Reading Comprehension in Flemish[1] Deaf Children

Exploring the sources of variability in reading comprehension after cochlear implantation

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Recent data on reading comprehension in deaf children have shown a large delay for those without a cochlear implant (CI) and better reading comprehension, although still a little delayed compared to their normal hearing peers, for deaf children fitted with a CI. Some light has been shed on possible causes of the delay and the discrepancy between CI users and non CI users, but the picture is far from complete. In the present study we investigated reading comprehension in 74 Flemish deaf children of which 44 are fitted with a cochlear implant. First, the level of reading comprehension was determined for both CI users and non CI users. Additionally, good and poor readers with cochlear implants were contrasted on phonological encoding during reading, morphosyntactic skills and a number of working memory measures. Flemish deaf children perform significantly better on reading comprehension than Dutch deaf children and overall children with cochlear implants perform better than children without. Phonological encoding cannot dissociate between good and poor readers like in hearing children. In contrast, a dissociation is observed in the morphosyntactic skills and working memory capacity. Additionally, age of implantation effects are found.

1. Introduction

1.1 Reading Comprehension & Deafness

Hearing impaired children are widely known to have major problems acquiring spoken language and it has also been shown that reading comprehension in these children is far below the level of their hearing peers. However, promising results have been reported concerning the language acquisition - through the auditory modality - of deaf children who have received a cochlear implant (CI). A cochlear implant is an auditory prosthesis that bypasses the cochlea by applying electrical stimulation directly to the cochlear nerve (see Figure 1). Although the speech signal is reduced to a limited number of frequency bands by a CI, enough information remains present in the signal to enable children with an implant to acquire language through the aural-oral modality.

However, not only a deviant or even highly limited access to auditory-oral communication can limit deaf children in their development. Literacy, and reading as a tool for learning in particular, is increasingly important in society and work settings. In this paper, the question will be addressed whether CI facilitates reading comprehension in an auditory-based educational setting and through which variables facilitation takes place. We will also explore the amount to which the reading process of children with CI's resembles that

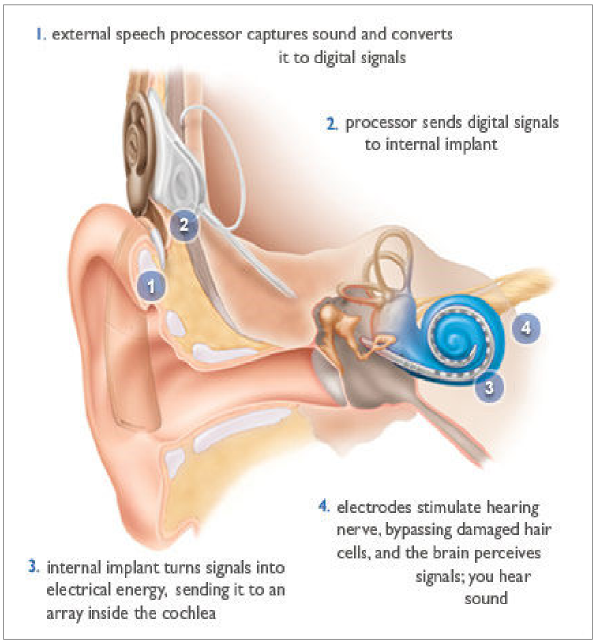


Figure 1: The cochlear implant system

[1]Inhabitants of the Dutch speaking part of Belgium.

of deaf children with conventional hearing aids and normal hearing children , specifically, which variables lead to differences in reading comprehension.

Although language acquisition of children with cochlear implants is a growing area of research, little has been explored about the acquisition of reading comprehension in children with CI-s. Therefore, there is not much consensus about to what extent children can benefit from their CI when it comes to reading comprehension, what processes take place when children with CI's learn to read and which factors lead to either poor or good reading comprehension skills in implanted children.

Low levels of reading comprehension performance have been reported in Dutch deaf children[2] (Wauters, van Bon, & Tellings, 2006). Children with cochlear implants have been shown to perform significantly better than their peers without cochlear implants, but still lagged behind normal hearing children matched for their amount of reading education (Vermeulen, van Bon, Schreuder, Knoors, & Snik, 2007). For both implanted children (Vermeulen et al., 2007) and deaf children without CI (Wauters et al., 2006), decoding skill could not predict performance on reading comprehension. Receptive vocabulary, however, could account for 29% of the variance after correction for the amount of reading instruction received. Within the framework of the "Simple view of reading" model by Hoover & Gough (1990), who stated reading comprehension can be seen as the product of decoding skill and language comprehension, this finding implies that the problems found in the reading comprehension of deaf children with and without CI's are likely to arise from poor language comprehension skills.

The present study aims to investigate the influence of a range of linguistic variables on reading comprehension in the hearing impaired and those that use a CI in particular. Because the above mentioned factors of vocabulary and decoding skill have already been addressed in previous research (e.g. Vermeulen et al., 2007), these are not included in the present study.

[2]The majority, but not all of the children studied by Wauters were fitted with conventional hearing aids. They relied on Dutch Sign Language for their daily communication and did therefore receive little or no spoken language input.

1.2 Sensitive period effects

Many of the earlier studies on language acquisition by children with a cochlear implant have linked the implications that an implant has for language acquisition to the notion of a sensitive period for language acquisition - which is well established within acquisition (e.g. Tomblin, Barker & Hubbs, 2007). According to this view, input has to be present within a neuro-maturational time window in order to trigger language development.

However, the role of the input can be even better explained when we adopt the Interactive Specialization Framework (Johnson, 2000). In this framework maturation is purely functional in the sense that pathways specialize according to the input they receive and initial biases. Auditory deprivation has been shown to result in functional changes which can be compensated for at an early age with CI stimulation (Dorman, Sharma, Gilley, Martin, & Roland, 2007). After stimulation by means of a cochlear implant, reorganization takes place in the cochleotopic maps of the central auditory system of neonatally deafened cats (Dinse, Godde, Reuter, Cords, & Hilger, 2003).

