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## Speech Performance and Training Effects in the Cochlear Implant Elderly

Annette Schumann, Anne Hast, Ulrich Hoppe

ENT Department, Cochlear Implant Center CICERO, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany

### Key Words

Cochlear implant · Aging · Auditory training · Quality of life · Speech performance

### Abstract

**Objectives:** Cochlear implantation requires acclimatization to the electrical input. Usually, cochlear implant (CI) listeners undergo an auditory rehabilitation program that includes auditory training sessions. Recently, it was shown that a phoneme-based training may improve speech perception abilities even in experienced CI listeners. The current study focuses on whether the effect of an auditory training program depends on the age of CI listeners. **Design:** Fifteen CI listeners took part in an auditory phoneme-based computer training program. Before and after training, speech recognition tests in moderate and difficult noise (+5 dB SNR and 0 dB SNR, respectively) were administered. Additionally, speech recognition was tested 6 months after the training (follow-up). A control group consisting of 12 subjects underwent audiometric testing without any auditory training. **Results:** Speech perception in moderate noise improved significantly during the training as revealed by comparing pre- and posttraining scores evaluated in the moderate noise condition. No significant change was observed for the difficult noise situation at 0 dB SNR. The speech perception measures of the control group remained unchanged. No significant effect of age on the training effect was observed. **Conclusion:** Speech recognition can be improved even in experienced CI listeners. When motivated to participate, senior CI users with long-term CI experience may benefit in a similar way from an auditory, phoneme-based computer training program as younger CI users.

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### Introduction

Hearing loss is one of the most frequent chronic diseases in patients older than 65 years. According to van Rooij and Plomp [1990], the proportion of elderly persons with problems in perceiving speech doubles per decade from 16% at the age of 60 to 32% at the age of 70 and to 64% at the age of 80.

Age-related changes occur not only in the middle ear and cochlea, but also in the central auditory pathways and the auditory cortex. It is well known that both outer and inner hair cells degenerate with age. The aging process is also associated with a decrease in spiral ganglion cells [Otte et al., 1978], changes in more central-auditory processes and a general decline in cognitive performance [Jeffrey and Jerger, 2005]. These problems of speech understanding among seniors may even be worse in more complex, noisy listening situations.

To evaluate the benefit of cochlear implantation in the elderly, it is necessary to take into account not only the risks of surgery and the development of speech recognition in quiet, but also in difficult noisy situations. Even for the best CI users, noise susceptibility remains a major challenge, and much work has been done to improve CI users' performance in noisy listening conditions [Fu and Nogaki, 2005].

There are a number of studies concerned with the outcome of cochlear implantation in older people; however, both methodology and results varied. Nonetheless, most of them report similar speech perception performance in quiet environments for older adults; however, some studies reported deteriorated speech understanding in background noise [Nakajima et al., 2000; Orabi et al., 2006]. Marginally poorer results of older CI listeners may be due to their reduced central plasticity and a reduced ability to interpret the electric input and artificial signal delivered by a cochlear implant (CI) system.

Evolving CI candidacy criteria have shown that the upper age limit of implantation has steadily increased over the past decades: An analysis of the deaf adults provided with a CI at the ENT Department in Erlangen revealed an increase from 55.5 years in 2004 to 61.0 years in 2013. This mean age increase in CI implantees is a consequence of both shorter surgical and fitting processes and a subsequently lower physical impact on the elderly as well as the increased communication demands of older subjects in their daily lives.

In a recent study performed with 50 CI listeners in Erlangen, it was shown that hearing-related quality of life as measured by the Oldenburg inventory was quite similar for two groups of CI users, younger (below 75 years) and older (above 75 years) [Hoppe et al., 2014]. No differences were found between the groups for speech perception ability in quiet or in noise. However, the study showed a tendency for older age to be associated with reduced speech perception ability; in particular, in complex listening situations having time-fluctuating noise.

Auditory training is an important aspect of CI rehabilitation, and has been shown to be an effective and efficient effort associated with further improvements in speech performance ability by numerous researchers [Henshaw and Ferguson, 2013; Schumann et al., accepted; Sweetow and Palmer, 2005]. It is primarily based on the belief that the plasticity of the central auditory system allows for improvement in speech perception in everyday listening. Training is of particular importance during the first months after implantation.

**Table 1.** Evaluation and training procedure for the training and control group participants

Time	Sessions	Participants	Evaluation and training
Week 1	session 1	training group control group	before training/before test: speech recognition scores at SNR = +5 dB and SNR = 0 dB
	<i>Auditory training</i>		
Week 2	session 2	training group	set 1 and set 2
	session 3	training group	set 3 and set 1
Week 3	session 4	training group	set 2 and set 3
	session 5	training group	set 1 and set 2
Week 4	session 6	training group	set 3 and set 1
	session 7	training group	set 2 and set 3
	session 8	training group control group	after training/after test: speech recognition scores at SNR = +5 dB and SNR = 0 dB
Week 30	session 9	training group	follow-up evaluation: speech recognition scores at SNR = +5 dB and SNR = 0 dB

Training was only performed for the training group in sessions 2–7 (as indicated by the grey background).

