Cochlear Implantation as a treatment for unilateral deafness associated with ipsilateral tinnitus: a case study

Büchner A, Lesinski-Schiedat A, Battmer RD, Khajehnouri Y, Lenarz T
Medical University of Hannover, Department of Otolaryngology, Hannover, Germany

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Of the overall population, 10 to 30% suffer from chronic tinnitus [1,2] and the percentage is significantly higher in the population of deafened people [3]. Still, no universal cure is available today for this widespread problem. Several treatments, such as retraining or masking, are based on acoustic input [4]. In subjects who are deaf in the ear also suffering from tinnitus, these types of treatment are impossible. However, tinnitus suppression utilizing electrical stimulation of the hearing nerve has been reported to be successful by various research groups [5,6].

Therefore, this study was initiated to investigate whether cochlear implantation is an appropriate treatment for unilaterally deaf subjects who also have tinnitus in the deaf ear. For subjects with near normal hearing (NH) on the non-implanted side, the acceptance of sound quality produced by a cochlear implant system may prove questionable. In order to achieve the best conditions for the acceptance of the cochlear implant (CI) the device should fulfill the following criteria: a) High stimulation and update rate to achieve a good temporal resolution. In addition a stimulation rate above 1000 to 1500 pps seems to enable the stochastic behaviour of the auditory nerve fibres [7] and may therefore be beneficial for masking or suppression of tinnitus. b) Implementation of intermediate channels to achieve a good spectral resolution; Therefore the HiRes90K device was selected for this study.

The study will be conducted as a single-subject repeated measures design, with each subject serving as his or her own control. Subjects will be evaluated preoperatively using a battery of medical, audiological and psychological tests to determine candidacy and to establish baseline speech perception performance and tinnitus status. At the initial device fitting, all subjects will be programmed with the High Resolution (HiRes) processing strategy or HiRes 120 which implements current steering. Subjects were evaluated during the rehabilitation phase and at one month, 3, 6 and 12 months of device use with the following test battery: NRI measurements, performance evaluation via CI, performance assessment CI plus NH side with the OlSa, medical evaluation, psychosomatic evaluation, characterization of tinnitus, Quality Assessment Questionnaire regarding CI sound quality [8] and questionnaire regarding tinnitus status. On a monthly basis, processor settings were modified to investigate programming influences on tinnitus, device acceptance, and speech understanding. During these additional follow-up sessions the following tests were conducted: performance evaluation via CI only, medical evaluation and psychosomatic Evaluation (if necessary), characterization of tinnitus, Quality Assessment Questionnaire reg. CI sound quality [8] and questionnaire regarding tinnitus status. A sound localization test was performed at 5 and 11 months.

When testing the CI ear alone the aux-input to the speech processor was used to prevent any input though the normal hearing ear. A special interest of the study was to investigate whether the CI can restore spatial hearing to some degree. Therefore the Oldenburger Sentence Test (OlSa) was tested in noise with separated signal and noise sources. In all conditions the signal was presented from the front while the noise was either presented from the right (90°), from the front (0°), or from the left (-90°). Also, sound localization ability was tested in a circle of 12 loudspeakers using a short sentence as signal.

Currently one subject is implanted and data up to the six month evaluation are available. The subject is 48 years of age with a threshold of less than 20dB on the left side and a sudden hearing loss in 2001 followed by tinnitus on the left side. He has a speech perception of 100% in the Freiburger Monosyllabic word test. Even though he decided to participate in the study for cure of his tinnitus and received an implant in September 2006.

At first fitting the subject described the sound quality as hollow; however, speech in quiet was understandable immediately. Further optimization of the program could improve the sound quality slightly. The IDR has proven to have a big impact on sound quality; he prefers a setting of 40dB. The T levels had only minor impact. Subjectively as well as objectively the optimal stimulation rate of 2056 pps was found, which is slightly lower than the highest possible rate. His current program is shown in figure 1.

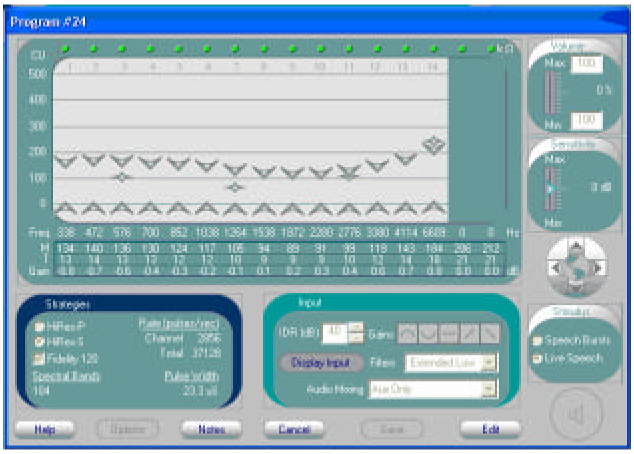

Figure 1: Preferred program: Current Steering strategy HiRes 120 with an IDR of 40dB, a pulse width of 23.3µs and T level at 10% of the M level