In the case of cochlear implantation this means that shorter auditory deprivation and providing CI stimulation as soon as possible gives the most possibilities for the reorganization of the pathways for auditory processing and processing of spoken language. Because it is likely that plasticity in language acquisition is a combinational result of the plasticity in underlying auditory, phonological, syntactic, semantic and motor systems (Thomas & Johnson, 2008) and the plasticity in lower level sensory systems tends to decline first (Huttenlocher, 2002), the phase in which auditory plasticity is still high needs to be exploited in order to reach adequate language acquisition. When the input starts later in life, other processes will be using the pathways with an initial bias for auditory and language processing and functional plasticity will be limited.

Because the first year of life is very important for language development, a child that receives an implant after this first year may already have missed out on the amount of linguistic input necessary for normal language development (Locke, 1997), with vast delays or permanent damage to the language system as a result.

One of the issues addressed in the present study concerns the extent to which deaf children benefit from early cochlear implantation in reading comprehension. Several studies have shown that early implantation leads to better results in phonological development (e.g. Schauwers, Gillis, Daemers, De Beukelaar, & Govaerts, 2004) and measures of morphosyntactic ability (e.g. Hammer, van der Kant, Coene, Gillis, Rooryck, & Govaerts, 2008). However, little has been known about the effects of the age at implantation and the amount of device experience on reading comprehension. Included in the present study is the a group of children that benefited from the universal newborn hearing screening program in Flanders (fully operational in 1999) and that was subsequently implanted at an early age. Because the first group of very early implanted children is now learning to read, the effects of early implantation on reading can now be explored for the first time among Dutch speaking CI children.

1.3 Influences on Reading Comprehension

Reading for comprehension is a complex process that can be influenced by many factors. According to earlier studies by Vermeulen and colleagues (Vermeulen et al., 2007) which were based on the Simple view of Reading (Hoover & Gough, 1990), all of the factors that complicate reading comprehension for CI children can be attributed to the factor language comprehension rather than decoding skills. In the present study, a number of language comprehension factors will be addressed. However, other variables, such as working memory capacity and phonological encoding, which are thought to influence reading comprehension as well as language comprehension, will also be evaluated.

One of the language comprehension factors investigated in the present study is the level of the morphosyntactic skills. Verhoeven and Vermeer (2006) found that general language skills at 4 years of age could predict reading comprehension outcome at 7 years of age in children with normal hearing. Additionally, a possible relationship between reading comprehension and morphosyntactic skills has been reported in hearing impaired children (Robbins & Hatcher, 1981). However, no elaborate data on the influence of morphosyntax on reading comprehension in CI children have been reported so far.

Comparing our data with a large body of literature will be complicated, because most studies address reading comprehension in college students. Different processes may play a role in the reading comprehension of these young deaf children. Already in 1981, Robbins & Hatcher (Robbins & Hatcher, 1981) suggested that reading comprehension difficulties of hearing impaired children were due to syntactic problems rather than inadequate word recognition or knowledge of word meanings. Svirsky and colleagues (Svirsky, Stallings, Ying, Lento, & Leonard, 2002) reported later development of morphosyntactic skill in deaf children with CI's compared to normal hearing children, partially because morphological markers are less salient for hearing impaired children as a result of the limitations of the CI signal.

Working memory is another factor that has been shown to be reliably connected to reading comprehension in hearing children (Yuill, Oakhill, & Parkin, 1989; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000). During reading for comprehension, working memory is recruited in order to build a mental model of the situations and events described in the text. Because a strong auditory component is present in working memory in normal hearing children (Hulme, Silvester, Smith, & Muir, 1986), deaf children might have more problems with overall working. Consequently, the influence of working memory on reading comprehension might be larger than in normal hearing children. The hypothesis is that low working memory capacity might be another factor contributing to poor reading comprehension skills in deaf children. This is conceivable, because the gist of a text is best understood when the most important content can be kept in working memory and adjusted on-line.

However, working memory and morphosyntax interact, also in development (Santi & Grodzinsky, 2007). Working memory is needed when relationships between linguistics items are established within strings of linguistic material (Lewis, Vasishth, & Van Dyke, 2006) and can therefore influence morphosyntactic ability. Taking this into account, not only the independent correlations of working memory capacity and morphosyntactic skill with reading comprehension will be assessed, but also the mutual dependence of these two factors.

1.4 Objectives of the present study

Bearing in mind the abovementioned findings on the effects of age at implantation, the question arises whether early implantation also positively influences reading comprehension. In

Flanders, children learn Dutch as their first language as in the Netherlands. Cochlear implant programs in Flanders, however, started with implantation before the age of twelve months, before programs in the Netherlands started such early implantations (Schauwers et al., 2004). Additionally, educational settings for deaf, otherwise normally functioning, children in Flanders are mainly based on communication through the auditory modality supported with signs, whereas Dutch Sign Language is widely used as a communication method in bilingual programs at schools for the deaf in The Netherlands with Sign Supported Dutch coming the second communication method. These differences and, on the other hand, a common language in both countries make a comparison between Dutch and Flemish deaf children with CI's and conventional hearing aids (HA) highly interesting and informative. The present study investigates the level of reading comprehension in Flemish CI and HA children and compares it to three reference groups of Dutch children. The first reference group consists of Dutch children with normal hearing (Aarnoutse, 1996). The second group consists of Dutch children with conventional hearing aids (Wauters et al., 2006). Finally, our data will be compared to reading comprehension data of Dutch children with cochlear implants (Vermeulen et al., 2007) in order to explore the influences of early implantation and an auditory based educational setting on performance in reading comprehension.

In line with ongoing studies on language acquisition of early implanted children (Hammer et al., 2008), higher scores are expected from these earlier implanted children compared to the children in the study by Vermeulen and colleagues (Vermeulen et al., 2007) who received their implants at a relatively later age.

From the variation within the groups of children with cochlear implants, both in the study by Vermeulen and colleagues (Vermeulen et al., 2007) and the present study, the second question emerges: How can the variance within the CI group be explained? In order to provide an answer to this question, the present study explores in detail the relation between working memory capacity, morphosyntactic ability, phonological encoding and reading comprehension in children with cochlear implants.

