The relationship between reading comprehension, working memory and language in children with cochlear implants

Asker-Árnason, Lena; Malin, Wass; Björn, Lyxell; Ibertsson, Tina; Sahlén, Birgitta

Published in:
Acta Neuropsychologica

2007

ORIGINAL ARTICLE

ACTA Vol. 5, No. 4, 2007, 163-186
NEUROPSYCHOLOGICA

THE RELATIONSHIP BETWEEN READING COMPREHENSION, WORKING MEMORY AND LANGUAGE IN CHILDREN WITH COCHLEAR IMPLANTS

Lena Asker-Árnason[1], Malin Wass[2], Tina Ibertsson[1], Björn Lyxell[2], Birgitta Sahlén[1]

[1] Section of Logopedics, Phoniatrics and Audiology, Department of Clinical Sciences, Lund University, Sweden

[2] Department of Psychology, University of Linköping, Sweden

Key words: *hearing impairment, cognition, phonological processing, lexical access*

SUMMARY

Working memory, language, and reading comprehension are strongly associated in children with severe and profound hearing impairment treated by cochlear implants (CI). In this study we explore this relationship in sixteen Swedish children with CI. We found that over 60% of the children with CI performed at the level of their hearing peers in a reading comprehension test. Demographic factors were not predictive of reading comprehension, but a complex working memory task was. Reading percentile was significantly correlated to the working memory test, but no other correlations between reading and cognitive/linguistic factors remained significant after age was factored out. Individual results from a comparison of the two best and the two poorest readers corroborate group results, confirming the important role of working memory for reading as measured by comprehension of words and sentences in this group of children.

BACKGROUND

In the present study we will examine how factors such as working memory capacity and language skills, especially phonological skills, relate to reading comprehension in Swedish children with severe to profound hearing impairment treated by cochlear implants (CI). We will also study the relationship between demographic factors, such as age at implantation and time with implant and reading. Most previous studies have examined English-speaking

children with CI, while the present study involves Swedish-speaking children. Spoken and written Swedish differs in many respects from spoken and written English, and cross-linguistic comparisons should be made with caution.

A cochlear implant is a surgically implanted hearing device that provides access to spoken language to children with profound or severe hearing impairment. A CI does not restore hearing to normal. The neural representations of the phonetic content will still be distorted and imprecise, which in turn will influence higher processing levels in the auditory system (Harnsberger et al., 2001). Deafness does not only have modality-specific consequences, other neural systems than the auditory system will be influenced by the limited sound and auditory stimulation early in development. A range of additional processing limitations have recently been found in children with severe and profound hearing impairments, such as reduced speaking rate, speech timing and limited visuomotor integration (Schorr, 2005; Pisoni, in press).

Generally speaking, results from studies of reading skills in deaf children with CI, deafened before three years of age, indicate that they reach higher levels of reading skills than children with severe to profound hearing impairment without CI, and that they often perform on a par with hearing children (Spencer et al., 1997; Spencer et al., 2003; Geers, 2003; Dillon & Pisoni, 2004). Geers (2003), in a comprehensive study of 181 eight to ten-year-old children with four to six years of implant experience, found that over 59% scored within one standard deviation of hearing controls on a test of reading comprehension. Reading competence was associated with higher nonverbal intelligence, higher socio-economic family status, female gender and onset of deafness before 36 months of age. Roth and Schorr (2006), in a sample of 39 children with congenital, profound hearing impairment with CI, could demonstrate that speech perception, age at implantation and time with implant did not significantly predict reading performance for children with CI, but different language variables did. Dillon & Pisoni (2004) studied 76 children with CI who also demonstrated higher-level reading skills than has previously been found for deaf children without CI. They were also able to show a relationship between phonological processing skills (as assessed with non-word repetition) and reading, even when lexical skills were controlled for. Their interpretation is that a CI facilitates the development and use of rapid automatized phonological processing skills. These factors are significant contributors above and beyond such traditional demographic factors as time with implant and duration of deafness before implantation, which have been shown to affect outcome and benefit following CI (Dillon & Pisoni, 2004). However, a few deaf children seem able to develop good orthographic strategies in a "phonological vacuum," i.e., without oral phonological representations. The conclusion is thus that children with CI use mainly phonological (coding) skills in reading (Dillon & Pisoni, 2004).

Working memory capacity refers to the memory system responsible for the simultaneous storage and processing of information over a brief period of

time (Baddeley, 2000). Working memory capacity develops over time and is fully developed by the end of adolescence (cf. Gathercole, 1999). Pisoni and Cleary (2003) and Pisoni (2000), using a digit span procedure to measure working memory capacity, found that individual variations in performance could contribute to the explanation of the variation in a range of outcome measures of speech and language performance in children with CI.

Developmental studies of cognition and language in Swedish children with CI are sparse. One study including congenitally deaf children with CI (Willstedt-Svensson, Löfquist, Almqvist & Sahlén, 2004) showed that lexical and grammatical development was better indexed by a measure of working memory than by demographic factors. Wass et al. (2007) investigated the development of speed and accuracy of processing of different aspects of working memory, phonological skills and lexical access in Swedish children with CI and compared their course of development with that of age-matched hearing children. The children with CI performed on the same level as the children with normal hearing on visuo-spatial working memory, while their performance was significantly lower and slower on the measures of general working memory, phonological processing, short-term memory and lexical access. The conclusion was that the more phonological complex information to process, the greater were difficulties the children with CI demonstrated.

Non-word repetition is often used to index phonological short-term memory, as the task does not allow for the use of lexical knowledge in long-term memory (Baddeley, 1986; Gathercole & Baddeley, 1990; Hansson, Forsberg, Löfqvist, Mäki-Torkko & Sahlén, 2004). In a longitudinal study, Gathercole et al., (1992) 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/literacy skills in children with typical 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 children with severe/profound hearing impairment and CI (Dillon & Pisoni, 2004; Willstedt-Svensson et al., 2004). The link between non-word repetition and reading is indirect and mediated by lexical skills (Gathercole, 2006). When incomplete representations are held in the phonological sub-component of working memory at the point of retrieval, lexical representations in long-term memory can be activated to reconstruct the missing parts by a process called reintegration. In children with language impairment non-word repetition shares stronger statistical association with semantic/lexical skills than reading ability, even if substantial deficits in the task are strongly associated with learning failures in both areas (Gathercole, 2006). Sahlén, Hansson, Ibertsson, and Reuterskiöld-Wagner (2004) also found that lexical skills were more directly related to reading comprehension in children with

mild to moderate sensorineural hearing impairment than non-word repetition (see also Gathercole et al., 2006, for similar conclusions). However, Dillon and Pisoni (2004) argue for a more direct link in children with CI. They found that when lexical influence was factored out from the relationship between non-word repetition and reading comprehension the correlation still remained significant. Lexical skills were measured by lexical diversity in spontaneous speech samples. In the present study two lexical tasks are used, both tapping lexical access but in different ways.

Purpose

The first purpose of the present study was to compare the level of reading comprehension in 16 Swedish children with CI with a group of age-matched hearing children. A second purpose was to examine the relationship between reading comprehension and demographic factors, working memory capacity and language skills. The group of children with CI is heterogeneous with respect to demographic data, and we will also conduct a case study including the two children with the highest performance on reading comprehension and the two children with the lowest level.

