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Chapter 6

Restoring speech perception with cochlear implants by spanning defective electrode contacts

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Abstract

Conclusion: Even with 6 defective contacts, spanning can largely restore speech perception with the HiRes120 speech processing strategy to the level supported by an intact electrode array. Moreover, the sound quality is not degraded.

Objectives: Previous studies have demonstrated reduced Speech Perception Scores (SPS) with defective contacts in HiRes120. The current study investigates whether replacing defective contacts by spanning, i.e. current steering on non-adjacent contacts, is able to restore speech recognition to the level supported by an intact electrode array.

Materials and methods: 10 adult cochlear implant recipients (HiRes90K, HiFocus1J) with experience with HiRes120 participated in this study. Three different defective electrode arrays were simulated (6 separate defective contacts, three pairs or two triplets). The participants received three take-home strategies and were asked to evaluate the sound quality in five pre-defined listening conditions. After 3 weeks, SPS were evaluated with monosyllabic words in quiet and in speech-shaped background noise.

Results: The participants rated the sound quality equal for all take-home strategies. SPS with background noise were equal for all conditions tested. SPS in quiet (85% phonemes correct on average with the full array) however, decreased significantly with increasing spanning distance with a 3% decrease for each spanned contact.

Introduction

The number of spectral channels in a cochlear implant (CI) created with the HiRes sound processing strategy (Advanced Bionics) is equal to the 16 intra cochlear electrode contacts. This number can be increased with either sequential (Kwon and van den Honert 2006; McDermott and McKay 1994) or simultaneous (Donaldson et al. 2005; Townshend et al. 1987) dual electrode stimulation. This is done in a more recent version of the HiRes speech processing strategy, HiRes120 (Brendel et al. 2008; Buchner et al. 2012; Buechner et al. 2008; Donaldson et al. 2011; Firszt et al. 2009), which makes use of simultaneous dual electrode stimulation ("current steering"). With this strategy, CI recipients are theoretically able to make use of 120 different spectral channels, which might lead to high levels of speech recognition in quiet and in noise in comparison with HiRes. Several studies (Brendel et al. 2008; Buchner et al. 2012; Buechner et al. 2008; Donaldson et al. 2011; Firszt et al. 2009) compared HiRes with HiRes120 and either found a small improvement in speech perception, no improvement or even deterioration, which differed per subject. However, sound and music quality was rated higher for HiRes120 by almost all users. In a European multi centre HiRes120 study some subjects from the study group had non-active electrodes in their programs. Their speech perception outcomes for the HiRes120 program were poorer than for the Hires program (Boermans et al. 2008; Buchner et al. 2012).

This can be explained by that fact that with the present implementation of HiRes120 the number of available channels will decrease by 16 with a single defective electrode contact, or by 8 if the missing contact is at either end of the array. When applying current steering on non-adjacent electrode contacts ("spanning") (Snel-Bongers et al. 2011a), such a defective electrode can be bridged and this decrease in number of channels can be compensated.

Unfortunately, current steering on non-adjacent electrode contacts, "spanning", has not the same qualities as current steering on adjacent electrode contacts, in terms of loudness and number of discriminable intermediate pitches. The number of intermediate pitches decreases when increasing the spanning distance (Snel-Bongers et al. 2011a). Furthermore, additional current is required to create equal loudness, when increasing the spanning distance, which shortens battery life. This could set a limit on the effectiveness of repairing defective contacts with spanning, and a degradation of speech perception might be expected when spanning is used in a speech coding strategy.

The purpose of the current study was to compare speech perception in quiet and in the presence of speech-spectrum shaped noise with HiRes120 using spanning to repair simulated defective (deactivated) electrode contacts. Each spanning program had 6 deactivated electrodes with various distributions. This is an extreme situation, as just 1% of all electrode contacts have been found to be non-functional (Hughes et al. 2004). However, the impact of a single deactivated contact was expected to be relatively small and might not be detectable with normal speech tests. Furthermore, a subjective sound quality rating was collected for each program under different listening conditions.

