Exploring the capabilities of modern cochlear implants : from electrophysiology to quality of life

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Chapter 4

Optimizing the number of electrodes with high-rate stimulation of the Clarion CII cochlear implant

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Abstract

Objective: This blind crossover study evaluates the effect of the number of electrodes of the Clarion CII cochlear implant on speech perception in silence and in noise using a "high-rate" continuous interleaved sampling (CIS) strategy.

Material and Methods: Nine users of this implant with 3–11 months of experience of an 8-channel CIS strategy [833 pulses per second (pps)/channel, 75 µs/phase] were fitted in a random order with 8-, 12- and 16-channel CIS strategies(±1400 pps/channel, 21 µs/phase). After 1 month of exclusive use of each strategy the performance was tested with consonant-vowel-consonant words in silence (sound only) and in speech-shaped background noise with signal-to-noise ratios (SNRs) of +10, +5, 0 and −5 dB.

Results: With "high-rate" strategies most patients' speech understanding in noise improved, although the optimum number of electrodes was highly variable. Generally, faster performers benefited from more active electrodes, whilst slower performers deteriorated. If each patient's optimal strategy was determined by a weighted sum of the test results at +10, +5 and 0 dB SNR, the average phoneme score improved from 57% to 72% at a SNR of +5 dB, and from 46% to 56% at a SNR of 0 dB. The average phoneme score in silence was ~85% for all strategies.

Conclusion: We conclude that speech perception (especially in noise) can improve significantly with "high-rate" speech processing strategies, provided that the optimum number of electrodes is determined for each patient individually.

Introduction

Multichannel cochlear implants (CIs) are firmly established as effective options for the (re)habilitation of adults and children with bilateral profound hearing impairment.[1] They are designed to take advantage of the tonotopic organization of the cochlea to encode spectral frequency cues. The incoming sound signal is filtered into frequency bands, each corresponding to a given electrode in the electrode array.[2] In persons with normal hearing there are ~18 so-called critical bands over the frequency range 500–5000 Hz.[3] Although this number is comparable to the number of contacts in modern multichannel CI systems, the effective number of independent channels in electrical hearing is likely to be fewer as a result of channel interaction and limited spatial selectivity.[4] Fishman et al.[5] found that 20 electrodes were no more effective than 7 in terms of vowel and monosyllable word identification, while recent studies[6–8] suggested that the susceptibility to noise of CI users is at least partly due to loss of spectral resolution.

Those studies showed an improvement in performance as the number of channels was increased up to eight, although additional channels resulted in little further improvement. The continuous interleaved sampling (CIS) strategy[9] aims to prevent channel interaction by sequential stimulation of the different contacts in the array.

Increasing the rate of stimulation in CIS may further increase speech performance by increasing the amount of temporal information per channel.[10]

However, few clinical studies[11,12] have shown improved performance at stimulation rates >500 pulses per second (pps)/channel. A high inter-subject variability has been reported, with some subjects showing little difference in performance as a function of stimulation rate, some showing a peak at a particular rate and some showing significantly better hearing. In a recent paper[13] we presented good speech perception results with our first 10 patients (9 adults, 1 child) implanted with the Clarion CII CI (with a HiFocus I electrode and separate positioner), operated in the so-called SCLIN emulation mode. In the present study, carried out as part of a multicentre study evaluating the faster speech processing capabilities of the CII, we evaluate the effect of increasing the number of electrodes up to 16 in a "high-rate" (±1400 instead of 833 pps/channel) CIS strategy on speech perception in silence and in noise.

Materials and Methods

All 9 post-lingually deafened adults [age 29–64 years, average duration of deafness >19 years (range 1–35 years)] presented in the previous paper[13] participated in this study. The subjects had 3-11 months of experience with their CII implant and all but 1 were using an 8-channel, 833 pps/channel monopolar CIS strategy (75 µs/phase). Further demographic details can be found in the previous paper.[13] On entering the study the subjects had an average phoneme score of 84% (range 63–93%; average word score 66%) on consonant-vowel-consonant (CVC) words in silence (sound only).

The study was designed as a blind crossover study of 3 new so-called "high-rate" (HR) CIS strategies with 8, 12 or 16 monopolar channels, available with the Bionic Ear Programming Software (version 2.0; Advanced Bionics). In all 3 strategies the pulse rate per channel was fixed at ±1400 pps by the introduction of gaps between the biphasic pulses of 21 µs/phase (Table 4.1).

