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Research Report

Linguistic profiles of children with CI as compared with children with hearing or specific language impairment

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Abstract

Background: The spoken language difficulties of children with moderate or severe to profound hearing loss are mainly related to limited auditory speech perception. However, degraded or filtered auditory input as evidenced in children with cochlear implants (CIs) may result in less efficient or slower language processing as well. To provide insight into the underlying nature of the spoken language difficulties in children with CIs, linguistic profiles of children with CIs are compared with those of hard-of-hearing (HoH) children with conventional hearing aids and children with specific language impairment (SLI).
Aims: To examine differences in linguistic abilities and profiles of children with CIs as compared with HoH children and children with SLI, and whether the spoken language difficulties of children with CIs mainly lie in limited auditory perception or in language processing problems.
Methods & Procedure: Differences in linguistic abilities and differential linguistic profiles of 47 children with CI, 66 HoH children with moderate to severe hearing loss, and 127 children with SLI are compared, divided into two age cohorts. Standardized Dutch tests were administered. Factor analyses and cluster analyses were conducted to find homogeneous linguistic profiles of the children.
Outcomes & Results: The children with CIs were outperformed by their HoH peers and peers with SLI on most linguistic abilities. Concerning the linguistic profiles, the largest group of children with CIs and HoH children shared similar profiles. The profiles observed for most of the children with SLI were different from those of their peers with hearing loss in both age cohorts.
Conclusions & Implications: Results suggest that the underlying nature of spoken language problems in most children with CIs manifests in limited auditory perception instead of language processing difficulties. However, there appears to be a subgroup of children with CIs whose linguistic profiles resemble those of children with SLI.

Keywords: expressive language, memory, cochlear implant, specific language impairment, hearing impairment, children.

What this paper adds?
What is already known on the subject?
Spoken language difficulties in profoundly deaf children with CIs can mainly be attributed to their limited auditory speech perception, however degraded or filtered hearing input may result in less efficient or slower language processing as well. Children with SLI who have intact hearing may suffer from predominantly auditory processing difficulties. Comparing the linguistic abilities and profiles of children with CIs with those of their HoH peers with conventional hearing aids and their peers with SLI may yield more insight into the underlying nature of the spoken language difficulties in children with CIs.

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What this paper adds?

We can clearly differentiate between the groups of children, despite the fact that they all run into communicative difficulties due to their auditory speech perception and/or language processing difficulties. The children with CIs were outperformed by the HoH children and children with SLI on most linguistic abilities. The linguistic profiles were similar for most children with CIs and most HoH children, whereas the majority of the children with SLI clearly differed from the children with hearing loss. This suggests that the spoken language difficulties of the children with CIs in our study are not due to their auditory processing difficulties, but rather due to their limitations in auditory speech perception. However, there appears to be a subgroup of children with CIs whose linguistic profiles resemble those of children with SLI.

Introduction

Language acquisition is a cognitive activity resulting from competing cognitive processes. Parents provide language input to children and these children, acting as problem solvers, extract meaning and structure from this input. The fact that language acquisition takes place in communicative contexts enables children to attach meaning to linguistic symbols and structures, resulting in the learning of phonological, semantic, morphosyntactic and pragmatic properties of language (MacWhinney 2005). Language acquisition results from using language in social situations, requiring cognitive skills in children such as pattern finding and intention reading (Tomasello 2005). According to Locke (1997), the acquisition of morphosyntax takes place in what he calls the analytical phase of language development. The appearance of morphosyntax is in Locke's view triggered by maturation and by pressure from the expanding vocabulary. This expansion requires decomposing stored elements in the mental lexicon into smaller units, resulting in the acquisition of grammar. If the expansion of vocabulary is delayed or does not take place, acquisition of morphosyntax will be hampered. The first precondition to successful language acquisition is the ability to perceive the parental language input and the second precondition is the ability to process language input adequately.

A hearing loss early in the life of a child typically leads to spoken language difficulties. These difficulties are attributed to limitations in auditory speech perception. One would therefore expect that if hearing, and thus auditory perception, is restored to a considerable extent by providing profoundly deaf children at an early age with cochlear implants (CIs), this would facilitate spoken language acquisition. Research into the effects of paediatric cochlear implantation convincingly shows that this indeed is the case, but not in all deaf children and not in all children to the same extent (Knoors and Marschark 2014). The reported benefits of paediatric implantation include enhanced levels of speech perception and of spoken language proficiency, the latter most prominently in the lexical domain (e.g., De Hoog *et al.* 2015, Duchesne *et al.* 2009, Geers *et al.* 2009, Svirsky *et al.* 2000). However, large variability in language proficiency among CI users is found. The relative lack of speech perception and spoken language proficiency improvement in some children may be caused by late intervention, receiving implant(s) after the age of 4;0 years, short duration of CI use, multilingualism, poor speech reading abilities or poor cognitive processing abilities such as working memory and executive functioning (e.g., Boons *et al.* 2012, Knoors and Marschark 2014, Pisoni *et al.* 2008).

A subgroup of children with CIs seems to experience severe language difficulties, unrelated to their hearing loss (e.g., Hawker *et al.* 2008). Szagun (2000) was one of the first to observe persistent deficiencies in the acquisition of morphosyntax in children with CIs, i.e., case-marked articles, copula forms and modal verbs. She noticed that these problems looked similar to the grammatical deficits of children with SLI and hypothesized that at least some deaf children not only suffer from limited auditory perception, but also from problems in spoken language processing. Other researchers (e.g., Hammer *et al.* 2014) have hypothesized that differences in underlying causes of spoken language problems would not result in differences in the acquisition of morphosyntax but would instead lead to similar linguistic profiles. However, this hypothesis was not confirmed with research data. Systematic comparison of the linguistic and, given the intertwining of linguistic and cognitive processes, cognitive profiles of children with CIs, hard-of-hearing (HoH) children and children with SLI may shed more light on this issue. Unfortunately only relatively few studies addressed such a comparison, cognitive factors rarely have been included, and to our knowledge so far no study has included all three clinical groups.