Material and Methods

Participants

The participants in this study were 9 postlingually deafened adults and 1 prelingually one who had been implanted with a HiRes90K device with HiFocus1J electrode array (Advanced Bionics, Sylmar, CA) at the LUMC. No complications were reported, either during surgery, or the rehabilitation program for any of the participants. All participants used a Harmony sound processor with a HiRes120 (also called Fidelity 120) speech coding strategy (pulse width and accordingly stimulation rates varied across implant recipients). The group consisted of three females and seven males, with an average age of 61 years (+/- 8). The average duration of implant use was 52 months (+/- 22).

The current study was approved by the Medical Ethical Committee of the LUMC (ref. P02.106.P). Written consent was obtained from each participant.

Speech coding strategies

Participants were tested with 5 different electrode array configurations as shown in Table 1. Strategy 1 (reference) was their current program, where the data from the clinical software Soundwave (Advanced Bionics, Sylmar, CA) was transferred and adapted to the research tool BEPSnet (Bionic Ear Program System, Advanced Bionics, Sylmar, CA). The BEPSnet research tool enabled us to program the participants’ speech processors and the research processors with HiRes120 and with the spanning strategies.

Strategy 2 (reference 125% PW) is the same as strategy 1 except for the pulse width (PW), which was increased to 125% of the pulse width used in the clinical program. Such a broader pulse width requires a lower stimulating current, making it one of the methods proposed to conserve energy. A 125% PW was also used in the other three strategies, in which different configurations of six electrode contacts were switched off. Strategy 3 (singles) has six single deactivated contacts, strategy 4 (doubles) has three disabled pairs and strategy 5 (triplets) has two groups of three neighboring contacts disabled, simulating various combinations of broken wires and short circuits. Each deactivated electrode contact was replaced by a spanned current steered signal (Snel-Bongers et al. 2011a). This resulted in 9 electrode pairs per strategy, as opposed to the 15 used in HiRes120. Like HiRes120 each analysis channel supported 8 current steered percepts, which resulted in 72 spectral channels along the array.

Table 1. Five different electrode array configurations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Reference strategy																
Reference 125% PW																
Singles				■		■		■		■		■		■		
Doubles			■	■				■	■				■	■		
Triplets			■	■	■							■	■	■		

■ *= non-active electrode*

The ability to perceive multiple percepts using current steering is described by the Just Noticeable Difference of the corrected α ($JND\alpha_c$) (Snel-Bongers et al. 2011a) or, more grossly the associated number of discrete percepts which can be perceived along the array (Firszt et al. 2007; Koch et al. 2007). For every participant a $JND\alpha_c$ was determined and the total number of discrete percepts calculated for each spanning condition

Sound quality rating

The participants made use of three speech processors during the testing period. On speech processor 1 and 2, the five different strategies were programmed in a randomized order, three strategies on processor 1 and two on processor 2. Three (the maximum capacity of the processor) of the five strategies (ref. 125% PW, singles and doubles) were programmed into speech processor 3, a research Harmony sound processor for the take home part of the study.

On the first appointment the current correction coefficient found to maintain equal loudness for spanning, found by Snel-Bongers et al. (Snel-Bongers et al. 2011a), was applied for all spanning strategies. This coefficient gives the average factor by which the total amount of current on the electrode pair has to be increased for $\alpha=0.5$ to obtain a percept with equal loudness to the apical electrode. For intermediate values of α, a linear interpolation was applied.

If a participant reported poor sound quality when the different programs were evaluated, the levels of the programs were manually adjusted as is done in clinical practice.

A single blind randomized controlled trial was used to determine whether there was a difference between these strategies in home situations. The participants used speech processor 3, with strategy 2, 3 and 4. The triplets were omitted, because this represented an extreme situation and was not believed appropriate for take home use. The participants were blinded for the strategies, but the researchers were not, since the programming had to be done manually. The participants were asked to use each strategy at home in five different situations (speech understanding in silence, with background noise, with ambient sound and with multiple speakers at the same time and, listening to music), and to use each strategy for at least 1 complete day. Over a three week period the sound quality of the three strategies relative to each other was rated on a Visual Analogue Scale (VAS).