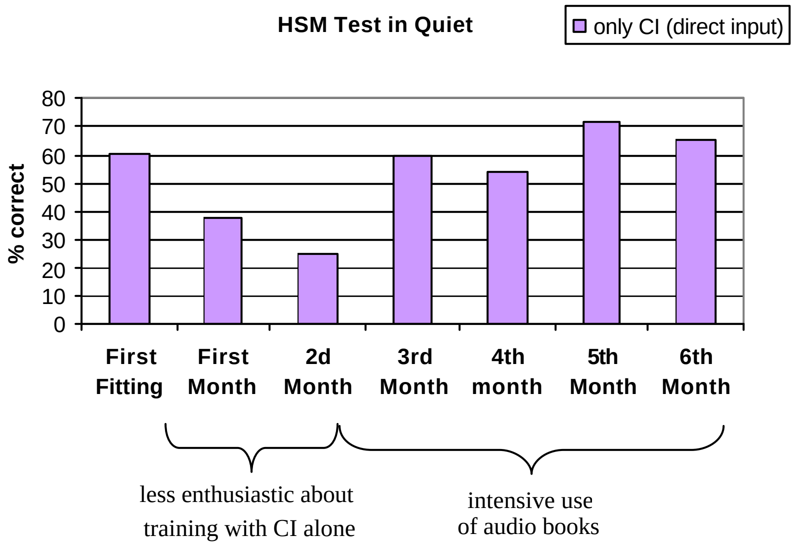

Fig. 2: Results in the HSM sentence test in quiet with the CI alone (signal coupled to the processor via auxilliary input)

For the two days directly after the surgery the subject was suffering from severe tinnitus. Without further treatment the tinnitus returned to a similar level as prior to surgery. Immediately after device switch on the tinnitus got softer and less detractive. However, when returning home the level increased again but without getting more detractive. During the last months the tinnitus got only debilitative twice, both in psychologically very stressful situations. The CI has only a short term effect on the tinnitus, i. e. the tinnitus returns to its previous level a couple of minutes after switching off the device.

Results of the HSM sentence test in quiet are shown in figure 2. During the rehabilitation phase where the subject stayed in the clinic for one week the CI side received specific training. The results obtained at the end of this week were better than during the following two months while the subject was not paying special attention to the CI alone. Therefore he was encouraged to regularly train the CI alone by listening to audio books via the direct input of the speech processor. In the following months the result in the sentence test increased again to about the same level as during the rehabilitation phase.

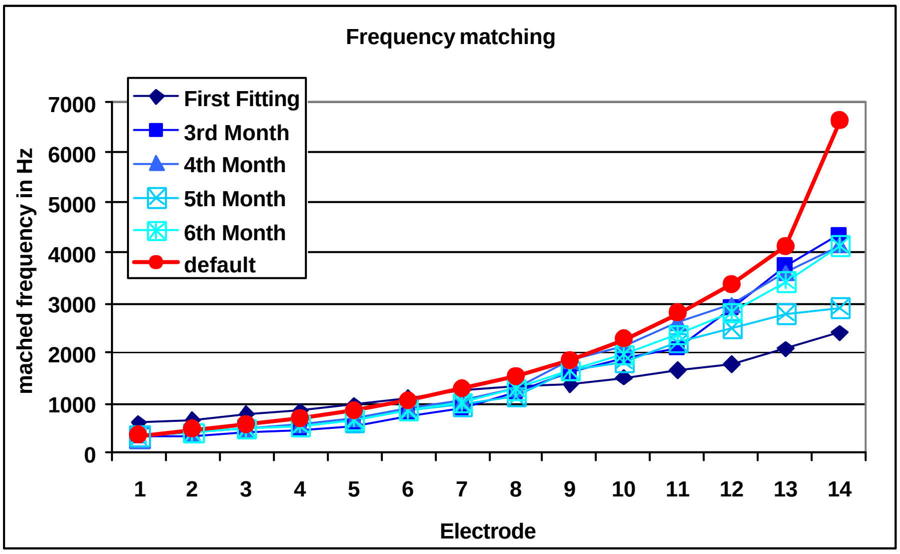

Fig. 3: Acoustically presented sinusoids matched in frequency to the pitch perceived through stimulation of physical contacts on the implanted side

When time allowed acoustically presented sinusoidal signals were matched to the pitch perceived when stimulating a single electrode, as shown in figure 3. During the rehabilitation phase the perceived frequency span was smaller than during the following months. Whether this indicates an increased frequency resolution following the CI usage or simply and adaptation to the default filter bank which is currently used needs to be investigated further.

A special interest of the study was also to investigate whether the CI can restore spatial hearing to some degree. Therefore the Oldenburger Sentence Test (OlSa) was tested in noise with separated signal and noise source. When noise was presented from the right, the CI brought mainly additional information regarding the noise. By adding the CI results stayed the same during the rehabilitation phase, decreased slightly at the three and four month appointment and increased at the half year appointment (Fig. 4a). When noise was presented from the left the CI improved the results as the subject benefits from the headshadow effect (Fig. 4b). Overall a slight improvement was also found when presenting signal as well as noise from the front (Fig. 4c). However, this benefit is not present during all appointments. The development of the improvement did not show any consistent direction and only the results of the headshadow effect were significant. Sound localization ability was tested in a ring of 12 loudspeakers using a short sentence as signal. The CI does not bring any significant improvement. However, the results using the normal hearing side alone are already in the order of bilateral cochlear implant users.

