Cognitive development in children with cochlear implants: Relations to reading and communication

Abstract

The purpose of the present article is to present an overview of a set of studies conducted in our own laboratory on cognitive and communicative development in children with cochlear implants (CI). The results demonstrate that children with CIs perform at significantly lower levels on the majority of the cognitive tasks. The exceptions to this trend are tasks with relatively lower demands on phonological processing. A fairly high proportion of the children can reach a level of reading comprehension that matches hearing children, despite the fact that they have relatively poor phonological skills. General working memory capacity is further correlated with the type of questions asked in a referential communication task. The results are discussed with respect to issues related to education and rehabilitation.

Key Words

Cochlear implant
Behavioural measures
Psychoacoustics/hearing science
Paediatric

Abstract

El propósito de este artículo es presentar una perspectiva de una serie de estudios realizados en nuestro laboratorio sobre el desarrollo cognitivo y comunicativo de niños con implante coclear (IC). Los resultados demuestran que los niños con IC rinden en niveles significativamente más bajos en la mayoría de las tareas cognitivas. Las excepciones a esta tendencia son las tareas que tienen una demanda relativamente menor en el procesamiento fonológico. Una buena proporción de los niños pueden alcanzar niveles de comprensión de la lectura equiparables a los de niños oyentes, a pesar del hecho de que tienen habilidades fonológicas relativamente pobres. La capacidad de memoria general se correlaciona además con el tipo de preguntas presentadas en una tarea referencial de comunicación. Se discuten los resultados con respecto a lo relacionado con la educación y la rehabilitación.

In the present paper we will give an overview of results from a set of studies focusing on the development of working memory capacity, phonological processing skills, and lexical abilities and how these three relate to reading and communication skills. Working memory capacity, phonological processing skills, and lexical abilities are cognitive components that are central for processing of information in most language-related activities (e.g. reading, speech understanding, communication). Furthermore, they are composite skills such that they are constituted by a number of different sub-components, where each sub-component serves a specific purpose (e.g. the phonological loop, which is responsible for processing and storage of phonological information in the working memory system, Repovs & Baddeley, 2006). A general strategy has been to examine three to five sub-components within each of the three components. This strategy will enable us to study whether the auditory stimulation from the CI promotes a general development (i.e. all sub-components) or whether the benefits of CI are restricted to some specific sub-components (e.g. the phonological loop in working memory).

Previous research on working memory in children with CI has demonstrated that their phonological storage capacity varies widely among the children. Dillon (2004), using a nonword...
repetition task, found that the performance of eight and nine-year old children varied between 8% and 76%. These results corroborate our own findings for Swedish children with CI (Willstedt-Svensson et al, 2004, Ibertsson et al, 2008) Nonword repetition scores were correlated with measures of word recognition, auditory language comprehension, and speech intelligibility. Similar results have been reported by Pisoni (Pisoni, 2003; Burkholder & Pisoni, 2003), who also demonstrated a relationship with type of communication mode. That is, children who used total communication (i.e. sign language in combination with orally spoken words) had shorter forward digit spans than those children who relied on oral communication only. These results indicate that the amount and quality of exposure to oral language may influence the development of the phonological component of working memory in deaf children with CI. The general (i.e. storage and processing) and the visual aspects of working memory are less well examined. Pisoni (2003) demonstrated that children with CI performed at a lower level than hearing children in a backward digit span task. The backward digit span task is assumed to tax both the storage and processing component of working memory. In the present set of studies, we have examined working memory capacity in children with CI by means of tests that assess general working memory capacity, the phonological loop, the visuospatial sketchpad, and the central executive (cf. Repovs & Baddeley, 2006).

Phonological skills refer to the ability to process phonological information. Phonological skills are important predictors for vocabulary learning and reading acquisition in young children with normal hearing (e.g. Kjeldsen et al, 2003; Muter et al, 2004). For children with CI, studies have found that measures of reading comprehension and word decoding correlated with phonological skills (Geers, 2003; Dillon & Pisoni, 2004; Asker-Arnason et al, in press). The implication from these results is that children with CI, as with hearing children, use phonological (coding) skills in reading.

