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RESEARCH REPORT

Early grammar-building in French-speaking deaf children with cochlear implants: A follow-up corpus study

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Abstract

Background: One of the most consistent findings reported in the paediatric cochlear implant (CI) literature is the heterogeneity of language performance observed more in grammatical morphology than in lexicon or pragmatics. As most of the corpus studies addressing these issues have been conducted in English, it is unclear whether their results can be generalized to other languages. In particular, little is known about languages known for their grammatical complexity, such as French.

Aims: The aim of this corpus study was to compare the productive use of function words (FWs) and some agreement features (AGRs) in children with CIs and children with typical development (TD) matched for mean length of utterance in words (MLU_{words}), a general index of grammatical complexity, and auditory experience, as measured by hearing age (HA) and chronological age (CA), respectively.

Methods & Procedures: Natural speech samples from 116 monolingual French-speaking children, including 40 children with CIs followed longitudinally and 76 TD children, were collected. FWs and AGRs were analysed using a Part of Speech Tagger (POS-T) from the Child Language Data Exchange System (CHILDES).

Outcomes & Results: The two groups differed by 3 years for HA and CA. No effect of family socio-economic status (SES) was found in the CI group. Stepwise regression analyses showed that the two groups did not share the same predictors of MLU_{words} : plurals and determiners predicted MLU_{words} in children with CIs, at 2 and 3 years of HA, whereas feminine markers and subject-pronouns were found to best predict MLU_{words} in TD children at 2 and 3 years of CA. Structural equation models (SEMs), a combination of confirmatory factor analysis (CFA) and path analysis, yielded a different hierarchical structure of grammatical relations (GRs). Selective difficulties affecting verbal clitics and other pronominal forms were found specifically in the CI group (object-pronouns, reflexive, relative and past participles). Dependency grammar analysis

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confirmed these contrasting developmental profiles in multiword utterances, such as preposition/nouns, subject/verbs, and verb/determiner/nouns.

Conclusions & Implications: Atypical grammatical patterns in children with CIs reflect a specific architecture of syntactic dependencies of FWs underpinning morphological complexity and syntactic connectivity. Clinical implications are discussed for assessment and intervention planning.

KEYWORDS

atypical development, cochlear implant, early grammar, French, function words, profound deafness

What This Paper Adds

What is already known on this subject

The productive use of FWs has been identified as a particular area of weakness in children with CIs compared with TD children. In addition, heterogenous grammatical performance has often been found after 1–3 years of CI use, regardless of demographic factors such as age at implantation, duration of deafness or SES.

What this paper adds to existing knowledge

Assessing the early building of FWs and AGRs in children with CIs helps to understand the syntactic complexity and hierarchical structure of their language. Since most corpus studies on grammatical morphology have been conducted in English, it is not clear whether their difficulties can be generalized to other languages. The French language has a system of FWs and inflections that determine the morphophonological properties of nominal and verbal forms. Early grammar learning in children with CIs born with profound deafness were compared with the two groups of TD children matched both for duration of auditory experience (i.e., HA of CI children, CA of TD children) and for MLU_{words} . We found a similar profile between groups at 2 years but not at 3 years for HA and CA. The two groups do not share the same predictors of MLU_{words} : namely, plurals and determiners for CI children versus feminine markers and subject pronouns for TD children. They show a different syntactic organization of GRs. Children with CIs struggle with selective difficulties affecting verbal clitics and pronominal forms (object-pronouns, reflexive, relative and past participles). Consistent with theories of morphophonological richness and syntactic connectivity, our results support the distributional learning hypothesis of language acquisition that infants and toddlers are sensitive to FWs and AGRs at an early age. Specific components of syntactic organization are disrupted in children with CIs.

What are the potential or actual clinical implications of this work?

This work has potential clinical implications because it unravels the limitations of morphophonological processing in children with CIs. Its results highlight a specific difficulty in learning FWs and AGRs in a verbal inflectional morphology context.

