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WORD-DECODING AND READING-RELATED SKILLS IN CHILDREN WITH COCHLEAR IMPLANTS

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SUMMARY

This study explores the role of working memory, language, and different time factors, including age at implant, time with implant, age at onset of deafness, duration of deafness, on word-decoding skills (rapid reading of isolated words and non-words) in eighteen Swedish children with cochlear implants, who lost their hearing before 36 months of age. In general there was wide variability in language and cognitive skills among the eighteen children. Decoding scores (accuracy) correlated significantly with most linguistic and working memory measures even when age and duration of deafness were partialled out. Speed and accuracy measures for word decoding also remained significantly correlated, but not for non-word decoding when age was factored out. As for the time factors, no significant correlations with decoding of words/non-words were found. In the second part of the study, fifteen of the children with CI were individually matched to hearing children studied by Lindström and Malmsten (2003). The children with CI were significantly less accurate, but they were faster decoding words and non-words than the age-matched hearing children. We found no significant difference between the groups on complex working memory, as measured by the CLPT (Competing Language Processing Task), nor on reading span tasks (word span and non-word span).

INTRODUCTION

A cochlear implant (CI) provides auditory sensations to deaf or severely hearing-impaired individuals. The auditory sensation from the CI opens up the possibility for a different course of development for deaf children in a wide variety of areas that would not have been possible without the CI (Anderson, Weichbold, & D'Haese, 2004; Geers, 2003; Manrique, Javier Cervera-Paz, Huarte & Molina, 2004; Spencer, Tomblin & Gantz 1997; Spencer, Baker & Tomblin 2003). In particular this is evident in areas where cognition and language are central features (e.g. speech perception and production, and reading; Pisoni, 2000; Pisoni & Cleary, 2003). Previous research has also demonstrated that demographic factors related to the implant (e.g. age at implant, duration of deafness, time with the CI) relate to the course of development (Anderson et al., 2004; Manrique et al., 2004). A general feature of the empirical picture is that early implantation is more beneficial for development than later implantation.

In this study we examined how factors such as working memory capacity and language skills relate to word decoding ability in deaf children with CI. Word decoding skill is a critical component of literacy in both hearing and deaf children (Lundberg, 2003; Dillon & Pisoni, 2004). In addition, the impact of time factors (duration of deafness, age at implant, time with implant etc.) on this relationship will be examined. Relatively few studies have examined these issues in this population. The combined empirical picture shows that most children with CI, deafened before 36 months of age, reach higher levels of reading skills than children with severe to profound hearing impairment without CI, and that they often perform within the average range for hearing children (Spencer et al., 1997; Spencer et al., 2003; Geers, 2003; Dillon & Pisoni, 2004). Geers (2003) studied 181 eight-to-ten-year-old children who had 4 to 6 years of implant experience. Over fifty percent scored within the average range of hearing controls. Reading competence was associated with higher non-verbal intelligence, higher family-socio-economic status, female gender and onset of deafness before 36 months of age. The factors that best predicted reading outcome were linguistic competence and speech production skill. Dillon & Pisoni (2004) in their study on 76 children with CI also demonstrated higher-level reading skills in their participants compared to earlier studies on deaf children without CI, and a clear relationship between phonological processing skills and reading. Their interpretation was that a CI facilitates the development of processes such as inner speech and verbal rehearsal in working memory.

Working memory capacity refers to the memory system responsible for simultaneous storage and processing of information over a brief period of time (Baddeley, 2000). Working memory capacity develops with age, and is fully developed at the end of adolescence (cf. Gathercole, 1999). Pisoni & Cleary (2003) and Pisoni (2000), using a digit span procedure to measure working memory capacity, found that individual variations in capacity could contribute to the explanation of the variation in a range of outcome measures of speech and language capacity in children with CI. Moreover, in an earlier study including 22 Swedish congenitally deaf children with CI, Willstedt-Svensson, Löfquist, Almqvist & Sahlén (2004) showed that the variation in outcome measures (lexical and grammatical development) was better indexed by a working memory measure (non-word repetition) than by age, duration of deafness or time with implant.

In the present study, working memory capacity was assessed with three tasks. One measure was of the capacity to store and process information simultaneously (the competing language processing task, CLPT; Gaulin & Campbell, 1994). Two tasks were used to examine one specific aspect of working memory, the phonological loop (sometimes referred to as phonological short-term memory):

- non-word repetition (Sahlén, Reuterskiöld Wagner, Nettelbladt, & Radeborg, 1999);
- a word/non-word span task (Lyxell & Holmberg, 2000).

The inclusion of these tasks enabled us to examine whether the auditory stimulation provided by the CI promotes development of the general storage/processing aspect of working memory, or whether it is tied to one specific aspect (i.e. the phonological loop).