MATERIAL AND METHODS

Participants

Sixteen children (6 boys and 10 girls, 7.2 to 13.4 years of age, mean 10.0 years) who had received a diagnosis of severe to profound bilateral hearing impairment before 36 months of age were included in the study. The etiology was unknown in 9 out of 16 children, hereditary in 2 children and caused by infectious disease in 5 children. Five children showed signs of progressive deterioration of hearing. As is routine in Sweden, all the children had been fitted with bilateral conventional hearing aids after the diagnosis of hearing impairment. 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 brainstem response recordings, which all showed the children to have profound hearing impairment. These children received CIs as part of the Pediatric Cochlear Implant Programs in Lund, Gothenburg, and Stockholm. The children had received their first implants between the age of 1.9 and 10.0 years (mean age at implantation 3.8 years) and had used their first implants for more than 3 years (mean length of use 6.6 years, range 3.4 – 11.7 years). Nine of the 16 children had bilateral implants.

All children were exposed to sign language before implantation in line with the Swedish education program for children with severe to profound hearing impairment. The children used oral communication as their main form of communication, but sometimes made use of sign language or signed support at

Table 1. Demographic data, 16 children with CI

Child no.	Gender	Age at diagnosis (months)	Duration of deafness (months)	Age at implantation CI 1 (months)	Age at implantation CI 2 (months)	Time with implant (months)	Age at testing (years;months)	School grade	Speech recognition Fb (%)	Commun. mode at home / in school
1	M	10	30	40	73	46	7;2	0	88	Oral+sign / oral+sign
2	F	16	7	23	50	56	6;7	1	88	Oral / oral
3	M	13	13	26	77	70	8;0	1	64	Oral / oral
4	F	7	23	30	73	61	7;7	1	80	Oral+sign / oral+sign
5	F	12	12	24	96	75	8;3	1	78	Oral / oral
6	M	24	24	48	-	68	9;8	2	00	Oral+sign / oral
7	F	10	11	21	96	88	9;1	2	72	Oral / oral
8	M	18	44	62	113	51	9;5	2	88	Oral / oral
9	F	24	0	24	104	72	9;0	2	34	Oral+sign / oral
10	F	11	19	29	-	109	11;7	4	88	Oral / oral
11	F	13	71	84	132	48	11;0	4	40	Oral+sign / sign
12	M	24	29	53	-	101	12;10	5	74	Oral / oral+sign
13	F	18	6	24	-	121	12;11	5	84	Oral+sign / oral+sign
14	M	20	9	29	-	139	12;0	5	96	Oral / oral
15	F	36	84	120	-	40	13;4	6	82	Oral+sign / oral+sign
16	F	12	48	60	-	95	12;11	6	86	Oral / oral

home or in school. All these children have hearing parents. For inclusion, a normal IQ was required, as measured by Raven's progressive coloured matrices (Raven, 1986) or the BLOCK Design test of the WISC-III battery (Wechsler, 1991). The demographic data are shown in Table 1.

Speech recognition scores were collected from medical records. *Speech recognition* was assessed by a method called *Maximum Speech Recognition* (Same, 1996). The test consists of phonetically balanced (PB) monosyllabic words in the end of a carrier phrase "Now you will hear..." (Swedish: "Nu hör du…."). The test words were presented on the 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. The numbers of words correctly repeated were calculated as a percentage of the number of test words in the list. Clinically, a score at or above 75% is considered satisfactory speech recognition. Speech recognition scores were only included as demographic data. Child 6 could not participate and therefore received a score of 0%.

Hearing children in the same grades as the children with CI were assessed on reading comprehension by the second and third authors. Descriptive data are reported in Appendices 1 and 2.

Procedure

The children were recruited from a comprehensive research project on cognition, communication and reading in Swedish children with CI (Sahlén, 2004), where children were studied aged 6 to 18 years, implanted and followed up by four different CI-teams. For the present study the children with CI were selected in appropriate ages to complete one of the standardized reading comprehension tests, SL or OS (Nielsen, Kreiner, Poulsen & Søegård, 1983, 1989, Swedish version by Magnusson & Nauclér, 1997). All the children were tested individually by the second and third authors in a separate room. The instructions were oral; only one child used the opportunity to

have them signed as well. During the test session, the child's verbal responses were only oral. For each test, the number of participating children is shown in Appendix 1. There are missing data in most of the tests due to the inadequate participation of some individual children.

The tests were administered in a fixed order and were performed in one session, lasting 35-50 minutes. All of the cognitive tests, except the WISC-III Block Design, the Raven's coloured matrices, the complex working memory tests, and the reading test, were selected from a computer-based test battery, the SIPS (Sound Information Processing System) (Wass et al., 2007).

Tests

The tests shown in Table 2 were used to assess different aspects of linguistic and cognitive skills.

Table 2. Tests

Area	Test (no. of children completing)	Quantification	Percentile	No. of children within 1 SD from hearing children
Reading comprehension	LS 40/60 (n=13, OS 64 (n=3)	Percentile	10/16 (≥ 25%)	10/16
		Percent accuracy (pca)	6/16 (≥ 50%)	
Complex working memory skills	Sentence completion and recall (SCR) (n=12)	% correct out of 18		3/12
	Complex language processing task (CLPT) (n=3)	% correct out of 42		3/3
	Combined working memory (CWM) related to distance in SD from mean value in the reference group (n=15)	1 (worst) – 5 (best)		6/15
Visuo-spatial working memory skills	Visual matrix patterns test (VMPT) (n=13)	% correct out of 8 levels		9/13
Phonological skills	Nonword repetition, consonants correct (NWR pcc) (n=14)	% consonants correct out of 120		0/14
	Nonword repetition supra-segmental accuracy (NWR psa) (n=14)	% correct, stress + length out of 48		0/14
	Nonword discrimination (ND) (n=14)	% correct out of 8 pairs		2/14
Lexical skills	Wordspotting (WS) (n=15)	% correct out of 9		2/15
	Semantic decision making (SDM) (n=16)	% correct out of 30		5/16

Reading comprehension

Reading comprehension was assessed by standardized reading tests, the SL 40 or SL 60 (Nielsen, Kreiner, Poulsen & Søegård, 1983, 1989, Swedish version by Magnusson & Nauclér, 1997), both measuring written sentence comprehension. The children were asked to match written forty or sixty sentences of increasing length to one of an array of pictures in no more than 15 minutes. For three younger children the OS 64 (Nielsen, Kreiner, Poulsen, Søegård, 1983, 1989, Swedish version by Magnusson & Nauclér, 1997), a written word comprehension test, was used (child 2, 3 and 4), since they were at the beginning of their reading development and could not participate in the sentence comprehension task. The results were reported in percentiles, and in percent correct responses.

Complex Working Memory

Sentence completion and recall was designed following the procedures developed by Towse, Hitch & Hutton (1998) to measure complex working memory, i.e. the capacity to simultaneously store and process information in younger children. An increasing number of sentences (2, 3 or 4) with the last word missing were auditorily presented to the child through the SIPS battery by a female speaker, with another sentence serving as a prompt, e.g.

Crocodiles are green. Tomatoes are …".

The task was to fill in and memorize the missing words. When the series at a certain level was presented, the child had to repeat back the words he or she had previously filled in. The answers were recorded on an external tape recorder, for later transcription. The results were scored as the total number of correctly reproduced words in all sentences taken together. For normative data from the SIPS battery, the results from the study by Wass et al., (2007) were used.