2. Reading Comprehension in Flemish CI and HA users vs. hearing peers

2.1 Methods

2.1.1 Participants

The Flemish Cochlear Implanted (CI) group consists of 44 children aged 6 years 10 months to 13 years 11 months (mean 10 years 5 months). All children are diagnosed with severe bilateral congenital hearing loss of >80dB and were therefore deaf according to Dutch norms (Terpstra-van der Werf, 2006). They do not have any known cognitive problems which are not dependent on their deafness and have a cochlear implant. They all attend 1^{st} to 6^{th} grade of primary school; with 1 to 15 children per grade (mean ~7). Children were recruited from schools for the deaf in Flanders via the "Commissie Ontwikkeling en Research ten aanzien van personen met een Auditieve beperking" (CORA). About 47% of the children attend main-stream education, but all children receive frequent speech and language therapy from within the schools of the deaf. All children are engaged in aural-oral oriented educational settings, where sign supported Dutch was used as the main method of communication. Within this group, ages at implantation range from 5 to 128 months (mean 48 months) and the mean length of device experience is 76 months (range: 3-122 months).

The Flemish Hearing Aided (HA) group consists of 30 children with a mean age of 10 year 7 months (range 7 years 6 months -12 years 10 months). For the Flemish Hearing Aided group, the abovementioned inclusion criteria, as for the Flemish CI group, apply. Only children from the 2^{nd} to 5^{th} grade met the inclusion criteria for the present study. Between 1 and 8 children per grade level participated (mean ~5). A matching on educational setting was obtained by recruiting the children in the Flemish HA group at the same schools as those from the Flemish CI group.

2.1.2 Procedure

Participants were tested on their reading comprehension using a revised version of the reading comprehension test ('begrijpend leestest', Aarnoutse (1996)). This test consists of short Dutch texts with questions about their content. Minor revisions were made to make the test suitable for Flemish speaking children. All revisions

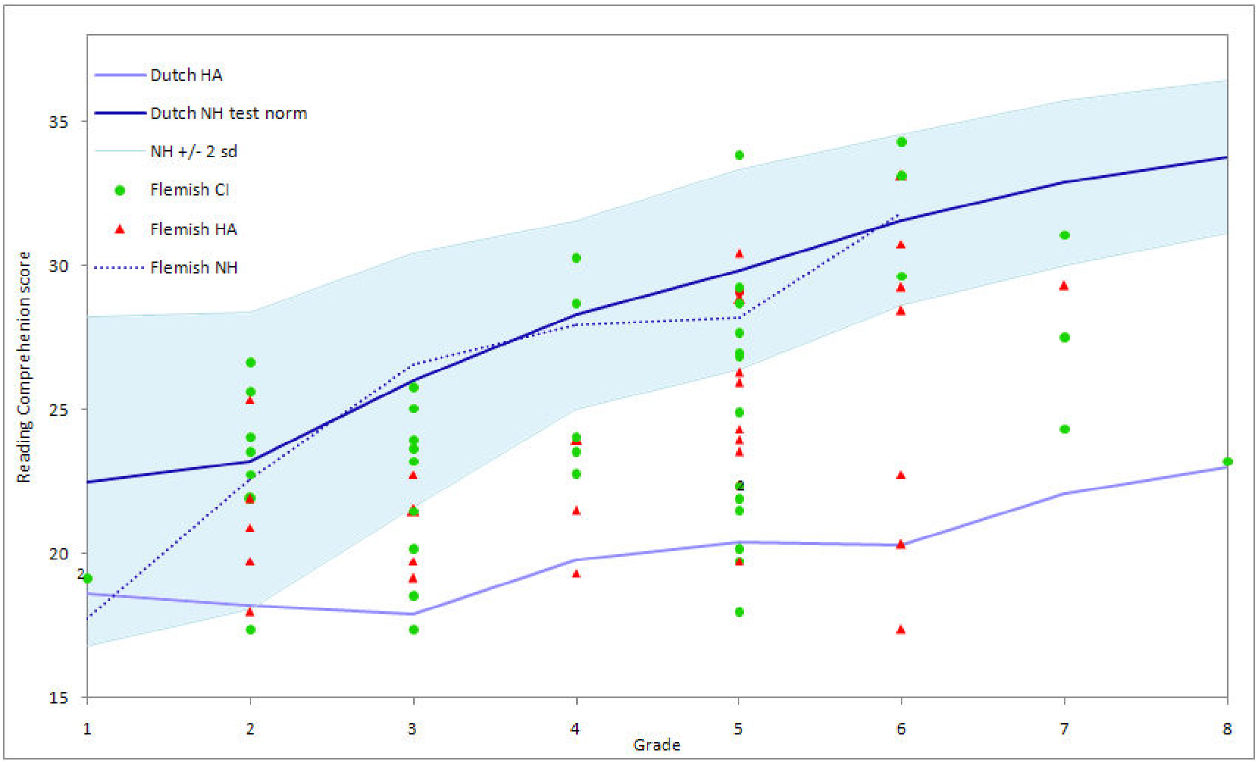


Figure 2: Reading comprehension scores for the individual CI and HA users, plotted against the mean for Dutch deaf children without cochlear implants (Dutch HA) and the Dutch norm for normal hearing children (NH)

made have been discussed in consultation with the author of the test.

Additionally, in order to control effects of the educational setting in Flanders compared to the Netherlands, an evaluation of the revised version was conducted for normal hearing children. A large sample of 247 Flemish normal hearing children within one mainstream primary school participated in this evaluation study. All hearing children completed the subtest suitable for their grade with a mean of 41 children per grade (range: 38-46 children). A middle/high social economic status is maintained within the evaluation sample by school selection[3]. Therefore, the present sample probably reflects the upper limit for the mean for Flemish normal hearing children. Apart from school selection, no inclusion criteria are maintained for this evaluation in order to select a representative sample of Flemish primary school children. With mean reading comprehension z-scores per grade ranging from -0,93 to 0,25 the evaluation shows that this Flemish sample does not perform differently from the Dutch norm sample on reading comprehension (see Figure 2). The first grade performed lower (Mean z-score:
-1,67), a caveat which can be attributed to the fact that these children completed the test a few months early and did therefore probably not have sufficient decoding skills. From this evaluation we conclude that the Dutch norm originally developed for the reading comprehension test can validly be used as a normal hearing reference group in the present study.