Table 4.1. Characteristics of the HR strategies used

No. of channels	Inter-pulse interval (µs)	Rate per channel (pps)	Overall rate (pps)
8	43	1470	11,760
12	21	1322	15,864
16	0	1488	23,808

For an 8-channel HR program either odd- or even-numbered contacts were used, depending on the patient's preference in the SCLIN mode. A 12-channel program generally contained more active channels in the basal part (the higher pitched contacts), based upon the observation that the differences in the percepts elicited by neighbouring contacts were more salient in the basal region. A typical 12-channel program has electrodes 2, 5, 9 and 14 disabled.

Fitting was performed by two of the authors (J.J.B. and R.M.B.), according to the fitting procedure commonly used in our centre. As described elsewhere[14], fitting aims both to avoid cross-turn stimulation[4] and to maximize the amount of high-frequency information. To ensure that only the person who did the fitting (and not the patient or other team members) knew the number of active channels in the program, T and M levels were always determined for all 16 electrodes in the array. To minimize learning effects, patients were randomly divided into 3 groups with different program sequences based on a modified Latin square (8-12-16, 12-16-8 or 16-8-12 active electrodes, respectively). After 1 month of exclusive use of a strategy in everyday life, speech performance was measured. Immediately afterwards, the program in the speech processor was replaced by a new one with a different number of electrodes. This process was repeated for 3 months until each patient had been tested with all 3 programs.

Speech performance was assessed in the same way as in the previous study[13] using the standard Dutch Society of Audiology CVC word lists (female speaker; 44 words/ presentation) on CD (15), presented through an audiometer and a calibrated loudspeaker in a sound-treated room. The noise (from the same CD) had a long-term frequency spectrum equal to that of speech. Speech was presented at 65 dB sound pressure level (SPL) with signal-to-noise ratios (SNRs) of infinity (i.e. in silence) and +10, +5, 0 and −5 dB.

In everyday life there is always some background noise (with SNRs of ~+5 dB as the most common condition). Therefore, we propose here three ways for determining the optimal program for each subject after the trial, based on the subject's performance in noise. The first proposal is the program with the highest performance at a SNR of +5 dB (henceforth referred to as "opt@+5 dB"). The second is that with an optimal weighted average of the scores at +10 dB, +5 dB (double weight) and 0 dB SNR ("opt@weighted"). The third method ("opt@SNR") involves choosing the program with the optimal speech reception threshold (SRT), defined as the SNR at which 50% of the phonemes are understood correctly.

The results with the three HR programs and the three optimized conditions were compared to the SCLIN outcome on an individual basis, allowing statistical analysis of benefit with a two-sided Student's *t* test for paired values.

Results

The individual speech perception scores for all tested strategies and SNRs are displayed in figure 4.1.