Lexical access is the process of finding and retrieving verbal labels from long-term memory. Lexical access (i.e. speed and accuracy) is a predictor of reading and spelling performance in children with normal hearing, independent of their phonological skills (Plaza & Cohen, 2003; Swan & Goswami, 1997). Children with reading disabilities usually display difficulties in tasks requiring lexical access, and the difficulties are usually associated with problems in identifying and discriminating phonologically similar syllables in oral speech (Mody et al, 1997). Less distinct phonological categories in long-term memory have been suggested to account for a substantial part of these difficulties (Elbro et al, 1998). Therefore, children with reading impairment may display difficulties in mapping written graphemes to phonemes in the long-term phonological store. Lexical access in children with CI has not, to our knowledge, been examined previously and it is reasonable to assume that these children may have less defined phonological categories in long-term memory due to their different auditory experiences (Svirsky et al, 2000). It is important to study lexical access skills in children with CI in order to investigate the quality of their phonological representations in long-term memory, and the speed with which these representations are accessed. This is particularly important because lexical access skills might help in predicting later reading and spelling performance in this population.

In a first set of studies the purpose was to examine and compare development of working memory capacity, phonological, and lexical skills in children with CI and normal-hearing children. A second purpose was to relate performance in these three cognitive abilities to performance on a global test of reading ability.

**Method**

**Participants**

Thirty-one children with cochlear implants participated in this set of studies (18 girls). The children were between 6 to 13 years old. Their median age was 8.6 years. All of the children with CI were deafened before 3.0 years of age and were implanted within the Paediatric Cochlear Implant Programs in Lund, Gothenburg, Linköping, or Stockholm and were seen in sessions at their school or at a regular summer camp for children with CI and their families. The children with CI were age-matched to a group of 96 normal-hearing Swedish children so that for each year between 6 to 13 years there were 12-14 hearing children. For further details on the children, the reader should consult Wass et al, (in press), and Asker-Arnason, (in press).

**Materials**

**Test of working memory**

*Serial recall of nonwords, and nonword repetition:* These two tests assess the phonological part of working memory. In the former test the task is to repeat lists of nonwords of increasing length and in the latter task, individual nonwords of increasing length from one to five 1-syllable-nonwords. In both tests, performance was scored both binary as either correct or incorrect, and as percent consonants correctly reproduced (pcc).

*Sentence completion and recall:* The test was designed following procedures developed by Towse et al (1998) and was used to assess general working memory. The task is to listen to a series of sentences, fill in the missing last word in each sentence, e.g. ‘Crocodiles are green. Tomatoes are . . .’, and thereafter to repeat the words of each of the sentences presented. The series of sentences included two, three, and four sentences.

*The visual matrix patterns test:* The test was designed following procedures developed by Della Sala et al (1999), and was used to assess visuospatial working memory. In this test, a pattern of filled cells in a five by five matrix is displayed for two seconds on the computer screen. Thereafter, the task is to replicate this pattern of filled cells in an empty matrix. The level of difficulty increases from one to eight filled cells.

**Tests of phonological skills**

*Phoneme segmentation:* The test assesses the ability to identify phonemes in real words. The child is asked to mark each phoneme in a number of words by pressing a computer key.

*Phoneme identification:* The test assesses the ability to identify phonemes in nonwords presented auditorily. The task is to decide whether a certain phoneme was present in an auditorily
presented nonword, and to confirm by pressing a computer key only when the phoneme was present. An example would be: ‘Is there an /sl/ in nessolâ?’

**Phonological representations:** This test assesses the quality of phonological representations of real words in long-term memory by asking the child to indicate which of five alternative productions of a word is correct or not. The representations of three different phonemes (s, n, t) were tested in three different positions of words, initial position, middle position, and final position.