Even though no general conclusions can be drawn from this single case the results are overall promising. The subject accepted the cochlear implant and used it significantly. The speech perception performance through the cochlear implant alone were significantly lower than that of the average cochlear implant user having similar pre-conditions with respect to the deaf side of our study subject. It could be shown that the hearing performance through the CI is very dependent on the individual training of the “electric” hearing. Therefore it can be anticipated that the normal hearing ear is dominant for speech understanding in everyday situations. More intensive training for the cochlear implant ear alone may further improve speech perception. One can only speculate whether this also increases the ability of spatial hearing, which is currently still poor.

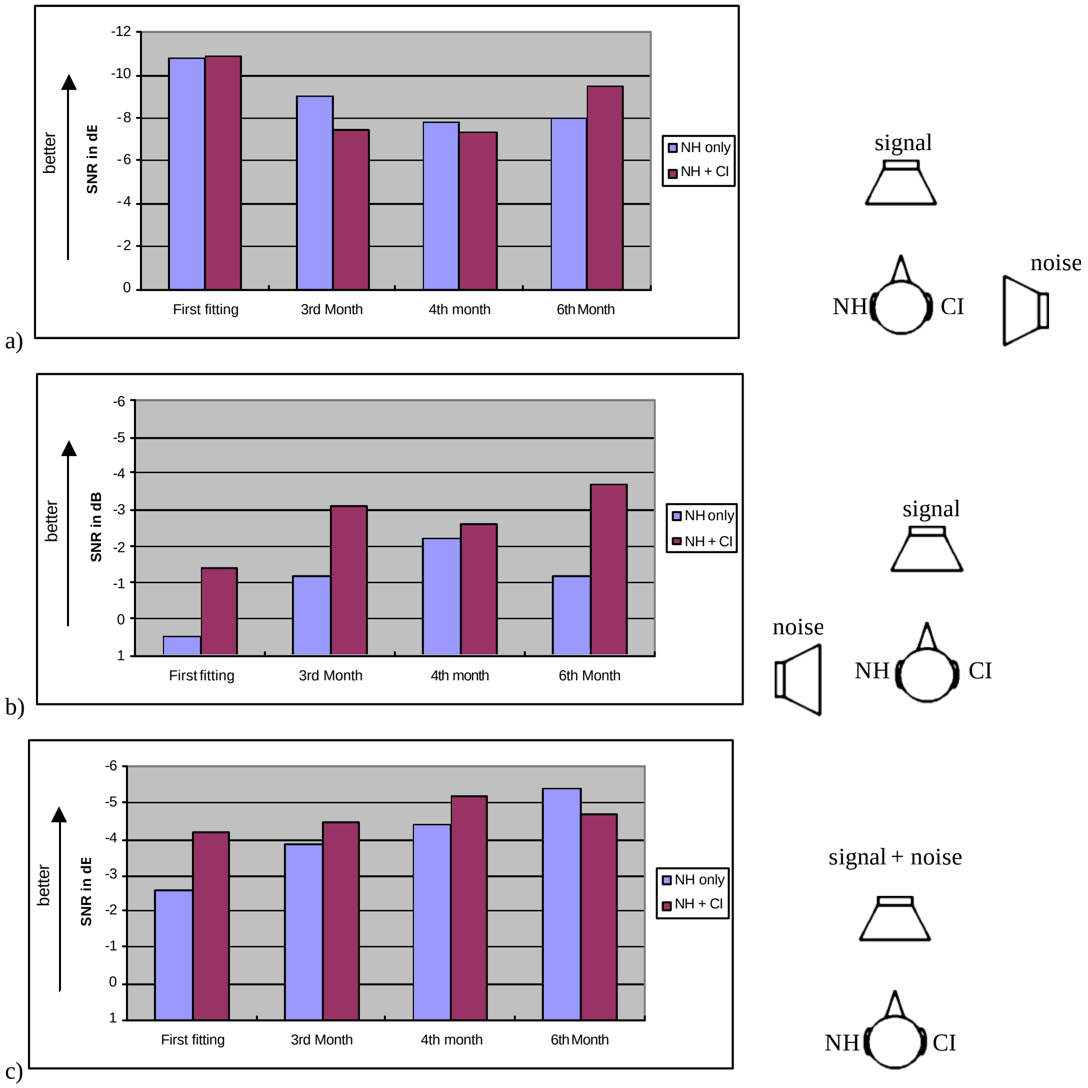

Figure 4: Results in the Oldenburger Sentence test with separated signal and noise sources; a) signal presented from the front, noise from the right; b) signal presented from the front, noise from the right; c) signal and noise presented from the front

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