The capacity of the phonological loop plays a significant role in supporting the acquisition of language, reading and other academic skills during childhood (Gathercole, 1999; Baddeley, Gathercole & Papagano, 1998). The phonological loop is a subcomponent in working memory, often referred to as phonological short term memory, which supports the learning of phonological structures of novel words. Non-word repetition is often used to index phonological short-term memory. Non-words do not have lexical representations, and repetition skills are therefore relatively independent of lexical knowledge in long-term memory (Baddeley, 1986; Gathercole & Baddeley, 1990; Hansson, Forsberg, Löfqvist, Mäki-Torkko & Sahlén, 2004). Gathercole, Willis, Emslie & Baddeley (1992), using a longitudinal design, found that non-word repetition predicted the development of vocabulary and grammar until the age of five in children with normal language development. A large amount of research provides support for a link between non-word repetition skills and the development of language and literacy abilities in children with normal language development (Adams & Gathercole, 1995), in children with specific language impairment (Gathercole & Baddeley, 1990; Montgomery, 1995; Sahlén et al., 1999), in children with mild and moderate sensorineural hearing impairment (Briscoe, Bishop & Norbury, 2001) and in deaf children with CI (Dillon & Pisoni, 2004; Willstedt-Svensson et al., 2004). Some researchers argue that limited non-word repetition capacity is a clinical marker of language impairment, but others claim that limitations are related to the phonotactic complexity and stress patterns of the particular language studied.

According to Stokes, Wong, Fletcher and Leonard (2006), poor non-word repetition by Swedish- or English- speaking children with language impairment may instead be due to the prosodic properties of the language, and not necessarily to poor phonological short term memory. This may explain, in their opinion, the fact that in Cantonese-speaking children, non-word repetition does not discriminate children with specific language impairment from younger language matched children with typical language development (Stokes, Wong, Fletcher & Leonard, 2006). In the present study we used the non-word repetition test developed by Sahlén et al. (1999) and two non-word reading tasks.

There is today no doubt that a range of skills are needed for reading, and that there seems to be a reciprocal causality between reading and phonological processing. Some authors strongly emphasize the role of phonological processing in early literacy development (Snowling & Gallagher, 2003; Velution, Fletcher, Snowling & Scanlon 2004). It is important to remember, however, that the role of phonological processing for reading is dependent on how transparent the orthography of a particular language is. Cross-cultural comparisons should therefore be made with caution. Swedish orthography can be considered semi-transparent (more transparent than English but less so than German). In an alphabetic orthography like Swedish, Swedish children must establish a system of correspondences between the letters or graphemes of most printed words and the phonemes of spoken words. The child needs well-specified phonological representations that provide the basis for the set of fine-grained mappings between phonological and orthographic representations. However, according to Castles and Coltheart (2004), no study has so far shown that there is a direct casual link between phonological representations in long term memory (as assessed by phoneme awareness tasks) and reading success. Some authors claim that the association might be more indirect and mediated by lexical skills (Gathercole, 2006). Phonological processing is sometimes used as an umbrella term for a range of skills measured by phoneme discrimination, non-word repetition, and phonological awareness tasks (rhyme judgement, phoneme identification etc). In the present study non-word repetition and non-word discrimination will be classified as working memory tasks, tapping phonological short term memory.

Many deaf children without a CI are able to read but are disadvantaged in the process compared to normally hearing children (Goldin-Meadow & Mayberry, 2001). According to Goldin-Meadow & Mayberry (2001), deaf children with good skills in sign language may have some advantages, but good sign-language skills do not guarantee normal reading development. They conclude that it seems to be essential to know how to use the phonological code on which the written language is based. According to these authors, however, there is no answer to the question as to whether this knowledge helps children become good readers or whether it is a result of their reading skill. In order to answer this question, the ideal design would, of course, include a comparison between deaf children with CI and deaf children without CI. Unfortunately, this possibility no longer exists in Sweden, since most (more than 90%) of deaf children are implanted, and there are probably too few deaf children without CI to give us a clear comparative picture. In the present study, we will study accuracy and speed in decoding of single words and non-words and accuracy in word/non-word span tasks and the relationship to other reading related skills in eighteen children with CI. Reference data from hearing children with typical language development, individually matched to fifteen of the children with CI, will be used for comparison (Lindström & Malmsten, 2004).

The present study has two parts. In the first part, which is an intra-group study, we explore the role of working memory, language production, language comprehension and different time factors (duration of deafness, age at implant, time with CI and age at testing) for decoding skills in eighteen children with CI. We will also explore the association between speed and accuracy in decoding tasks. In the second part, which is an inter-group comparison, fifteen of the children with CI are individually matched to hearing children described in a study by Lindström and Malmsten (2003) for a comparison on the above mentioned measures.

MATERIAL AND METHODS

Eighteen children (nine boys and nine girls, aged 7 years 2 months to 12 years 5 months, mean age 9 years 2 months) with bilateral deafness (hearing lost before 36 months) were included in the first part of the study. Twelve of these children were congenitally deaf. The aetiology was unknown in eleven of these eighteen children, hereditary in four children, and caused by infection in three children. Only three children showed signs of progressive deterioration of hearing. All these children had been fitted with bilateral conventional hearing aids after the diagnosis of hearing impairment, as is routine in Sweden. None of the children showed any benefit of amplification, e.g. no measurable improvement in sound reactions or communication development. This was in accordance with the test results obtained in sound field measurements and auditory brain stem response recordings, which all showed the children to have profound hearing impairment. The children were implanted with the Nucleus multichannel cochlear implant at the Lund University Paediatric Cochlear Implant Program and were seen as part of their regular routine post-implant appointments. Full insertion of the 22-electrode array was accomplished in all the children. The children had received their implants between the age of 2 years 1 month and 6 years 2 months (mean age at implant 4 years) and had used their implant for more than 2 years 5 months (mean length of use 5 years 2 months, range 2 years 5 months to 7 years 10 months). The twelve congenitally deaf children received their implants between 2 years 1 month and 6 years 1 month (mean age 3 years 11 months), and the other six children between 2 years 5 months and 6 years 2 months (mean age 4 years 1 month). The duration of deafness differed between congenitally and non-congentially deaf children, as seen in Table 1. Among the 12 children with congenital deafness, six had been deaf for more than 4 years before implantation. Among the 6 children who were not congenitally deaf, only one child was implanted before 4 years of age. Due to the small size of the community of children with CI in Sweden, individual information on the aetiology of the children's deafness cannot be revealed for ethical reasons.