All of the participating deaf children completed the subtest that was suitable for their estimated reading comprehension level which was taken from teacher and language therapists' reports. Raw scores are transformed into latent scores and z-scores per grade level. Deaf and normal hearing children were compared, while controlling for the amount of reading instruction received, exposure to print and overall academic performance. These factors are expressed in the present paper as a grade equivalent. Because deaf children tend to start their reading education at a later age and than normal hearing children, a matching on grade gives a better indication of the actual reading comprehension development compared to a matching on chronological age.

[3]Children were recruited from a primary school, in Zonhoven, near Hasselt, where the SES is relatively high

**p < = .05, **p < = .01, ***p < = .001, ns, not significant (p> 0.05)*

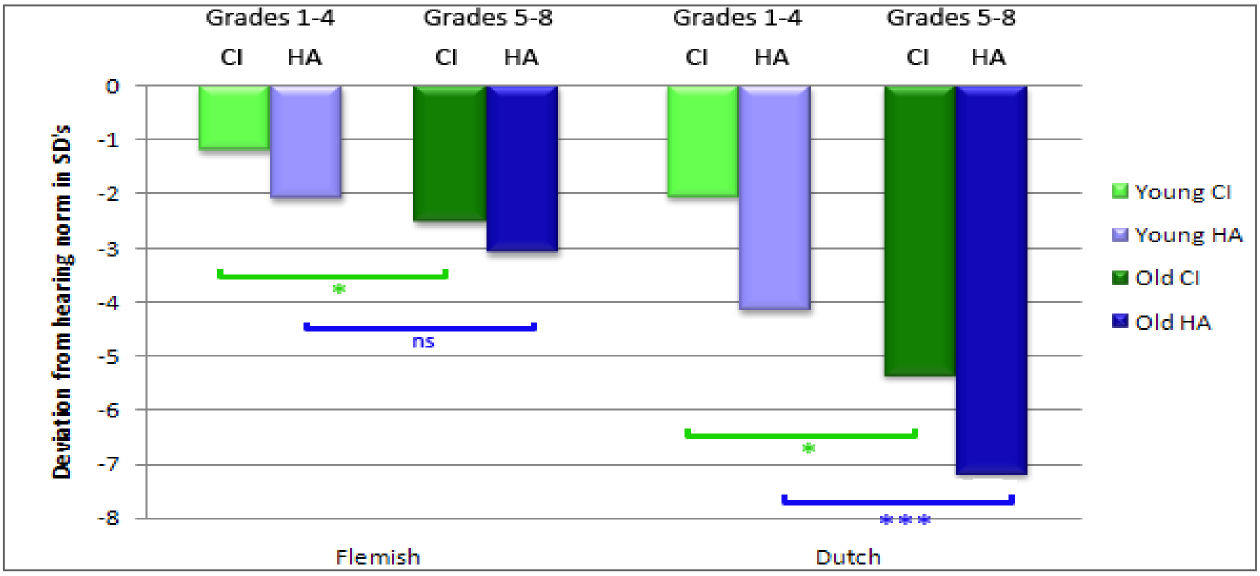


Figure 3: Reading Comprehension z-scores

2.2 Results & Discussion

2.2.1 Flemish CI and HA Reading Comprehension

Reading Comprehension scores of the individual Flemish CI and HA users are plotted in Figure 2. This Figure also shows the mean scores of the (Dutch) NH control group, the Flemish NH test evaluation group and the Dutch HA group reported in the study by Wauters and colleagues (Wauters, van Bon, & Tellings, 2006). One extreme outlier in the Flemish CI group was excluded from all further analyses.

Within the Flemish CI group, 57% of the participants score within the range of two standard deviations from the mean reading comprehension scores of their normal hearing peers and does therefore not show a reading comprehension deficit. Only 37% of the Flemish HA children score within this range. However, this apparent difference was not confirmed by non-parametric Mann-Whitney U-tests for group comparison on z-scores (see below for details). As can be seen from the plot in Figure 2, the delay largely develops after the second grade, when the gap between the scores of the NH control and Dutch HA children also becomes apparent. However, the scores of almost all CI users exceed those of the Dutch HA children studied by Wauters and colleagues (2006).

2.2.2 Deviations of Reading Comprehension from hearing peers

Mean Reading Comprehension z-scores for all groups are plotted in Figure 3. Scores are computed based on the mean reading comprehen-

*FCI = Flemish CI, DCI = Dutch CI, FHA = Flemish HA, DHA = Dutch HA; *p < = .05, **p < = .01, ***p < = .001, ns, not significant (p> 0.05)*

(a)

5-8 / 1-4	FCI	DCI	FHA	DHA
FCI		*	ns	***
DCI	ns		ns	*
FHA	ns	ns		***
DHA	***	**	***	

(b)

	FCI	DCI	FHA	DHA
FCI	*			
DCI		*		
FHA			ns	
DHA				***

Table 1: Significance levels of Mann-Whitney U tests for group comparison on z-scores (a) Comparisons of Dutch versus Flemish and CI versus HA children for grades 1-4 (below diagonal) and grades 5-8 (above diagonal) show higher scores in Flanders and an effect of device only for the Dutch group. (b) Comparisons of grades 1-4 versus grades 5-8 show higher scores for younger children due to early fitting.

sion level of Dutch children with normal hearing (Aarnoutse, 1996), with 0 as the hearing mean.

Figure 3 shows three trends: firstly, Flemish children perform better than Dutch children secondly, within both groups, the younger group performs better than the older group. Finally, within the Dutch group, children fitted with cochlear implants perform better than children with conventional hearing aids or no hearing aid at all.