Speech perception

After three weeks the participants were seen again for their second appointment. They handed in their VAS scores of the five different situations in home situations. Further, speech perception in quiet and with background noise was investigated during this appointment, using the standard Dutch monosyllabic (CVC) word test on a Decos Audiology Workstation (Decos systems B.V., Noordwijk, the Netherlands) with speech processor 1 and 2 (all five strategies). The results are expressed as the percentage of phonemes perceived correctly. The different strategies were tested in random order, counterbalanced across participants. Four runs, each containing 11 words, for a total of 132 phonemes were administered to each participant. Words were presented in free field at 65 dB SPL. Participants were familiar with this test method, as it is used routinely in the clinical setting. The experiment started by determining the Speech Reception Threshold (SRT), the signal-to-noise ratio (SNR) at which 50% of phonemes were perceived correctly using the participant's own HiRes120 program. The signal, as well as the competing speech-spectrum-shaped background noise, was delivered from a loudspeaker placed 1 meter in front of the participant. The signal level was maintained at 65 dB SPL. The noise level was increased until the participant was able to understand around 50% of the phonemes. The SNR found was then used to test speech reception with the other strategies for this participant.

Results

Sound quality rating

The VAS ratings of the participants, obtained in the take-home period of three weeks, for the five different situations described before (silence, background noise, appreciation of music, ambient sound and, multiple speakers at the same time) are shown in Figure 1 in a box plot. The median with quartiles range is shown and the

outliers are indicated with a dot. Each situation demonstrates a large variation between subjects in sound quality score, particularly the appreciation of music and listening to multiple speakers. The group mean scores however, are not significantly different between the three strategies tested (2, 3 and 4) for any of the five situations (p = 0.385), as determined with a linear mixed model.

Speech perception

The box plot in Figure 2 shows the phoneme scores for the five different strategies in quiet and with speech-spectrum-shaped background noise, obtained at the second appointment. In quiet the average score is around 80%, and by intent the scores in noise at SRT are around 50% (indicated by the dashed line). As expected on the basis of Figure 2 no difference was found between group mean scores for the normal pulse width and the125% pulse width, with a Wilcoxon Signed Rank test in quiet (82.7% vs. 84.7%; p = 0.475) and with a paired Student's T-test at SRT noise level (47.5% vs. 47.9%; p = 0.875).

When using a linear mixed model, no significant difference (p = 0.06) was found between the speech perception scores in quiet and in noise between the strategies with the 125% pulse widths (strategy 2, 3, 4 and 5). Since there was a difference between phoneme scores in quiet and in noise, the strategies were also compared for the two situations separately. In Figure 2 a negative trend can be observed for the results in quiet; strategy 2, an intact electrode array with a pulse width of