According to the Swedish education program for deaf children, all these children had been exposed to sign language before implantation. Because of parental choice, local educational policy or the performance of the child, three of the children continued to use sign language in school after implantation, while fifteen began to use oral communication (six with and nine without signed support) as their major form of communication. Thirteen of the children were receiving or had previously received direct support from a speech pathologist or a special education teacher. Only five children had not been enrolled in any speech pathology/special education programs. All these children had hearing parents and all used oral language with or without signed support at home at the time of testing. For inclusion, a non-verbal IQ of at least 75 was required, as measured by Raven's progressive or coloured matrices. The mean non-verbal IQ for the children was 104.5, ranging from 81 to 130 (SD=14.2). The demographic data are shown in Table 1.

The oral language status of all the children was independently classified by the first and second authors into the following broad categories; preverbal, transitional and functional use of oral language (Dyar, 1993). Two children were in the transitional phase, while fourteen were in the functional phase of development. Two children were still in the preverbal phase of oral language communication.

In the second part of our study, fifteen hearing children, 8 boys and 7 girls, with typical language development (NH), were individually age-matched with the children with CI. Their mean age was 9 years 2 months (SD 1 year 5 months). The comparative data were taken from a study on working memory and reading by Lindström and Malmsten (2003) involving 41 Swedish hearing children with typical language development.

The tests shown in Table 2 were used to assess different aspects of linguistic and cognitive skills. Parts of the procedure (comprehension of grammar, non-word discrimination, non-word repetition) were identical to the procedure used in our earlier study on congenitally deaf children (Willstedt-Svensson et al., 2004).

The children were assessed by the second author in the clinic at the Audiology Section of the Lund University Hospital. All tests were administered in a quiet room, except for non-word repetition, non-word discrimination and speech recognition, which were administered in a sound-treated room used for hearing threshold measurements. The non-words in the non-word repetition task and in the non-word discrimination task were administered by audiotape. The words and the non-words were recorded by a female speaker into a Macintosh G4 computer at a sampling rate of 32 kHz, and were presented to the children by means of Apple Pro speakers at an SPL of 65-70 dB(A). An audiotaped presentation was used in order to ensure that presentations of stimuli were identical for all children regarding segmental as well as regarding suprasegmental aspects (word stress and accents[1]). The verbal instructions given by the second author were sometimes supported by sign language. During the test session, however, the child's responses were oral,

Table 1. Demographic data for each child

child	gender	onset of hearing impairment (years; months)	duration of deafness (years; months)	age at implant (years; months)	time with implant (years; months)	age at testing (years; months)	raven (%) IQ	linguistic status of oral language at testing	communication mode at home / in school at testing
1	boy	1;9	2;4	4;1	7;10	11;11	(50) 100	functional	oral language / oral language
2	boy	1;6	2;10	4;4	6;11	11;3	(50) 100	functional	oral language / oral language
3	girl	0;0	4;10	4;10	6;7	11;5	(10) 81	preverbal	oral language + sign language / sign language
4	boy	0;0	6;0	6;0	6;5	12;5	(10) 81	functional	oral language / oral language
5	girl	2;3	1;0	3;3	6;2	9;5	(50) 100	functional	oral language / oral language
6	boy	0;0	2;1	2;1	6;1	8;2	(75) 111	functional	oral language / oral language
7	girl	1;1	1;4	2;5	5,7	8;0	(50) 100	functional	oral language / oral language
8	boy	0;0	2;5	2;5	7;3	9;8	(50) 100	functional	oral language / oral language
9	boy	1;5	3;0	4;5	4;9	9;2	(10) 81	functional	oral language / oral language + sign language
10	boy	0;0	3;6	3;6	5;4	8;10	(90) 118	functional	oral language + sign language / sign language
11	girl	0;0	2;9	2;9	4;9	7;6	(90) 118	functional	oral language / oral language + sign language
12	boy	1;0	5;2	6;2	3;10	10,0	(50) 100	functional	oral language / oral language
13	girl	0;0	4,4	4;8	3;11	8,3	(95) 130	functional	oral language / oral language
14	girl	0;0	5;0	5;0	3;2	8;2	(90) 118	transitional	oral language / oral language + sign language
15	girl	0;0	2;8	2;8	5;8	8;4	(70) 107	functional	oral language / oral language
16	boy	0;0	2;1	2;1	5;1	7;2	(75) 111	functional	oral language / oral language
17	girl	0;0	6;1	6;1	2;6	8;7	(90) 118	preverbal	oral language + sign language / sign language
18	girl	0;0	5;2	5;2	2;6	7;8	(75) 111	transitional	oral language / oral language

[1] In Swedish the placement of word stress is distinctive, and a trochaic stress pattern (strong-weak) is more usual than iambic patterns (weak-strong). Compared to English, Swedish has a relatively complex prosodic system and is often referred to as a pitch accent language. Thus, in addition to the contrasts of word stress, there are contrasts of tonal word accents, i. e. Accent I and Accent II. Studies on Swedish children with language impairment have shown that prosodic aspects of non-word repetition must be taken into consideration. For example, unstressed syllables in pre stressed position in non-words were six times more vulnerable to omission than unstressed syllables in post stressed position (Sahlén et al., 1999).