Previous studies comparing linguistic abilities of children with CIs and HoH children are rare. In a study by Hammer (2010), for example, verbal morphology in four different age groups of 48 children with CIs (aged 4;0, 5;0, 6;0 and 7;0 years) was examined compared with 31 age-matched HoH peers with moderate to severe hearing loss. The children were implanted at a mean age of 16 months (range 5–43 months). Over the years, the increase of finite verb production of children with CIs was steeper than that of their HoH peers. Furthermore, in a study by Yoshinaga-Itano *et al.* (2010), 49 children with CIs aged 4;0–7;0 years, with a implantation age ranging from 12 to 75 months, performed better on expressive vocabulary than 38 age-matched HoH peers with severe hearing loss. Baldassari *et al.* (2009) assessed receptive language skills in 36 profoundly deaf children with CIs between the age of 4;0 and 9;0 years. Their mean age of implantation was 33 months (range 11–77 months). The implanted children performed better on receptive vocabulary, grammar, and auditory comprehension than their age-matched peers with profound hearing loss who used hearing aids. Svirsky *et al.* (2000) compared expressive language structure, content and vocabulary of 23 profoundly deaf children with CIs, aged 1;5–7;0 years and a mean age at implantation of 54 months, with 113 age-matched peers with profound hearing loss who used conventional hearing aids. Results showed that the children with CIs had overall better language scores than their peers with hearing aids. In a study by Tomblin *et al.* (1999), sentence comprehension and expressive grammar was examined in 29 profoundly deaf children with CIs with a mean age of 10;0 years. Their mean age of implantation was 56 months (range 24–156 months). Results showed that the children with CIs outperformed 29 age-matched peers with profound hearing loss who used conventional hearing aids on sentence comprehension and expressive grammar. In contrast, a study by Ibertsson *et al.* (2008) revealed that 13 children with CIs, aged 5;2–8;11 years, with a mean implantation age of 45 months, performed significantly worse than 13 age-matched HoH peers with mild–moderate hearing loss on non-word repetition. In a study by De Hoog *et al.* (2015), 25 profoundly deaf children with CIs aged 8;1–11;3 years, with a mean implantation age of 35 months, performed similarly as 13 age-matched HoH peers with moderately severe hearing loss on a picture naming task. In conclusion, in most studies comparing children with CIs with HoH children, the first group outperformed the latter in both vocabulary and grammar, but there are exceptions to this pattern. The reasons for variation in results are not really clear, but it does not seem implausible to assume that differences in speech recognition after provision of hearing aids or implants, the broad age range of implantation in most studies, or differences in intensity of support of families and children may account for part of the variation.

Comparative studies of children with CIs and children with SLI are even more rare. In a study by De Hoog *et al.* (2015), 25 profoundly deaf children with CIs aged 8;1–11;3 years, with a mean implantation age of 35 months, performed better on a picture naming task than 20 age-matched peers with SLI. A study by Löfkvist *et al.* (2014) revealed that 34 children with CIs, aged 5;6–9;0 years, with a mean age of implantation of 22 months also outperformed 12 age-matched peers with SLI on picture naming and receptive vocabulary. Hammer *et al.* (2014) studied verbal morphology in 48 children with CIs in four different age groups (aged 4;0, 5;0, 6;0 and 7;0 years), with a mean implantation range of 5–43 months. On ages 5;0 and 6;0 years, the children with CIs outperformed 38 age-matched peers with SLI on finite verb production. On the contrary, in a study by Ibertsson *et al.* (2008), 13 children with CIs, aged 5;2–8;11 years, with a mean implantation age of 45 months, performed significantly worse than 13 age-matched peers with SLI in repeating non-words. The low number of studies and the considerable variation in tasks and in age of participants do not allow for any general conclusions other than that comparison of linguistic profiles of all three clinical groups has yielded mixed results.

Hence, there is a need for studies that compare linguistic profiles of children with CIs with those of HoH children and children with SLI, focusing on both lexical and grammatical language proficiency and taking into account both auditory (thus perceptual) and cognitive (thus processing) factors. Since linguistic profiles may change over age, different age groups were included. We conducted such a study, explorative by nature given the relative lack of earlier studies, examining performance on a range of test measures and exploring the linguistic profiles, based on these measures, of children with CIs, compared with HoH children with moderate to severe hearing loss and children with SLI. In the present study, we compared linguistic profiles of two different age cohorts of Dutch children, i.e., a young age cohort (aged five, six and seven years) and an old age cohort (aged 8, 9 and 10 years). We addressed the following research questions:

- To what extent do the linguistic abilities of children with CIs differ as compared with those of HoH children and children with SLI, as a function of age?
- Which components underlie children's linguistic abilities and can these components be interpreted in terms of auditory perception versus language processing?
- To what extent do the underlying components constitute differential linguistic profiles in the three different clinical groups?

Methods

Participants

Three clinical groups were included in the study, i.e., children with CIs, HoH children with conventional

Table 1. Characteristics of children with cochlear implants (CI), hard-of-hearing (HoH) children and children with specific language impairment (SLI) in the young and old age cohorts

	CI		HoH		SLI	
	Young *n* = 18	Old *n* = 29	Young *n* = 29	Old *n* = 37	Young *n* = 60	Old *n* = 67
Mean age, months (SD)	75 (6.90)	111 (6.60)	75 (6.36)	109 (6.71)	74 (5.66)	107 (6.14)
Gender (%):						
Male	56	45	59	60	77	66
Female	44	55	41	40	23	34
Education type (%):						
Mainstream	50	41	52	70	40	42
Special	50	59	48	30	60	58
Mean nonverbal intelligence stanine score on CPM (SD)	5.94 (2.00)	6.14 (1.66)	6.01 (1.65)	5.68 (1.85)	5.29 (1.87)	5.44 (2.00)
Mean age at first CI/HA implantation, months (SD)	22 (15.14)	37 (28.02)	32 (17.83)	40 (20.78)	n.a.	n.a.
Average unaided hearing loss better ear in dB HT, PTA (SD)	≥81	≥81	60.21 (15.14)	58.73 (12.86)	n.a.	n.a.