Non-parametric Mann-Whitney U-tests for group comparison showed that the reading comprehension z-scores of both the Flemish CI children and the Flemish HA children differed at a highly significant level from those of the Dutch HA children in all grade equivalents. A significant difference between the reading comprehension z-scores of Flemish and Dutch CI children develops in the second grade group (grades 5-8), when children have received at least 4 years of reading instruction. There is no significant difference in reading comprehension z-scores between both Flemish groups; neither do the Flemish HA users differ significantly from the Dutch CI group. The findings are summarized in Table 1, completed with the results of Vermeulen (Vermeulen et al., 2007) which showed that the reading comprehension level of Dutch CI children differs significantly from that of Dutch HA children.

These results can be explained by three different factors that influence reading scores. Firstly, cochlear implantation is shown to facilitate reading comprehension. This effect is clearly for Dutch, but not for Flemish deaf children (compare the green with the blue for each grade and countryin Figure 3). This effect is probably attributable to the larger amount of spoken language input deaf children receive in Flanders due to the more auditory-based approach to education for the deaf. Additionally, different indication policies for cochlear implantation influence the amount of children with great hearing losses that still depend on conventional hearing aids it is and therefore conceivable that the Dutch HA group contains more children with great hearing losses that score poorly on reading comprehension.

The second factor that influences scores in both the Flemish CI and HA group is the universal newborn hearing screening in Flanders that was operational from 1999. Within the Flemish CI group, the younger children, who have benefited from neonatal screening and early implantation, score significantly higher than the older children, who have not been included in these screening programs (compare the light with the dark bars within the Flemish group in Figure 3). The increase of the reading comprehension scores for Flemish HA children is not significant. However, neonatal screening did also lead to earlier fitting of conventional hearing aids, which can explain the higher scores fr HA children in the lower grades.

Finally, there are large differences between the educational settings for deaf children in Flanders in the Netherlands. Figure 3 clearly shows an advantage for Flemish compared to Dutch children when reading comprehension is considered. This effect is probably due to the very different amounts of spoken language input Dutch and Flemish deaf children receive. As mentioned earlier in the present paper, Flemish schools for the deaf have aural-oral oriented programs where signs are mainly used to support the spoken language, whereas the Dutch educational setting for deaf children mainly uses Dutch Sign Language combined with Sign Supported Dutch. Therefore, in Flanders, children get enough spoken language input to acquire Dutch at a relatively high level, which in turn influences reading comprehension

These findings confirm our hypotheses that a cochlear implant can facilitate reading comprehension, but that both early and frequent spoken language input is of great importance in order for a child to benefit maximally from the device.

The results obtained are solid and explainable, because for children with normal hearing, as opposed to deaf children, there is no difference in reading comprehension level between Flanders and the Netherlands. These differences can therefore not be the result of general differences in educational setting.

2.2.3 *Effects of the start and duration of Cochlear implant experience on reading comprehension*

In addition to the better performance of the early implanted Flemish CI group compared to the Dutch CI group, a clear effect of age at implantation is present within the Flemish CI group. Linear regression (Figure 4) shows that, after removal of the effect of length of use of the CI, the age at implantation was associated with the reading comprehension z-score at a small but significant level ($R^2=.263$, $p=0.001$). In other words, with the amount of reading instruction and the length of device experience controlled for, children who received their implant at an earlier age performed

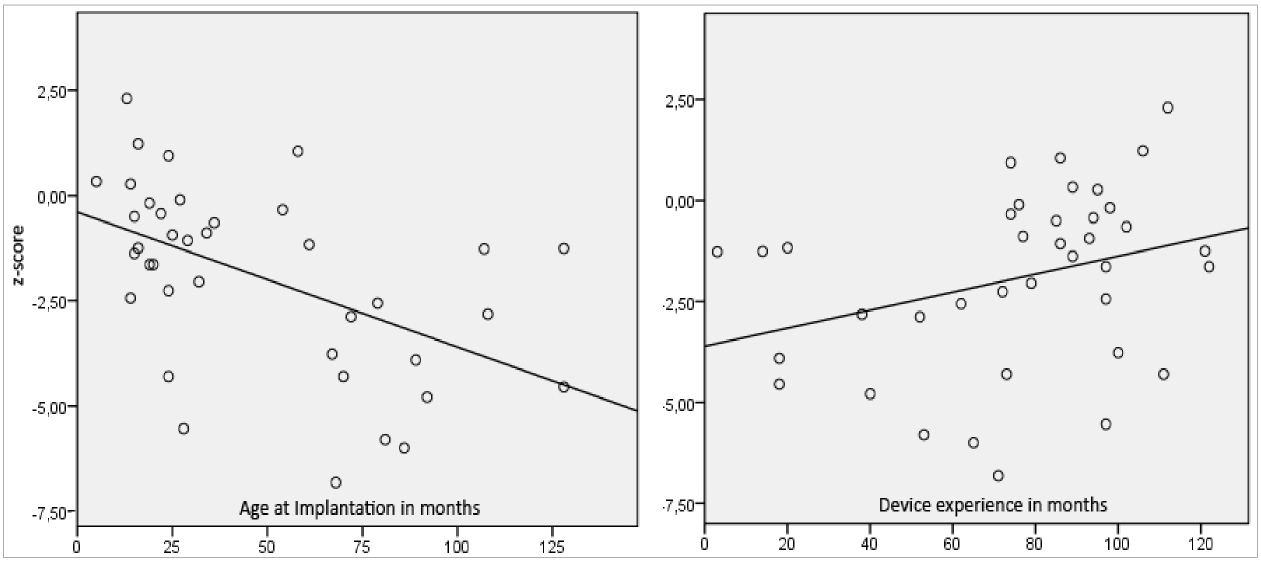


Figure 4: Estimated regression lines for the factors age at implantation and device experience

better on the reading comprehension test. However, there is a strong correlation between the age at implantation and the length of use of a CI, which makes these factors difficult to disentangle. Together, Age at Implantation and Length of Use can account for 56% of the variance in reading comprehension z-scores ($R^2 = .313$).

Although it cannot be claimed that sensitive period effects for hearing and language are the crucial factor for variance in reading comprehension performance, it is clear from these findings that early as well as longer exposure to speech through a cochlear implant facilitates reading comprehension skills.