For three older children (child 12, 14, 17), another test of complex working memory was used, not included in the SIPS battery. The simultaneous processing and storing of verbal information was instead assessed by the Competing Language Processing Task (the CLPT, Gaulin & Campbell, 1994, Swedish version by Pohjanen & Sandberg, 1999). Forty-two sentences constructed as semantically acceptable or semantically unacceptable sentences were administered, divided into 12 sets with 1 to 6 sentences in each set. 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 sequence of word recall did not have to match that of sentence presentation. Responses were scored as correct if the child produced the last word of the sentences 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 maximum score of 42 was possible. Swedish hearing children (10-11 years old, grade 4-5) with typical language development reached a mean score of 81.1% (SD 13.2%) of the total score of this test (Ahlgren & Grenner, 2005).

Relative score of complex working memory (CVM)

Two different tests of complex working memory were thus used, which made comparisons difficult. We therefore developed a relative score for complex working memory (CVM), where scores are related to standard deviations in reference populations for the particular test. A score of 5p thus indicates that the score is at or above -1 SD of the reference group, 4p corresponds to a performance below –1SD in the reference population, 3p below –2 SD, 2p below -3 SD and 1p for –4 SD below the reference population.

Visuo-spatial working memory.

The Visual Matrix Patterns Test (VMPT, adapted from Della Sala, Baddeley, Allamano & Wilson, 1999) was designed to measure visuo-spatial

working memory. A pattern of filled cells in a 5 by 5 matrix was displayed on the computer screen. When the filled cells disappeared, the child was asked to mouse-click on those cells that were previously filled in an empty matrix. The level of difficulty increased from 1 to 8 filled cells. The results were automatically stored in the computer. All items in two out of three tasks had to be correct on a certain level for that level to be judged as correct. The children received span-credits for the highest level of difficulty at which they correctly reproduced two out of three items. For example, if a child could correctly reproduce two patterns of four filled cells, he/she received a visual span score of four. The maximum score was 8. Thirteen children completed this test. Age references from Wass et al. (2007) were used.

Phonological skills

Phonological short-term memory was assessed by *non-word repetition* (NWR), measured both in percent consonants correct (pcc) and percent suprasegmental accuracy (psa) and a *non-word discrimination* (ND) *task*. For *non-word repetition* the Swedish non-word repetition test consisting of non-words of two, three, four and five syllables each (for a total of 24 non-words) was administered to the children. The non-words were constructed according to Swedish phonotactic rules. The children's production of the non-words was transcribed by the first author, using both audio- and videotaped recordings. They included 120 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). Minor articulation errors were scored as correct, but phoneme substitutions were scored as incorrect. Swedish hearing children with typical language development (3-4 years) reached a mean score of 69 percent (SD 13.7) and children (5-6 years) reached a mean score of 85.5 percent (SD 7.4%) of consonants correctly produced in the non-word repetition test used in this study (Göransson & van der Pals, 2003). Older Swedish children (10-11 years old, grade 4-5) reached a mean score of 95.1 percent (SD 3.6%, Ahlgren & Grenner 2005).

A test of *non-word discrimination* was also included. Four non-words from each level of syllable length in a non-word repetition test were chosen. Each non-word appeared in two versions with 8 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). Both pairs of non-words had to be correct for a score of 1. The maximum score in the test was 8. Swedish hearing children with typical language development (3.2-4.0 years) reached a mean of 36% (SD 4.4) and children 6.4 –7.4 years old reached a mean score of 93% (SD 0.7%) of the total score on this test (Forsén & Lindsjö, 2005).

Lexical skills

Lexical skills were assessed in two tests: *Wordspotting (WS)* and *Semantic Decision Making (SDM).* In the tests, nouns were auditorily presented through the SIPS battery. In the *Wordspotting test*, the child was required to identify real words in a context of non-words, by pressing a key on the computer. The percentage of correctly indicated real words out of the nine words was computed.

In *the Semantic Decision Making* the task was to press the space key on the computer if an orally presented noun belonged to a certain, predefined semantic category. The percentage of correct responses out of a total of 30 possible correct responses was measured.

RESULTS

In this section we will first present descriptive data of the children in comparison with their hearing peers. Further, simple correlations between all measures will be presented and partial correlations relevant for our research questions. Finally, we will give a more detailed description of four cases, the two children with CI reaching the highest level of reading comprehension and the two children with the lower performance.

In Table 2, the tests and the areas represented by the tests are presented, as well as the quantification principles. For the reading tests, percentiles and reading categories are reported. For all other tests (including the reading measure showing percent correct answers in the reading comprehension tests) the number of children within 1 SD of the hearing children in the age-reference groups will be presented. The number of children completing each task is also shown. For individual data see Appendix 1.

Reading comprehension

Thirteen children completed the written sentence comprehension test, the SL 40 or the SL 60, depending on school grade. Three children were given the OS 64, which is a written word comprehension test. This was given when the sentence comprehension test was too challenging for the child. The results from the reading comprehension tasks are presented in two ways:

– *Reading percent correct answers* (*pca*) is the number of correct answers in relation to the total number tasks in the test, since the number differs depending on which test the child has completed. Ten children performed within one standard deviation compared to the hearing controls.
– *Percentile* shows the number of correct answers in relation to age and to the Swedish norms for these tests.

Complex working memory

As for the complex working memory task, the SCR (Sentence Completion and Recall), twelve children completed the SCR, and three children out of

twelve performed within – 1SD from the controls. For the three children completing the CLPT (Complex Language Processing Task), all three actually performed better than the twenty-seven hearing peers (Ahlgren & Grenner, 2007), who reached a mean of 67%, SD 8.51. For the CWM (the relative Complex Working Memory measure, scaled 1-5), six of the fifteen children reached category 5, i.e. at or above -1 SD as compared to reference groups.

Visual working memory

Thirteen children completed the VMPT (Visual Matrix Patterns Test). Nine children out of thirteen performed within 1 SD as compared to hearing peers in Wass et al. (2007).

Phonological skills

Non-word repetition was analysed in percent consonant correct, NWR (pcc), and in percent suprasegmental accuracy: NWR (psa). Two children did not participate in this task. The hearing children reached a mean of 85-93 pcc (depending on age) in this task and reached the ceiling on NWR (psa), mean 92.5-99 (psa) depending on age (see Appendix 1). For NWR (pcc) and NWR (psa) none of the children with CI scored within 1 SD of the reference population. For ND (non-word discrimination), only two children scored within 1SD of the hearing children. Here the ceiling effect for the hearing children in the reference groups was even more obvious, their range of performance was 98.8-100%.

Lexical skills

Word spotting and semantic decision making

For WS (Word Spotting), two out of fifteen children with CI performed within 1 SD, and for SDM (Semantic Decision Making) five children out of sixteen performed within 1SD. One child, child 7, could not participate in the WS.

Summation

In sum, compared to hearing children the children with CI seemed to have particular difficulties with the two phonological tasks, the NWR (pcc) and the NWR (psa) and the ND, but also with one of the lexical tasks, the WS.

Correlations

Table 3 shows simple correlations (Pearson's two-tailed) between reading measures, demographic and linguistic/cognitive factors. Reading (pca) was significantly correlated to the other reading measure, reading percentile ($r = 0.537$, $p < o.05$), as well as to the VMPT ($r = 0.669$ $p < 0.05$), the NWR (pcc) ($r = 0.679$ $p < 0.01$) and the ND ($r = 0.541$ $p < 0.05$).

Significant correlations were also found between the reading percentile and the complex working memory measure, the SCR, ($r = 0.674$, $p < 0.05$).