Note: SD, standard deviation; CPM, coloured progressive matrices; HA, hearing aid; dB HT, decibel hearing threshold; PTA, pure tone average; n.a., not applicable.

hearing aids and children with SLI. An overview of their characteristics is given in table 1. All children were selected by speech–language pathologists and psychologists working at the schools of the children, meeting the criteria of having no developmental disorders (e.g., autism or attention deficit hyperactivity disorder) or neurological problems. The children had nonverbal intelligence within normal limits as assessed by the Raven's Coloured Progressive Matrices (Van Bon 1986). The diagnosis of SLI was established by a multidisciplinary team of specialists including a physician, a psychologist, special educators, and a speech therapist. In the Netherlands, SLI is diagnosed when performance of at least two out of four separate language tests (speech production, auditory processing, grammar and semantics–lexicon) is below 1.5 standard deviations (SDs) of the age norm or when the total score on a general speech and language test is lower than 2 SDs from the age norm.

The young age cohort consisted of 18 children with CIs, 29 HoH children and 60 children with SLI. The age of first implantation of the children with CIs ranged from 7 to 55 months. Two children had a progressive hearing loss and were implanted relatively late (i.e., at the age of 47 and 55 months). We included these two children in the study since they became deaf before the age of 2 years. The mean speech recognition score of the group with CIs was 83% (range 30–97%) at a level of 65 dB SPL, as measured by the Dutch Nederlandse Vereniging Audiologen (NVA) Woordlijsten (Dutch Audiology Society Word Lists) (Bosman and Smoorenburg 1995). Fourteen children with CIs had hearing parents, from two children both parents were HoH, and from two children it was unknown whether their parents were hearing, HoH or deaf. The HoH children had a mean unaided pure tone-average hearing loss of 60 dB HL. According to the World Health Organization's (WHO) criteria for degree of hearing loss, four children had a mild hearing impairment (26–40 dB HL), 13 children had a moderate hearing loss (41–60 dB HL), 11 children had a severe impairment (61–80 dB HL), and one child had a profound hearing loss (> 81 dB HL) (Mathers *et al.* 2000). Twenty-two HoH children had hearing parents, three children had one HoH parent and from four children it was unknown whether their parents were hearing, HoH or deaf.

The old age cohort included 29 children with CIs, 37 HoH children and 67 children with SLI. The mean speech recognition score of the children with CIs, as measured by the Dutch NVA word lists, was 84% (range 10–100%) at 65 dB SPL. The age of first cochlear implantation of the children ranged from 12 to 103 months. Three children had a progressive hearing loss. Two of them were implanted relatively late (i.e., at the age of 96 and 103 months). We included these three children in the study since they became deaf before the age of two years. Twenty-one children with CIs had hearing parents, from one child both parents were deaf, one child had one deaf parent, three children had one HoH parent, and from three children it was unknown whether their parents were hearing, HoH or deaf. From the group of HoH children, three children had a mild hearing impairment (26–40 dB HL), 22 children had a moderate hearing loss (41–60 dB HL), nine children had a severe impairment (61–80 dB HL), and three children had a profound hearing loss (> 81 dB HL). Twenty-five HoH children had hearing parents, seven children had one HoH parent and from five children it was unknown whether their parents were hearing, HoH or deaf.

Instruments and procedure

All language tests were taken from the Dutch Testinstrumentarium Taalontwikkelingsstoornissen voor Kinderen van 4 tot 10 Jaar (Test Instruments Developmental Language Disorders for Children aged 4 to 10 Years Old) by Verhoeven *et al.* (2013). The test battery consisted of tests that were administered by an experimenter and tests that were pre-recorded and offered on the laptop computer. The computer-administered tests were conducted to the children with CIs via the Solaris Transmitter induction loop system, the HoH children received the receptive tests through loudspeakers, and children with SLI used headphones. The children were tested while wearing their CI(s) and hearing aid(s). The software program *Delphi 6* was used to present the tests on the laptop computer. All tests started with a brief explanation of the task and two examples.

The test battery consisted of 11 tests. The first was the morphology test, which was a sentence completion test that measured the production of bound morphemes. The test consisted of four subtests, measuring plural (e.g., *een mes* [one knife]—*twee messen* [two knives]), degree of comparison (e.g., *groot* [tall]—*groter* [taller]—*grootst* [tallest]), simple past tense (e.g., *breken* [breaking]—*brak* [broke]) and past participle (e.g., *bouwen* [building]—*gebouwd* [has built]). Children were shown pictures and were asked to finish the sentence that was read aloud by the experimenter (e.g., *Dit is één mes, dit zijn twee* ___ [This is one knife, these are two ___]). The second test was a computer-administered syntax test in which children were asked to select the correct picture out of four pictures, that corresponded syntactically with the sentence they had heard (e.g., *De jongen staat achter de auto* [The boy stands behind the car]). The third test was the expressive vocabulary test, in which children were asked to name pictures that were shown by the experimenter (e.g., *eekhoorn* [squirrel]; *knie* [knee]). No timing was involved. The fourth test was the computer-administered receptive vocabulary test. In this test, children were asked to select the correct picture out of four pictures that corresponded with the word they had heard (e.g., *fles* [bottle]; *dun* [slim]). The fifth test was the computer-administered auditory discrimination test, in which minimal pairs of words were offered and the children were instructed to decide whether they had heard the same words or two different words (e.g., *man*—*maan* [man—moon]). The sixth test was the computer-administered spoken word recognition test which consisted of existing words that were manipulated. Parts of the words were deleted. Children were asked to guess which word they had heard (e.g., *_ordijn* = *gordijn* [*_urtain* = curtain]). Subsequently, the experimenter scored the answers of the children. The seventh test was the computer-administered non-word repetition test, in which children needed to repeat a non existing word in exactly the same way as they had heard it (e.g., gluisem). The experimenter subsequently scored the answers of the children. The eighth and ninth test were auditory memory tests, in which children were asked to repeat either a string of words or sentences in exactly the same manner and order that was read aloud by the experimenter, with increasing difficulty of the test (e.g., *pet*—*kam*—*boot* [hat—comb—boat]; *Het meisje is een mooi boek aan het lezen* [The girl is reading a nice book]). The final two tests were the digit span tests from the Wechsler Intelligence Scale for Children—III, Dutch Edition (Wechsler 2005), in which both forward and backward repetition of digits were to be repeated by the children. The string of digits that were read by the experimenter, increased in number.

