**Phonological representation and speech understanding with cochlear implants in deafened adults**

BJÖRN LYXELL¹, JAN ANDERSSON³, ULF ANDERSSON¹, STIG ARLINGER², GÖRAN BREDBERG³ and HENRIK HARDER²

Departments of ¹Education and Psychology, ³Technical Audiology, Linköping University, ²Audiology, Södersjukhuset, Stockholm


In the present study cognitive performance in 15 deafened adult cochlear implant candidates was examined and related to level of speech understanding after 12 months of experience with the implant. The implant group performed on par with normal hearing controls in all cognitive tasks used in the study with one exception: Performance was significantly lower in cognitive tasks where use of a phonological representation of sound is a key task-demand. Observations of the implanted individuals’ level of speech understanding indicate that only those individuals who, pre-operatively, were in possession of phonological representations comparable to that of normal hearing could follow and understand a speaker that was out of sight. The results are discussed with respect to (a) deterioration in the phonological representation of sounds as a function of absence of external auditory stimulation, and (b) the role of cognitive factors in predicting success in speech understanding with the implant.

**Key words:** Cochlear implants, phonological representation, cognition.

Björn Lyxell, Department of Education and Psychology, Linköping University, S-581 83 Linköping, Sweden. Email: bly@ipp.liu.se

The purpose of a cochlear implantation is to provide useful forms of auditory sensations to deaf or severely hearing-impaired individuals. The outcome of such implantation varies, however, widely among the recipients; some individuals are capable of following a conversation over the telephone, whereas others only can differentiate between the presence and absence of sound (Cohen et al., 1989; Lyxell et al., 1996; Summerfield & Marshall, 1995). In the present study, we will examine some possible cognitive, pre-operative predictors of post-operative speech perception performance 12 months after the implantation.

Three types of cognitive tasks will be focused on and related to post-operative level of speech understanding: phonological representations of sound (Campbell, 1991, Baddeley & Wilson, 1985; Conrad, 1979; Leybart & Charlier, 1996), verbal information-processing speed (Rönberg, 1990) and short-term/working memory capacity (Baddeley, 1997). All three tasks have previously proved to account for varying proportions of the variance in speech perception conditions where the stimuli are less well specified (visual, audio-visual and tactually supported speechreading, Rönberg, 1995; Rönberg et al., in press; Rönberg et al., 1996).

Previous studies have demonstrated that post-lingually deafened adults perform at a significantly lower level than normal hearing controls in cognitive tasks that require utilization of phonological representations (Lyxell et al., 1994; Lyxell et al., 1996). This is especially evident in tasks where the requirements of using phonological representations are explicit (e.g., rhyme-judgement tasks), whereas there is typically no difference between the groups when the requirements of using a phonological representation are existing, but less explicit (e.g., name matching; cf., Posner & Mitchell, 1967, or semantic decision making; cf., Shoben, 1982). Furthermore, a negative significant correlation between performance in rhyme-judgement tasks and the number of years the individual has been deaf indicates that access to phonological representations deteriorates as a function of duration of deafness.

An intact phonological representation should, at least intuitively, be important for individuals who receive cochlear implants. That is, a cochlear implant gives the individual auditory sensations and it is important that these sensations can be matched against existing phonological representations. Previous research has demonstrated that only those deafened adults who, pre-operatively, were in the possession of phonological representations comparable to normal hearing individuals could understand speech when the speaker was out of sight. So far this result applies to a follow-up made six months post-operatively.