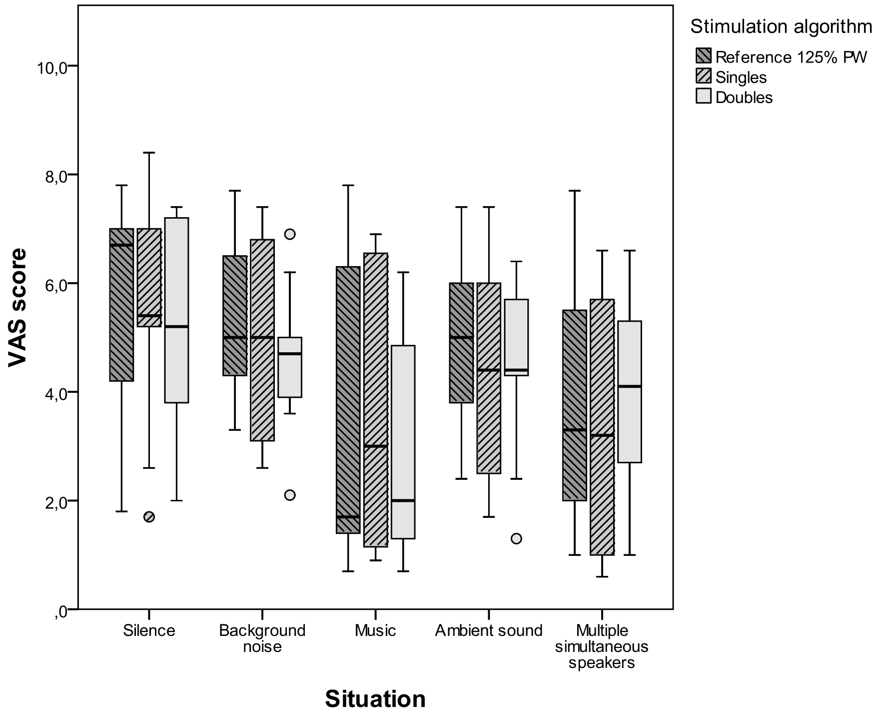

Figure 1. *The VAS-ratings (on the y axis) for the appreciation of the sound of three strategies (ref. 125% PW, Singles and Doubles) in 5 different situations (silence, background noise, appreciation of music, ambient sound and, multiple speakers at the same time) on the x-axis demonstrated with a box plot.*

125%, had a phoneme score of 84.7%, while strategy 5 (two spanned triplet gaps) had a score of 75.2%. Analyzing these data with a linear mixed model gave a significant decrease ($p < 0.001$) in speech perception with approximately 3% per extra spanned contact. No effect of the different strategies on speech perception was found when testing with speech-spectrum-shaped background noise ($p = 0.258$).

Number of discriminable percepts

On average the total number of discrete percepts found along the array for neighboring contacts, or spanning a single, double or triple contact gap was 28, 24, 22 or 17 percepts, respectively in the present study group. The number of intermediate pitches decreased significantly ($p = 0.040$) with increasing spanning distance. In a post hoc analysis with a linear mixed model, speech perceptions scores were compared with JNDα$_c$, in order to investigate whether JNDα$_c$ can be used as a predictor for speech perception scores for the different spanning conditions. However no association could be demonstrated between a high JNDα$_c$ and low speech perception score for the different spanning pairs (p = 0.789). Two of the participants showed a larger increase in JNDα$_c$ than the rest, namely up till 2, when increasing the spanning pair's separation. Leaving these subjects out the analysis of speech perception did not change the outcome of this analysis.