INTRODUCTION

Heterogeneity of language development in children with cochlear implants (CIs)

Early cochlear implantation has been shown to promote language development in children born deaf (Blamey et al., 2001; Nicholas & Geers, 2007). However, the variability observed in the language performance of deaf children with cochlear implants (CIs) is more or less important according to the domains studied (Young & Killen, 2002). Thus, the progression of comprehension and production language levels does not occur at the same rate after cochlear implantation, and the developmental trajectories between these two domains are not identical (Schramm et al., 2010). Wie (2010) showed that after 12–48 months of regular implant use, 81% of deaf children have a receptive level within the norm for normal hearing children, while at the same time only 57% have an expressive level within the norm. Similarly, Geers et al. (2009) found that at the age of 5–6 years, a greater proportion of deaf children with CIs scored within the norm for normal hearing children in receptive language than in expressive language. However, the trend is reversed when considering the lexical domain alone, with 50% of children with CIs scoring in the normative range for receptive language and 58% for expressive language. In general, children with CIs perform better in some language domains, and seem to have better control of these than others. Vocabulary is often better preserved than other language domains. In fact, there is a lag of about 1 year between lexical progression and grammatical development in deaf children with CIs (Le Normand & Moreno-Torres, 2014). Thus, the difficulties observed in their grammatical and pragmatic skills are often greater than would be expected by considering vocabulary level alone (Rinaldi et al., 2013). Several studies have shown that about half of children with CIs have language levels within the norm on tests such as lexical diversity, grammatical complexity as measured by mean length of utterance in words (MLU_{words}) or narrative skills, while fewer than half perform within the norm on tests such as morphosyntactic comprehension or use of bound morphemes (Duchesne et al., 2009; Geers et al., 2003). Thus, not all children with CIs show similar deficits in each of the language domains. Rinaldi et al. (2013), for example, reported that about 36% of them are deficient in all three domains of lexicon, morphosyntax and pragmatics. Similarly, other studies have found that about a third perform within the norm of normal hearing children on all vocabulary and morphosyntax tests used (Schorr et al., 2008; Soleymani et al., 2016).

One of the most consistent findings reported so far in the paediatric CI literature is the tremendous variability

in individual performances observed, particularly in grammar (Caselli et al., 2012; Duchesne et al., 2009; Geers et al., 2009). Whereas some children seem to catch up with their age-matched peers after 4 years of implant use (Jung & Ertmer, 2018), other subjects continue to struggle to develop syntax and show a strong and persistent language deficit beyond this period. Corpus studies have shown that after 1–3 years of implant use, some deaf children demonstrate language skills consistent with their chronological age (CA), but others still lag behind their typically developing (TD) peers (Szagun, 2000, 2004). In recent years, the productive use of function words (FWs) in children with CIs and those with TD has been the subject of debate and controversy among researchers. Some authors have reported that children with CIs have difficulties mainly with inflectional morphology, clitic pronouns, determiners and prepositions (Duchesne et al., 2009; Svirsky et al., 2002), but have relatively robust lexical acquisition and even seem to catch up with TD children (Duchesne et al., 2009; Svirsky et al., 2002). The effects of age at implantation or duration of implant use on spoken language outcomes could explain these strengths and weaknesses (Gagnon et al., 2021; Wiseman et al., 2021, for a recent review). Children with CIs show heterogeneous language performance in the first 2–3 years of implant use, as has been observed for early grammar (Szagun & Schramm, 2016). They show a selective deficit in grammatical morphology (de Hoog et al., 2015), which supports the possibility that some CI children may also have a language impairment (de Hoog et al., 2016; Geers et al., 2016). Deaf children with persistent difficulties despite CI would therefore present with a language disorder independently of the deafness but whose manifestations would be aggravated by this condition. However, it remains unclear whether these large individual differences in early grammar are due to the duration of implant use or to environmental factors such as the socio-economic status (SES) of the family.

Chronological versus hearing age (HA)

CA reflects the time elapsed since birth, while the HA of a child born profoundly deaf reflects the period of actual exposure to speech sounds through the CI. The influence of HA on the language skills of deaf children has been investigated in several studies. Some authors have reported no influence of HA on language development (Dillon et al., 2004; Duchesne et al., 2009; Hess et al., 2014; Rinaldi et al., 2013). Having a language profile within the norm of normal hearing children or very poor on the contrary would not be correlated with HA. Thus, children with the best

language outcomes are not necessarily those with the longest duration of CI use (Duchesne et al., 2009). On the contrary, other authors claimed that HA is an important factor in the development of speech and language skills (Nicholas & Geers, 2007; Tavakoli et al., 2015). Indeed, the number of deaf children scoring in the norm of normal hearing children would increase with HA (Wie, 2010). Similarly, Nicholas and Geers (2006) found that children's language skills increased with each additional month of implant wear after 1 year of use. Thus, the benefits of the implant in terms of language development would increase over time. Several studies have confirmed that HA is predictive of language skills, particularly in comprehension and morphosyntactic expression (Artières et al., 2009; Flipsen & Kangas, 2014; Schorr et al., 2008; Volpato & Vernice, 2014).