Table 3. Correlations between all variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Reading % acc.															
2 Reading percentile	.537*														
3 Age at testing	.390	.131													
4 Age at diagnosis	.031	.157	.497*												
5 Duration of deafness	.065	-.063	.457	.328											
6 Age at implant.	.066	-.010	.534*	.562*	.966**										
7 Time with CI	.324	.154	.480	-.072	-.501*	-.461									
8 SCR %	.485	.674*	.527	.188	.467	.450	.034								
9 CWM	.254	.204	.349	.036	.404	.366	.083	.832**							
10 VMPT %	.669*	.501	.500	-.115	.428	.337	.147	.614*	.458						
11 NWR pcc	.679**	.442	.508	.220	.103	.150	.456	.527	.456	.614*					
12 NWR psa	.211	.032	.668**	.191	.187	.216	.545*	.430	.410	.263	.579*				
13 ND %	.541*	.352	.627*	.155	.329	.328	.294	.669*	.348	.678*	.592*	.465			
14 WS %	-.118	.304	.235	.479	.183	.288	.042	.426	.417	.028	.672*	.352	.403		
15 SDM %	-.022	.201	.113	.025	-.052	-.040	.201	.152	.124	-.170	.495	.475	.442	.631*	

As for the demographic factors (age at testing, age at diagnosis, duration of deafness, age at implantation, time with CI), no factor correlated significantly with the reading measures.

Age at testing and time with CI both correlated significantly with NWR (psa): $r = 0.668$, $p < 0.001$, $r=545$, $p < 0.05$, respectively. Age at testing also correlated significantly with ND ($r = 0.627$, $p < 0.05$), age at diagnosis ($r = 0.497$, $p < 0.05$) and age at implantation ($r = 0.534$, $p < 0.05$). There were also significant correlations between age at diagnosis and age at implant ($r = 0.562$, $p < 0.05$) and between age at implant and duration of deafness ($r = 0.966$, $p < 0.01$) and also between time with CI and duration of deafness ($r= -0.501$, $p < 0.05$).

For the linguistic and cognitive factors, the following significant correlations were obtained:

– between NWR (pcc) and ND ($r = 0.592$, $p < 0.05$);
– between NWR (pcc) and WS ($r = 0.672$, $p < 0.05$);
– between ND and SCR ($r = 669$, $p =< 05$);
– between NWR (pcc) and VMPT ($r = 0.614$, $p < 0.05$).

VMPT also correlated significantly with SCR ($r = 0.614$, $p < 0.05$) and with ND ($r = 0.614$, $p < 0.05$) and with the two non-word repetition measures, NWR (pcc) and NWR (psa): $r = 0.579$, $p < 0.05$. A significant correlation was also present between the two lexical measures, WS and SDM ($r = 0.631$, $p < 0.05$), and also between the CWM and SCR ($r = 0.832$, $p < 0.01$). NWR also correlated significantly with NWR (psa): $r = 0.545$, $p < 0.05$.

In sum, the significant simple correlations found between the reading measures and the cognitive/linguistic measures were as follows:

– between reading (pca) and two of the phonological measures, NWR (pcc) and ND;
– between reading (pca) and the visual working memory measure, the VMPT;
– between the reading percentile and NWR (pcc).

Partial correlations

The influence of chronological age

The significant correlations between the three reading measures and linguistic/cognitive factors disappeared when chronological age at testing was factored out. One of the reading measures was already related to chronological age, the reading percentile; therefore no partial correlations were carried out for that variable. Two new significant correlations appeared when age was factored out: between reading (pca) and the two complex working memory measures, the SCR ($r = 0.732$ $p < 0.05$) and the CWM ($r = 0.662$, $p < 0.05$, see Table 4).

Table 4. Simple correlations, 2-tailed and below, with age factored out (not for reading percentile, which is already age related) between dependent variables and linguistic and cognitive factors. The number of children in each task within brackets, if different from the number stated to the left. The CLPT with 3 participants is not included

Reading	WS (15)	SDM	VMPT (13)	SCR (12)	CWM (15)	ND (14)	NWR (pcc) (14)	NWR (psa) (14)
Simple percent correct	-.118	-.022	.669*	.485	.254	.541*	.679**	.211
Partial (controlled for age at testing)	-.210	-.518	.494	.732*	.662*	-.266	.316	-.067
Simple percentile (age already controlled for)	.304	.201	.501	.674*	.204	.352	.442	.032

The influence of demographic factors

When demographic factors were factored out, successively, an obvious association between the two complex working memory measures and reading (pca) was revealed. When the influence of duration of deafness, time with CI, age at diagnosis, and age at implantation were removed, significant correlations appeared between:

– reading (pca) and the CWM measure;
– reading (pca) and the SCR ($r = 0.804$, $p < 0.01$; $r = 0.747$, $p < 0.05$; $r = 0.736$, $p < 0.05$; $r = 0.789$, $p < 0.01$, respectively);
– reading percent correct and the CWM ($r = 0.777$ $p < 0.05$; $r = 0.778$, $p < 0.05$; $r = 0.714$, $p < 0.05$; $r = 0.740$, $p < 0.05$).

The correlation between reading (pca) and the VMPT remained significant when we factored out age at diagnosis ($r = 0.633$, $p < 0.05$). For the reading percentile the only significant correlation that remained was that with the SCR when duration of deafness was factored out ($r = 0.664$, $p < 0.05$, cf. Table 5).

Table 5. Significant partial correlations, 1-tailed, between dependent variables and demographic or/and cognitive factors, with, one at a time, demographic variables partialled out: Time as deaf, Time with CI, Age at diagnose, and Age at implantation, and also with the two lexical variables, Wordspotting and Semantic decision making factored out

	Duration of deafness	Time with CI	Age at diagnosis	Age at implantation	Wordspotting	Semantic decision making
Reading pa	SCR .804** CWM .77*	SCR .747* CWM .778*	SCR .736* CWM .714* VMPT .633*	SCR .789** CWM .740*	SCR .803** CWM .753* NWR pcc .745*	SCR .789** CWM .703* NWR pcc .716*
Reading, percentile	SCR .664*	No significant corr.	No significant corr.	No significant corr.	NWR pcc .769*	NWR pcc .689*

The influence of lexical factors

With the lexical factors, the WS and the SDM factored out, one at a time, there were significant correlations between the reading (pca) and the two complex working memory measures, the SCR and the CWM:

– between the reading (pca) and the SCR with WS factored out ($r = 0.803$, $p < 0.01$) and with SDM factored out ($r = 0.789$, $p < 0.01$).
– between the reading (pca) and the CWM with the WS factored out ($r = 0.753$, $p < 0.05$) and with the SDM factored out ($r = 0.703$, $p < 0.05$).

There were also significant correlations between the reading (pca) and the NWR (pcc) with the WS factored out ($r = 0.745$, $p < 0.05$) and with the SDM partialled out ($r = 0.716$, $p < 0.05$). Significant correlations also emerged between the reading percentile and the NWR (pcc) with WS factored out ($r = 0.769$, $p < 0.05$) and with SDM factored out ($r = 0.689$, $p < 0.05$, cf. Table 5).

In sum, the significant correlations between the reading (pca) and the VMPT only remained when age at diagnosis was factored out. The significant correlation between reading percent correct and NWR (pcc) remained when the two lexical factors were factored out, one at a time.

When controlling for lexical influence, a significant correlation appeared between reading percentile and NWR (pcc). Further, significant correlations appeared between the reading (pca) and the two complex working memory measures, SCR and CWM, when controlling for demographic as well as for lexical influence.