Table 2. Tests used to assess different aspects of linguistic and cognitive skills

Area	Test	Quantification
written word/non-word decoding	word decoding accuracy and (pcc)#	correct/incorrect and % consonants correct
	word decoding (speed)	seconds
	non-word decoding accuracy and (pcc)	correct/incorrect and % consonants correct
	non-word decoding (speed)	seconds
written decoding and recall	word span	% correct out of 24
	non-word span	% correct out of 24
language	comprehension of grammar	% correct out of 20 blocks
	output phonology (pcc)	% consonants correct
complex working memory	CLPT##	% correct out of 30
phonological short term memory	non-word discrimination	% correct out of 16
	non-word repetition (pcc)	% consonants correct
speech recognition	maximum speech recognition	% correct out of 100
non-verbal IQ	Raven's progr./col. matrices	percentiles

pcc = percent consonants correct
CLPT = Competing Language Processing Task

and responses in sign language were not accepted. The complete assessment was recorded both by video- and audiotape. Transcriptions, analyses and scorings of data were made after the test session based on the recording. For each test, the number of participating children is shown in Table 3. Some missing data is shown in most tests due to insufficient participation of the individual child.

Parts of a computerized reading test (Text Information Processing System, TIPS, Lyxell & Holmberg, 2000) were used to assess decoding (speed and accuracy) of thirty single words and thirty non-words of one to four syllables, as well as decoding and recall of words (word span) and non-words (non-word span).

Decoding of words and non-words: In the test of decoding, a written word or a non-word was shown on the screen, and the child was asked to read it as accurately and as fast as possible.

Analysis and scoring: decoding of the words and non-words was scored as correct/incorrect and as percent of consonants correct (pcc). The words included 93 consonants, and the non-words 79 consonants. Small deviations of articulation were accepted, for example, if the child was lisping (produced low frequent /s/) or if a voiced consonant /d/ was occasionally devoiced. Regular substitutions of consonants were scored as incorrect. Transcriptions were made by the second author, who also scored the transcribed data together with the first author. Consensus was reached by discussion in a few cases of uncertainty.

Decoding speed was registered by the computer and measured in seconds for all words or non-words. The computer registered the time from the appearance of the word/s on the screen to the end of the child's utterance. Swedish children in grades 2-5 with normal hearing and normal language development reach a mean of 99.2 percent consonants correct (pcc) for decoding of words and a mean of 98.3 pcc for decoding of non-words (Lindström & Malmström, 2003).

Decoding and recall: A word span and a non-word span task were used. The test taps decoding (grapheme-phoneme conversion) and phonological short-term memory (see introduction). In this test, 24 items appeared on the screen in groups of 3-5 single words/non-words. All of the items were of simple CVC form, except for one word that had a CCVC form. Every group of words/non-words was presented on the screen for a display duration of one second per item and an interstimuli interval of 0.0875 seconds. The child was asked to read them silently. All items were used one time only. The child's task was then to recall the words/non-words by repeating them orally. The child did not have to repeat the items in the correct order.

Scoring was based on correct whole word/non-word recall. A maximum score of 24 was possible in word span/non-word span As in the decoding tasks, minor articulation errors were accepted.

Comprehension of grammar: Receptive grammar was assessed with a Swedish version of the TROG (Bishop, 1989), translated by Holmberg & Lundälv (1998), with Swedish norms. The instructions were given orally with the opportunity to lip-read. This is a multiple-choice test designed to assess the understanding of grammatical constructions. The examiner reads a sentence and the child is asked to select the appropriate picture for the sentence from among an array of four pictures located in front of the child. The TROG consists of 20 blocks, each block containing four sentences tapping the same grammatical structure. All four items in a block had to be correct in order for the block to be considered correct. A maximum of 20 correct blocks was possible; Swedish children with normal language development at 10 years of age reach a mean of 17 blocks (SD 1.3) (Holmberg & Lundälv, 1998).

Output phonology was assessed by a picture-naming test, a shortened version of the Swedish Phoneme test (Hellqvist, 1991). The percentage of correctly produced consonants in the correct position within the word was calculated (pcc). The total number of consonants in the test was 178.

Complex working memory: The simultaneous processing and storing of verbal information, or complex working memory, was assessed by the Competing Language Processing Task (the CLPT, Gaulin & Campbell, 1994; Swedish version by Pohjanen & Sandberg, 1999). Thirty sentences constructed as semantically acceptable or semantically unacceptable sentences, divided into five sets with two to five sentences in each set, were administered. The child was first asked to judge semantic acceptability (yes/no) for each sentence and then, after each set of sentences, to recall the last word/s of the sentences. The true/false judgements were not taken into consideration for the scoring. As for the recall component, the sequence of word recall did not have to match that of sentence presentation. Responses were scored correct if the child produced the last word of a sentence within the target group, regardless of whether the order of recall corresponded to that in which the sentences had been presented. For every word correctly recalled a score of 1 point was given.