Family SES

The role of family SES in grammar learning in children with CIs is still under debate. Nittrouer et al. (2012) suggested that family SES is related to deaf children's expressive vocabulary level. Cruz et al. (2013) argued that it is the language facilitation strategies used by parents that are more predictive of the child's language development than their SES. Indeed, greater use of high-level strategies, such as rephrasing, using open-ended questions or having a strong feeling of being 'tuned-in', are associated with better expressive language development in the deaf child. Moreover, the use of these strategies is not associated with family SES. Several authors have also observed that greater parental linguistic richness is a positive predictor of child language (Szagun & Schramm, 2016; Szagun & Stumper, 2012). Similarly, the degree of investment of the family in the child's care would be significantly correlated with the child's language performance (Moeller, 2000; Monteiro et al., 2016). Parents from high versus low SES family groups differ in the amount and type of language input they provide to children. In particular, mothers from high-SES families tend to talk more to their children and use longer utterances involving more complex syntactic constructions (Bee et al., 1969; Hammer & Weiss, 1999; Hoff-Ginsberg, 1991; Huttenlocher et al., 2002; Vasilyeva et al., 2008). Children with CIs may experience difficulties in grammar due to (1) greater difficulty in attending to multiple conversations conducted simultaneously compared with one-to-one interactions (the acoustic effect) and (2) greater difficulty in developing social interactions dependent on socio-cultural level. Children with CIs may therefore experience additional levels of difficulty in coping with the combined effects of social and acous-

tic challenges. The question here is whether 2–3 years of implant use will have an impact on the productive use of FWs and on grammatical construction in implanted children from low SES families.

Rationale of the study

The process of early grammar learning in children with CIs compared with young TD children remains a central question for clinicians. Detailed descriptions of FWs can contribute to more effective diagnostic and therapeutic approaches. For congenitally or prelingually deaf children with CIs, it is well known that the signal converted by the implant into phonetic cues is likely to be distorted, since current implanted devices fail to convey all details of the acoustic signal and represent an efficient, albeit imperfect, tool for processing speech sounds. Typically, the perception and memory representation of categorical phonemes occurs at a very early age (Eimas & Miller, 1980; Miller, 1983). However, phonological representations stored in memory (e.g., phonemes, syllables and words) may emerge with difficulty in young CI users who have never had fully normal auditory function during neurodevelopment, affecting the activation of phonological processes that mediate lexical access and word combinations.

All children with CIs experience a period of sensory deprivation during their early development, with no or very limited auditory input and no exposure to language. Children who are born deaf lack the amount of auditory information needed to extract the phonetic and prosodic structure of their native language from the speech signal. When inner hair cell function is damaged, the lack of physiological acoustic processing prevents young deaf children from segmenting speech sounds into phonemes and assembling words to construct multi-word utterances. Restoration of hearing by CIs provides perceptual information and enhances speech perception, allowing access to segmental features of speech, which in turn improves spoken language performance (Niparko et al., 2010).

One way to improve understanding of grammatical difficulties in children with CIs is to examine whether their productive use of FWs parallels that of TD children, albeit with a delay related to the language domain of interest. Because of the interactions between perceptual and production processing, it is difficult to know to what extent the productive use of FWs in children with CIs is similar to that in TD children. Investigating FWs and some agreement features (AGRs) in French-speaking CI users would improve syntactic knowledge about the properties of language that are common to the universal process of language learning and those that are determined by the