All children were tested individually in a quiet room at the school of the child. The experiment was performed in two sessions of approximately 45 min each and was administered in a fixed order. The experimenter always remained in the same room to be able to help the child with any problems. The tests were administered by a qualified linguist (i.e., the first author) and four MSc students of the Radboud University Nijmegen in the Netherlands. All students were instructed and trained by the first author in a 4-h meeting, in which the tests and procedures were explained. A strict protocol was used to administer the tests in the same way for all children.

Statistical analysis

To examine whether clinical group type (e.g., CI, HoH and SLI) and age cohort influenced linguistic abilities, a multivariate analysis of variance (MANOVA) was executed, with the 11 test measure scores as dependent variables and group and cohort as the independent variables. Post-hoc tests and pairwise comparisons with significance thresholds adjusted for multiple comparisons, using a Bonferroni correction, were conducted as follow-up tests to analyze differences between the three clinical groups of children and between the two age cohorts more specifically.

To explore the different linguistic profiles of the children, four steps were taken. First, factor analyses with varimax rotation were conducted to explore the different components underlying the test measures for the complete sample of children, i.e., test measures of children with CIs, HoH children and children with SLI combined. Three cases with missing values were excluded prior to analyses. Secondly, the standardized

Table 2. Mean raw scores and standard deviations for linguistic test measures obtained by the three clinical groups (i.e., CI, HoH and SLI) per age cohort; results of the MANOVAs and Bonferroni post-hoc group differences

	CI		HoH		SLI		Group × Cohort			Group			Cohort		
	Mean	SD	Mean	SD	Mean	SD	*F*	d.f.	*p*	*F*	d.f.	*p*	*F*	d.f.	*p*
Expressive morphology							1.97	2, 231	.017	8.15	2, 231	< .001	125.56	1, 231	< .001
Young	9.33	6.70	13.52	7.58	12.80	5.58									
Old $_{\text{a***, c**}}$	19.52	9.50	26.30	4.91	22.01	5.59									
Receptive syntax							1.16	2, 231	.010	9.54	2, 231	< .001	41.42	1, 231	< .001
Young	18.06	5.23	21.45	6.57	20.00	5.31									
Old $_{\text{a,*** b***}}$	21.38	8.73	27.19	3.60	26.48	4.16									
Expressive vocabulary							0.39	2, 231	.003	3.50	2, 231	.032	77.38	1, 231	< .001
Young	12.39	4.91	14.83	7.19	13.15	5.15									
Old $_{\text{a*}}$	20.00	9.69	24.84	7.97	22.60	6.88									
Receptive vocabulary							1.07	2, 231	.009	11.68	2, 231	< .001	90.85	1, 231	< .001
Young	14.31	8.15	19.55	10.28	21.08	10.46									
Old $_{\text{a***, b***}}$	25.86	15.47	37.41	12.08	37.36	9.14									
Auditory discrimination							4.91	2, 231	.041	34.53	2, 231	< .001	35.94	1, 231	< .001
Young $_{\text{a*, b**}}$	3.19	5.36	5.48	4.73	12.20	6.69									
Old $_{\text{a***, b***, c***}}$	5.93	5.51	10.65	7.64	23.21	4.56									
Spoken word recognition							9.69	2, 231	.077	108.19	2, 231	< .001	53.92	1, 231	< .001
Young $_{\text{b***, c***}}$	13.81	5.65	18.10	4.32	18.29	4.62									
Old $_{\text{a**, b***, c***}}$	16.03	4.83	21.03	3.65	24.49	3.85									
Non-word repetition							5.83	2, 231	.048	31.08	2, 231	< .001	32.52	1, 231	< .001
Young	5.19	3.99	5.83	5.01	8.80	6.02									
Old $_{\text{a**, b***, c***}}$	5.97	5.22	11.14	7.52	16.34	3.86									
Auditory memory words							2.35	2, 231	.020	10.66	2, 231	< .001	15.61	1, 231	< .001
Young $_{\text{c*}}$	3.56	1.42	4.00	1.10	3.37	1.06									
Old $_{\text{a***, c**}}$	3.79	1.84	5.27	1.47	4.18	1.11									
Auditory memory sentences							8.02	2, 231	.065	24.38	2, 231	< .001	57.14	1, 231	< .001
Young $_{\text{c*}}$	1.67	1.82	2.76	1.77	1.87	1.40									
Old $_{\text{a***, c***}}$	2.66	2.06	6.41	2.60	3.76	1.87									
Digit span forward							1.93	2, 231	.016	15.19	2, 231	< .001	20.53	1, 231	< .001
Young $_{\text{c**}}$	4.72	1.74	5.41	1.88	4.28	1.44									
Old $_{\text{a***, c***}}$	5.21	2.02	7.08	1.89	5.49	1.27									
Digit span backward							0.41	2, 231	.003	6.23	2, 231	.002	76.73	1, 231	< .001
Young	1.72	1.64	2.24	1.33	1.58	1.37									
Old $_{\text{c**}}$	3.55	1.76	4.05	1.63	3.18	1.07									

Notes: a = CI versus HoH, b = CI versus SLI and c = HoH versus SLI.
*$p < .05$ **$p < .01$ ***$p < .001$

factor scores derived from the factor analyses were used in cluster analyses to cluster all children on the basis of their factor scores in such a way that differences between clusters on these factor scores were as large as possible and differences between children within the same cluster were as small as possible. Box plots were used to visualize the profiles of the clusters, searching for groups of children with different linguistic profiles that were based on their factor scores. The cluster analyses were performed in two stages. First, the best cluster solution was determined by means of Ward's (1963) hierarchical cluster analysis. In the second stage, *K*-means cluster analyses were performed over the factor scores with the established number of clusters from Ward's cluster solution. Third, the standardized factor scores derived from the factor analyses of each separate clinical group of children were visualized in box plots. The fourth and final step was to compare the profiles that were found on the basis of the factor scores (step 2) with the profiles of the separate clinical groups of children (step 3). The factor and cluster analyses were conducted separately for the young and old age cohorts.

