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Syntagmatic and paradigmatic development of cochlear implanted children in comparison with normally hearing peers up to age 7

Jolien Faes [a,*], Joris Gillis [b], Steven Gillis [a]

[a] Computational Linguistics and Psycholinguistics Research Centre, Department of Linguistics, University of Antwerp, Prinsstraat 13, B-2000 Antwerp, Belgium
[b] Mobile Vikings Belgium, Hasselt, Belgium

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ABSTRACT

Objective: Grammatical development is shown to be delayed in CI children. However, the literature has focussed mainly on one aspect of grammatical development, either morphology or syntax, and on standard tests instead of spontaneous speech. The aim of the present study was to compare grammatical development in the spontaneous speech of Dutch-speaking children with cochlear implants and normally hearing peers. Both syntagmatic and paradigmatic development will be assessed and compared with each other.

Method: Nine children with cochlear implants were followed yearly between ages 2 and 7. There was a cross-sectional control group of 10 normally hearing peers at each age. Syntactic development is measured by means of Mean Length of Utterance (MLU), morphological development by means of Mean Size of Paradigm (MSP). This last measure is relatively new in child language research.

Results: MLU and MSP of children with cochlear implants lag behind that of their normally hearing peers up to age 4 and up to age 6 respectively. By age 5, CI children catch up on MSP and by age 7 they caught up on MLU.

Conclusion: Children with cochlear implants catch up with their normally hearing peers for both measures of syntax and morphology. However, it is shown that inflection is earlier age-appropriate than sentence length in CI children. Possible explanations for this difference in developmental pace are discussed.

1. Introduction

The current paper examines the development of grammatical language skills of Dutch-speaking congenitally deaf children who underwent cochlear implantation (CI) at an early age in comparison with normally hearing peers (NH) up to age 7. Early cochlear implantation has been shown to considerably foster language development in congenitally deaf children [1,2]. Some CI children are found to manifest age-appropriate language skills after 1–4 years of device use, while others still lag behind on their NH peers even after more than 4 years of device use [3,4]. Language development in CI children is thus subject to a large amount of interindividual variation as only some CI children seem to catch up with their NH peers. However progress and acquisition rates are also dependent on the particular linguistic field studied. For instance receptive language skills of CI children are faster age-appropriate than their expressive language skills [3,5]. In addition, CI children are found to have particular difficulties with syntax and morphology, in contrast to lexical development [5]. In other words, most CI children are found to catch up with their NH peers on vocabulary measures, but not on measures of productive morphology and syntax (grammatical aspects of language use).

Language development can be studied in different ways: standard tests can be used to assess children's grammatical competence or language measures based on spontaneous speech. A frequently used standard test for grammatical development is the Reynell Developmental Language Scale (RDLS). For instance Duchesne, Sutton and Bergeron [5] used the RDLS and showed that after 6 years of implant use, more than half of the CI children had receptive and expressive age-appropriate language skills at the word level, while less than 50% of the same group of children had receptive and expressive age-appropriate language skills at the sentence level. Even though other standardised tests were used,

* Corresponding author. Tel.: +32 03 265 5231.
E-mail addresses: jolien.faes@uantwerp.be (J. Faes), joris.gillis@gmail.com (J. Gillis), steven.gillis@uantwerp.be (S. Gillis).

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similar outcomes were found in for instance Young and Killen [6], Schorr, Roth and Fox [7], Geers, Nicholas and Sedey [8] and Caselli, Rinaldi, Varuzza, Giuliani and Burdo [9]. In studies of spontaneous speech, a similar relative developmental pace of lexicon and grammar is found: the delay of CI children comprises a shorter period for lexical development as compared to grammatical development, measured by, for instance, Mean Length of Utterance (MLU) [10] and adjectival inflection [11]. Contrastingly from outcomes on standard tests, early implanted CI children are found to catch up with their NH peers by approximately age 5 when studying their spontaneous speech [1,11]. Like in standard tests, most literature on spontaneous speech studied only one aspect of grammatical development. In contrast, the present paper focuses not only on spontaneous speech, but also on two specific aspects of grammatical development, viz. syntagmatic and paradigmatic complexity. Furthermore, the development of those two aspects in CI children is compared with each other.

CI children seem to have particular difficulties with grammatical development. Even in NH children, grammatical development is a slow and gradual process [12,13]. Grammatical development is generally considered to involve syntactic development, i.e. combining words into sentences, and morphological development, i.e. combining morphemes into larger units as in, e.g. inflection, compounding and derivation. Hence grammatical development exhibits a syntagmatic dimension, i.e. how words are ordered in sentences, and a paradigmatic dimension, e.g. the different forms of a particular root or stem. Both dimensions interact as can be seen in congruence: in languages such as English and Dutch a singular subject requires a singular form of the (finite) verb (e.g. the man <u>is</u> working), and a plural subject requires a plural form of the verb (e.g. four men <u>are</u> working). In the present paper, grammatical skills are analysed in both NH and early implanted CI children. More specifically, the present paper focuses on syntagmatic and paradigmatic development, operationalised by implementing Mean Length of Utterance (MLU) and Mean Size of Paradigm (MSP) respectively.

1.1. Mean Length of Utterance (MLU)

MLU is a widely used measure of general language development linked to morphology and syntax and thus grammar in general. Even though MLU, as presented by Brown (1973), is not a direct measure of syntactic development – for instance, it does not take correctness of word order into account – it provides an indication of the degree of sentence complexity [14]. Recently, Mimeau, Plourde, Ouellet and Dionne [15] showed that MLU is a valid and reliable measure of morphosyntactic complexity up to school ages. When children are combing more words into longer sentences, MLU becomes higher, which indicates at least the knowledge of some syntagms. Therefore, MLU is considered as a measure of syntagmatic development.

MLU can be calculated in several ways: Brown [16] suggested to divide the number of morphemes, i.e. the smallest meaningful units, words or word parts, by the number of utterances (MLU in morphemes). However, strong correlations of MLU in morphemes with MLU in words [17–20] and in syllables [17] are found. More detailed information about MLU calculation is given in Section 2.