structure of the language to which the child is exposed. Like other Romance languages, French has a system of inflections that determine the morphophonological properties of lexical word forms (nouns, adjectives and verbs): for example, nominal AGR between the article and the noun in 'le garçon' (the boy) or verbal AGR between the subject pronoun and the verb in 'il/elle dort versus ils/elles dorment' (he/she sleeps versus they sleep). It should be noted that subject-verb AGR depicting third-person singular and plural forms are homophonic while their spellings differ, for example, 'il/elle mange versus ils/elles mangent' (he/she eats versus they eat). This is the case for 90% of the French verbs belonging to the first group—which corresponds to the infinitive form in -er. The other 10% of verbs belong to two other morphophonological groups corresponding to the infinitive form in -ir—for example, 'il/elle dort' (he/she sleeps)—and to the infinitive form in -re or -oir—for example, 'il/elle met' (he/she put) and 'il/elle boit' (he/she drinks).

French is an interesting test case for the study of FWs and AGRs in children with CIs because nominal clitics such as determiners include a large set of definite, indefinite and partitive articles marking gender and number, such as *le, la, les, un, une, des, du* and *au*, compared with the simple 'a' and 'the' in English. Bound morphemes are inflected for gender (masculine and feminine) and number (singular or plural). For nouns, plural forms are pronounced the same as the singular, even if they are spelled differently: for example, *bébé* (baby) and *bébés* (bab-ies). Adjectives are inflected according to the number and gender (masculine or feminine) of the nouns to which they refer: for example, *content* (happy) becomes *content-e*. Verbs are inflected according to tenses and persons that precede them: for example, *venir* (to come). All these bound morphemes express a certain morphological richness and complexity through a variety of distinct AGRs.

The aim of this study was to examine how children with CIs learn FWs and AGRs to build early grammar and syntactic knowledge. Early grammar is considered, in the present corpus study, to be a surface knowledge of basic grammatical relations (GRs) that young TD children construct gradually, using the distributional regularities of the input language (Le Normand et al., 2013). That is, children encode formal GRs to build a generalized knowledge of their native language. All analyses presented herein are in line with the so-called theory of 'syntactic connectivity' (Ninio, 2011) according to which children learn grammar as an interconnected system based on the syntactic dependency analysis which is based on a relation between two words in a sentence with one word being the governor 'its head' and the other being the dependent of the relation 'the root'. According to this linguistic theory of long tradi-

tion (Tesnière & Fourquet, 1988), a head can theoretically have an unlimited number of dependents, as shown in the example 'c'est|la maman|qui conduit|la voiture' where the root *maman* 'mummy' has several heads which govern three adjacent and one non-adjacent GRs (Figure 1).

Four questions were addressed in the present corpus-based study:

What is the role of maturational and environmental factors in grammatical complexity?

In other words, does HA in children with CIs versus CA in TD children have an impact on the learning of FWs and AGRs? Does family SES in children with CIs impact on learning FWs and AGRs? By examining the role of maturational and environmental factors, we predict that if early grammar is seen as an input-driven construct, then similar processes are expected to occur in children with CIs and TD. On the contrary, if early grammar is seen as an atypical process, then we might find differences between them.

Which FW(s) best predict(s) MLU_{words} in children with CIs and TD?

It is well known that MLU is correlated with a variety of syntactic milestones (Blake et al., 1993; Brown, 1973; Valian, 1986, 1991) and linguistic complexity (Ambridge et al., 2015). The determinants of MLU also relate to the roles those different systems external to language, such as cognitive and motor systems, play in development (Berk & Lillo-Martin, 2012; Moore & Maassen, 2004). By doing so, young children could acquire FWs and build syntax as a complex system which is not innate but learned from a context of multiword input sentences. By examining the contribution of FWs and AGRs to MLU_{words} , we can compare grammatical profiles in spontaneous speech samples in children with CIs and TD. If children with CIs and TD share the same predictors, it can be inferred that the latter primarily follow the same, although delayed, developmental path as the former. If not, one may assume that grammatical development is atypical in children with CIs. If that is the case, then the atypical early grammar-building could be related to both a deficit in low-level auditory processing leading to low perceptual saliency of grammatical forms (Guo et al., 2013; Kronenberger & Pisoni, 2019; Leonard & Finneran, 2003; Svirsky et al., 2002). According to this cognitive view, the young child is sensitive to phonological, prosodic and distributional patterns of language and relies on general (non-language-specific) cognitive mechanisms to generalize these patterns into a complete