Results

Group differences

The overall two-way interaction group (i.e., CI, HoH, SLI) × cohort (i.e., young, old) was significant (Wilk's Lambda, $F = 2.97$, $p < .001$). Furthermore, significant main effects were found for group (Wilk's Lambda, $F = 16.20$, $p < .001$) and cohort (Wilk's Lambda, $F = 15.96$, $p < .001$). Table 2 provides the mean raw scores, SDs, and the MANOVA results for the test measures obtained by the children with CIs, the HoH children and the children with SLI. According to the MANOVA results, most of the children's linguistic abilities were influenced by group and age cohort. Within each group, differences between the age cohorts existed and within each age cohort, differences between the groups occurred. Only for the test measures 'spoken word recognition' and 'auditory memory sentences', no two-way interaction was present.

To examine the specific impact that each significant independent variable had on the dependent variables, post-hoc tests with pairwise comparisons using a Bonferroni correction were conducted. Results of the post-hoc tests are provided in table 2, in which significant differences between the clinical groups per age cohort are indicated with the letters 'a', 'b' and 'c'. Concerning the differences between the two age cohorts, as might be expected, pairwise comparisons revealed that for each test measure the old age cohort performed significantly better than the young age cohort (all $p < .001$).

Factor analyses

Factor analyses with varimax rotation were conducted to explore the different components underlying the test measures for the complete sample of children. In the young age cohort, varimax rotation factor loadings suggested three components representing *language*, *verbal working memory* and *speech decoding*. Results of the factor analysis are presented in table 3. The three components had eigenvalues of 5.3, 1.4 and 1.2 respectively, and together they explained 71% of the variance in the test measures of the young age cohort. The first component was labelled *language* and consisted of tests that measured morphosyntactic (i.e., expressive morphology and receptive syntax) and lexical (i.e., expressive and receptive vocabulary) language skills, but also the test measure auditory memory sentences. This latter test measure apparently assessed a combination of language and memory skills, as it had a factor loading of .69 on the language component and .50 on the verbal working memory component. On the second component, high factor loadings were found for tests measuring verbal memory skills, i.e., auditory memory words, digit span forward and digit span backward. This component was therefore labelled *verbal working memory*. The final component was labelled *speech decoding*, because it involved tests that acquired speech decoding skills (i.e., spoken word recognition, non-word repetition and auditory discrimination).

For the old age cohort, varimax rotation factor loadings suggested the exact same three components as for the young age cohort, but component 2 and 3 were reversed, i.e., the first component represented *language*, the second *speech decoding and* the third *verbal working memory*. Table 4 provides the results of the factor analysis for the old age cohort. The three components had eigenvalues of 5.0, 2.0 and 1.0 respectively, and together they explained 73% of the variance in the test measures. The components were comprised of the same tests as the components in the young age cohort.

Linguistic profiles

The standardized factor scores derived from the factor analyses were used in cluster analyses to find different clusters (i.e., groups of children) that were formed on the basis of the data and not on the basis of their diagnoses (as is the case for each clinical group). It could be concluded that a two-cluster solution was the most appropriate to cluster the complete sample of children in both age cohorts. Figure 1 presents the two-cluster linguistic profiles in the young and old age cohorts. In the young cohort, the profile of the first cluster indicated relatively high scores on *verbal working memory* and relatively low scores on *speech decoding*, compared with the profile of the second cluster, in which opposite

Table 3. Varimax rotated three-factor solution for the young age cohort ($n = 104$)

	Component		
	1	2	3
	Language	Verbal working memory	Speech decoding
Receptive vocabulary	**.83**	–.01	.28
Expressive vocabulary	**.79**	.26	.05
Expressive morphology	**.78**	.34	.26
Receptive syntax	**.76**	.27	.26
Auditory memory sentences	**.69**	.50	.11
Auditory memory words	.13	**.86**	.10
Digit span forward	.23	**.85**	.08
Digit span backward	.27	**.54**	.28
Spoken word recognition	.20	.10	**.86**
Non-word repetition	.09	.33	**.83**
Auditory discrimination	.44	–.02	**.59**

Note: Factor loadings > .50 are shown in bold text.

Table 4. Varimax rotated three-factor solution for the old age cohort ($n = 133$)

	Component		
	1	2	3
	Language	Speech decoding	Verbal working memory
Expressive vocabulary	**.84**	.13	.13
Expressive morphology	**.82**	.14	.31
Receptive vocabulary	**.80**	.41	.06
Auditory memory sentences	**.76**	.06	.36
Receptive syntax	**.63**	.47	.24
Spoken word recognition	.13	**.92**	–.14
Non-word repetition	.18	**.83**	.13
Auditory discrimination	.19	**.81**	.07
Digit span backward	.03	–.01	**.79**
Auditory memory words	.39	.09	**.73**
Digit span forward	.35	.04	**.72**

Note: Factor loadings > .50 are shown in bold text.

results were found (i.e., low scores on *verbal working memory* and high scores on *speech decoding*). The first cluster consisted mostly of children with CIs ($n = 13$ or 76.5%) and HoH children ($n = 21$ or 75%), whereas cluster 2 mostly contained children with SLI ($n = 46$ or 78%). In the old cohort, the profile of the first cluster indicated relatively low scores on *verbal working memory*, compared with the profile of the second cluster, in which the opposite result was found (i.e., high scores on *verbal working memory*). Cluster 1 consisted of all children with CIs ($n = 29$ or 100%) and a large amount of HoH children ($n = 31$ or 83.8%), whereas cluster 2 mostly contained children with SLI ($n = 55$ or 82.1%).