Tests of short-term/working memory capacity are included because parts of the spoken signal transmitted by the implant may be missing or ambiguous. This in its turn requires the individual to temporarily store information to be able to fill in missing information (cf. Pichora-Fuller, 1996). Verbal information-processing speed represents the speed with which lexical items can be accessed from long-term memory and is assessed in this context because the spoken stimuli is degraded and relatively short-lived. Thus, a relatively slow access to verbal information would hinder and inhibit allocation of resources to other necessary processes (cf., Lyxell et al., 1996; Lyxell & Rönberg, 1992; Rönberg, 1990).
We will focus on the type of spoken communicative activity that the individual can manage after 12 months of experience with the implant and the subjects will be classified (based on clinical observations from members of cochlear implant teams, and self-reports from the implantees) into one of four categories with respect to their functional communicative ability. The categories are arranged on an ordinal scale, where the lowest level is awareness of environmental acoustical stimuli, the second is improvement in speechreading with the implant, next is the ability to understand speech when the speaker is out of sight, and finally, the highest level is the ability to understand speech transmitted by the telephone (cf., Brimacombe et al., 1990; Cohen et al., 1989; Lyxell, et al., 1996).

METHOD

Participants

Fifteen cochlear implant candidates (mean age 49.8 years) participated in the study and were given the cognitive tests at the time when they were candidates for implantation and visited the clinics for medical examination. None of the implant candidates had any functional residual hearing according to their most recent medical records. Fourteen of the participants received the Nucleus 22-channel implant and one the Ineraid system. Their post-operative hearing threshold after the implantation was determined by sound field testing, using warble tones and calibrating in terms of dB HL, with data according to ISO 226 (1987) as reference. The mean hearing threshold levels with the implant were for 500 Hz 34 dB, for 1 kHz 35 dB and for 2 kHz 33 dB.

Nineteen normal hearing individuals (mean age 54) matched for age, sex and verbal ability participated as controls on a voluntary basis.

Materials and Procedure

The cognitive tests were presented by means of a computer where the subjects had to respond by pressing pre-defined buttons (i.e., the reaction-time tests) or by means of oral responses (i.e., the memory tests). The tests presented here have previously been used to study speechreading, tactile-supported speechreading and speech understanding with cochlear implants under similar conditions as those mentioned above. A condensed description of the tests will therefore be presented here. For more detailed descriptions, the reader should consult Rönnberg (1995).

Tests

Name matching. The subjects’ task was to match as fast as possible two letters as having the same or different names (cf., Posner & Mitchell, 1967).

Lexical decision-making. The subjects’ task was to decide whether a string of letters constituted a real word or not (cf., Baddeley et al., 1985).

Semantic decision-making. The subjects’ task was to decide as fast as possible whether two simultaneously presented words rhymed or not (cf., Baddeley & Wilson, 1985).

Rhyme-judgement. The subjects’ task was to decide as fast as possible whether a presented word belonged to a pre-defined category of words or not (cf. Shoben, 1982).

Reading span test. The subjects’ task was to comprehend sentences and to recall either the first or the final words of a presented sequence of sentences in correct serial order (cf., Baddeley et al., 1985).

Word Span. The subjects’ task was to recall in correct serial order a string of words, which were presented one at a time on the computer screen. The first span size employed (after a practice session) was three words, the next was four and so on up to eight words.

RESULTS

The results will be presented in two parts, where the first part examines the cognitive performance in the two groups, and the second the relationship between pre-operative cognitive performance and post-operative level of speech understanding.

Cognitive performance

Similar to previous studies where cognitive performance in deafened adults has been examined there are no differences in performance compared to normal controls when tasks assessing working memory and speed of performance are considered (Lyxell et al., 1996; Lyxell et al., 1995). However, when level of accuracy is analyzed, the deafened adults perform at a significantly lower level (p < 0.05) in one condition of the lexical decision task (i.e., the pseudo-homophone condition) and in two of the conditions of the rhyme-judgement task: when the words in the word-pair are rhyming, but orthographically dissimilar in spelling and when the words are not rhyming, but orthographically similar in spelling (see Table 1). Performance in these three conditions is also significantly negatively correlated with duration of deafness (in the range of r = −0.50−−0.55; cf., Summerfield & Marshall, 1995). Clinical observations suggest a possible relationship between the individuals’ overt speech and their accuracy level on the rhyme-judgement tasks, such that the participants with a relatively intact overt speech were those with a high level of accuracy on the rhyme-judgement task.