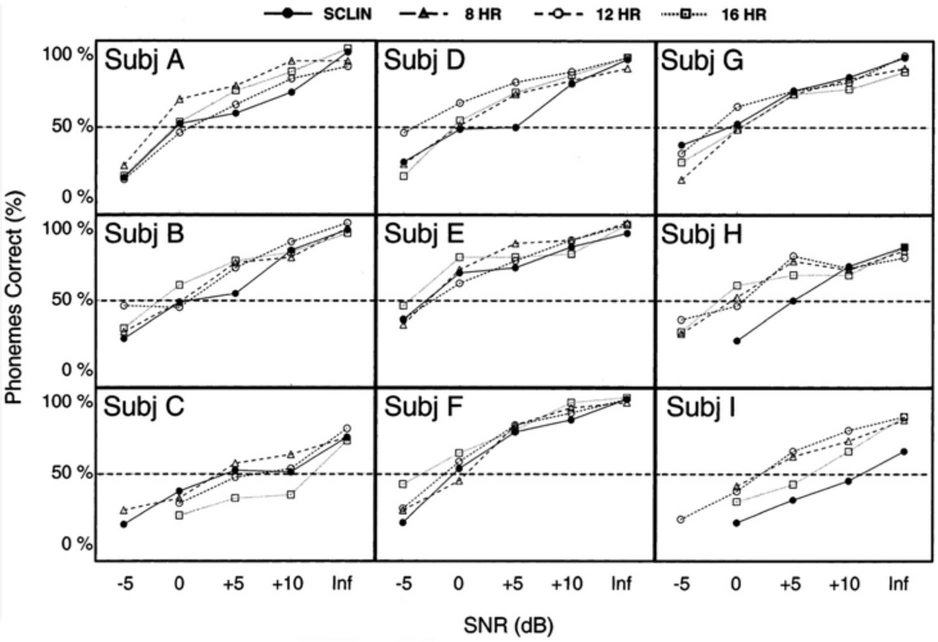

Figure 4.1: The percentage of phonemes understood correctly in the CVC monosyllable word test (65 dB SPL; sound only) for all subjects as a function of SNR for the 8-channel “low-rate” (SCLIN) program and the 8-, 12- and 16-channel HR programs. The horizontal broken lines indicate the 50% level, corresponding to the SRT.

As expected, performance deteriorated with increasing noise level. Clearly, no single program was optimal for all patients. Also, a program that was optimal in silence was not always optimal in noise. Generally, performance with the SCLIN program was worse than that with the HR programs, with subjects H and I being the most striking examples. In the latter patient the SRT (indicated by crossing of the 50% line) improved from >10 dB with SCLIN to 2.5 dB with 8- and 12-channel

HR strategies. For subject C all 4 strategies were equivalent in quiet, but in noise the scores with the 16-channel HR strategy were lower than those with any other strategy.
Figure 4.2 shows the average speech perception scores in silence and varying noise conditions for each program and with the optimized HR conditions.

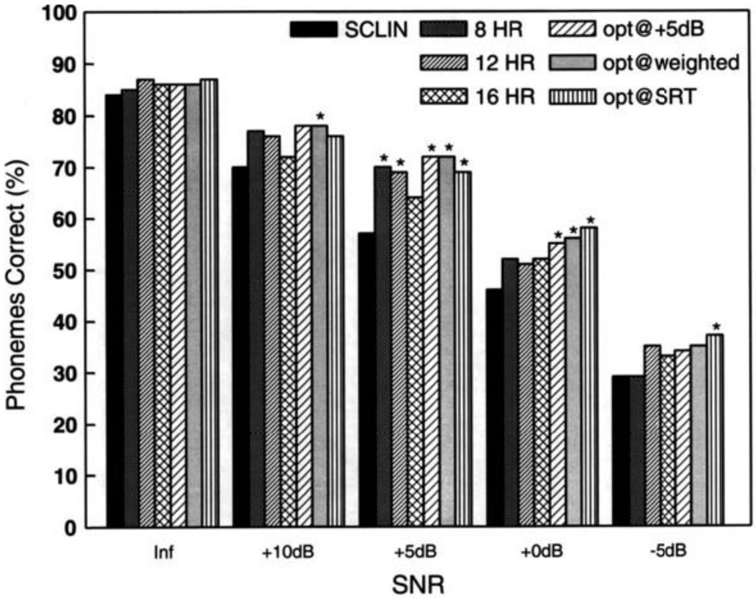

Figure 4.2: The average phoneme score on the CVC monosyllable word test (65 dB SPL; sound only) for all 5 SNRs tested. Results are shown for the 8-channel "low-rate" (SCLIN) program, the 8-, 12- and 16- channel HR programs and the 3 different optimization strategies. An asterisk indicates that the result is significantly different (p< 0.05) from the SCLIN score.

In line with the above-mentioned observation that no single strategy is superior for all patients, just 2 basic HR conditions (8- and 12-channel at a SNR of +5 dB) showed a statistically significant improvement over SCLIN. However, all optimized HR conditions yielded significant improvements over SCLIN (but not over the basic HR conditions) for SNRs of +5 and 0 dB. For a SNR of 10 dB the "opt@weighted" condition and for a SNR of −5 dB the "opt@SRT" condition were also significantly better than SCLIN (p<0.05).

Table 4.2 shows the average phoneme recognition threshold (PRT; defined as the SNR yielding 50% of the performance in quiet) and SRT values for the different strategies. The best results for both measures of speech perception in noise (PRT=-3.1 dB and SRT=-2.0 dB; improvements of 2.5 and 4.4 dB, respectively, relative to SCLIN) were found for the "opt@SRT" condition, although the PRT was not very sensitive to the optimization strategy used.