Next, profiles of each separate clinical group in both age groups were visualized in box plots by using the standardized factor scores derived from the factor analyses, to receive a better picture of the groups that were formed on the basis of the diagnoses (i.e., CI, HoH and SLI) of the children. Figure 2 presents the linguistic profiles of each separate clinical group. In the young age cohort, children with CIs showed a profile of relatively low scores on *speech decoding* and relatively high scores on *verbal working memory*. The HoH children in this group showed a similar result as their peers with CIs. The children with SLI in the young age cohort had an opposite profile, in which they scored relatively high on *speech decoding* and relatively low on *verbal working memory*. In the old age cohort, children with CIs showed a profile of relatively low scores on *verbal working memory* and relatively high scores on *speech decoding*. The HoH children in this cohort showed a profile with relatively high scores on *language* and on *speech decoding* and relatively low scores on *verbal working memory*. The children with SLI in the old age cohort had a profile in which they scored relatively high on *verbal working memory* and relatively low on *speech decoding*.

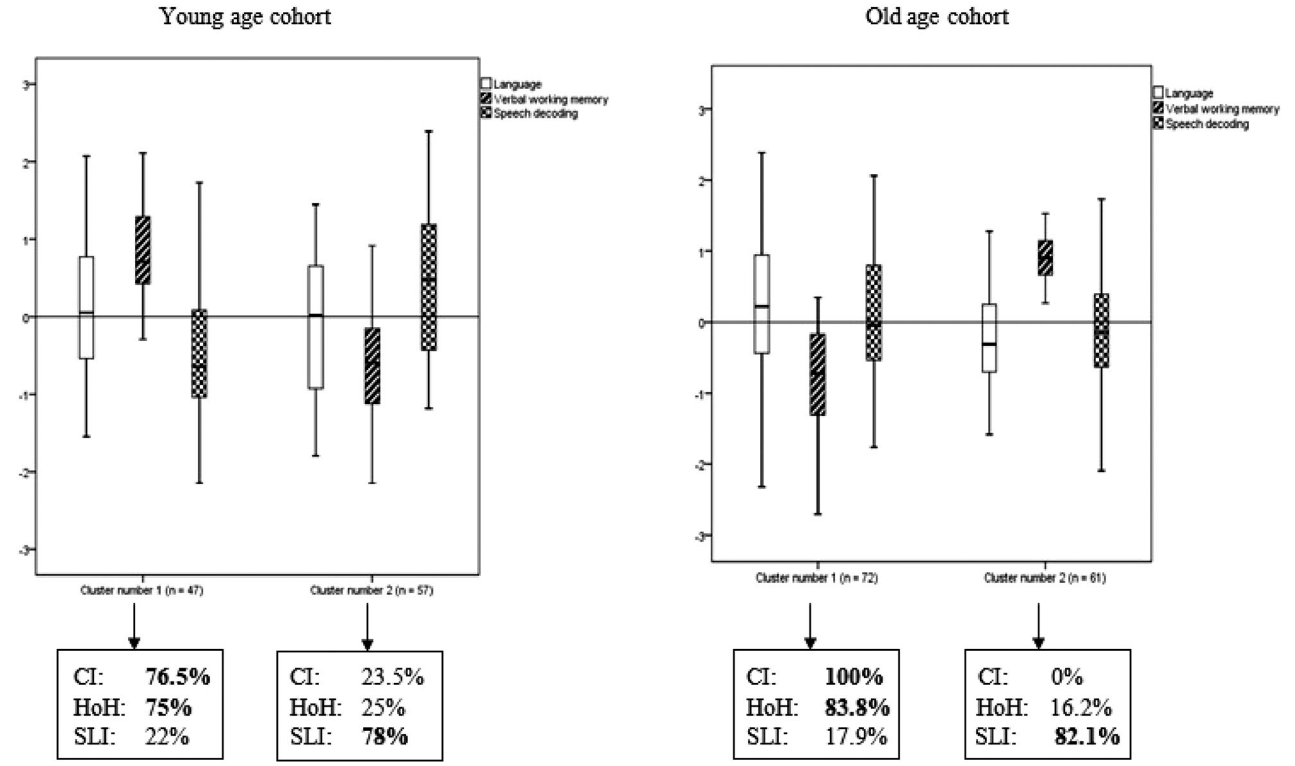

Figure 1. Box plots for two-cluster linguistic profiles of the complete sample of children. The left picture presents linguistic profiles of the children in the young age cohort, the right picture shows profiles of the old age cohort.