Table 1. Mean performance (correct responses) for the two groups on the tests used in the study

<table>
<thead>
<tr>
<th>Test</th>
<th>Cochlear implants</th>
<th>Normal hearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading span</td>
<td>0.40</td>
<td>0.41</td>
</tr>
<tr>
<td>Word span</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td>Name matching</td>
<td>0.93</td>
<td>0.97</td>
</tr>
<tr>
<td>Semantic decision</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Lexical decision</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>No: homophones</td>
<td>0.81</td>
<td>0.94*</td>
</tr>
<tr>
<td>No: non-homophones</td>
<td>0.90</td>
<td>0.96</td>
</tr>
<tr>
<td>Rhyme-judgement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes: visually similar</td>
<td>0.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Yes: visually dissimilar</td>
<td>0.65</td>
<td>0.94*</td>
</tr>
<tr>
<td>No: visually similar</td>
<td>0.66</td>
<td>0.87*</td>
</tr>
<tr>
<td>No: visually dissimilar</td>
<td>0.89</td>
<td>0.99</td>
</tr>
</tbody>
</table>

*p < 0.05
The results from the present study constitute a replication of previously presented results when similar populations of individuals have participated (Andersson & Lyxell, in press; Lyxell et al., 1995; Lyxell et al., 1996). Deafened adults perform worse on cognitive tasks explicitly requiring the involvement of phonological representation. It is, however, important to note that the deafened adults perform on par with the controls on tasks that require use of phonological representations, but to a less explicit degree (e.g., semantic decision-making or the reading span task). Thus, the deterioration in the quality of their phonological representation is not a question of all or none.

**Cognitive performance and level of speech understanding with the implant**

The fifteen implantees were classified into one of four categories with respect to their functional communicative ability. Four individuals can (to various degrees) communicate with other individuals by means of telephone. Four individuals can with some effort follow a conversation when a familiar speaker is out of sight and when the topic is somewhat familiar. Furthermore, three individuals improve their speechreading with the implant (on average with 30% compared to a visual condition), two skilled speechreaders do not improve their speechreading, but report that their speechreading is less effortful with the implant. Finally, two subjects experience only sound awareness and some ability to identify environmental sounds.

An examination of the individuals’ cognitive capacity suggests that there is a correspondence between pre-operative verbal cognitive performance and post-operative level of speech understanding. Common to all eight individuals who manage a conversation when the speaker is out of sight and when the topic is somewhat familiar. The seven individuals who improve their speechreading or receive some sound awareness perform, on the other hand, poorly on the lexical decision-making and the rhyme-judgement tasks. The individuals in the four categories performed roughly equal on the name matching and the semantic decision-making tasks.

The picture is less clear when the memory tests are considered. The eight individuals who manage to listen to speech when the speaker is out of sight outperform the other individuals with a factor of 1.5. It is, however, interesting to note that two individuals in the “better” group of implant users, perform relatively poorly on the two memory tasks. Thus, it seems to be possible to understand a speaker that is out of sight with a relatively poor working memory capacity, whereas this is not possible without an intact representation of sounds. Therefore, the cognitive support picture is even simpler compared to the 6 months follow-up.

**CONCLUSIONS**

The present study was designed to examine some possible pre-operative cognitive predictors of post-operative levels of speech understanding. The results can be summarized in the following way: the quality of the deafened adults’ phonological representation is deteriorating as a function of absence of external auditory stimulation and this deterioration is possibly related to the level of speech understanding with 12 months experience with the implant.