MLU increases with age [20,21] between approximately 1;06 (years;months) and 5;00. MLU is useful in detecting language problems in children [22]. For instance in children with specific language impairment (SLI), MLU is lower in comparison to typically developing peers [20,23]. With respect to CI children, Tobey and Hasenstab [24] found no increase in MLU after 1 year of implantation. Note however that the mean age at implantation was 6;00 (SD = unknown). In contrast, for instance Blamey, Barry, Bow, Sarant, Paatsch and Wales [2], Moreno-Torres and Torres [10] and Schauwers [25] found an increase of MLU with longer implant use. Participants in these studies were implanted at younger ages: mean ages at implantation are 3;09 (SD = 1;00), 1;04 (case study) and 1;00 (SD = 0;05) respectively.

Comparisons of NH and CI children can reveal delays in syntagmatic development of CI children. In Table 1, the outcomes of some recent studies in various languages are shown. Even though the study design (longitudinal or cross-sectional, number of CI participants) and mean ages at implantation differed across studies, Table 1 shows that MLU of CI children is mainly found to lag behind that of NH peers up to approximately age 8;00. But, Nicholas and Geers [1] and Hammer [14] concluded that early implanted CI children catch up with their NH peers by age 4;06 and 8;00 respectively.

In the literature, the reported delays of CI children with respect to MLU have been explained by deficits of the short-term phonological working memory of those children [30–32]. For instance Willis and Gathercole [33] showed that an effect of phonological working memory capacities on sentence repetition accuracy. Working memory involves short-term storage, rehearsal and handling of information [34]. In longer and more complex sentences, more phonological information must be stored and handled. Furthermore, the cognitive load will be higher in longer sentences, which reduces the efficiency of the phonological short-term working memory [32]. As CI children have lower short-term phonological working memory capacities [30–32], their sentence length and complexity will be affected negatively. For instance Charest, Johnston and Small [35] showed a decrease in MLU with increasing load of the working memory in NH children. Similarly, Willis and Gathercole [33] showed a decrease in sentence repetition accuracy with increasing sentence length and thus an increase in cognitive load. A similar process is assumed to be present in CI children.

The present paper examines MLU development in 9 early implanted Dutch-speaking CI children up to age 7 and compares those children to age-matched NH children.

Table 1
Literature overview MLU in CI and NH children.

Authors	Language	# CI children	Design[a]	Mean age at implantation (SD)	Outcome: MLU CI < NH at age[b]	Do CI children catch up?
Ouellet, Le Normand and Cohen [26]	French	5	L	3;09 (1;02)	5;02	Not reported
Szagun [27] and Szagun [4]	German	22	L	2;05 (0;08)	5;06	Not reported
Schauwers [25]	Dutch	9	L	1;00 (0;05)	2;06	Not reported
Nicholas and Geers [1]	English	76	L	1;11 (unknown)	3;04	Catch up at 4;06
Hammer [14]	Dutch	48	C	1;04 (0;09)	6;00	Catch up at 7;00
Nittrouer, Caldwell-Tarr, Sansom, Twersky and Lowenthein [28]	English	55	PL	1;09 (1;02)	8;04	Not reported
Nittrouer, Sansom, Low, Rice and Caldwell-Tarr [29]	English	55	PL	1;09 (1;02)	7;08	Not reported

[a] L = longitudinal, C = cross-sectional, PL = one data point as part of a longitudinal design.
[b] Ages are represented in years;months.

1.2. Mean Size of Paradigm (MSP)

Not only syntagmatic richness, but also paradigmatic richness, as considered by MSP, is essential for children's grammatical development. MSP is presented by Xanthos and Gillis [36] as a measure of paradigmatic complexity, and more specifically inflectional diversity. Inflectional diversity gives an indication of the number of different inflected word forms per lemma, i.e. root. When children have more inflected word forms for a lemma, there inflectional diversity is higher. MSP gives the average of the number of inflected word forms over all lemmas [36]. In its simplest form, MSP is thus calculated by dividing the number of distinct word forms, i.e. number of inflected word forms, by the number of lemmas [36]. The present paper examines MSP development in children's language. More detailed information is given in Section 2.

MSP has been used to examine the influence of paradigmatic variation in child-directed speech on children's speech in different languages [37,38]. These cross-linguistic studies revealed that the more inflectional diversity in the input, the faster the child's development of inflectional diversity. Paradigmatic richness in child-directed speech is thus positively correlated to development of paradigmatic richness in the child's speech. Laaha and Gillis [37] examined total MSP input in child-directed speech of different languages. For Dutch, MSP is 1.07 for nouns and 1.82 for verbs. By way of comparison, MSP of Turkish is 1.91 for nouns and 3.93 for verbs [37]. Higher MSP is an indication of a morphologically richer inflecting language. Thus, Dutch is a language with 'poor' morphology and Turkish is language with 'rich' morphology. In the present paper MSP will be used to compare the development of inflectional diversity in Dutch-speaking NH and CI children.

The development of CI children's inflection is found to lag behind compared to NH peers. For instance for German, Szagun [4] showed that inflectional morphology of CI children is less advanced compared to MLU-matched NH children. More precisely, case and gender marking of articles and noun plurals are less accurate in CI children. With respect to plurals, NH children are found to make errors, but CI children simply do not mark plurals, and therefore avoid erroneous complex morphology [4]. Likewise, Laaha, Blineder and Gillis [39] showed that Dutch and German CI children produce significantly more singular nouns compared to age-matched NH peers in an elicitation task of plurals. With respect to articles, the same trend as in nouns is found: NH children erroneous use, while CI children frequently omit articles [4]. Whereas CI children have difficulties with morphology of nouns and articles, no differences with respect to verbal morphology are found [4]. For English, Guo, Spencer and Tomblin [40] showed that tense marking is less accurate in CI children as compared to NH peers up to 5 years of implant use. For Dutch, Laaha, Blineder and Gillis [39] found few differences in noun plural marking in 4.5 year-olds in an experimental task. However, similar to Szagun [4], CI children did not mark the plural at all and responded with an imitation of the singular prompt. Hammer [14] found similar results as Guo, Spencer and Tomblin [40]: CI children acquiring Dutch are delayed with respect to verb morphology, subject–verb agreement and past tense marking. Nevertheless, CI children seem to catch up for nominal and verbal morphology by age 7 [14].