**Word discrimination:** The word discrimination test was designed as a complementary test to the test of phonological representations. In this test, each target word was presented in live voice by the experimenter, once together with one of its corresponding distracters from the phonological representations test, and once then together with an identical target word. The task was to decide whether each pair of words/nonwords was identical or not. The purpose of the test was to find out whether the children could discriminate between the speech sounds.

**Nonword discrimination task:** The task was used to assess the ability to decide whether two auditorily presented nonwords were identical (Reuterskiöld-Wagner et al, 2005). The nonwords were presented in 16 pairs and each target nonword was presented in two conditions, once together with an identical nonword and once together with a similar nonword, differing by one single phoneme, e.g. patinadrup- patinadrup, patinadrup-patinavrup. The task was presented on the computer, and the task was to press a computer key when hearing two identical test stimuli.

**Tests of lexical skills**

**Passive naming test:** The test was designed following procedures developed by Johnson et al (1996). The child is asked to identify an auditory presented noun by clicking on the corresponding picture out of four alternatives displayed on the computer screen.

**Wordspotting:** The test was designed following procedures developed by Cutler (1997), and assesses the ability to identify a real word in a context of nonsense words.

**Semantic decision making test:** The test was designed following procedures developed by Hällgren et al (2001) and assesses the ability to identify words of a predefined semantic category. The task is to press a key on the computer when presented with a noun that belongs to a certain, semantic category.

**Nonverbal intelligence:** Nonverbal intelligence was tested by means of the block design test from the WISC-III battery (Wechsler, 1991). This test was chosen because it does not require oral/auditory skills, and because the scores estimated from this test are correlated with performance on the entire WISC-III battery.

**Tests of reading comprehension**

Reading comprehension was assessed by the Woodcock reading comprehension test and the SL 40/SL 60 (Swedish tests of reading comprehension). The SL 40 is adapted for children aged six to nine years, and the SL 60 for children aged 10 to 14 years. The Woodcock reading comprehension test was used in one set of studies, and the SL 40/60 in a second set of studies.

**Procedure:** The tests were presented by means of a computer-program, SIPS (sound information processing system). This program is computer-based and enables presentation of stimuli in two modalities, auditory and text. The program also gives opportunity to record the participants’ responses in two ways, speed of performance and level of accuracy.

**Results**

The results from the cognitive tasks and the tests of reading comprehension are summarized in Tables 1 and 2. The results were analysed by means of group comparisons (t- and F-statistics), and at an individual level by means of an analysis of how children with CI differ from hearing children in the tasks in the study, and by means of correlational analysis.

There were no differences in non-verbal intelligence between children with CI and hearing children. In the cognitive tasks, the children with CI had a generally lower level of performance than the hearing children in all tests, except for the visuo-spatial WM test, and the latency measure of the phonological skills measure. Standard deviations were generally larger in the group of children with CI. The results for tasks assessing phonological and general (i.e. storage and processing) aspects of working memory is in line with results reported by Pisoni & Cleary (2003), whereas the results for the task assessing the visual part of working memory is a novel finding. The results for the phonological tasks are also in line with previous reported results (Asker-Arnason et al, in press; Pisoni & Cleary, 2003). It is, though, interesting to note that there is no difference between children with CI and hearing children in one condition; the response-time was similar for those items in both the phonological and lexical tasks.

**Table 1.** Comparisons of performance between children with CI and hearing children. The signs < and > indicate a statistical significant difference between the two groups.