A slight modification of the procedure proposed by Gaulin & Campbell (1994) has been made in the Swedish version used in this study of children with CI and children with normal hearing, as follows: If the child recalled the last word in a sentence after prompting with the first syllable of the complete sentence a score of 0.5 was given. A maximum score of 30 was possible. Swedish children (8-9 years old, grade 2-3) with normal hearing and normal language development reach a mean score of 59.9% (SD 9.3%) of the total possible score on this test (Lindström & Malmsten 2003).

Phonological short-term memory was assessed by *non-word repetition* and *non-word discrimination tasks*. For *non-word repetition* the Swedish non-word repetition test (Barthelom & Akesson, 1995; Sahlén et al, 1999) was used, in which 24 non-words of two, three, four or five syllables were administered to the children by audio-tape. The non-words were constructed according to Swedish phonotactic rules. The child's production of the non-word was transcribed by the first author, using both audio- and videotaped recordings. The targets included 110 target consonants. Of the total number of consonants in the non-words, the percentage of correctly repeated consonants in the correct position of the target word was calculated (pcc), as for the decoding tasks and output phonology task. Minor articulation errors were scored as correct, but phoneme substitutions were scored as incorrect. The principles are described in Ibertsson, Willstedt-Svensson, Radeborg and Sahlén (in press). Swedish children (4-6 years) with normal hearing and typical language development reach a mean score of 76.5% (SD 12%) of consonants correctly produced in non-word repetition (Hörman & Kring, 2002). Older Swedish children (8-9 years old, grade 2-3) reach a mean score of 93.8% (SD 3.7%) (Lindström & Malmsten, 2003). The non-words in the non-word repetition test from 20% of the children were transcribed with broad phonetic transcription by the first and the second author independently. The overall agreement between the two authors' transcriptions was 80%. In cases of disagreement, consensus was reached by discussion.

For children with severe problems of output phonology, non-word repetition cannot be a reliable measure of phonological short-term memory capacity. We therefore included a test of non-word discrimination. Reuterskiöld-Wagner, Nyman, & Sahlén (in press) suggest that non-word discrimination and non-word repetition may tap into the same underlying processing skill in children with output phonological problems.

For *non-word discrimination* four non-words of 2, 3, 4 or 5 syllables, chosen from a non-word repetition test (Sahlén et al., 1999), were used to create thirty-two non-word pairs (Nyman, 1999). Each non-word appeared in two versions with sixteen pairs per version. In one version the non-word was paired with an identical item (same) and in the other with a construction making up a minimal pair (different). The minimal pair item had only one phoneme (a consonant) that differed from the non-word (e.g. sallotan/sallovan). The child was asked to judge whether the non-words were "the same or different." Both pairs of non-words had to be correct for a score of 1. The maximum score was 16. Swedish children (4-6 years old) with normal hearing and typical language development reach a mean score of 67% (SD 30%) of the total score on this test (Hörman & Kring, 2002).

Speech recognition was assessed by the *Maximum Speech Recognition* (Same, 1996) method. The test consists of phonetically balanced (PB) monosyllabic words at the end of a carrier phrase "Now you will hear..." (Swedish: "Nu hör du….”). The test words were presented on a level that is assumed to be the most comfortable listening level, often 30 dB above the speech reception threshold. The children were instructed to repeat the test words as they heard them. They were also encouraged to make a guess when they were uncertain. Complete lists of 50 words were used, and the numbers of words missed were noted. The number of words correctly repeated was calculated as a percentage of the number of test words in the list. Speech recognition scores will only be presented as descriptive data.

Non-verbal intelligence was assessed by *Raven's coloured progressive matrices* (Raven, 1986) for the younger children, and for the older children by *Raven's standard progressive matrices* (Raven et al., 1992). Raw scores were transformed into percentiles according to the manual, and from percentiles to IQ. No significant correlations between nonverbal intelligence and the tasks assessing decoding were found (decoding of words and non-words, word span and non-word span). Since the relationship between nonverbal intelligence and decoding skills was not within the scope of this paper, it will not be discussed further.

RESULTS

Descriptive data for each test will be presented first, followed by simple correlations (Pearson) and partial correlations (controlling for age and duration of deafness) between the decoding tasks and linguistic/cognitive measures for the eighteen children with CI (part 1). (In the text we report only r and p-values for correlations not reported in tables). Finally, in part 2, comparisons (t-tests) will be presented between the fifteen age-matched hearing children and fifteen of the eighteen children with CI.

Descriptive data

The means and standard deviations for each test are shown in Table 3. The number of children participating in each task is also indicated.

Intergroup comparison – correlational data

Simple correlations between the decoding/reading span tasks and time factors are shown in Table 4, and correlations between the dependent variables, decoding of words/non-words and reading span tasks, and the linguistic and working memory tasks are shown in Table 5.

Table 3. Mean scores, standard deviations (SD) and number of participating children for all variables. Test results were computed in % except for speed, which was measured in seconds

Tests		mean %	SD %
word decoding (pcc) #	n = 18	83.2	18.9
word decoding (accuracy)	n = 18	68.2	23.5
non-word decoding (pcc)	n = 18	84.1	16.0
non-word decoding (accuracy)	n = 18	60.1	23.8
word span	n = 17	49.8	26.4
non-word span	n = 18	18.1	11.2
comprehension of grammar	n = 18	59.2	25.7
output phonology (pcc)	n = 18	74.7	25.7
non-word discrimination	n = 17	60.1	20.1
non-word repetition (pcc)	n = 18	68.3	26.7
		mean sec	SD sec
word reading (speed)	n = 18	65.8	32.2
non-word reading (speed)	n = 18	84.1	25.4

pcc = percent consonants correct

As can be seen in Table 4, there were no significant correlations between time factors and the dependent variables (the decoding of words/ non-words and span tasks), except for one significant correlation between onset of deafness and non-word span.