The influence of gender

A t-test was carried out in order to explore differences in the results between boys and girls. No significant differences were found.

Individual cases

Our population of children were heterogeneous with respect to most demographic factors.

One way to further explore the results is to conduct case studies on high and low performing children. We will report individual data for four of the participating children:

– children 5 and 13, who were the best performers;
– children 8 and 10, who had the lowest performance levels (see Fig. 1).

Their scores in reading percentile, complex working memory (*SCR*), lexical measures (WS and SDM), phonological measures NWR (pcc and psa) and ND and the visual working memory task, VMPT, were compared to the mean scores of the age-matched group of hearing children (cf. Fig. 2). Child 5 and 13 (both girls) were the only children in this group of participants who reached the 75th reading percentile and therefore they were chosen as higher performers (child 5 did not complete one of the phonological measures, the ND, which is why the score for the hearing group is not presented). Six of the children were in the 10th reading percentile, and from among them one

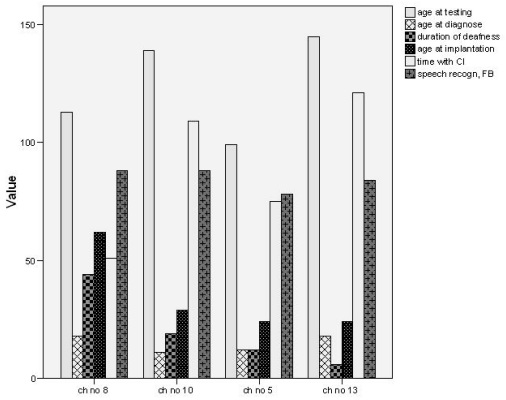

Fig. 1. Demographic data for four individuals, poorer readers

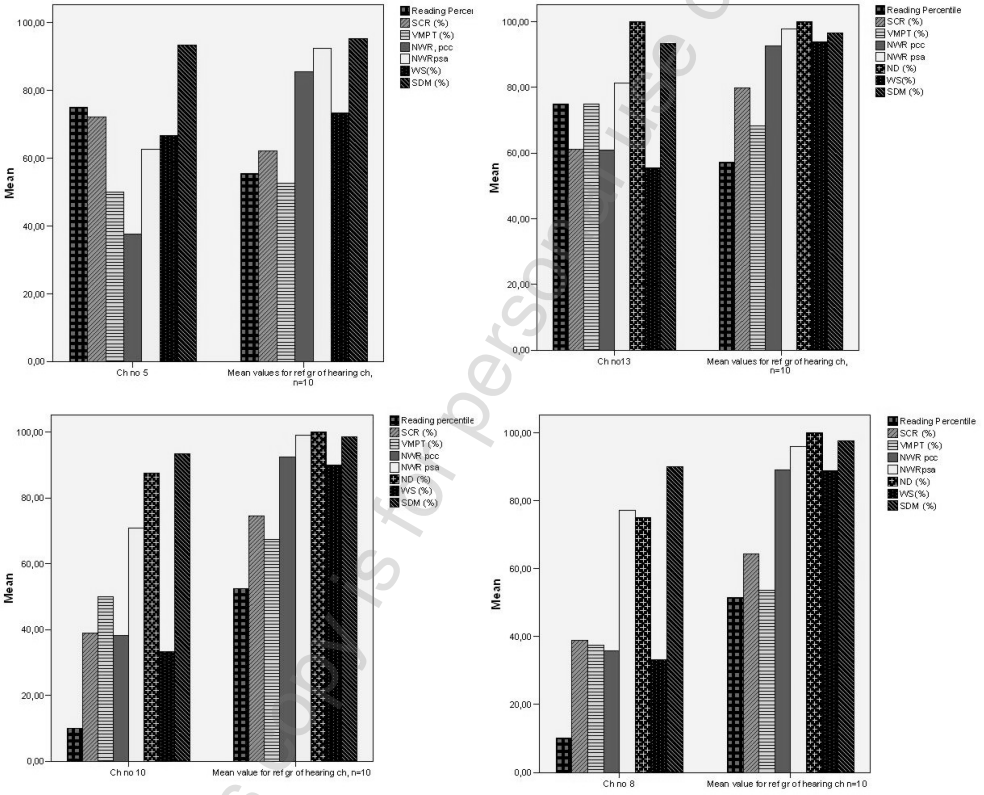

Fig. 2. Individual data on one reading measure (percentile), one complex working memory measure (SCR), the visuo-spatial working memory measure, VMPT, the phonological measures (NWRpcc, NWRpsa and ND), and the lexical measures (WS and SDM) for four children, two classified as better readers (nos. 5 and 13) and poorer readers (nos. 10 and 8)

boy and one girl (children 8 and 10) were selected to represent the poorest readers, since they both completed all tests.

Demographics

As can be seen in Fig. 1, all four children, the two better performers and the two poorer performers, had acceptable speech recognition scores, ranging from 78% to 88%. They were all diagnosed as severely or profoundly hearing impaired before 18 months of age (11-18 months) and can thus be considered as prelingually deaf. Child 10 had a later CI implantation (at age 5;2), and thus a longer duration of deafness (3;8 years) than the other children. The three remaining children received their implants at the age of around 2 years (2;0-2;5 years) and consequently had a shorter duration of deafness. Child 8 had a duration of deafness of 19 months, and the two better performers, child 5 and child 13, had a duration of deafness of 12 and 6 months respectively.

The children differed in chronological age at testing:

– child 5, 8;3 years;
– child 13, 12;11 years;
– child 8, 9;5 years;
– child 10, 11;7 years.

All the children had worn their implants for more than 4 years. The two better performers, child 5 and child 13, had worn their CI's for 6;3 and 10:1 years respectively, and the children who performed more poorly, child 8 and child 10, had worn their implants for 4;3 and 9;1 years respectively.

Linguistic/cognitive measures

Regarding complex working memory measures (see Fig. 2), phonological measures and lexical measures, the first striking similarity between the two better readers was that their complex working memory scores were at a par with those of their age matched peers, whereas the two poorer readers had a complex working memory score below the mean of the reference groups.

For the word spotting, there was also a similarity between the better readers, who both performed better than the poorer readers. None of them reached the mean score for the reference groups of hearing children, but child 5 was close to the mean score for hearing children. For the other lexical task, the semantic decision-making, both the better and the poorer readers performed almost at a par with their hearing peers.

Both better readers performed on par with the group of hearing children on the visual working memory task; child 13 was even better than her hearing peers in her grade, whereas the two poorer readers performed far below the mean for their reference groups.

For the phonological measures, child 13 had a non-word discrimination score on a par with hearing peers (100%) and the second best non-word repetition score (pcc and psa) in the group of children with CI. The other better

reader, on the other hand, had a score on the NWR task below mean for the group (this child did not participate in the ND task).

In sum, the two better readers performed at the same or almost the same level with their age matched peers on the complex working memory task and the visual working memory task, but the poorer readers did not. For non-word repetition the picture was not so clear: compared to the whole group of children with CI, one of the better readers (child 13) performed better than average, but child 5 was on a par with the poorer readers on this task.