<table>
<thead>
<tr>
<th>Working memory</th>
<th>Group comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>General capacity</td>
<td>NH &gt; CI</td>
</tr>
<tr>
<td>Visual WM</td>
<td>NH = CI</td>
</tr>
<tr>
<td>Phonological WM</td>
<td>NH &gt; CI</td>
</tr>
<tr>
<td>Phonological tasks</td>
<td></td>
</tr>
<tr>
<td>Proportion correct answers</td>
<td>NH &gt; CI</td>
</tr>
<tr>
<td>Response-time</td>
<td>NH &lt; CI</td>
</tr>
<tr>
<td>Response-time for correct answers</td>
<td>NH = CI</td>
</tr>
<tr>
<td>Lexical tasks</td>
<td></td>
</tr>
<tr>
<td>Proportion correct answers</td>
<td>NH &gt; CI</td>
</tr>
<tr>
<td>Response-time</td>
<td>NH &lt; CI</td>
</tr>
<tr>
<td>Response-time for correct answers</td>
<td>NH = CI</td>
</tr>
<tr>
<td>Reading ability</td>
<td></td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>NH = CI, NH &gt; CI</td>
</tr>
</tbody>
</table>
For the reading comprehension task, the children with CI performed on par with hearing children in one study (Waas et al., 2008) and at a slightly lower level in a second (Arnason et al., in press. It should be noted that the children in the two studies had similar background characteristic). These results are roughly similar to results reported by Geers and her colleagues (this issue) for children in the same age-span. A novel finding is that the children with CI performed on par with hearing children on the decoding tasks (Wass et al., 2008).

The correlational pattern displays a similar pattern between children with CI and hearing children. The general trend is that the magnitude of the correlation coefficients are somewhat stronger in the group of children with CI. Reading comprehension is significantly correlated with the tests of working memory, and most of the phonological and lexical tasks. It should be noted though, that the correlation between reading comprehension and the lexical skills disappears when chronological age is partialled out. Lexical skills are more strongly correlated for the younger group of children.

An analysis of variation of the proportion of children with CI that perform within one standard deviation (SD) from the mean of the hearing children is presented in Table 2. The results indicate that 45–65% of the children with CI perform within one SD for the tasks that tax general working memory capacity and lexical access. For the tasks that taps the phonological working memory and the phonological tasks used in the present study, only 11–20% reach the criterion of one SD.

In summary, children with CI perform at a significantly lower level on most cognitive tasks used in this study. However, the magnitude of difference is dependent on the type of task, such that there is a large difference in tasks where the demands on phonological processing are more prominent, and the difference is smaller in tasks with less demands on phonological processing.

**Table 2. Proportion of children with CI performing within 1 SD of normal-hearing children.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Proportion of Children with CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>General WM capacity</td>
<td>65%</td>
</tr>
<tr>
<td>Lexical access tasks</td>
<td>45%</td>
</tr>
<tr>
<td>Phonological WM</td>
<td>20%</td>
</tr>
<tr>
<td>Phonological tasks</td>
<td>11%</td>
</tr>
<tr>
<td>Reading comprehension</td>
<td>84%, 66%</td>
</tr>
</tbody>
</table>

Referential Communication and Cognitive Skills

Most studies of children with CI are experimental studies using test paradigms or analyses of structural aspects of language. Few studies explore how children with CI communicate with peers in everyday verbal interaction (Ibertsson et al., 2008). The purpose in this part of the project was to examine everyday communication in children with CI. Conversational skills were assessed by means of a referential communication task requiring the description of pictures depicting faces. The task is to describe something or someone so that the listener can identify what she/he is describing (Lloyd, 1999). The degree of success that individuals with hearing impairment achieve in conversations has been measured by the extent to which the conversation partner requests clarification (Erber, 1996). Requests for clarification are used in order to avoid misunderstandings or communication breakdowns caused by a message not being heard or understood. Previous studies on the use of requests for clarification in conversation in children with severe to profound hearing impairment show a limited use compared to hearing children (Tye-Murray & Geers, 2003; Lederberg & Everhart, 2000).

Procedure: Conversational skills were assessed in a referential communication task where the children with CI and a hearing partner chosen by each of the children with CI, were seated on each side of a 30-cm tall screen. The dialogues were compared to dialogues between two hearing children, where one child was matched to the child with CI. The task was to describe a set of 16 pictures depicting faces so that the partner could identify each face from another set of 24 pictures and arrange the set of pictures in the same way as the set in front of the describer (e.g., he has green eyes, red hair, and a hat). Both the child with CI and the hearing partner acted as describer as well as receiver.