Inflectional development of CI children is thus poorer as compared to NH peers, due to reduced auditory speech input and thus poor perception of already low salient grammatical morphemes [40,41]. For instance Svirsky, Stallinfs, Ying, Lento and Leonard [41] showed that the most prominent grammatical markers are acquired before less prominent ones in CI children. Grammatical morphemes are less salient in speech perception. As a result of the limitations of the cochlear implant, CI children are assumed to poorly perceive such low salient morphemes. Nevertheless, the perception of such morphemes is indispensable for their production, as perception is a prerequisite for production [42]. A limited perception of low salient items, like grammatical morphemes, is thus assumed to negatively influence their production.

2. Methods

2.1. Subjects

A longitudinal design was set up to assess language development of CI children: 9 CI children were followed yearly between 2 and 7 years of age [25]. Before implantation, all CI children suffered from a congenital profound hearing loss with a mean PTA of 112.56 decibels hearing level (dB HL) (SD = 9.12 dB HL). The causes of deafness were a mutation in the connexin-26 gene (5 children), a mutation in the connexin-31 gene (1 child), a cytomegalovirus infection (1 child), genetic (1 child) and unknown (1 child). All children received a Nucleus-24 cochlear implant before 1;08 (mean = 0;11.28 (years;months.days), SD = 0;05.08). After implantation, the mean PTA improved to 32.22 dB HL (SD = 7.11 dB HL) at age 5. Furthermore, 6 out of 9 children received a second implant between 1 and 7 years of age. Implant types of the second device were Nucleus-24 (2 children), Nucleus Freedom (2 children), Digisonic SP20 (1 child) and unknown (1 child). Mean age at implantation of the second device was 4;06.15 (SD = 2;03.01). More detailed information can be found in Table 2.

With respect to the control group, a cross-sectional design was set up with 61 NH children between 2 and 7 years of age. This group consisted of 10 two-year-olds (mean = 2;00.19, SD = 0;01.02), 9 three-year-olds (mean = 2;11.27, SD = 0;01.02), 12 four-year-olds (mean = 4;00.13, SD = 0;01.12), 10 five-years-olds (mean = 5;00.13, SD = 0;01.12), 10 six-year-olds (mean = 6;00.06, SD = 0;02.25) and 10 seven-years-olds (mean = 6;11.15, SD = 0;01.24). All children were monolingual Dutch.

2.2. Data collection and transcription

For each data point, approximately a 1-h video recording of spontaneous speech was made at the child's home. The four youngest groups of children (2- to 5-year-olds) were video recorded in an unstructured parent–child interaction, while the video recordings in the two oldest groups of children (6- and 7-year-olds) were semi-structured: those children were asked to spontaneously tell a story based on large, busy images or a picture book ("Frog, where are you?" [43]). A selection of approximately 20 minutes of each recording was then orthographically and phonemically transcribed in CHILDES' CLAN utility according to the

Table 2
Demographics of the CI group.

ID	PTA[a] unaided	PTA[a] CI (at age 5)	Age[b] 1st CI	Age[b] activation 1st CI	Age[b] 2nd CI
S1	120	35	1;01.15	1;02.27	6;03
S2	120	27	0;06.21	0;07.20	4;08
S3	115	25	0;10.00	0;11.20	5;10
S4	113	42	1;06.05	1;07.09	–
S5	93	32	1;04.27	1;05.27	6;04
S6	120	37	0;08.23	0;09.20	–
S7	117	23	0;05.05	0;06.04	1;03
S8	112	42	1;07.14	1;09.04	–
S9	103	28	0;08.21	0;09.21	1;11
Mean	112.56	32.33	0;11.28	1;01.04	4;06.15
SD	9.12	7.11	0;05.08	0;05.12	2;03.01

[a] PTA = Pure Tone Average (in dB HL = decibel hearing level).
[b] Ages are presented in years,months.days.

CHAT conventions [44]. All word forms were automatically tagged and manually disambiguated using CLAN's MOR utility. Each word form was lemmatised, morphologically decomposed, and received an appropriate part-of-speech tag.

Interrater reliability is computed on 65% of the data. A second investigator retranscribed the complete 20-min selections orthographically. Thereof, two different percentages of agreement were calculated: firstly, the agreement of the number of words per utterance and secondly, the agreement on the words themselves. The agreement on number of words per utterance is of importance with respect to the analyses of utterance length and the agreement on the words identified is of importance when examining inflectional development. The median agreement of number of words per utterance equals 90.88% (range: 81.50–97.25%). The median agreement on the identified words themselves equals 81.38% (range: 69.50–92.63%).

2.3. Language measures and statistical analyses

Language development is assessed by means of two language measures. Firstly, we calculate MLU in words in order to give an indication of syntagmatic richness of children's speech. MLU in words is calculated by dividing the number of words by the number of utterances. Consider for instance the two utterances in example 1:

(1)	Child utterance 1	ik boek mama	(I book mummy)
	Child utterance 2	ik ook lezen boek	(I also read book)

For each utterance, the number of words in that utterance is counted: 3 words in utterance 1 and 4 words in utterance 2. Next, the total number of utterances is tallied, which equals two in this example. Subsequently, the Mean Length of Utterance (MLU) is the ratio of the total number of words (7) on the total number of utterances (2) and equals 3.5. Therefore, MLU in words actually reflects mean sentence length.

Secondly, we assess paradigmatic richness of children by measuring MSP of each child. As expressed in equation A, MSP is the ratio of the size of the inflected lexicon |F| – which includes only distinct word forms – to the size of the root lexicon |L|, i.e. the lemmatised word forms (Xanthos & Gillis [36]: 180). Consider a sample of, for instance, $N = 7$ with the following English inflected word forms: *am, are, were, book, books, are, car*. In this sample, the inflected lexicon F contains 6 distinct word forms (*am, are, were, book, books, car*) and the root lexicon L consists of 3 lemmas (*be, book, car*). Consequently, the MSP equals 2.

$$\text{A} \quad MSP = \frac{|F|}{|L|}$$

We used the *weighted entropy-based MSP* option in the open sourced software *MSPMeter* as developed by Gillis [45], which takes into account the entropy of each paradigm as well as the relative frequency of each individual inflected form [36]. More detailed information of MSP calculation can be found in Xanthos and Gillis [36].