DISCUSSION

The 16 Swedish children with CI had a relatively good reading comprehension in relation to Swedish hearing children. Two different ways of analyzing the reading comprehension tests were used. Ten out of 16 (63%) children performed at or above the 25th percentile and ten out of 16 (63%) children performed within 1 SD of hearing children when percent sentences/ words correct was measured. Our results are consistent with those reported by Geers (2003), although slightly better. It should be noted, however, that the children in Geers' study (2003) are not quite comparable to the children with CI in our study. The participants in her study consisted of a population of children that were more homogenous with respect to age and time factors than in the present study: they were all between 8 and 9 years, they were all implanted earlier and they had all worn their implants for more than four years. Another factor that may explain the differences relates to the fact that Swedish and English differ in orthography. Dillon and Pisoni (2004) claim that most deaf children with CI use phonological coding skills. If so, the better performance in the Swedish children with CI can be explained by the fact that Swedish has a more transparent orthography than English, which may make reading easier for children relying mainly on a phonological strategy.

For the linguistic and cognitive factors, it is obvious that the children with CI in comparison to hearing children exhibit most problems with non-word repetition, non-word discrimination and lexical access. One of the complex working memory tests, the SCR, also proved to be difficult for the children with CI. Wass et al. (2007) conclude that they performed on a level with the children with normal hearing on visuo-spatial working memory, while their performance was significantly lower on the measures of complex working memory. The children with CI appeared to have specific problems with storage and processing of phonological and lexical information compared to the children with normal hearing. The more phonologically complex the information used to test working memory capacity, the more difficulties children with CI exhibited (Wass, 2007).

Predictors of reading comprehension

None of the demographic factors correlated with reading measures. This is in line with several previous studies on children with CI (c.f. Dillon & Pisoni,

2004; Sahlen et al., 2007). However, there were some significant correlations between age and time factors and the cognitive and linguistic factors: that is, between age at testing and non-word repetition (as measured by suprasegmental accuracy) and non-word discrimination. The significant correlations, however, disappeared when age was controlled for. There were also several significant correlations between reading comprehension and linguistic/cognitive factors, which all disappeared when age at testing was factored out. The conclusion is thus that the associations with reading comprehension were strongly influenced by chronological age in this study. The only association found was that between reading percentile and the complex working memory task (SCR).

Lexical skills did not correlate significantly with reading comprehension. With the lexical factors, the WS and the SDM factored out, the only correlation from the correlations between reading and the independent variables that remained significant was between non-word repetition (pcc) and reading comprehension as measured by percent correct. These results thus partly corroborate the results by Dillon & Pisoni (2004), who found a direct link between non-word repetition and reading in children with CI when lexical skills were factored out.

Interestingly, several new significant partial correlations appeared between reading comprehension and demographic factors, when age (Table 4) and other demographic factors (Table 5) were controlled for. The partial correlations between working memory measures (SCR and CVM) and reading (percent correct) and reading (percentile) then reached significance. Our interpretation is that the age and time factors in our data are strongly masking a relationship between reading and working memory.

Suprasegmental aspects of non-word repetition

There are several pitfalls involved in using non-word repetition in clinical populations. One is the strong influence of output phonology. Another pitfall is not taking suprasegmental aspects into account, which was emphasized in a study by Sahlén et al. (1999). Pre-stressed syllables in non-words were much more vulnerable to omission than post-stressed syllables in Swedish children with language impairment, even when the length of the non-words was held constant. Goswami (2003) envisions prosody as a new field for research in phonological processing and emphasizes that research in literacy development should shift the focus from the segmental to the supra-segmental temporal level. Phonological representations in children are not developed and generated automatically only because speech is perceived categorically in terms of phonetic contrasts. Instead, syllable-based encoding operates, with early sensitivity to features that discriminate between syllables. Such features are duration, pitch and stress, according to the author. Children with CI may have instable categorical perception and might thus be more dependent on suprasegmental cues than hearing children (Ibertsson et

al., in press). In the present study, then, non-words were analyzed both segmentally and suprasegmentally. Imitation of suprasegmental features was easier for the children with CI than imitation of segmental features in non-words, as can be seen in Appendix 1. The comparison to hearing children shows that the children with CI performed much more poorly than age-matched hearing children and younger hearing children at age six (Forsén & Lindsjö, 2005) and four years (Göransson & van der Pals, 2003). Suprasegmental accuracy in non-word repetition is thus acquired very early in hearing and typically developing children, and the analysis should not be neglected in children with speech production problems in longitudinal studies (Ibertsson et al., in press).

A non-word discrimination task was also used, which does not tap speech production either. Non-word discrimination correlated with non-word repetition as measured by suprasegmental and segmental accuracy, but the correlations disappeared when age was factored out. Non-word discrimination does not necessarily require phoneme discrimination abilities or precise segmental representations, but can rely on discrimination on a suprasegmental level based on duration, pitch and stress. One expectation was that these children would perform better on this task, but only two children with CI actually performed within 1 SD of the hearing children in the reference groups. In Appendix 1 it can be seen that the performance of the children with CI varies between 0 and 100%.

For non-word repetition we also found that all significant correlations with time factors (cf. Table 3) remained when the time factors were factored out one at a time (see Table 5). Our interpretation is that non-word repetition is related to maturation and not to factors related to deafness.

Measures of working memory and lexicon

Sahlén et al. (2007) found no significant difference between the 15 Swedish children with CI and individually age-matched hearing children on the CLPT. The three children with CI in our study who were assessed with the competing language processing task, the CLPT, performed within 1 SD compared to age peers. However, only three out of the twelve children who were assessed with the sentence completion and recall task, the SCR, performed within 1 SD as compared to age matched children.

When a combined score of complex working memory was applied in our set of data, only 6 out of 15 children performed within 1 SD compared to hearing children. Towse, Hitch and Hutton (1998) recommended the use of a sentence completion and recall task (the SCR) for younger children. In our study only older children, above age 11, were given the CLPT. There are two possible explanations for the difference between results in older and younger children. One interpretation is that our data mirror the fact that complex working memory develops with age. There is, however, one more possible but less plausible explanation. The SCR and the CLPT might tap somewhat dif-

ferent skills. Both measures require a verbal response (words), but the retrieval of the words is prompted in different ways in the first processing component of the tasks. The processing component in the SCR requires lexical retrieval (word mobilization), whereas the processing component in the CLPT requires judgement of the semantic acceptability of sentences (only yes/no answers). The recall component in SCR is thus more dependent on whether the child actually had the time to retrieve the actual word in the processing component, whereas the recall component in the CLPT requires the recall of the last words of sentences given by the examiner.

The first explanation is consistent with the view that language becomes more and more independent of cognition over time. In a previous study by Sahlén et al. (2004) on reading comprehension in children with mild/moderate hearing impairment, it was found that lexical/semantic skills were more closely related to reading comprehension than working memory. The children with mild/moderate hearing impairment were generally more developed linguistically and might have automatized their reading to a greater extent than the severely/profoundly hearing impaired children with CI in this study.

We were somewhat surprised by the outcome of the lexical access tasks. One of the lexical measures, the semantic decision-making (SDM), was thought to be more difficult than the word spotting task, the WS. In the WS, recognition or "fast mapping" between the test item (a real word) and a lexical representation is needed, and also the inhibition of responses to a non-word. In the SDM more semantic-lexical processing is required, since the child has not only to recognize but also to categorize words. Our results show the opposite, the children perform more poorly on the WS than on the SDM. Our interpretation is that the WS is more demanding phonologically, since real words are mixed with non-words. For children with imprecise phonological representations, it might be a greater challenge to identify words in a context of non-words than to categorize well-known and familiar words as in the SDM.