3. Sources of Reading Comprehension variability in cochlear implant users

3.1 Methods

Based on the reading comprehension data, one group of children with high scores (the Good Reading Comprehension group; GRC) and one group with poor scores (the Poor Reading Comprehension group; PRC) were selected. These groups are contrasted on their working memory capacity scores, including verbal and non-verbal working memory, and their morphosyntactic ability[4]. With these contrast groups, our aim is to investigate which mechanisms contribute to poor versus high scores on reading comprehension in children with cochlear implants.

Additionally, phonological encoding was tested in order to explore to what extent the sound structure of words influences reading comprehension in cochlear implanted children. This is important because sound structure does influence reading to a great extent in hearing children, but not in deaf children with large hearing losses (Harris & Moreno, 2004). After cochlear implantation, however, the influence of sound structure is expected to grow with CI experience. Phonological processing skills comparable to hearing peers were reported recently (Spencer & Tomblin, 2008). We will explore whether the automatic top-down influence of phonological knowledge during reading known to be present in hearing children can also be found in children with CI's.

3.1.1 Participants

The children selected for these sub-studies all have a cochlear implant and were recruited from KIDS Hasselt.

The Poor Reading Comprehension (PRC) group consisted of 3 children, all males, aged 13 years 11 months, 12 years and 11 years 4 months who received reading education equivalent to hearing children in the 7th and 5th grade. The children are implanted at 67, 24 and 70 months and have Reading Comprehension levels that falls at -3,77 and -4,3 SD compared to the mean for normal

[4]A morphosyntactic listening span procedure was used to assess the extent to which morphosyntax could facilitate working memory when repeating sentences. However, the results are not easily interpretable and are therefore excluded.

Component	Modality	Test
Working memory	Visual	LDT picture sequences
	Auditory non-linguistic	WISC-III number repetition
	Auditory linguistic	LDT word repetition
	Auditory linguistic	TAK sentence production
Morphosyntax		TAK sentence comprehension
Phonological encoding		PE procedure by Vermeulen (2007)

Table 2: Tests for assessment of working memory capacity and morphosyntactic skills

hearing children (z-scores). This means that a reading comprehension deficit is present. In the remainder of this paper, we will refer to the individual PRC children as PRC 1 and 2 respectively.

The Good Reading Comprehension (GRC) group contained 3 children, one female, aged 9 year 8 months, 9 year 4 months and 9 year 11 months with 2nd and 3th grade equivalents. They are implanted at 18, 34 and 25 months of age (mean 25,7 months). Reading Comprehension z-scores of the GRC group are all greater than -1. These children score within one standard deviations from the mean for NH control children and do therefore not exhibit a reading comprehension deficit. We will refer to the individual GRC children as GRC 1, 2 and 3 respectively.

3.1.2 Procedure

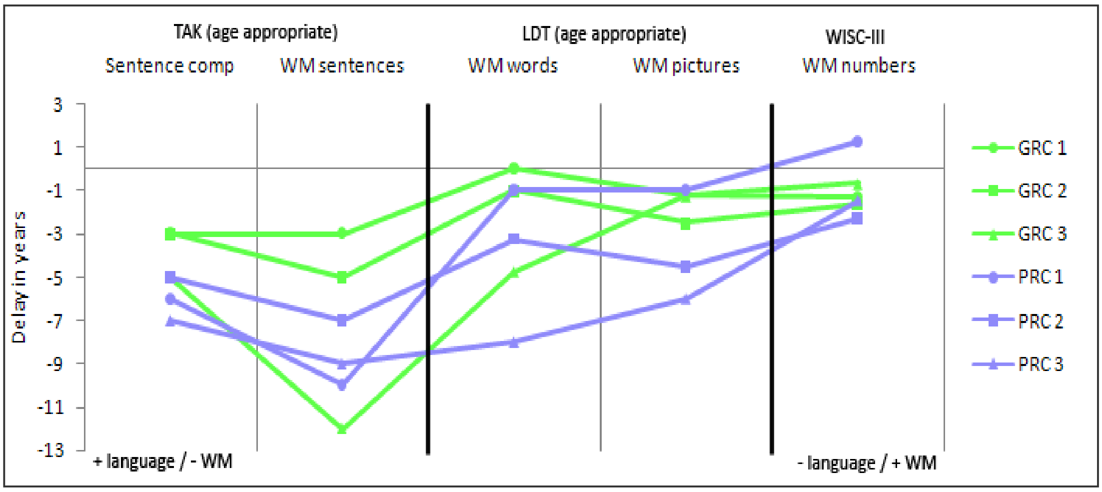
The factors that distinguish between the good and the poor readers within the group of cochlear implanted children were investigated by testing the PRC and GRC groups on different measures of morphosyntactic ability, working memory and phonological encoding. The test battery used is summarized in Table 2.

The battery of working memory tests illustrated in Table 2 has been developed in such a way that a clear distinction could be made between genuine working memory factors and factors that comprise linguistic skills or vocabulary as these factors can also directly influence reading comprehension scores. The selection of subtests from these particular standardized tests is based on the extent to which they can measure the desired abilities. Some subtests were ultimately selected with regard to practical issues of availability at the participating schools.

Components of working memory were tested using sub-tests from test batteries designed for school-aged children. For visual working memory the "Leidse Diagnostische Test" (Leiden Diagnostics Test - LDT) (Schroots & Van Alphen de Veer, 1976) was used, in which children were asked to remember and point out picture sequences in normal in reversed order. The sentence production task from the Dutch standardized Taaltest Alle Kinderen (TAK) (Verhoeven & Vermeer, 2006), in which children repeat sentences, is used to measure linguistic working memory. Finally, a task from the Dutch version of the Wechsler Intelligence Scale for Children, third edition (Wechsler, 2002), hereafter referred to as WISC-III, is employed to measure numerical working memory. In this task, children are requested to repeat number sequences in normal and reversed order

Morphosyntactic ability is assessed by administration of a subtest of the TAK, which tests sentence comprehension. In this test, sentences are read aloud to the child, while presenting him/her with three pictures for each sentence. Based on the meaning of the sentence, the child is requested to point to the picture belonging to the sentence. The semantic content of the pictures differs in the assignment of thematic roles within the sentence presented, case marking by morphemes and the interpretation of function words. All children in both the GRC and PRC group fall outside the age range for which the TAK is standardized, therefore age cannot be directly controlled for in the comparison with normal hearing peers. For the present study, the mean growth-curve for normal hearing children was used to compute the delay in years for each CI child.