Statistical analyses were done in the open source software R [46] by means of fixed occasion multilevel models (package *lme4*). Outliers, defined by means of the interquartile rule, were omitted. At each age (2;00, 3;00, 4;00, 5;00, 6;00 and 7;00), the dependent variable was MLU, respectively MSP, and the independent variable was the children's hearing status (NH or CI). *t*-Tests were used to investigate MLU and MSP in NH children at consecutive ages. An analysis of the longitudinal data of the CI children was done in order to examine the growth curve of MLU and MSP. Hearing age, i.e. length of device use, was also entered as independent variables. A random intercept was entered for each child separately in the mutual comparisons of NH and CI children in order to consider the variation between children. In the longitudinal analyses of CI children, random effects for each child and each hearing age, i.e. time after cochlear implantation, were added and resulted in random intercepts and slopes for each child at each age. A significance level of $p < 0.05$ was set.

3. Results

3.1. Mean Length of Utterance (MLU)

Table 3 displays syntagmatic richness, expressed in MLU, of NH and CI children at each age. Even though the data of the NH children are cross-sectional, estimates in Table 3 and the growth curve in the top pane of Fig. 1 show an increase of MLU with age. MLU values at age 2;00 are 1.6203 (SE = 0.1711) for NH children and 1.0955 (SE = 0.1241) for CI children. At age 7;00 MLU has increased to 5.7243 (SE = 0.5276) for both groups of children. Post hoc analyses by means of *t*-tests indicate that the yearly increase of MLU is significant for NH children (in each *t*-test, $p < 0.0001$). For CI children, longitudinal data were available. Analyses indicated a significant linear increase of MLU up to age 7;00: MLU increases with 0.0754 (SE = 0.0052, $p < 0.0001$) per year. The increase of MLU is plotted in the top pane of Fig. 1.

Next, as shown in Table 3, the initial difference between NH and CI children disappears at age 7;00. More specifically, our analyses indicate that MLU values of CI children are significantly lower than MLU values of NH children from age 2;00 up to age 6;00 (Table 3). As Table 3 shows, no significant differences between NH and CI children are found at age 7;00 ($p = 0.4405$). Differences between both groups of children are plotted in the top pane of Fig. 1.

3.2. Mean Size of Paradigm (MSP)

Table 4 displays paradigmatic richness, expressed in MSP, of NH and CI children at each age. Estimates range between 0.9795 and 1.5227. As the bottom part of Fig. 1 indicates, MSP increases over time. Post hoc analyses by means of *t*-tests indicate a significant yearly increase of MSP up to age 6;0 for NH children (in each *t*-test, $p < 0.0001$). A longitudinal analysis of CI children showed a linear increase of MSP up to age 7;00: MSP increases with 0.0064 (SE = 0.0017, $p = 0.0001$) per year. The development of MSP is plotted in the bottom part of Fig. 1.

Next, some effects of hearing status are found, as shown in Table 4. Paradigmatic richness is significantly lower in CI children compared to NH children at ages 3;00 ($p < 0.0001$) and 4;00

Table 3
Fixed effect results of syntagmatic richness (MLU).

Age (years; months)	Fixed effects	Estimate (SE)	*t*-Value	*p*
2;00	Intercept	1.0955 (0.1241)	8.8258	<0.0001
	Hearing status NH	0.5248 (0.1711)	3.0374	0.0022
3;00	Intercept	2.2406 (0.2899)	7.7292	<0.0001
	Hearing status NH	1.0548 (0.4100)	2.5730	0.0101
4;00	Intercept	3.2635 (0.2694)	12.1136	<0.0001
	Hearing status NH	1.3091 (0.3633)	3.6036	0.0003
5;00	Intercept	3.7075 (0.3941)	9.4074	<0.0001
	Hearing status NH	1.0557 (0.5314)	1.9867	0.0470
6;00	Intercept	4.6032 (0.3839)	11.9908	<0.0001
	Hearing status NH	1.1359 (0.5276)	2.1527	0.0313
7;00	Intercept	5.7243 (0.5276)	10.8502	<0.0001
	Hearing status NH	0.5306 (0.6879)	0.7714	0.4405

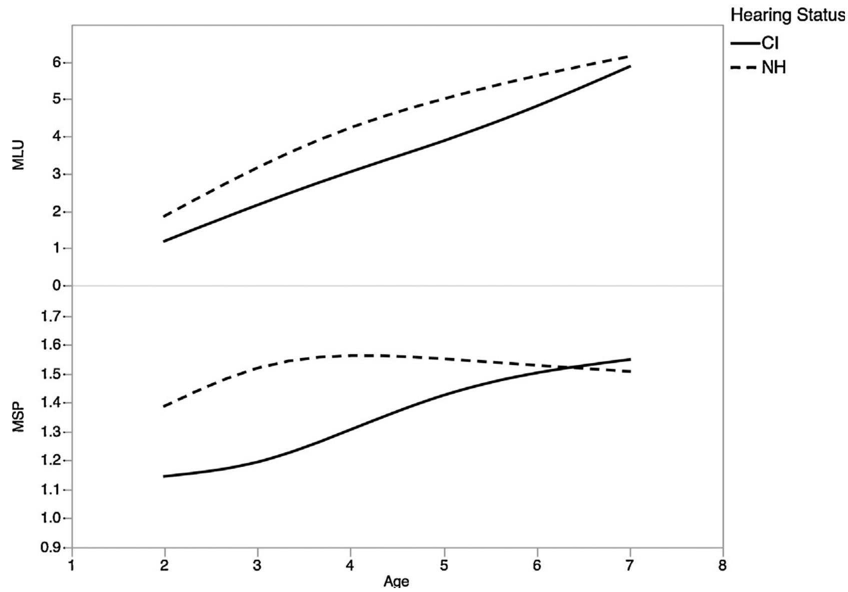

Fig. 1. Development of MLU and MSP in CI (longitudinal) and NH (cross-sectional).