Good versus poor readers

For the group of children with CI there were also significant correlations *between* the demographic factors. The older the children were when they received their diagnosis as severely or profoundly hearing impaired, the later they received the implant. Further, the later the age at implantation, the longer the duration of deafness. All these associations seem logical. There is, however, a great heterogeneity in our data as to the age and time factors. We therefore presented individual data for two "stars" (reading comprehension above 75th percentile) and for two children that performed poorly on reading comprehension (reading comprehension below 10th percentile). The two children with better reading performance had been deaf for a shorter time before implantation than the poorer performers. Speech recognition could not explain differences in reading performance. The two poor readers did not have lower speech recognition scores than the best readers. As a matter of fact, at

a group level the three children with poor speech recognition (below 40%) were not the poorest performers on reading tasks. This result corroborates the result obtained by Roth and Schorr (2006). Non-word discrimination does not seem to differentiate the two better from the two poorer readers. The most obvious differences between the better and the poorer readers is the performance on working memory tasks and on one of the lexical tasks. Further, although all four children have difficulties repeating non-words, the "stars" are obviously better than the poorer readers.

CONCLUSION

To conclude, more than 60% of the Swedish children with CI in this study had a reading comprehension at the level of hearing peers. Demographic factors were not predictive of reading comprehension, but a complex working memory task was. No other correlations between reading and cognitive/linguistic factors remained significant after age was factored out. Non-word repetition and reading remained significantly correlated when lexical skills were factored out. The result from the comparison of the best and the poorer readers corroborate group results, confirming the important role of working memory for reading as measured by comprehension of words and sentences. It should be remembered that reading comprehension is a complex skill and much more than only comprehension of sentences and words is required.

ACKNOWLEDGEMENTS

First of all, we would like to thank all the children and their parents for participation. We are also grateful to the Swedish Council of Working Life and Social Science (FAS) and to the Sunnerdahl Disability Foundation for financial support. We thank Barnplantorna and the clinical CI teams for helping us recruit the children, and to Dr. Elina Mäki-Torkko and Dr. Jan Grenner for audiological advice.

REFERENCES

Adams, A.M. & Gathercole, S.E. (1995). Phonological working memory and speech production in preschool children. Journal of Speech and Hearing Research, 38, 403-414.

Ahlgren, H. & Grenner, E. (2005). Samband mellan arbetsminnet och skrivprocessen hos normalspråkiga barn i åldern tio till elva år. Master's thesis, Department of Logopedics, Phoniatrics and Audiology, Lund University.

Baddeley, A.D. (2000). The episodic buffer: a new component of working memory? Trends in Cognitive Sciences, 4 (11), 417-423.

Baddeley, A.D. (1986). Working memory. Oxford Psychology Series, 11. Oxford: Clarendon Press.

Briscoe, J., Bishop, D.V.M & Norbury, C.F. (2001). Phonological processing, language and literacy: A comparison of children with mild-to-moderate sensorineural hearing loss and those with specific language impairment. Journal of Child Psychology and Psychiatry, 42(3) 329-340.

Della Sala, S., Gray, C., Baddeley, A., Allamano, N. & Wilson, L. (1999). Pattern span: a tool for unwelding visuo-spatial memory. Neuropsychologica, 37, 1189-1199.

Dillon, C.M. & Pisoni, D.B. (2004). Nonword repetition and reading in deaf children with cochlear implants. International Congress Series, 1273, 304-307.

Forsén, J. & Lindsjö, J. (2005). Relationen mellan språkliga förmågor och arbetsminne hos barn i förskoleklass samt barn i år 1 - en undersökning med hjälp av ett datorbaserat testbatteri. Master's thesis, Department of Logopedics, Phoniatrics and Audiology, Lund University.

Gathercole, S.E. (2006). Nonword repetition and word learning: The nature of the relationship. Applied Psycholinguisitcs, 27, 513-543.

Gathercole, S. (1999). Cognitive approaches to the development of short-term memory. Trends in Cognitive Sciences, 3(11), 410-419.

Gathercole, S.E., Willis, C.S., Emslie, H. & Baddeley, A.D. (1992). Phonological memory and vocabulary development during the early school years: a longitudinal study. Developmental Psychology, 28, 887-898.

Gathercole, S.E & Baddeley, A.D. (1990). Phonological memory deficits in language disorded children: is there a casual connection? Journal of Memory and Language, 29, 336-360.

Gaulin, C. & Campbell, T. (1994). Procedure for assessing verbal working memory in normal school-age children: some preliminary data. Perceptual & Motor Skills, 79, 55-64.

Geers, A. (2003). Predictors of reading skill development in children with early cochlear implantation. Ear & Hearing, 24, 59-68.

Goswami, U. (2003). Why theories about developmental dyslexia require developmental designs. Trends in Cognitive Sciences, 7(12), 534-540.

Göransson, K. & van der Pals, K. (2003). Vilka faktorer påverkar förskolebarns förmåga att böja verb? Undersökning av arbetsminnets och den lexikala förmågans betydelse. Master's thesis, Department of Logopedics, Phoniatrics and Audiology, Lund University.

Hansson, K., Forsberg, J., Löfqvist, A., Mäki-Torkko, E. & Sahlén, B. (2004). Working memory and novel word learning in children with hearing impairment and children with language impairment. International Journal of Language and Communication Disorders, 39, 401-422.

Harnsberger, J.D., Svirsky, M.A., Kaiser, A.R., Pisoni, D.B., Wright, R. & Meyer, T.A. (2001). Perceptual "vowel spaces" of cochlear implant users: Implications for the study of auditory adaptation to spectral shift. Journal of the Acoustical Society of America, 109, 2135-2145.

Ibertsson, T. , Willstedt-Svensson, U. , Radeborg, K. & Sahlén, B. (In press). A methodological contribution to the assessment of nonword repetition – a comparison between children with specific language impairment and hearing impaired children with hearing aids or cochlear implant. To appear in Logopedics, Phoniatrics and Vocology.

Montgomery, J.W. (1995). Sentence comprehension in children with specific language impairment: the role of phonological working memory. Journal of Speech and Hearing Research, 38, 187-199.

Nielsen, J.C, Kreiner, S., Poulsen, A. & Søegård, A. (1983, 1989). SL 60 and SL 40. Swedish version copyright © 1997, Dansk psykologisk Førlag. Translated and adapted by E. Magnusson & K. Nauclér. Löddeköpinge: Pedagogisk Design.

Nielsen, J.C, Kreiner, S., Poulsen, A. & Søegård, A. (1983, 1989). OS 64 and OS 120. Swedish version copyright © 1997, Dansk psykologisk Førlag. Translated and adapted by E. Magnusson & K. Nauclér. Löddeköpinge: Pedagogisk Design.

Pisoni, D.B., Kronenberger, W., Conway, C.M., Horn, D.L., Karpicke, J. & Henning, S. (2008). Efficacy and effectiveness of cochlear implants in deaf children. Manuscript, to appear in M. Marschark, P. Hauser (eds.), Deaf cognition: foundations and outcomes. New York: Oxford University Press.

Pisoni, D.B. & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. Ear & Hearing, 24, 106-120.

Pisoni, D.B. (2002). Cognitive factors and cochlear implants: Some thoughts on perception, learning and memory in speech perception. Ear & Hearing, 24, 106S-120S.

Pohjanen, A. & Sandberg, M. (1999). Arbetsminnet hos svenska fem-, sju- och nioåriga barn med normal språkutveckling. Master's Thesis at the Department of Logopedics and Phoniatrics, Lund University.