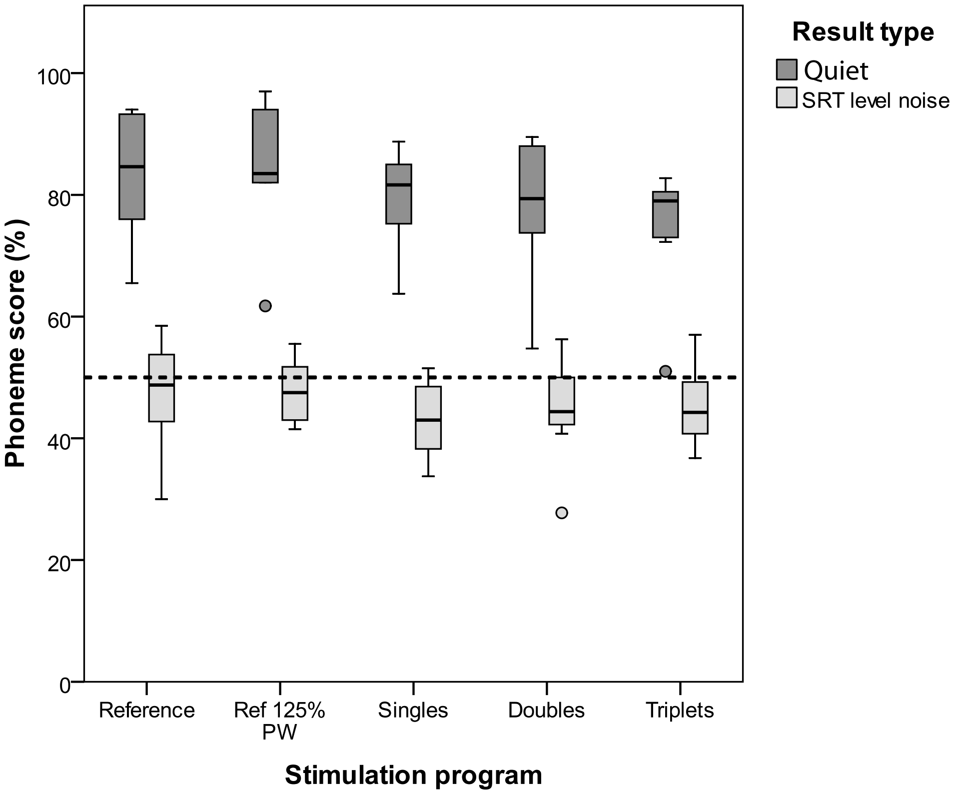

Figure 2. *Box plot of the speech perception data in quiet (dark grey) and with SRT level noise (light grey). The strategies (reference, ref 125% pw, Singels, Doubels and Triplets) are denoted on the x axis and the phoneme scores expressed in percentages on the y axis.*

Discussion

Earlier research concluded that spanning has reduced specificity with increasing distance, yet is a potentially useful mechanism to bridge a defective electrode contact in a speech coding strategy (Snel-Bongers et al. 2011b). To test the effectiveness of spanning in a real life situation, rather than in controlled psychophysical experiments, implementation of the spanning methodology in a speech coding strategy is required and comparative tests need to be performed. This study showed that HiRes120 with spanning yields on average the same scores as HiRes120 with current steering on adjacent contacts. However, the speech perception score measured in quiet showed degradation when increasing the spanning distance. In the European HiRes120 multicentre study of Buechner et al, participants with non-active contacts on their electrode arrays experienced major reductions in the number of analysis channels and had poorer speech perceptions scores (9; Boermans et al. 2008). One option could be to replace the HiRes120 strategy in such cases by a HiRes program, for which it is well-known, that even with 8 contacts good speech perception can be achieved (Frijns et al. 2003). The present study, however, indicated that such implant recipients would also benefit from implementation of spanning, which would enable them to continue using the HiRes120 speech strategy, especially because the non-active electrode contacts were always single contacts flanked by active electrode contacts.

Our participants used the various strategies (2, 3 and 4) in different situations at home and indicated that the sound quality of these different speech programs was the same. As expected, no overall difference between the five listening situations was found. Listening to music showed a diverse response from the participants, but no difference was found between the different strategies.

All the strategies were fitted individually, because even with the loudness correction from Snel-Bongers et al. (Snel-Bongers et al. 2011a), the participants were not content with the quality and loudness of their program. However, no significant difference was found between the levels of the different strategies. This indicates that individual fitting is still necessary to optimize listening and speech perception for bridged contacts, and thus that the Snel-Bongers et al. (Snel-Bongers et al. 2011a) correction may not be relied upon as a definitive fitting method. An easy solution would be to implement fitting the M-levels for the bridged virtual contacts just like the ones for the physical contacts in the clinical fitting software.

In line with previous research (Snel-Bongers et al. 2011a) the number of intermediate pitches decreased significantly ($p = 0.040$) with increasing spanning distance. Since no association could be demonstrated between a high JNDα$_c$ and low speech perception score for the different spanning pairs the number of intermediate pitches cannot be used to predict whether a participant will benefit in terms of speech perception from spanning when the electrode array contains one or more defective electrode contacts.

In the HiRes120 speech strategy, each of the 15 electrode pairs supports 8 spectral channels, resulting in 120 spectral channels. In this study we made use of 9 electrode pairs. With 8 spectral channels per pair, this led to a total of 72 spectral channels, resulting in a tonotopic reorganization and a change in rate compared to the participant's own program. The take-home experience was used to allow acclimatization to this new frequency distribution along the array, before the speech perception tests were performed. In future implementations this reduction in number of spectral analysis channels can be compensated by replacing a defective electrode contact with a spanned signal containing two new virtual pairs, each pair generating 8 spectral channels. This will also keep tonotopy and stimulation rate between defective and non-defective electrode arrays constant. As the number of perceived intermediate pitches decreased for several participants with increasing spanning distance, it would be of extra interest to test this new strategy in a follow-up study to determine the influence on speech perception, especially for larger spanning distances.

This more sophisticated approach is promising, as the present study already demonstrated that spanning defective electrode contacts in a HiRes120 speech coding strategy largely restores speech recognition scores in quiet and in noise to the level of an intact electrode array, while preserving the sound quality.

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