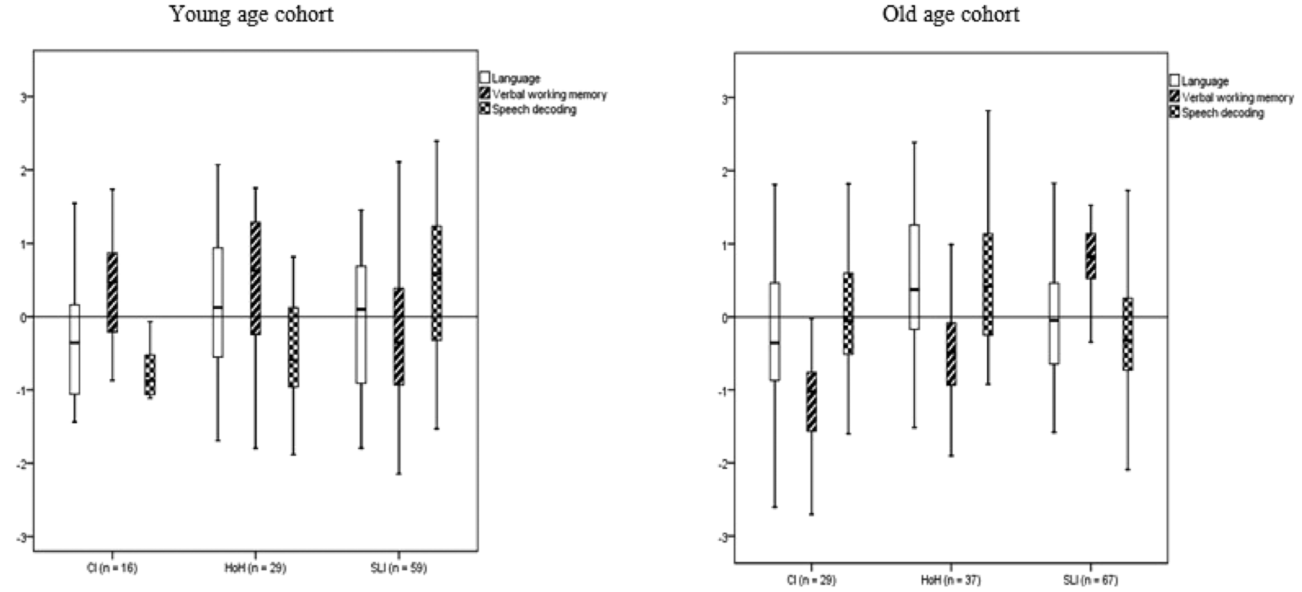

Figure 2. Box plots for two-cluster linguistic profiles of each clinical group separately. The left picture presents linguistic profiles of the children in the young age cohort, the right picture shows profiles of the old age cohort.

Discussion

In the present study, performance on linguistic test measures of children with CIs, HoH children with moderate to severe hearing loss and children with SLI in two age cohorts was explored, followed by examination of underlying components of these linguistic abilities in terms of auditory perception versus auditory processing. Furthermore, linguistic profiles of the three clinical groups were investigated. Finally, profiles of clusters of children that were formed on the basis of the factor scores were visually compared with those of the clinical groups that were formed on the basis of their diagnoses.

With regard to the first research question on group differences concerning the linguistic abilities, results showed that the HoH children outperformed the children with CIs on all but one (i.e., digit span backward) test measures. These results are contrary to most previous studies comparing children with CIs and HoH children, in which children with CIs outperformed their HoH peers with hearing aids on linguistic measures (Baldassari et al. 2009, Hammer 2010, Svirsky et al. 2000, Tomblin et al. 1999, Yoshinaga-Itano et al. 2010). The results however correspond to findings by Ibertsson et al. (2008), in which HoH children outperformed their peers with CIs on non-word repetition. Differences between the present study and previous studies may be explained by the fact that the HoH children in the present study had a moderate to severe hearing loss on average (i.e., 60 dB HL in the young age cohort and 58 dB HL in the old age cohort), whereas the HoH children in previous studies overall had severe or profound hearing loss. Noticeable is that the type of hearing loss of the HoH children in the study by Ibertsson et al. (2008) corresponds with the present study. Furthermore, the children with SLI in our study outperformed the children with CIs on receptive syntax, receptive vocabulary, auditory discrimination, spoken word recognition and non-word repetition. These results correspond partly to findings from Ibertsson et al. (2008), in which children with SLI outperformed children with CIs on non-word repetition. However, the results are contrary to a comparative study by Löfkvist *et al.* (2014), in which children with CIs outperformed their peers with SLI on receptive vocabulary. Differences between studies might be explained by the fact that a different type of language test was used to measure receptive vocabulary (i.e., Löfkvist *et al.*, 2004, used the Peabody Picture Vocabulary Test—III, whereas in the present study the Dutch Test Instruments Developmental Language Disorders for Children Aged 4 to 10 Years Old by Verhoeven *et al.* 2013 was used), or by the fact that different population samples were included in the studies. For instance, the distribution of children attending different types of education varies between the present study and previous studies. This could indicate that children with different cognitive and linguistic abilities are compared. It could also mean that children with differential communicative-educational settings, and hence mixed language input are compared. From previous research it is known that higher speech intelligibility scores and better receptive language abilities, including vocabulary skills in children with CIs correlate with an educational setting that emphasizes spoken communication development (Langereis and Vermeulen 2015). In the present study, a relatively high percentage (55%) of the participating children with CIs attended special education schools, in which a combination of (supportive) sign language and spoken language input was offered to the children, whereas in previous studies a smaller percentage of children with CIs attended special education schools (i.e., 28% in De Hoog *et al.* 2015, 26% in Löfkvist *et al.* 2014, and 27% in Hammer *et al.* 2014). Moreover, in the present study, 59% of the children with SLI attended special schools, whereas a larger percentage of children with SLI in the previous studies did (i.e., 65% in De Hoog *et al.* 2015, 100% in Löfkvist *et al.* 2014, and 100% in Hammer *et al.* 2014). It should be noted that in the study by Ibertsson *et al.* (2008), in which corresponding results were found with the results of the present study concerning non-word repetition, 44% of the children with CIs followed special education and all children with SLI attended mainstream schools. Ideally, in future research, types of environmental factors, like language input in education should be controlled for as they could account for part of the variation.

Furthermore, linguistic test performance of children in the young and old age cohorts was compared, within each clinical group. Results showed significant differences between the young and the old age cohorts for all three groups of children. The children in the old age cohorts performed significantly better on all linguistic test measures than the young age cohorts. This finding of language performance increasing as a function of age development was in accordance with earlier research on the clinical groups of children as well as on typically developing children with normal hearing (e.g., Hoff 2009; Rice 2013; Yoshinaga-Itano *et al.* 2010).

With respect to the second research question concerning the components that underlie children's linguistic abilities and the potential interpretation of these components in terms of auditory perception versus auditory processing, we found three different components representing *language*, *verbal working memory* and *speech decoding*. The component *language* consisted of tests that measured morphosyntactic and lexical language skills and also auditory memory sentences. The component *verbal working memory* included tests measuring memory skills, i.e., auditory memory words, digit span forward and digit span backward. These skills can be interpreted in terms of language processing, as these tests measure cognitive elements of language information processing. The final component, *speech decoding*, consisted of tests that acquired speech decoding skills, i.e., spoken word recognition, non-word repetition and auditory discrimination. The speech decoding skills can be interpreted in terms of auditory perception, as qualitatively good speech perception skills are necessary to decode speech sounds.

