relevant to be able to determine in advance to what extent a patient is able to discriminate extra pitches created with DES, it was investigated whether the number of intermediate pitches created with DES can be predicted from SOE, channel interaction measures, current distribution in the cochlea, or distance of the electrode to the medial wall. It turned out there was no significant difference between dual and single electrode stimulation for the SOE curves and sequential channel interaction. This led to the hypothesis that dual electrode stimulation can be used in CIS like strategies without degradation of speech perception. Furthermore, the displacement found, the excitation site of dual electrode stimulation relative to the region of excitation induced by the neighboring single electrode contact, was in line with expectations. Unfortunately, only the sequential channel interaction index showed a significant correlation with the number of intermediate pitches created with DES along the array on a per-patient basis. Therefore, it could be concluded that no clinically useful predictor for the number of intermediate pitches was found.

With Phantom stimulation, a pulse with opposite-polarity on the basal electrode contact of the pair of DES is used to create a pitch beyond the electrode array in the apical direction. This pitch is than shifted away from the apical electrode and therefore is lower in pitch than the one of the apical electrode contact with SES. This phantom stimulation was explored in **chapter 3** by using psychophysical experiments and computational modeling of the cochlea. It turned out, that phantom stimulation was effective in all patients tested. Next, it was demonstrated that phantom stimulation indeed needed more current and that a current correction was necessary to maintain equal loudness with varying pitch shifts. In this respect, the psychophysical data was comparable with the computational modeling data. Finally, the place of stimulation of phantom stimulation was explored. Each patient was able to perceive a lower pitch in the apical region, with a maximum pitch shift of approximately 1.1 mm along the basilar membrane. The model showed a smaller overall pitch shift and predicted that the shift is larger with an electrode array in a lateral position in the scala tympani than in a medial position.

The last three chapters further explored the possibilities and qualities of simultaneous DES. In **chapter 4** the possibility is explored to bridge defective electrode contacts with DES applied on non-adjacent electrode contacts (spanning). With psychophysical experiments spanning was compared with DES on adjacent electrode contacts in terms of the number of intermediate pitches, loudness effects and linearity of the current weighting coefficient with respect to the perceived pitch. Data showed that spanning is feasible up till 4.4 mm, but that with increasing distance between the electrodes, a gradual increase in loudness adjustment and decrease in pitch discrimination precision occurs. The pitch distribution is linear with α, where α is denoted as the proportion of the total current directed to the more basal contact of the dual electrode contact pair. This coefficient varies from $\alpha = 0$, where all current is directed to the apical electrode to $\alpha = 1$, where all current is directed to the basal electrode. Further was shown that the data were not influenced by the apical to basal location of electrode contacts in the cochlea.

The experiments in all former chapters were performed on Most Comfortable Loudness (MCL) level. When DES will be used in a speech coding strategy, it is also of interest to know what happens at Threshold Level (TL). In the clinical fitting procedure, TL is the level where the patient indicates that the signal is just audible. **Chapter 5** describes the efficiency of DES at lower levels, with the focus on the requirements to correct for threshold variations along the array. TLs were determined both psychophysically and with computational modeling, where the computational model utilized three different neural morphologies with different stages of degeneration. We concluded that with present electrode arrays DES is possible at low current levels and no current adjustment is necessary to compensate for loudness variations in most cases. Furthermore, comparison of the psychophysical data with the data from the computational model led to the hypothesis that degeneration of apical auditory nerve fibers in humans mainly involves loss of unmyelinated terminals rather than loss of complete peripheral processes.

After fundamental experiments with DES, the challenge remained if implementation of spanning in a speech coding strategy would be possible and would not decrease the performance and the quality of sound. In **chapter 6** three different speech coding strategies were designed, with 1, 2 or 3 defective electrode contacts next to each other. Each of the programs simulated to have a total of 6 defective electrode contacts. Patients were asked to use these different strategies in five different home situations and indicated no difference in sound perception between these situations. Further, speech perception scores were measured in quiet and with speech-weighted background noise. No significant difference was found between the strategies. However, in quiet an increasing spanning distance showed a small but significant decrease in speech perception scores (from 84.7% to 75.2%).

Chapter 7 presents an overall discussion of the major results and conclusions of the studies described in this thesis. Furthermore, implications for clinical practice and areas of future research are discussed.