($p < 0.0001$). At age 2;00, no difference between both groups of children is found ($p = 0.1057$). This was expected as inflectional development starts about this age. At that age, each lemma is represented by only one word form, and hence MSP is around its bottom value. From age 5;00 onwards differences in MSP values between the two groups of children disappeared (Table 4). The development of both groups of children is also plotted in the bottom part of Fig. 1.

4. Discussion

The present paper studies the grammatical development of Dutch-speaking early implanted CI children in comparison with NH age-matched peers. Grammatical development is assessed in two ways. First of all, syntagmatic richness is measured by means of MLU in words, and secondly, paradigmatic richness is measured by MSP. Longitudinal yearly data of 9 CI children between 2;0 and 7;0 were available as well as cross-sectional data of approximately 10 NH peers at each age. Analyses revealed three important findings, which will be dealt with in the following sections.

Table 4
Fixed effect results of paradigmatic richness (MSP).

Age (years; months)	Fixed effects	Estimate (SE)	*t*-Value	*p*
2;00	Intercept	1.3126 (0.0460)	28.5248	<0.0001
	Hearing status NH	−0.0912 (0.0564)	−1.6180	0.1057
3;00	Intercept	0.9795 (0.0805)	12.1736	<0.0001
	Hearing status NH	0.7537 (0.0053)	143.4638	<0.0001
4;00	Intercept	1.3539 (0.0322)	42.0953	<0.0001
	Hearing status NH	0.1806 (0.0059)	30.4393	<0.0001
5;00	Intercept	1.5102 (0.0540)	27.9565	<0.0001
	Hearing status NH	−0.0054 (0.0725)	−0.0721	0.9401
6;00	Intercept	1.4561 (0.0486)	29.9821	<0.0001
	Hearing status NH	0.1224 (0.0687)	1.7818	0.0748
7;00	Intercept	1.5227 (0.0413)	36.8927	<0.0001
	Hearing status NH	−0.0219 (0.0538)	−0.4073	0.6838

4.1. Syntagmatic development

The first finding concerns syntagmatic development and more specifically the development of sentence length. Our results revealed that MLU of CI children lags behind that of NH children up to age 6, but CI children caught up by age 7. This is in accordance with for instance Szagun [4], Schauwers [25], Ouellet, Le Normand and Cohen [26], Szagun [27], Nittrouer, Caldwell-Tarr, Sansom, Twersky and Lowenstein [28] and Nittrouer, Sansom, Low, Rice and Caldwell-Tarr [29], who all found lower MLU in CI children as compared to NH children. However, our results show that CI children have age-appropriate MLU scores by age 7. This is in line with and Nicholas and Geers [1] and Hammer [14], who both found a catch up of CI children by age 7 and age 4.5 respectively.

Thus, syntagmatic development of CI children is delayed up to age 6. A possible explanation for this observation might be poorer phonological short-term working memory skills in CI children. Syntagmatic development was measured by means of MLU, which reflects sentence length. In the production of a sentence (sentence planning), children need to store phonological information of sequences of words in the short-term phonological memory. However, in the literature, exactly a deficit in storage is found for CI children [47].

Even though working memory is not limited to the phonological short-term, it is particularly this part of the working memory, also called the phonological loop, that is related to sequence learning and phonological coding [32] and thus to the production of (long) sentences. For instance Willis and Gathercole [33] showed that higher phonological short-term working memory capacities result in better sentence repetition accuracy in NH children. Thus, the capacity of the phonological short-term working memory influences sentence production. The phonological short-term working memory is often assessed by forward digit spans in children [32]. Forward digit spans comprise the repetition of an increasing number of digits in the order as presented and involve the temporal and linear storage of sequences of items [48]. Therefore forward digit spans reflect linguistic abilities and are shown to be related to for instance sentence intelligibility [48] and accuracy [49]. Forward digit span scores are smaller in CI children as compared to NH peers [30–32,50–53]. Shorter forward digits spans indicate that the phonological short-term working memory is poorer in CI children. As this part of the working memory influences speech production, it is likely that the sentence length lags behind in CI children.

Furthermore, while phonological short-term working memory is mainly active in speech perception and production, the general executive of working memory is also active [34]. A greater cognitive load will increase the activity of the general executive and therefore decrease the activity of the phonological short-term working memory [32]. An increase in sentence length enlarges the cognitive load as more information must be stored and handled, as shown by for instance Willis and Gathercole [33]. Consequently, phonological short-term working memory will have fewer resources available, which results in more difficulties with longer sentences. Thus, an increase in cognitive load will reduce sentence length [35]. In CI children, longer sentences will reduce the already poorer short-term phonological memory, resulting in poor performances. For instance Young and Killen [6] showed that CI children are weak in remembering and repeating sentences of increasing length and complexity. Thus, sentence length has an influence on CI children's short-term phonological working memory. Long sentences are difficult in CI children, explaining why MLU of CI children lags behind on MLU of NH peers. In a similar vein, Valian [54] proposed that processing limitations affect sentence length in NH children, as children simply omit, for instance, auxiliaries. When processing limitations decrease, omission rate will be reduced and utterances will become longer.

4.2. Paradigmatic development

The second finding concerns morphology and more specifically the development of inflectional diversity. Analyses showed lower MSP in CI children at ages 3 and 4 as compared to NH children. While MSP as used as a measure of inflectional development in CI children is new in the present study, noun, verb and article inflection are studied in the literature. For instance Hammer [14] and Guo, Spencer and Tomblin [40] found a delay in verb morphology in CI children as compared to NH children. Similarly, CI children are also delayed in case and number marking of German nouns [4,39] and German articles [4]. However, our results show that MSP of CI children is age-appropriate from age 5 onwards. In a similar vein, Hammer [14] showed that CI children catch up on verbal morphology, be it by age 7.