Regarding the third research question, whether the underlying components constitute differential linguistic profiles in the three different subgroups, cluster results on the basis of the factor scores showed that the children with CIs and their HoH peers shared the same linguistic profiles in both age cohorts (figure 1). The majority of children with CIs (76.5%) and the majority of HoH children (75%) in the young age cohort obtained relatively low scores on speech decoding skills, i.e., auditory perception, and relatively high scores on verbal working memory skills, i.e., language processing. The majority of children with SLI (78%) in the young age cohort showed opposite results, with relatively high scores on the speech decoding measures and relatively low scores on verbal working memory skills. In the old age cohort, all children with CIs (100%) and the majority of the HoH children (83.8%) shared similar linguistic profiles of relatively low scores on verbal working memory skills, i.e., language processing. The majority of children with SLI (82.1%) showed relatively high scores on verbal working memory skills. It seems from these results that the underlying nature of the spoken language difficulties in children with CIs and HoH children is different from that of children with SLI. Children who experience difficulties with auditory perception appear to have different linguistic profiles based on their scores in the test battery used in the present study than children who show problems with language processing. This is in line with the results found by Hammer *et al.* (2014), who found a clear distinction between the linguistic profiles of children with CIs and children with SLI. However, it should be noted that in the present study, some overlap between the children in the clinical groups was found. In the young age cohort, 25% of the HoH children and 23.5% of the children with CIs shared the linguistic profiles of the majority of the children with SLI, and 22% of the children with SLI had similar profiles as the majority of children with CIs and HoH children. Some overlap was also found between the groups of children in the old age cohort, i.e., 16.2% of the HoH children shared the profiles of the majority of children with SLI, and 17.9% of the children with SLI had similar profiles as the children with CIs and the majority of HoH children. These results are consistent with Szagun (2000), who hypothesized that the lack of perceptual salience might not be the only explanation for language deficits in children with hearing loss. A subgroup of children with CIs and HoH children seems to have linguistic profiles which may reflect the same basis as is seen in children with SLI, with co-occurring language processing problems. From the late nineties, the diagnosis of SLI had been given to children if a language learning impairment existed, despite normal development in nonverbal IQ and non-linguistic aspects of development. Language difficulties could not be accounted for by hearing loss or brain damage (Leonard 1998). The requirement for normal hearing meant that children with sensorineural hearing loss were excluded from a diagnosis of SLI. Since 2014, the definition of SLI changed and the term *specific* is employed more broadly. Leonard (2014) stated that SLI cannot be attributed to a hearing impairment, but that the hearing impairment can be present alongside the language problems. Since about 4% to 6 % of the population of normally hearing children have the diagnosis SLI, it could be expected that this would also be the case for children with hearing loss (Hawker *et al.* 2008).

When looking at the scores on a clinical group level (figure 2), we found that in the old age cohort the children with CIs and the HoH children obtained the exact opposite results as they obtained in the young age cohort. In the young cohort, the children scored relatively low on speech decoding skills and relatively high on verbal working memory skills, whereas in the old cohort, they scored relatively high on speech decoding skills and relatively low on verbal working memory skills. This was even more clear for children with CIs than for their HoH peers. Verbal working memory is a complex skill, which could improve with age when qualitatively good language input is offered, and if necessary, sufficient intervention and speech–language therapy. One aspect of working memory is the phonological loop, which plays a crucial role in language learning (Baddeley *et al.* 1998). When a deficit in the phonological loop occurs, as is the case in children with an auditory speech perception deficit, training working memory skills in general and language learning in particular may be more problematic. It may be assumed that most children involved in the present study received speech–language training. However, filtered auditory input and limited stimulation, as is the case for children with hearing loss, might lead to the inability to train the phonological loop. This could result in the lack of improvement of the verbal working memory skills by the children with CIs and their HoH peers in the old age cohort in the present study. The children with SLI in the young age cohort showed relatively low scores on verbal working memory skills and relatively high scores on speech decoding and language skills, whereas the children in the old age cohort showed relatively high scores on verbal working memory skills and relatively low scores on speech decoding and language skills. These results suggest that indirect training of the phonological loop could improve their verbal working memory skills with age. Moreover, the speech decoding and language skills of the children with SLI at an older age are relatively falling behind after intervention and speech–language training, as compared with their verbal working memory skills. This provides support for the fact that an impaired language system is the core problem for the children with SLI, which appears to be difficult to train in children that are still diagnosed with SLI at an older age. However, longitudinal research is necessary to provide more evidence that the children indeed stagnated or improved their skills over time.

Some limitations apply to the present study. First, differences between the young and old age cohorts cannot be interpreted as improving over time, since we used a cross-sectional design. It would be very interesting to look at the growth of linguistic abilities in terms of profiles longitudinally, when controlling for intervention. Secondly, the mean speech recognition score was obtained only for the children with CIs. As the HoH children were diverse in severity of unaided hearing loss and compared with the group of children with CIs, it would have been better to test the speech recognition score of the HoH group as well. In that way, the children could have been matched on speech recognition scores, which is something we recommend for future research. Finally, a measure of parent's education level was unavailable in the present study. It is known from previous research that this measure can be of influence on the spoken language outcomes in children with CIs (e.g., Geers *et al.* 2009). Therefore, in future studies on spoken language performance of children with CIs, a measure of parent's education level should be incorporated.

In conclusion, results of the present study showed that children with CIs produced lower scores on most linguistic test measures, as compared with their HoH peers with moderate to severe hearing loss and peers with SLI. Concerning the linguistic profiles that were based on these linguistic test measures, we found similar profiles for the largest group of children with CIs and the HoH children. The linguistic profiles observed for most of the children with SLI were different from those of their peers with hearing loss in both age cohorts. Apparently, children with auditory perception difficulties reveal different linguistic profiles than children who have language processing problems. This suggests that the underlying nature of the spoken language difficulties in most children with CIs mainly lies in limited auditory perception instead of language processing problems. However, there appears to be a considerable subgroup of children with CIs whose profiles resemble those of children with SLI.

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