It is important to note that the deterioration of the quality of the phonological representation is not complete across all cognitive tasks, rather it is restricted to those tasks where the demands on utilization of phonological representations are most explicit (c.f., Hanson & McCarr, 1989). In the present study, we can observe this effect in conditions of the rhyme-judgement task and the lexical decision-making task. This does not, however, preclude the possibility that the deterioration effect is also present in short-term/working memory performance. It may well be the case that this effect is observable on short-term/working memory tasks given that a more pronounced phonological manipulation of the material to-be-remembered is made. Support for such an assumption comes from results recently gathered in our laboratory (Andersson & Lyxell, in press).

A correlation between performance on those tasks and duration of deafness suggests that this deterioration is progressive in nature. Independent evidence for such a claim comes from studies using the PET-scan methodology where declining metabolic activity in the auditory cortices correlates with duration of deafness (Ito et al., 1993). However, the correlation is far from perfect; some individuals manage to keep their phonological representations intact despite the fact that they have been deaf for a substantial number of years. A question for further research is to specify more precisely the factors that make it possible for some individuals to maintain their phonological representation relatively intact.

The results suggest that the role of an intact phonological representation in cochlear implantees is that the individual must possess an ability to match the experience of external sound with an existing internal representation of sounds. Given that this possibility does not exist the individual will inevitably suffer from difficulties to interpret the sensations of sounds from the external world. In the present population, we can observe two individuals who are capable of following a telephone conversation despite a less capacious working memory, but who are in possession of intact phonological representations. The outcome from these two individuals implies that a capacious working memory is not a necessary feature for auditory speech understanding, if the demands on working memory are normal in the conversation. That is, given that the individuals’ phonological representations are intact, less spoken
Table 2. Accuracy level for the tests of working memory, lexical decision making and rhyme-judgement for each category.

<table>
<thead>
<tr>
<th></th>
<th>Telephone conversation</th>
<th>Listening</th>
<th>Speechreading improvement</th>
<th>Sound awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading span</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = 5</td>
<td>n = 3</td>
<td>n = 5</td>
<td>n = 2</td>
</tr>
<tr>
<td>Yes</td>
<td>0.54</td>
<td>0.39</td>
<td>0.40</td>
<td>0.06</td>
</tr>
<tr>
<td>No: homophones</td>
<td>0.96</td>
<td>0.95</td>
<td>0.93</td>
<td>0.87</td>
</tr>
<tr>
<td>No: non-homophones</td>
<td>0.98</td>
<td>0.90</td>
<td>0.63</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Rhyme-judgement:

<table>
<thead>
<tr>
<th></th>
<th>Yes: Visual similar</th>
<th>Yes: Visual dissimilar</th>
<th>No: Visual similar</th>
<th>No: Visual dissimilar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0</td>
<td>0.88</td>
<td>0.88</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>0.99</td>
<td>0.87</td>
<td>0.86</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>0.90</td>
<td>0.41</td>
<td>0.40</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>0.90</td>
<td>0.37</td>
<td>0.43</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Information will be missing or ambiguous, thus reducing the demands on the individual to keep decoded parts of the conversation in working memory. Working memory might, for the same reason, be critical for those individuals with less intact phonological representations as parts of the spoken signal always will be missing or ambiguous to them. Thus, it is critical for the outcome that they have the capacity to store as many parts as possible of the parts of the conversation that they have been able to understand and then to use this information to make inferences about missing pieces of information or to disambiguate ambiguous parts.

In the present study we have demonstrated that the phonological representation of deafened adults deteriorates progressively as a function of absence of auditory stimulation. The question is whether a cochlear implantation can alter this state of affairs. Results from cognitive testing at the 6- and 12 months follow-up suggest that this is the case such that we do not observe signs of further deterioration in the individuals with less intact phonological representations. On the other hand, we have not yet observed improvements in these individuals.

The present research was supported by a grant from the Swedish Council for Social Research awarded to the first author. Parts of the results from this study was presented at the AVSP ’97 Conference (Sept. 1997), Rhodes, Greece. Ulla-Britt Persson is thanked for checking the language.

REFERENCES