Thus, paradigmatic development of CI children is delayed up to age 4. This observation is most likely explained by two related factors, namely speech perception and lexical organisation. A first explanation is the poorer speech perception in CI children. Inflected word forms comprise suffixes in Dutch. Such suffixes are less salient in the acoustic speech signal. Even in NH children, grammatical morphemes are more difficult to perceive, as they are unstressed and therefore less salient. Thus, in NH children, highly salient items are better perceived. Furthermore, perception is indispensable for production [12]. In other words, perception of grammatical morphemes, even though they are low salient, is a prerequisite for their production. However, in CI children, speech perception is negatively affected by their history of auditory deprivation before implantation and limitations of the cochlear implant after implantation. For instance Bouton, Serniclaes, Bertoncini and Colé [55] found poorer categorical precision, i.e. accuracy in feature discrimination and identification, in CI children as compared to NH children. In addition, CI children are found to pay less attention to speech sounds and to the ambient language as compared to NH children [56,57]. Attention deficits are a key part of executive functioning. Similarly, CI children are shown to have deficits in executive functioning [58]. As a result of poor speech perception and poor attention and thus executive functioning, CI children are expected to focus more on salient items in the speech signal and are therefore probably missing low salient grammatical morphemes. This results in poorer production of such morphemes. The focus on salient items in speech perception and the reflection on speech production is for instance shown by Svirsky, Stallinfs, Ying, Lento and Leonard [41]. They found the most prominent grammatical markers to be acquired first in CI children, while prominence is not shown to influence acquisition order in NH children. Likewise, Guo, Spencer and Tomblin [40], Hammer [14] and Szagun [4] connect poor inflectional development of CI children to the reduced auditory input.

The second explanation, namely deficits in lexical organisation and retrieval, is also linked to poor speech perception in CI children. Weak attention to the speech signal and poor speech perception in CI children influence phonological representations in CI children [32,47]. For instance Lund, Werfel and Schuele [59] showed poor phonological awareness in CI children. However, poor phonological representations have a negative influence on word learning [56,57]. In a similar vein, Wechsler-Kashi, Schwartz and Cleary [60] reported problems in the lexical organisation of CI children. Limited phonological representations result in poor lexical organisation and poor connections between words in CI children. Therefore, lexical organisation is considered to be problematic for CI children. As a result, Wechsler-Kashi, Schwartz and Cleary [60] reported that CI children have problems to retrieve words in a verbal fluency task in which children were asked to name as many phonological or semantic related words as possible to a given word. In order to accomplish this task, children must search the mental lexicon and switch from one subcategory to another inside the mental lexicon. For this last task, good connections between words are indispensable [60]. In MSP, the number of inflected word forms per lemma in spoken language is tallied. There are two possibilities, either the difficulty of CI children lies only in retrieval or the difficulty lies in storage and retrieval. With respect to the first possibility, CI children might have no problems in storage of word forms. But even though CI children may have stored an equal amount of inflected forms per lemma in their mental lexicon than NH children, poor lexical organisation in CI children may cause them not to be able to retrieve those words when needed. As a result, MSP is lower in CI children as compared to NH children. With respect to the second possibility, the difficulty in CI children is dual. CI children might have stored less word forms in their mental lexicon, as exactly storage of word forms is shown to be problematic in CI children [47]. It is likely that the fewer words stored in the mental lexicon, the lower MSP will be. Less stored words mean fewer different word forms per lemma and thus lower MSP values in CI children. The effect of lexical organisation and retrieval problems adds to the poorer storage of word forms. In the already fewer stored words, CI children also have difficulties in retrieving them, resulting in lower MSP performances. Further research is recommended to examine this hypothesis.

4.3. Relationship between syntagmatic and paradigmatic development in CI children

The third finding of the present paper involves the relationship between syntagmatic and paradigmatic development in CI children. CI children are found to have earlier age-appropriate paradigmatic language skills than age-appropriate syntagmatic language skills. When comparing syntagmatic and paradigmatic development of CI children with NH children, results suggest that CI children catch up with their NH peers. However, CI children catch up with paradigmatic richness earlier than with syntagmatic richness. Thus, morphological development is delayed for a shorter period than syntactic development. A similar finding with respect to late talkers is reported by Rescorla and Turner [61]: by age 5, the group of late talkers had caught up with their typically developing peers on morphology, but not on syntax.

A possible explanation concerning the relatively fast catch up on paradigmatic richness can be formulated. This explanation is related to the representation of inflected word forms in the mental lexicon. One of the generally accepted views is that each lexical item has its own representation and thus its own separate entry in the mental lexicon. According to one view in the literature, inflected word forms also have unique entries in the lexicon [62–65]. The assumption that inflected word forms have separate lexical representations indicates that learning inflected word forms is closely related to learning new words and thus to lexical development. For instance Song, Sundara and Demuth [66] showed that children with larger vocabularies have more accurate third person –s productions, suggesting a close relationship between lexical and inflectional development. In the literature, age-appropriate language skills of CI children are found sooner in the lexical domain as compared to syntax and morphology [5,8–10,67]. As CI children are found to catch up earlier on lexical than on grammatical development, it is evident that the same trend is visible with respect to paradigmatic, measured there by MSP, and syntagmatic development, measured here by MLU.

5. Conclusion

CI children are found to lag behind on sentence length and inflectional development as compared to NH children. However, CI children catch up on their NH peers for both syntax and inflection. Nevertheless, inflectional development is earlier age-appropriate as compared to sentence length. This is due to the different nature of both aspects of grammatical development.