According to Table 5, significant correlations were obtained for word and non-word decoding (pcc) with almost all language and working memory tests,

Table 4. Correlations between dependent variables and time factors

	onset of hearing impairment	duration of deafness	age at implant	time with implant	age at testing
word decoding (n=15)					
pcc	0.39	-0.40	-0.25	0.42	0.20
accuracy	0.34	-0.37	-0.23	0.40	0.20
non-word decoding (n=15)					
pcc	0.22	-0.12	-0.02	-0.10	-0.15
accuracy	0.20	-0.23	-0.16	-0.01	-0.13
word span (n=14)	0.21	-0.03	0.08	0.38	0.48
non-word span (n=15)	0.47 (*)	-0.19	-0.04	0.22	0.26

** Correlation significant at the level of $p < 0.01$ (2-tailed).
* Correlation is significant at the level of $p < 0.05$ (2-tailed).

Table 5. Correlations between dependent variables and linguistic and cognitive factors

	comprehension of grammar	output phonology	complex working memory	non-word discrimination	non-word repetition
word decoding (n=18)					
pcc	0.70**	0.84**	0.80**	0.72**	0.77**
accuracy	0.74**	0.91**	0.87**	0.69**	0.77**
non-word decoding (n=18)					
pcc	0.39	0.59*	0.59*	0.74**	0.64*
accuracy	0.48*	0.66**	0.52*	0.67**	0.62*
word span (n=17)	0.39	0.62**	0.59*	0.60*	0.54*
non-word span (n=18)	0.56*	0.73**	0.66**	0.62*	0.65**

** Correlation significant at the level of $p < 0.01$ (2-tailed).
* Correlation is significant at the level of $p < 0.05$ (2-tailed).

with the exception of comprehension of grammar and non-word decoding (pcc). When accuracy was measured in the tests of word and non-word decoding, significant correlations with all linguistic and cognitive tasks appeared.

As for the span tasks (silent decoding and recall), word span turned out to correlate significantly with output phonology, complex working memory, non-word discrimination and non-word repetition. Non-word span correlated significantly with comprehension of grammar, output phonology, complex working memory, non-word discrimination and non-word repetition.

There were also several significant correlations *between* the developmental factors. Age at testing and time with implant correlated significantly (r=0.61, p<0.01), age at implant and duration of deafness (r=0.88, p<0.01), time with implant correlated negatively with duration of deafness (r=-0.56, p<0.05) and duration of deafness correlated negatively with onset of hearing impairment (r=-0.48, p<0.05).

Partial correlations

The only significant correlation between onset of hearing impairment and non-word span disappeared when age was controlled for. In table 6 the partial correlations between dependent variables and cognitive/linguistic factors with age and duration of deafness partialled out are presented. When we controlled for age, some of the significant correlations between dependent variables and cognitive/linguistic factors also disappeared. The correlation between comprehension of grammar and three tests – non-word decoding (accuracy), word decoding (pcc) and non-word span – disappeared. All other

Table 6. Partial correlations with age at testing and duration of deafness (within brackets) partialled out separately

	comprehension of grammar	output phonology	complex working memory	nonword discrimination	nonword repetition
word decoding (n=18)					
pcc	0.44 (0.45)	0.86** (0.88**)	0.77** (0.79**)	0.72** (0.71**)	0.71** (0.64**)
accuracy	0.52 (0.54*)	0.91** (0.93**)	0.87** (0.88**)	0.56* (0.56*)	0.71** (0.67**)
nonword decoding (n=18)					
pcc	0.23 (0.27)	0.58* (0.62*)	0.59* (0.59*)	0.59* (0.63*)	0.61* (0.67**)
accuracy	0.27 (0.26)	0.61* (0.59*)	0.53* (0.50*)	0.47 (0.47*)	0.47 (0.49*)
word span (n=17)	0.18 (0.32)	0.50* (0.72**)	0.51* (0.61*)	0.57* (0.65**)	0.54* (0.578*)
nonword span (n=18)	0.40 (0.46)	0.68* (0.75**)	0.61* (0.65**)	0.62* (0.66**)	0.68** (0.69**)

significant correlations remained.

When duration of deafness was partialled out from the significant correlations between dependent variables and cognitive/linguistic factors, two significant correlations disappeared, between comprehension of grammar and word decoding (pcc) and between comprehension of grammar and non-word decoding (accuracy) To sum up, when controlling for age and duration of deafness all significant correlations between the four reading tasks and the working memory and output phonology tasks remained.

Speed and accuracy in decoding

Significant correlations were found between word decoding (accuracy) and word decoding speed ($r=-0.75$, $p<0.01$) and word decoding (pcc) and word decoding speed ($r=0.80$, $p<0.01$). Non-word decoding (accuracy and pcc) did not correlate significantly with non-word decoding (speed). Decoding speed of words and non-words correlated significantly ($r=-0.93$, $p<0.01$). Table 6 shows that the significant correlation between speed and accuracy in word decoding remained when age was partialled out. When time with deafness was partialled out from the significant correlations between speed and accuracy in the word/non-word decoding tasks, the significant correlations remained, as did the correlations between non-word decoding speed and word decoding speed (Table 6).