Children are tested on their phonological encoding using an orthographic decision experiment developed by Vermeulen (2007), which makes use of the E-prime (Psychology Software



	Age	AaI
GRC 1	9 yrs	19 m
GRC 2	9 yrs	34 m
GRC 3	9 yrs	25 m
PRC 1	13 yrs	67 m
PRC 2	11 yrs	24 m
PRC 3	12 yrs	70 m

Figure 5: Scoring profile of the individual children from the GRC and PRC groups. Ranging from the most language-related task to the most WM-related task, this graph gives an indication of which areas dissociate between GRC children and PRC children. The delay on the tasks is given in years with 0 as the age appropriate score. Age-correction was only possible for TAK and LDT, therefore, the ages of the children have to be taken into account when interpreting the WISC-III scores. The choronological ages (Age) and ages at implantation (AaI) of the children are given for clarity.

Tools, 1996-2002) program. During this procedure the child is seated facing a laptop computer screen on which words are shown in large print. Three word types are presented to the participants: base words (e.g. /rug/ *'back'*), homophones (e.g. /ruch/) and pseudo-homophones, which differ from the base word in one phoneme. Both the homophones and the pseudo-homophones do not represent words of Dutch. Children are instructed to indicate by means of a button press as soon as possible whether or not a word is 'spelled correctly', a task which corresponds to lexical decision in adults. The difference in reaction times between the homophones and the pseudo-homophones is used as a measure of phonological encoding.

3.2 Results & Discussion

3.2.1 Working memory

Results of the various working memory tests are plotted in Figure 5. Good readers overall perform better on working memory tests than poor readers. It should also be noted that the poor readers in this panel are on average two years older than the good readers and should thus perform better on these tests. The clearest dissociation is seen in the results of the number repetition subtest (WM numbers), the only subtest that could be sufficiently corrected for chronological age. Limited working memory recourses could lead to lower reading comprehension scores independent from syntactic ability and sentence comprehension for the PRC group, because these recourses are needed for understanding text coherence.

Figure 5 also shows more dissociation between the GRC and PRC groups on WM sentences, WM words and WM numbers as opposed to WM pictures. This result suggests that the auditory and verbal components of working memory play a more important role in reading comprehension than visual working memory. This again points to a larger role for language comprehension factors than would be expected when reading comprehension in children with cochlear implants would be purely based on using print. In the latter case one would expect an influence from visual working memory. Together with the findings reported by Wauters et a. (2006) and Vermeulen et al. (2007), this finding suggests that the factor language comprehension plays a by far more important role in reading comprehension of deaf children than visual word recognition.

3.2.2 Morphosyntactic ability

Sentence comprehension scores indicate that children with poor reading comprehension skills also have difficulties understanding the structure of sentences that were presented to them auditorily. The delays that the individual children show on sentence comprehension are plotted in Figure 5. Compared to working memory, language measures are more delayed in both good and poor

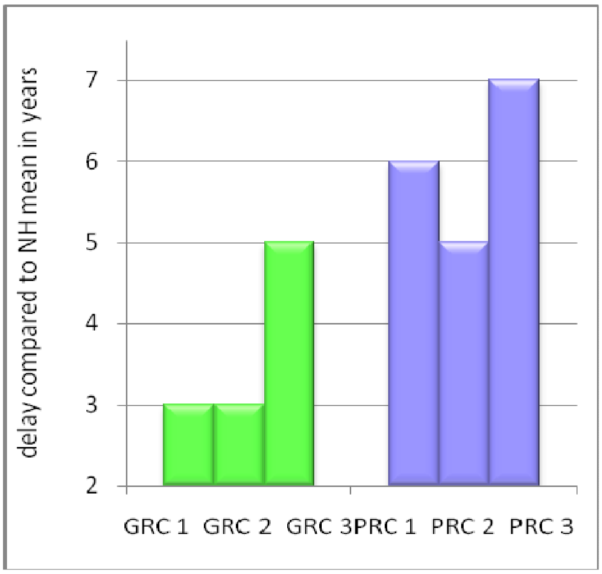


Figure 6: Scores on sentence comprehension task for the individual GRC and PRC children expressed as their delay in years compared to the mean for normal hearing children. PRC children show larger delays than GRC children.

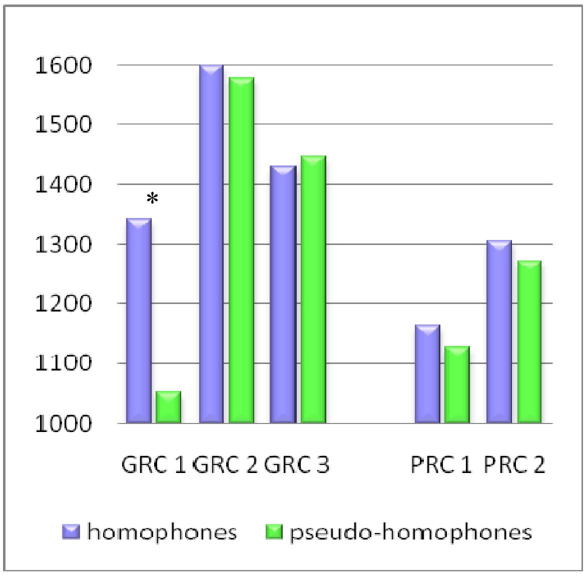


Figure 7: Mean reaction times (in ms) to homophones and pseudo-homophones for the individual CI children. GRC 2 shows a significant difference *($p<0.01$)* and therefore evidence for phonological encoding.

readers within the Flemish CI group.

The results of the sentence comprehension test show that there is a relation between the levels of reading comprehension and morphosyntactic skills. However, nothing can be concluded about the precise nature of the processes underlying this influence.