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References

[1] J. Nicholas, A. Geers, Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss, J. Speech Lang. Hear. Res. 50 (2007) 1048–1062.
[2] P. Blamey, J. Barry, C. Bow, J. Sarant, L. Paatsch, R. Wales, The development of speech production following cochlear implantation, Clin. Linguist. Phonet. 15 (2001) 363–382.
[3] O. Wie, Language development in children after receiving bilateral cochlear implants between 5 and 18 months, Int. J. Pediatr. Otorhinolaryngol. 74 (2010) 1258–1266.
[4] G. Szagun, The acquisition of grammar in young German-speaking children with cochlear implants and with normal hearing, Antwerp Pap. Linguist. 102 (2002) 40–60.
[5] L. Duchesne, A. Sutton, F. Bergeron, Language achievement in children who received cochlear implants between 1 and 2 years of age: group trend and individual patterns, J. Deaf Stud. Deaf Educ. 14 (2009) 465–485.
[6] G. Young, D. Killen, Receptive and expressive language skills of children with five years of experience using a cochlear implant, Ann. Otol. Rhinol. Laryngol. 111 (2002) 802–810.
[7] E. Schorr, F. Roth, N. Fox, A comparison of the speech and language skills of children with coclear implants and children with normal hearing, Commun. Disord. Q. 29 (2008) 195–210.
[8] A. Geers, J. Nicholas, A. Sedey, Language skills of children with early cochlear implantation, Ear Hear. 24 (2003) 46S–58S.
[9] M. Caselli, P. Rinaldi, C. Varuzza, A. Giuliani, S. Burdo, Cochlear implant in the second year of life: lexical and grammatical outcomes, J. Speech Lang. Hear. Res. 55 (2012) 382–394.
[10] I. Moreno-Torres, S. Torres, From 1-word to 2-words with cochlear implant and cued speech: a case study, Clin. Linguist. Phonet. 22 (2008) 491–508.
[11] E. Tribushinina, S. Gillis, S. De Maeyer, Infrequent word classes in the speech of two- to seven-year-old children with cochlear implants and their normally hearing peers: a longitudinal study of adjective use, Int. J. Pediatr. Otorhinolaryngol. 77 (2013) 356–361.
[12] M. Le Normand, I. Moreno-Torres, C. Parisse, G. Dellatolas, How do children acquire early grammar and build multiword utterances? A corpus study of French children aged 2 to 4, Child Dev. 84 (2013) 647–661.
[13] M. Le Normand, I. Moreno-Torres, The role of linguistic and environmental factors on grammatical development in French children with cochlear implants, Lingua 139 (2014) 26–38.
[14] A. Hammer, The acquisition of verbal morphology in cochlear-implanted and specific language impaired children, Unpublished doctoral dissertation, University of Leiden, 2010.
[15] C. Mimeau, V. Plourde, A. Ouellet, G. Dionne, Comparison of measures of morphosyntactic complexity in French-speaking school-aged children, First Lang. 35 (2015) 163–181.
[16] R. Brown, A First Language. The Early Stages, George Allen & Unwin Ltd., London, 1973.
[17] T. Hickey, Mean length of utterance and the acquisition of Irish, J. Child Lang. 18 (1991) 553–569.
[18] P. Flipsen, K. Kangas, Mean length of utterance (MLU) in children with cochlear implants, Volta Rev. 114 (2014) 135–155.
[19] M. Parker, K. Brorson, A comparative study between mean length of utterance in morphemes (MLUm) and mean length of utterance in words (MLUw), First Lang. 25 (2005) 365–376.
[20] M. Rice, F. Smolik, D. Perpich, T. Thompson, N. Rytting, M. Blossom, Mean length of utterance levels in 6-months intervals for children 3 to 9 years with and without language impairments, J. Speech Lang. Hear. Res. 53 (2010) 333–349.
[21] J. Blake, G. Quartaro, S. Onorati, Evaluating quantitative measures of grammatical complexity in spontaneous speech samples, J. Child Lang. 20 (1993) 139–152.
[22] T. Klee, M. Fitzgerald, The relation between grammatical development and mean length of utterance in morphemes, J. Child Lang. 12 (1985) 251–269.
[23] L. Hewitt, C. Scheffner Hammer, K. Yont, B. Tomblin, Language sampling for kindergarten children with and without SLI: mean length of utterance, IPSYN, and NDW, J. Commun. Disord. 38 (2005) 197–213.
[24] E. Tobey, S. Hasenstab, Effects of a Nucleus multichannel cochlear implant upon speech production in children, Ear Hear. 12 (1991) 48S–54S.
[25] K. Schauwers, Early speech and language development in deaf children with a cochlear implant: a longitudinal investigation, Unpublished doctoral dissertation, Antwerp University, 2006.
[26] C. Ouellet, M. Le Normand, H. Cohen, Language evolution in children with cochlear implants, Brain Cognition 46 (2001) 231–235.
[27] G. Szagun, Language acquisition in young German-speaking children with cochlear implants: individual differences and implications for conceptions of a 'sensitive phase', Audiol. Neuro-Otol. 6 (2001) 288–297.
[28] S. Nittrouer, A. Caldwell-Tarr, E. Sansom, J. Twersky, J. Lowensthein, Nonword repetition in children with cochlear implants: a potential clinical marker of poor language acquisition, Am. J. Speech-Lang. Pat. 23 (2014) 679–695.
[29] S. Nittrouer, E. Sansom, K. Low, C. Rice, A. Caldwell-Tarr, Language structures used by kindergartners with cochlear implants: relationship to phonological awareness, lexical knowledge and hearing loss, Ear Hear. 35 (2014) 506–518.
[30] W. Kronenberger, D. Pisoni, S. Henning, B. Colson, Executive functioning skills in long-term users of cochlear implants: a case control study, J. Pediatr. Psychol. 38 (2013) 902–914.
[31] D. Pisoni, M. Cleary, Learning, memory and cognitive processes in deaf children following cochlear implantation, in: F.G. Zeng, A.N. Popper, R.R. Fay (Eds.), Cochlear Implants: Auditory Prostheses and Electric Hearing, Springer, New York, 2004.
[32] D. Pisoni, W. Kronenberger, A. Roman, A. Geers, Measures of digit span and verbal rehearsal speed in deaf children after more than 10 years of cochlear implantation, Ear Hear. 32 (2010) 60S–74S.
[33] C. Willis, S. Gathercole, Phonological short-term memory contributions to sentence processing in young children, Memory 9 (2001) 349–363.
[34] A. Baddeley, Working memory and language: an overview, J. Commun. Disord. 36 (2003) 189–208.
[35] M. Charest, J. Johnston, J. Small, Lexical activation effects on children's sentence planning and production, Appl. Psycholinguist. First View (2015).
[36] A. Xanthos, S. Gillis, Quantifying the development of inflectional diversity, First Lang. 30 (2010) 175–198.
[37] S. Laaha, S. Gillis, Typological perspectives on the acquisition of noun and verb morphology, Antwerp Pap. Linguist.: Vienna/Antwerp (2007).
[38] A. Xanthos, S. Laaha, S. Gillis, U. Stephany, A. Aksu-Koç, A. Christofidou, et al., On the role of morphological richness in the early development of noun and verb inflection, First Lang. 31 (2011) 461–479.
[39] S. Laaha, M. Blineder, S. Gillis, Noun plural production in preschoolers with early cochlear implantation: an experimental study of Dutch and German, Int. J. Pediatr. Otorhinolaryngol. 79 (2015) 561–569.
[40] L. Guo, L. Spencer, B. Tomblin, Acquisition of tense marking in English-speaking children with cochlear implants: a longitudinal study, J. Deaf Stud. Deaf Educ. 18 (2013) 187–205.
[41] M. Svirsky, L. Stallinfs, E. Ying, C. Lento, L. Leonard, Grammatical morphological development in pediatric cochlear implant users may be affected by the perceptual prominence of the relevant markers, Ann. Otol. Rhinol. Laryngol. 111 (2002) 109–112.
[42] C. Stoel-Gammon, Relationships between lexical and phonological development in young children, J. Child Lang. 38 (2011) 1–34.
[43] M. Mayer, Frog, Where are You? Dial Press, Dial Books for Young Readers, New York, 1969.
[44] B. MacWhinney, The CHILDES Project: Tools for Analyzing Talk, Lawrence Erlbaum Associates, Mahwah, NJ, 2000.