The requests for clarification were first classified into the main categories non-specific and specific requests for clarification. Specific requests were further classified into different sub-categories. Four types of requests for clarification were counted: non-specific requests for clarification (e.g., 'What?' or 'Huh?'), requests for confirmation of new information (e.g., 'Has he got blue eyes?'), requests for confirmation of already given information (e.g., 'Did you say that he had blue eyes?'), requests for elaboration (e.g., 'What colour are his eyes?'). For each conversation we measured the time it took for each pair to solve the task, the number of requests for clarification, and the different types of requests for clarification. Cognitive skills were assessed by means of the same cognitive tasks previously described.

Results

General working memory capacity was significantly correlated with the types of requests the children made. A positive correlation was obtained for questions requesting new information (i.e., pushing forward the conversation) and a significant negative correlation was displayed for conditions where they requested confirmation of whether they had understood the message (i.e., not being sure). The implication of this outcome is general working memory serves an important function with regard to how the child can handle a complex processing situation such as a referential communication task.

Additional results also demonstrated that children with CI used more requests for confirmation of new information than hearing children, and also that they used less request for confirmation of already given information and requests for elaborations. A somewhat unexpected result was that the children with CI asked more often for confirmation of new information (i.e. requests formed as yes/no questions) than the hearing children.

General discussion

The results from the present set of studies demonstrate that children with CI perform on a lower level than hearing children on most cognitive tasks. This is an empirical pattern that is in line with previous research in the area (see, Pisoni et al., in press, for an overview). It is, however, important to note that the magnitude of difference between the children with CI and
hearing children is dependent on the type of cognitive task employed. There is generally a large difference in tasks requiring extensive phonological processing (cf. phonological working memory), whereas the difference is much smaller and sometimes eliminated in cognitive tasks with less extensive demands on phonological processing. One implication of the results is that it is necessary to adopt a research strategy on children with CI that allows for a careful examination of how cognitive skills develop in order to document which aspect (or sub-component) of a given cognitive skill (e.g. working memory) follows a normal developmental trend, and which aspect deviates from such a trend. The type of knowledge that might be gained from such strategy might be used to assess the efficacy in different rehabilitation and educational programmes.

Most children in our study reached a fairly high level of reading comprehension. This is not a new result for children with CI in this age-span; similar results have been reported previously by other researchers (cf. Geers, in press, Pisoni et al, in press, for overviews). Reading, and specifically the process of reading acquisition, is a cognitive process that draws heavily on phonological processing and it is interesting to observe that they can reach fairly high levels of reading comprehension, despite the fact that they have relatively poor phonological skills. One candidate for explanation for this mismatch is that the CI-users are employing other word-decoding strategies than hearing children. For example, they may use decoding strategies that include the orthographical and phonological properties of printed words. It is a task for further research to more precisely determine this issue.

Results from the referential communication task demonstrated that there is a relation between the children's general working memory capacity and their communicative behaviour (i.e. in terms of type of questions asked). Furthermore, children with CI asked for more clarification of new information than hearing children.

The finding that general working memory capacity correlates with communicative behaviour is an important novel finding and may also have implications for design of rehabilitation programmes, particularly those aspects of programmes that focus on communication skills (Ibertsson et al, 2008). That is, it is important that the child is instructed to use a communication strategy that matches his/her level of cognitive skill. Children with CI asked for more clarifications of new information than hearing children, and the interpretation of this outcome is that the children with CI, by using this strategy, are controlling the conversation and leading it forward, to increase their control over the response from the conversational partners. The results are also an implication that the children have some awareness of the consequences of their hearing impairment and this awareness makes them more active (they request more) with the partner in order to anticipate misunderstandings.

Acknowledgements
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References


Spencer P.E. 2004. Individual Differences in Language Performance after Cochlear Implantation at One to Three Years of Age: Child, Family, and Linguistic Factors.