3.2.3 Phonological Encoding

Only one of the children in the GRC group (GRC1) showed a significant difference in reaction time between homophones and pseudo-homophones. No significant differences were found within the PRC group. Mean reaction times of the individual CI children are summarized in Figure 5. Accurateness on the lexical decision ranged from 83% to 100% correct. Therefore, the short reaction times in the PRC children cannot be due to guessing.

These results suggest that only one of the studied CI children uses phonological encoding in this lexical decision task and in reading in other situations. It is striking that the child with a reading comprehension that diverges least from his hearing peers and that is implanted at the earliest age is the only one to use phonological encoding. However, the other children in the GRC group did not show phonological encoding; suggesting that phonological encoding during reading is not a factor that can distinguish between the good and poor readers under investigation. This also suggests that the phonological processing skills found by Spencer and Tomblin (Spencer & Tomblin, 2008) are not enough for good reading comprehension. We can not conclude from our findings that phonological encoding distinguishes between children with good and poor reading comprehension. However, phonological encoding appears to enable good reading comprehension.

4. General discussion and conclusion

The present study investigated to which extent and in which way school-age pediatric CI recipients in Flanders benefit from their cochlear implant in reading comprehension and which factors influence the development of reading comprehension skills in these children.

The first part of the present study, which compares Flemish CI and HA children with Dutch CI and HA children and their normal hearing peers, shows that scores of both groups of Flemish children exceed those of deaf children in the Netherlands. However, there is no clear advantage of cochlear implants over conventional hearing aids within the Flemish group of deaf children. In the Netherlands conventional hearing aids cannot prevent an increasing delay in reading comprehension compared to hearing children whereas this is possible in Flanders. Children with CI's, although mildly delayed, develop reading comprehension skills at a rate closer to that of their normal hearing peers. We therefore conclude that cochlear implantation can indeed facilitate the acquisition of reading comprehension skills. However, an aural-oral educational setting provides the best surroundings for the development of reading comprehension skills in deaf children both with cochlear implants and conventional hearing aids.

The present study also shows that the age at which children received their implant and the amount of experience children have with the device influence their reading comprehension skills, independent of the amount of reading instruction these children received. This finding is in accordance with the results of James, Rajput, Brinton and Goswami (2008), who found that word reading in early implanted (at 2-3.6 years of age) school-age children was less delayed than in children who received their implant later in their childhood. Our results contradict the findings of Geers (2004), which did not show an effect of age of implantation on reading comprehension skills. However, in that study, implantation between the ages 2 and 4 years was considered "early", whereas in the present study a linear regression model was used in a sample with a mean age at implantation of 48 months and many children who received their implant before the second year of life. Additionally, no effect of early implantation on speech and language skills was found by Geers, an effect which has been found in several recent studies with earlier implanted groups (e.g. Hammer et al., 2008, Schauwers et al., 2004).

Although some children performed exceptionally well, there is still a large amount of variability, particularly within both CI groups, which originates from many factors. Vermeulen (2007) showed that vocabulary size is one of the sources of this variability. The results of the present study suggest that age of implantation, device experience and phonological encoding also play a role. However, even with all of these factors accounted for, the variability remains larger within CI users than HA users. General cognitive factors might have a larger effect in the CI population, because the nature of stimulation is not entirely natural in CI children. Using a degraded signal like that of a CI for language acquisition might require more cognitive recourses than using an amplified speech signal, resulting in a larger variability within the CI population.

One could argue that the variability found here is due to an underlying attentional deficit in the HA and CI groups compared to the NH group which influences overall performance on reading comprehension as well as working memory and language tasks. However, this is unlikely, because in that case both the HA and CI groups should score lower on all measures that require attention. This is not the case, because neither in the Dutch CI group (Vermeulen et al., 2007) nor in the Dutch HA group (Wauters et al., 2006), problems were found in visual word recognition.

In the case of the present sample, a longitudinal approach will be necessary in order to complete the picture of the development of reading comprehension skills in CI and HA children. In this way, it can become clear whether these children will develop their reading comprehension skills further to match that of their normal hearing peers at some time or whether the poor reading comprehension skills reported in the present study will cause problems in adulthood.

In the second part of this study, possible sources of reading comprehension variability within the Flemish CI group were investigated. Working memory capacity, morphosyntactic skills and phonological encoding were assessed in five children of which three with high and two with low scores on the reading comprehension.

A tendency was found towards better morphosyntactic as well as better working memory skills in the Good Reading Comprehension Group compared to the Poor Reading Comprehension Group. The dissociation was especially clear on verbal and auditory working memory tasks compared to visual working memory tasks. These results suggest a relationship between auditory and verbal working memory as well as morphosyntax on one side and reading comprehension on the other side in Flemish congenitally deaf children fitted with cochlear implants. This relationship implies that the "simple view of reading" is also applicable to Flemish CI children in the sense that language skills comprise a large part of reading comprehension skills and that a CI gives a child enough information to develop reading comprehension skills based on spoken language and auditory/verbal memory recourses as in normal hearing children. However, we will have to bear in mind that this part of the study in highly explorative. Therefore, these findings should be viewed as new directions for research in the field of reading in deaf children rather than conclusive results.

As a result of the explorative nature of this part of the study, few definite conclusions can be drawn with respect to the exact influences of the factors under investigation on reading comprehension in children with cochlear implants. The results suggest an influence similar to that in normal hearing children (Verhoeven & Vermeer, 2006) and children with conventional hearing aids (Robbins & Hatcher, 1981). To gain full insight in the interplay between reading comprehension, morphosyntactic skills, working memory capacity and phonological encoding, studies which investigate all of these factors in a large sample of implanted children are needed. However, a study of this scale is beyond the scope of the present paper.

When placed in a neuroscientific perspective, this study suggests that cochlear implants give the brain enough information to enable reorganization and that this reorganization can lead to, amongst others, the emergence of a phonological system.

However, to this point, any inferences about functional or structural changes in the brain of children fitted with cochlear implants remain speculative. Neuroimaging studies could provide insights about these changes. However, these studies will take some time to emerge due to the large complications that emerge from the combination of CI's and neuroimaging methods, including unsolvable artifacts and high risks.

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