The aim of our study was to investigate whether specific phoneme discrimination training could improve speech perception in noise in experienced CI listeners; in particular, we were interested in differences in the performance of younger and older CI listeners.

## Methods

**Participants.** Twenty-seven CI adult listeners with more than 2 years' CI experience were randomly allocated to a training group (15 subjects) and a control group (12 subjects). All participants were provided with CI24RE, CI24R or CI512 implants from Cochlear (Cochlear Ltd., Sydney, N.S.W., Australia); no medical or surgical complications associated with implantation were noted, and no relevant comorbidities were known. Participants were native German speakers. Participants' age is representative of the CI listeners in our CI center (61 years). All of the participants had comparatively high communication demands and similar exposure to conversation in daily life at home and/or at work. All participants were willing to spend effort to increase auditory skills.

**Training Group:** Fifteen profoundly deaf adults (4 males, 11 females) took part in the auditory training. Age ranged from 49 to 75 years (mean age = 60 years), and the mean years of usage of the CI system was 4.2 years. The majority of participants were postlingually deafened with a mean duration of deafness of 17 years. Seven subjects were bilateral CI users and 8 were unilateral CI users. The mean monosyllabic speech recognition score (Freiburg test) was  $79 \pm 12\%$ .

**Control Group:** Five males and 7 females formed the control group. Age ranged from 34 to 76 years, with a mean age of 61 years. CI subjects used their CI system for 4.6 years on average. They were asked to complete speech perception tests; neither active nor passive auditory training took place. Comparable to the training group, the participants were postlingually deafened. The mean duration of deafness was 14 years. Three subjects used bilateral, 9 used unilateral CI systems. Speech perception in terms of monosyllabic score was comparable to the training group ( $77 \pm 11\%$ ).

**Training Procedure and Setup.** Table 1 shows the general auditory training procedure for the training group and control group participants. Training group participants completed a total of 9

sessions within a training period of 3 weeks (session 2–7) twice per week, and speech perception tests in sessions 1 (pretraining), 8 (posttraining) and 9 (6-month follow-up). Control group participants were tested and retested (session 1 and 8, respectively); no follow-up measures were done.

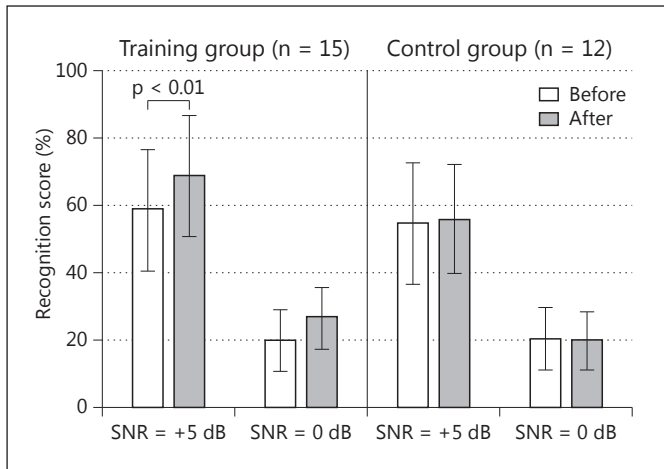
The training material used in the present study was part of a special computerized auditory training program for hearing-impaired adults [Serman, 2012]. The training package was designed to be user friendly, even for older participants, providing orthographical and auditory feedback, as well as optional repetition of the target sound. The participants could leave the training at any time. The duration of a complete session lasted between 45 and 60 min. Training was provided in a quiet room in the clinic supervised by a rehabilitationist.

Training material consisted of different syllable combination for consonants (VCV) and vowels (CVC), grouped in 3 training sets (set 1, set 2, and set 3). In each session, 2 of these 3 sets were trained. Each set included 30 target sounds in total; 14 CVCs and 16 VCVs. Only the variation of VCV combinations was different: VCV with /a/ (e.g. 'alla', 'appa', 'azza'), VCV with /e/ (e.g. 'elle', 'eppe', 'ezze'), and VCV with /i/ (e.g. 'illi', 'ippi', 'izzi'). Vowel combinations were part of each set as CVCs /m/ and /l/ (e.g. 'mumm', 'mimm', 'loll', 'lall'), each with 7 target sounds.