[45] J. Gillis, MSPMeter, 2013, https://github.com/jorisgillis/MSPMeter.
[46] R Core Team, R: A Language and Environment for Statistical Computing, 2013, http://www.R-project.org/.
[47] S. Nittrouer, A. Caldwell-Tarr, J. Lowenstein, Working memory in children with cochlear implants: problems are in storage, not processing, Int. J. Pediatr. Otorhinolaryngol. 77 (2013) 1886–1898.
[48] J. Montag, A. AuBuchon, D. Pisoni, W. Kronenberger, Speech intelligibility in deaf children after long-term cochlear implant use, J. Speech Lang. Hear. Res. 57 (2014) 2332–2343.
[49] C. Dillon, M. Cleary, D. Pisoni, A. Carter, Imitation of nonwords by hearing-impaired children with cochlear implants: segmental analyses, Clin. Linguist. Phonet. 18 (2004) 39–55.
[50] R. Burkholder, D. Pisoni, Speech timing and working memory in profoundly deaf children after cochlear implantation, J. Exp. Child Psychol. 85 (2003) 63–88.
[51] L. Edwards, S. Anderson, The association between visual, nonverbal cognitive abilities and speech, phonological processing, vocabulary and reading outcomes in children with cochlear implants, Ear Hear. 35 (2014) 366–374.
[52] M. Cleary, D. Pisoni, A. Geers, Some measures of verbal and spatial working memory in eight- and nine-year-old hearing-impaired children with cochlear implants, Ear Hear. 22 (2001) 395–411.
[53] D. Pisoni, M. Cleary, Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation, Ear Hear. 24 (2003) 106S–120S.
[54] V. Valian, Syntactic subjects in the early speech of American and Italian Children, Cognition 40 (1991) 21–81.
[55] S. Bouton, W. Serniclaes, J. Bertoncini, P. Colé, Perception of speech features by French-speaking children with cochlear implants, J. Speech Lang. Hear. Res. 55 (2012) 139–153.
[56] D. Houston, T. Bergeson, Hearing versus listening: attention to speech and its role in language acquisition in deaf infants with cochlear implants, Lingua 139 (2014) 10–25.
[57] D. Houston, D. Pisoni, K. Kirk, E. Ying, R. Miyamoto, Speech perception skills of deaf infants following cochlear implantation: a first report, Int. J. Pediatr. Otorhinolaryngol. 67 (2003) 479–495.
[58] W. Kronenberger, J. Beer, I. Castellanos, D. Pisoni, R. Miyamoto, Neurocognitive risk in children with cochlear implants, JAMA Otolaryngol. Head Neck Surg. 140 (2014) 608–615.
[59] E. Lund, K. Werfel, M. Schuele, Phonological awareness and vocabulary performance of monolingual and bilingual preschool children with hearing loss, Child Lang. Teach. Ther. 31 (2015) 85–100.
[60] D. Wechsler-Kashi, R. Schwartz, M. Cleary, Picture naming and verbal fluency in children with cochlear implants, J. Speech Lang. Hear. Res. 57 (2014) 1870–1882.
[61] L. Rescorla, H. Turner, Morphology and syntax in late talkers at age 5, J. Speech Lang. Hear. Res.: Newly Published (2015) 1–11.
[62] J. Stemberger, B. MacWhinney, Frequency and the lexical storage of regularly inflected forms, Mem. Cogn. 14 (1986) 17–26.
[63] G. Lukatela, C. Cerello, M. Turvey, Lexical representation of regular and irregular inflected nouns, Lang. Cogn. Proc. 2 (1987) 1–17.
[64] G. Lukatela, B. Gligorijevic, A. Kostic, M. Turvey, Representation of inflected nouns in the internal lexicon, Mem. Cogn. 8 (1980) 415–423.
[65] J. Sereno, A. Jongman, Processing of English inflectional morphology, Mem. Cogn. 25 (1997) 425–437.
[66] J. Song, M. Sundara, K. Demuth, Phonological constraints on children's production of English third person singular –s, J. Speech Lang. Hear. Res. 52 (2009) 623–642.
[67] P. Rinaldi, F. Baraffaldi, S. Burdo, M. Caselli, Linguistic and pragmatic skills in toddlers with cochlear implant, Int. J. Lang. Commun. Disord. 48 (2013) 715–725.