Raven, J.C. (1986). Coloured Progressive Matrices. London: H. K. Lewis.
Roth, F. & Schorr, E.A.(2006). Poster presented at the ASHA convention, Miami, USA.
Sahlén, B., Willstedt-Svensson, U., Ibertsson, I. & Lyxell, B. (2007). Word-decoding and reading-related skills in children with cochlear implants. Unpublished manuscript.
Sahlén, B., Hansson, K., Ibertsson, T. & Reutersköld-Wagner (2004). Reading in children of primary school age – a comparative study of children with hearing impairment and children with specific language impairment. Acta Neuropsychologica, 2(4), 393-407.
Sahlén, B., Reuterskiöld-Wagner, C., Nettelbladt, U. & Radeborg, K. (1999). Non-word repetition in children with language impairment – pitfalls and possibilities. International Journal of Language and Communication Disorders, 34, 337-351.
SAME. (1996). Metodbok i hörselmätning. Solna: C-A Tegnér.
Schorr, E.A. (2005). Social and emotional functioning of children with cochlear implants. Unpublished Master's Thesis, University of Maryland, College Park, Maryland, USA.
Spencer, L., Baker, B.A. & Tomlin, B.J. (2003). Exploring the language and literacy outcomes of pediatric cochlear implant users. Ear & Hearing, 24(3), 236-247.
Spencer, L., Tomblin, J., & Gantz, B. (1997). Reading skills in children with multichannel cochlear-implant experience. Volta Review, 99, 193-203.
Towse, J. N., Hitch, G. J. & Hutton, U. (1998). A reevaluation of working memory capacity in children. Journal of Memory and Language, 39, 195-217.
Wass, M., Hällgren, M., Ibertsson, T., Larsby, B. & Sahlén, B. (2007). SIPS (Sound Information Processing System). Manuscript. Inst. för beteendevetenskap, Linköpings Universitet.
Wechsler, D. (1991) Wechsler Intelligence Scale for Children (third ed.), WISC-III Manual, The Psychological Corporation, USA.
Willstedt-Svensson, U., Löfqvist, A., Almqvist, B., & Sahlén, B.(2004). Is age at implant the only factor that counts? The influence of working memory on lexical and grammatical development in children with cochlear implant. International Journal of Audiology, 43(9), 506-515.

Correspondence address:
Lena Asker-Árnason
Department of Logopedics, Phoniatrics and Audiology
Lund University Hospital
22185 Lund
phone: 004646177839
e-mail: lena.asker-arnason@med.lu.se

Received: 10 October 2007
Accepted: 28 December 2007

Appendix 1. Results, 16 children with CI, 10 girls and 6 boys in grade 0-6

Age references from Wass et al. (ms) for the following: Sentence completion and recall (SCR), Visual matrix pattern test (VMPT), Nonword repetition (NWR), percent consonants correct (pcc) and percent suprasegmental accuracy (psa), Nonword discrimination (ND), Word spotting (WS), Semantic decision making (SDM): Age references from Ahlgren & Grenner 2005, n=27, gr. 4-5 for the following: Complex language processing task (CLPT). CWM is the relative score for complex working memory in relation to SD in the normative data. For normative data on Reading measures, see Appendix 2.

Child Grade	Reading % SL /(OS)	Reading & corr. SL/(OS)	SCR/ (CLPT) %	CWM	VMPT %	NWR pcc	NWR psa	ND %	WS %	SDM%
1 Gr 0 Norm. ref.	25	45.0	47.2 / 48.6 / 10.0	5 / 5	37.5 / 39.0 /7.1	- 85.1 / 8.0	- 97.9 / 3.0	- 98.8 4.0	55.6 / 72.2 / 19.8	100.0 / 94.4 / 4.7
2 Gr 1	(10)	(59.1)	11.1	1	37.5	39.0	60.4	37.5	55.6	90.0
3	(25)	(95.3)	47.2	4	62.5	33.0	68.8	75.0	22,2	80.0
4	(25)	(93.8)	44.4	4	50.0	48.0	70.8	12.5	33.3	83.3
5 Norm. ref.	75 (55.5) (27.3)	88.3 / (96.2) / (8.1)	72.2 / 62.2 / 12.1	5 / 5	50.0 / 52.5 / 11.5	37.5 / 85.6 / 7.1	62.5 / 92.5 / 5.4	- 98.8 / 4.0	66.7 / 73.4 / 11.9	93.3 / 95.3 / 5.3
6 Gr 2	10	31.7	-	-	25.0	17.5	70.9	0.00	-	76.7
7	25	95.0	44.4	3	50.0	-	-	62.5	0.00	86.7
8	10	66.7	38.9	2	37.5	35.8	77.1	75.0	33.3	90.0
9 Norm. ref.	50 51.5 33.1	90.0 / 84.2 / (18.2)	25.0 / 64.4 /8.8	1 / 5	25.0 / 53.8 / 19.6	32.5 / 89.2 / 4.5	62.5 / 95.2 / 3.7	25.0 / 100 / 0	11.1 / 88.9 / 12.8 /	86.7 / 97.7 / 4.2
10 Gr 4	10	72.5	38.9	2	50.0	38.3	70.9	87.5	33.3	93.3
11 Norm. ref.	50 52.3 28.7	95.0 / 92.05 / (7.6)	55.6 / 73.2 / 10.6	4 / 5	87.5 / 67.0 / 11.6	40.0 / 92.4 / 7.6	64.6 / 99.0 / 1.5	73.3 / 100 / 0	11.1 / 89.9 / 7.8	73.3 / 98.5 / 1.7
12 Gr 5	10	90.0	(71.4)	5	-	51.2	70.8	75.0	46.7	80.0
13	75	100	61.1	3	75.0	60.8	81.3	100	55.6	93.3
14 Norm. ref.	50 57.3 28.8	95.0 / 95.3 / (5.4)	(76.2) / 79.9 / 9.4 / (67.0) / (8.5)	5 / 5	68.2 / 18.8	67.8 / 92.7 / 3.6	86.3 / 97.7 / 2.2	75.0 / 100 / 0	66.6 / 93.9 / 7.6	96.0 / 96.7 / 3.0
15 Gr6	50	97.5	72.2	5	62.5	59.2	77.1	100.0	88.9 /	96.7
16 Norm. ref.	10 29.0 26.7	85.0 / 93.3 / (4.1)	(76.2) / 81.1 / 13.2 / (67.0) / (8.5)	5 / 5	63.8 / 12.4	38.3 / 93.1 / 4.3	58.3 / 97.3 / 2.0	62.5 / 98.8 / 4.0	33,3 / 96.7 / 5.4	95.0 / 99.0 / 1.6
Total (10 girls, 6 boys	16	16	12 + (3)	15	13	14	14	14	15	16

Appendix 2. Reading comprehension, hearing children
Grade 3 is not discussed in the text.

Grade	Mean	Range	SD	Test	N
1 Percent correct Percentile	96.2 55.5	73.4-100 10-90	8.1 27.3	OS 64	10
2 Percent correct Percentile	84.8 51.5	43.3-100 10-90	18.2 33.1	SL60	10
3 Percent correct Percentile	64.6 45	41.7-83.3 10-90	12.3 31.0	SL 40	10
4 Percent correct Percentile	92.0 52.3	80.0-100 10-90	92.0 28.7	SL 40	11
5 Percent correct Percentile	95.5 10-90	82.5-100 10-90	3.1 28.8	SL40	11
6 Percent correct Percentile	93.3 29.0	87.5-100 10-90	4.1 26.7	SL40	10