Table 4.2: Average PRT and SRT for the 8-channel "low-rate" SCLIN program, the 8-, 12- and 16-channel HR programs and the 3 optimization conditions.

	SCLIN	8 HR	12 HR	16 HR	Opt@+ 5 dB	Opt@ weighted	Opt@SRT
PRT (dB)	-0.6	-1.8	-2	-1.3	-2.8	-3	-3.1
SRT (dB)	2.4	-0.1	0.2	0.6	-0.9	-1.1	-2

Although all patients performed better with a HR strategy, the optimal number of channels was highly dependent on the individual patient and the optimization strategy (Table 4.3).

Table 4.3: The optimal number of channels according to the three optimization conditions for patients A-I, sorted according to their 1-week post-hook-up phoneme scores on the CVC test.

Patient	1-week phoneme score (%)	Opt@+5dB	Opt@weighted	Opt@SRT
C	25	8	8	8
I	27	12	12	8
A	39	8	8	8
F	40	12	12	12
D	45	12	12	12
G	53	12	12	16
H	62	8	8	16
B	69	16	16	16
E	76	12	16	16

To identify patient characteristics that could help to predict the optimal program, differences between subjects were analyzed. The best predictor found was the learning speed, measured by means of the 1-week phoneme score in silence: those who will benefit from more channels are those who acquire speech understanding more rapidly. As shown in Table 4.3, this is most clearly visible with the "opt@ SRT" condition. Unfortunately, we could not identify any other factor, such as duration of deafness, age at implantation or preoperative speech perception, which correlated with the optimal number of channels.

Discussion

This paper presents the results of a blind crossover study evaluating the effect of the number of contacts on speech perception in silence and in noise using a HR (1400 pps/channel) monopolar CIS strategy with the Clarion CII CI and a perimodiolar HiFocus I electrode. Although the patients already had remarkably good speech perception results with an 8-channel, "low-rate" (833 pps/ channel) SCLIN strategy, both in quiet and in noise, compared to the literature [for comparisons see Frijns et al.[13] all patients could benefit from a HR strategy, especially in noisy conditions. This led, for example, to an average improvement in the SRT of as much as 4.4 dB (to -2.0 dB) without the use of special microphones. In silence, ceiling effects occurred, although an (non-significant) improvement in the CVC phoneme score from 84% (SCLIN) to 87% (12 HR and opt@SRT conditions) was observed. Theoretically, higher stimulation rates with the CIS strategy provide better envelope cues, although the results in the literature are inconsistent.[11,12] Fu and Shannon[16] suggested that the limiting factor is perceptual, rather than inherent to signal processing, as their CI users could not benefit from temporal sampling of the speech signal as the stimulation rate was increased from 150 to 500 pps/electrode, i.e. within the range of pulse rates that individual nerve fibres can follow on a pulse-by-pulse basis. The pulse rates used in the present study, however, were above that limit, and apparently led to improved speech perception in noise. Possibly, further improvements could be achieved with rates of ≥4000 pps, which may lead to acoustic-like stochastic neural discharge patterns.[10] As described in the Introduction, most previous studies using traditional electrodes and older implant electronics could not identify a clear benefit from increasing the number of channels beyond seven or eight electrodes[5], probably due to a lack of spatial selectivity and/or stimulation rates that were too low. However, the present study shows that the speech perception of individual patients in noise can benefit from HR stimulation with up to 16 channels with the perimodiolar HiFocus electrode which, at least theoretically, is more selective in the basal turn.[5] To what extent centre-specific factors play a role in this result is not yet clear: the positioner was inserted partially so as to place the electrode only perimodiolarly in the basal turn; and a new, model-based, fitting strategy was used.[14]

An important finding in the present study was that the optimal number of electrodes had to be selected for each patient individually and, apart from the observation that subjects with steeper learning curves tend to be able to use more electrodes (Table 4.3), we currently do not have a better way to choose the optimal strategy than by using trial and error. Therefore, we are now studying whether objective (neural response imaging) and subjective (psycho-physical) measures of electrode selectivity can be used to select the optimal electrode configuration for an individual patient. It is expected that results can be further improved, and the workload for the team and the patient reduced, if an (nearly) optimal strategy can be predicted in individual patients.

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