In sum, the data presented here indicate a stronger link between the decoding and reading-span tasks and language/working memory factors than between the dependent variables and time factors. Most correlations between the dependent variables (decoding and reading-span tasks) and language/working memory factors remained when age and duration of deafness was controlled for separately, although some significant correlations between comprehension of grammar and dependent variables disappeared when age and duration of deafness was partialled out. Speed and accuracy also remained significantly correlated for word decoding when age was partialled out, but not for non-word decoding. Speed and accuracy in both word and non-word decoding tasks remained significantly correlated when duration of deafness was controlled for.

Intergroup comparison – children with CI and age-matched hearing children

Fifteen of the eighteen children with CI were matched for chronological age with a hearing child (NH). A comparison between with CI and NH children is shown in Table 7. To enhance comparability, all results are computed in mean percentage, except for reading speed, which is measured in seconds, and nonverbal intelligence, which is measured in percentiles. Significant differences between CI and NH children occurred on five measures:

- decoding of words, pcc ($df=14$, $t=3.2$, $p<0.01$);
- decoding of non-words, percent correctly repeated consonants (pcc)

Table 7. Group means in percentile, percent and seconds for children with CI and NH. The numbers of participating children as well as the significant differences between groups are also shown in the table

		Children with cochlear implant (CI) mean (SD)	Normally hearing children (NH) mean (SD)	t-test significance level
non-verbal intelligence (percentile)	n=15	61.3 (27.7)	71.0 (29.4)	n.s.
word decoding (pcc)#	n=15	85.4 (16.2)	98.9 (1.4)	p<0.01
word decoding (accuracy)	n=15	68.2 (23.7)	95.9 (4.3)	p<0.01
non-word decoding (pcc)	n=15	83.3 (17.1)	97.1 (3.3)	p<0.01
non-word decoding (accuracy)	n=15	58.1 (25.5)	89.4 (8.7)	p<0.01
word span (%)	n=14	51.3 (24.7)	54.5 (22.0)	n.s.
non-word span (%)	n=15	19.5 (12.1)	28.1 (18.4)	n.s.
non-word repetition (pcc)	n=15	41.6 (17.7)	95.3 (2.0)	p<0.01
complex working memory (%)	n=12	62.2 (23.8)	61.4 (13.6)	n.s.
word reading, speed (seconds)	n=15	60.0 (24.3)	66.1 (35.7)	n.s.
non-word reading, speed (seconds)	n=15	80.4 (18.5)	104.9 (43.7)	p<0.05

pcc =percent consonants correct

(t=3.1, p<0.01);

- non-word repetition (t=11.3, p <0.01) where the children with CI performed worse or slower.

There was also a significant difference on the decoding of non-words (speed) (df=14, t=2.2, p<0.05), where the children with CI were faster (although significantly less accurate).

Statistically significant differences between the children with CI and NH were not found in the following comparisons:

- non-verbal intelligence;
- word-span;
- non-word-span;
- complex working memory;

- decoding of words (speed).

In sum, performance in the CI children was significantly poorer than in the group of age-matched hearing children on decoding of words and non-words (pcc) and on non-word repetition.

DISCUSSION

This study investigated word-decoding skills in a group of deaf children with CI. In accordance with previous work (Geers, 2003) our findings indicate great individual variation with respect to reading achievements in the group of children with CI. Except for non-word reading speed and non-word span, standard deviations were higher in the children with CI than in the children with NH (see table 7).

Our results from the group of eighteen children with CI indicate a closer association between cognitive and linguistic factors and reading tasks than between reading tasks and time factors. We found no significant correlations between time factors and reading tasks when age and duration of deafness were controlled for.

The relationship between working memory tasks, as measured by the CLPT and the non-word repetition test, and the reading tasks turned out to be more robust against the influence of time factors (age and duration of deafness) than the relationship between comprehension of grammar and reading. The association between output phonology and reading also remained when age and duration of deafness were controlled for.

Considering the relationship between speed and accuracy in decoding tasks, the faster readers turned out to be significantly more accurate in word decoding. However, for non-word decoding the relationship between speed and accuracy was not significant. Our interpretation is that these children had orthographic representations in long term memory for the real words and therefore read them out rapidly and accurately. In the non-word decoding task it was not possible to rely on orthographic representations in long term memory. Coping strategies might therefore have differed: some children with CI took their time but some children probably used an inefficient coping strategy in this task. An awareness of one's shortcomings as to the precise and well-articulated reading aloud of non-words may be hidden behind a speedy but inaccurate performance.

In the second part of our study, the comparison between the children with CI and the hearing children, it was revealed that the children with CI were significantly faster and less accurate in both decoding tasks. It was not a surprise that the children with CI as a group were less accurate than age matched peers in decoding word/non-words. It was, however, somewhat surprising that their decoding speed was significantly higher for both words and non-words. The children with CI did not differ significantly from controls regarding the accuracy in reading span tasks, requiring silent decoding before the recall of words and non-words. Perhaps the fact that they were instructed not only to decode the words/non-words, but also to recall the items, made them read more carefully and slowly in the span task than in the decoding of words/non-words tasks.