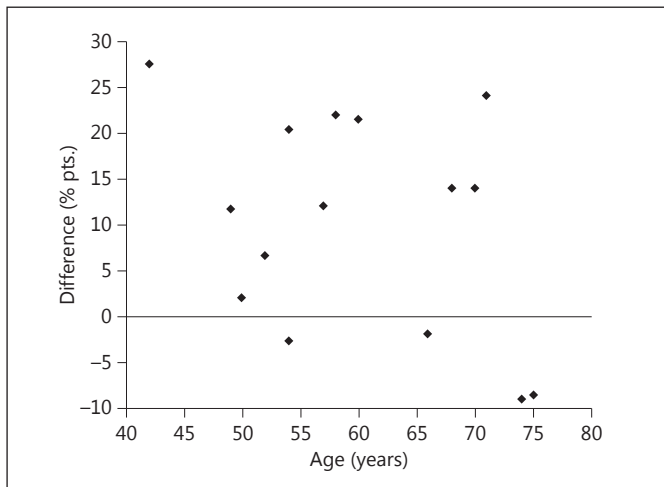
**Evaluation of Sentence Recognition in Noise.** The participants' sentence recognition in noise was measured with the Goettingen Sentence Test [Kollmeier and Wesselkamp, 1997] at two different noise conditions: a fixed +5 dB SNR (moderate noise), and a fixed 0 dB SNR (difficult noise). Speech and noise were presented from a frontally ( $S0^{\circ}N0^{\circ}$ ) placed loudspeaker. All test materials were presented in binaural conditions (two CIs or CI + HA), while the training condition was dependent on the preference of the CI listeners (all HA were switched off for training; bilateral CI users trained with 1 or 2 speech processors).

## Results

All 27 participants completed the 3-week study protocol. Most of the training group subjects reported that the training was helpful to them in dealing with everyday life listening situations.



**Fig. 1.** Sentence recognition scores for the two different noise conditions at +5 dB and at 0 dB SNR.



**Fig. 2.** Sentence recognition in the moderate noise condition (+5 dB SNR) as a function of age for all training participants.

*Sentence Recognition in Noise.* Figure 1 plots recognition performance for the training group and the control group separately on the left- and the right-hand side, respectively. On the left-hand side, the bars illustrate pretraining and posttraining performance for the training group participants on the 2 sentence tests in noise from left to right at +5 dB SNR and at 0 dB SNR, respectively, showing percent correct response. On the right-hand side the bars illustrate pretest and posttest performance for the control group participants on the 2 sentence tests in noise from left to right at +5 dB SNR and at 0 dB SNR, respectively, showing percent correct response.

Regarding the training group, a significant improvement is demonstrated only for the score at +5 dB SNR (two-sided paired t test,  $p = 0.005$ ), comparing pre- with posttraining test. Although an increase was shown for the difficult 0 dB SNR noise condition, no significance ( $p = 0.076$ ) was revealed. No significant differences

were obtained for the performance in the two different sentence recognition in noise for the control group (+5 dB SNR,  $p = 0.541$ , and 0 dB SNR,  $p = 0.642$ ).

*Training Effect as a Function of Age.* Figure 2 displays the score difference (score after – score before) for the sentence recognition in the moderate noise condition at +5 dB SNR as a function of age for all training group participants.

Evidently, most (11 out of 15) benefit from the training. Data suggest a negative influence of age; however, correlation analysis revealed no significant age effect (Pearson correlation:  $r = -0.37$ ,  $p = 0.17$ ).

## Discussion

The present study demonstrates that a structured phoneme-discrimination auditory training program is an effective intervention to further improve speech perception even in older experienced adult CI listeners. The amount of change in speech perception performance varies with the listening condition and individual characteristics. Interestingly, the training effect was not only for the speech material used in the training but the benefit was transferred to performance on conventional speech-in-noise tests with a moderate noise level (+5 dB). In more difficult situations with an SNR of 0 dB, no benefit from training was found. By implementing a control group, we confirmed that the improvements were not due to repeated measurements.

Regarding the training-induced changes for speech perception in noise at +5 dB SNR (fig. 2), the youngest subject demonstrated the highest benefit from the auditory training, while the performance of the 2 oldest subjects slightly decreased. Regarding these interindividual results, cognitive skills like attention, auditory memory span and speed of processing [Wong et al., 2009] may influence speech recognition particularly in a complex noisy environment. However, by using short phonemes as training material, the influence of these cognitive skills like the auditory memory span on the training can be assumed to be low. Besides, a different training setup, like a face-to-face training with a rehabilitationist, may be more effective for older subjects because of possible reticence in using computers. These issues might indicate that phoneme discrimination training is less effective in CI seniors, although statistical analysis revealed no significant correlation for speech perception and age in the current study. However, due to the limited number of subjects at this time, further research is needed.

Additionally, one must take into account that only motivated CI listeners were included in the study. This might have influenced the results in addition to the above-named aspects. The mean age of both the control (60 years) and training (61 years) groups was identical to the average age of CI listeners in our center in Erlangen (61 years); therefore, no systematic influence of age in the randomized selection of subjects for the study is evident.

## Conclusion

Phoneme-based training improves the speech perception of CI listeners; moreover, compared with a structured auditory training program, it benefits the speech perception performance of senior CI users above 65 years of age with long-term CI experience. The training may also benefit their hearing performance with unfamiliar speech material. No significant effect of age was observed on the amount of training effects obtained.

## Disclosure Statement

The authors state that there is no conflict of interest to be disclosed.

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Corresponding author:

Prof. Dr. Dr. Ulrich Hoppe  
Leiter Audiologische Abteilung und CI Centrum CICERO  
Hals-Nasen-Ohrenklinik, Universitätsklinikum Erlangen  
Waldstrasse 1, DE-91054 Erlangen (Germany)  
E-Mail ulrich.hoppe @ uk-erlangen.de