Non-word decoding can be considered as a more nearly "pure" decoding task than decoding of real words, since novel material is used. The child has to use a phonological strategy and cannot rely on orthographic or visual cues to the same extent. For the group of forty-one hearing children in the study by Lindström & Malmsten (2003), the decoding of non-words was less accurate and slower than the decoding of words. Although there seemed to be a difference in accuracy between word- and non-word decoding in the eighteen children with CI in the first part of our study, the difference was not dramatic when the simple means (measured by pcc) were compared (see table 3). Given the relative weakness in phonological skills in the children with CI, we had expected the children with CI to demonstrate a relatively greater performance gap than hearing children between the decoding of words and the decoding of non-words. However, the differences between the performances in the two tasks were quite similar for the two groups when simple means were compared for the eighteen children with CI in the first part of this study and the forty-one hearing children in the study by Lindström and Malmsten (2003).

In line with Dillon and Pisoni (2004), our interpretation of our findings is that deaf children with CI do not use orthographic strategies to a greater extent than hearing children in decoding tasks.

One might argue that the decoding tasks requiring the child to read words/non-words aloud are simply mirroring the child's oral language time level. Output phonology was associated with the reading tasks even when time factors were controlled for. However, we believe this would be an oversimplification. Two children in our study were in the preverbal phase of oral communication (child 3 and child 17). Their speech production skills were thus relatively poor. One might predict poorer decoding skills, since decoding was assessed by reading aloud words/non-words. Child 3 and child 17 were, however, not the poorest performers on all reading tasks. Only on non-word decoding did child 3, together with child 10, achieve the lowest scores in the group of eighteen children with CI. Good literacy outcome for children classified as having isolated problems with output phonology in preschool was reported by Catts & Kamhi (2005). The authors claim that the ability to discriminate phonemes, taxed in a non-word discrimination task, seems to be more crucial for and predictive of decoding skills than output phonology in children with phonological problems.

The inter-group comparison showed that the children with CI did not differ significantly from the children with NH on the complex working memory test (the CLPT). This finding is not in accordance with findings by Pisoni and co-workers (Pisoni & Cleary, 2003; Burkholder & Pisoni, 2004). They used digit span (forward and backward recall of digits) as measures of working memory, and found children with CI to be weaker than controls. One reason for the difference in results between the studies is that our measure of complex working memory (i.e. the CLPT) is different from digit recall. The CLPT emphasizes the simultaneous processing and storing of more complex verbal information (phonological, syntactic and semantic/lexical) than digit recall.

The children with CI in the second part of our study performed significantly poorer than the hearing children on the other working memory measure, the non-word repetition test. It thus seems as if the difference between the children with CI and their peers with NH is more related to a weakness in phonological short-term memory than to limitations in complex working memory. But the lack of a significant difference between two groups of only fifteen children does not mean that they perform equally well. A larger sample size might have shown a difference.

Our findings have implications for educational programs and planning for reading instructions. Problems of discrimination, phonological short term memory and output phonology should be identified and taken care of early in children with CI. We believe that many children with CI would benefit from more direct phonological training than what is currently being offered in our country. The widely used early auditory-verbal intervention program (Wray, Flexer & Vaccaro 1997) seems to lead to very positive results in oral language communication for a great number of children with CI. General auditory and language stimulation is indeed necessary, but we do not believe that it is sufficient for children with CI who are at risk for language impairment.

Swedish sign language (a system comparable to American Sign Language) has a unique position, since all deaf children in our country are exposed to it, but the use of sign language is seldom a static phenomenon. In a Swedish longitudinal case study of four children with CI, the authors concluded that the children with CI and their parents successively dropped sign language as oral language develops (Nordqvist & Nelfelt 2004). In our study, the children attended different educational settings with different communication modes, which also changed over time. Although the children included in the present study were mainly oral, they were also to some extent "bilingual," some more than others. This means that they were exposed to oral language at home and at school at the time of testing, but some of them sometimes used Swedish sign language or key signs. Some puzzling correlations between time factors can be explained by this complexity. A range of medical, cultural and educational factors may explain why six out of the twelve congenitally deaf children in our data were deaf more than 4 years before implantation, and why only one child out of the six non-congenitally deafened children had such a long duration of deafness before implantation.

CONCLUSIONS

In the present study we have focused on decoding skills in children with

CI. Reading is much more than decoding and recalling of words and non-words. Decoding is, however, a critical component of literacy, and is essential for the development of good reading comprehension. Our intra-group comparison of 18 children with CI revealed that complex working memory, non-word repetition, non-word discrimination and output phonology strongly influenced decoding skills in deaf children with CI. Comprehension of grammar was, however, not as closely associated. Generally, time factors seemed less closely linked to decoding of isolated words/non-words or to reading-span tasks compared to linguistic/cognitive factors. Speed and accuracy were associated for word decoding but not for non-word decoding, indicating that the better the decoding skill, the faster the decoding of real words. Non-word decoding is more taxing than word-decoding, and the children with CI probably used different coping strategies in this task. The inter-group comparison revealed that the hearing children and the children with CI did not differ significantly on complex working memory, nonverbal IQ or reading span tasks. However, as a group the children with CI had higher decoding speed and were less accurate than the hearing children, which in turn might hamper their reading comprehension.

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