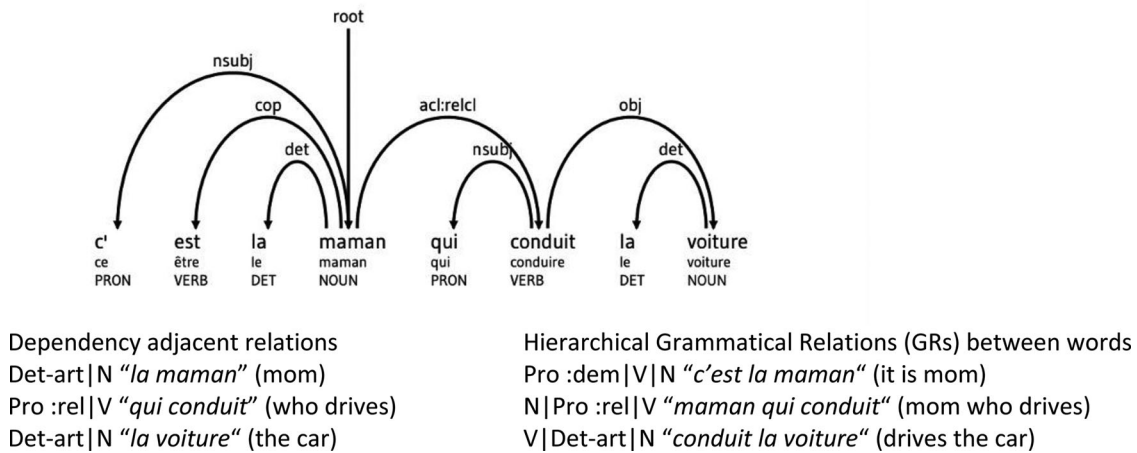


FIGURE 1 Syntactic tree from dependency grammar (French Meta Grammar, <https://alpage.inria.fr/frmgdemo>)

grammar. In this hypothesis, considering the recurrent phonological, prosodic and distributional characteristics that FWs generally share, young children could derive useful information from them to (1) segment the continuous speech stream into a set of distinct constituents and (2) learn about the syntactic class of words and sentences. As a result, young children could use a comprehensive strategy in sentence processing, which integrates not only the meaningful units (i.e., content words), but also the functional elements of language.

How do children with CIs structure GRs compared with TD children?

To learn syntax, children need to organize the positional syntactic regularities of different FWs from speech input. Neurobehavioral data have shown that local structure-building processes are acquired continuously during the second and third years of life and that a complex abstract system is present by the age of 3 years (Friederici, 2006). These data suggest that the hierarchical organization of FWs and AGRs occurs during this period and open new perspectives for clinical assessment and intervention. Simple FWs, such as determiners, prepositions, demonstratives and subject pronouns, can be expected to be easy to learn because they are very predictable and frequent, in contrast to FWs requiring complex multiword utterances, such as reflexive, relative, interrogative and object pronouns. To test this hypothesis, a path diagram will be run to extract the best hierarchical model by means of an exploratory functional analysis (EFA) and a confirmatory functional analysis (CFA). The rationale here is to make fine-grained distinctions between CI and TD children, estimating the respective developmental weights of FWs.

Do multiword utterances in children with CIs reflect a specific architecture?

Although this question is still a matter of debate among child language researchers (Szagun & Schramm, 2019), it can be expected that young CI users have more difficulties with verbal clitics and AGRs than with nominal clitics, which underlies both adjacent and non-adjacent syntactic dependencies with AGRs (gender, number, and case information). The use of determiners or subject pronouns in French, for example, requires the child to follow obligatory GR contexts. With respect to dependency grammar, the use of adjacent and non-adjacent GRs in the learning process of multiword utterances such as GRs between determiner/nouns, preposition/nouns, subject/verbs and verb/determiner/nouns will be compared between children with CIs and TD.

MATERIALS AND METHODS

Participants

Children with CIs

A total of 20 monolingual French CI children (11 boys and 9 girls) were followed at 2 and 3 years of HA (40 samples). Age at implantation ranged from 19 to 76 months. A total of 10 were from low SES families and 10 from high SES families. The children were implanted at different CI centres in France. All were born to hearing parents and all had been diagnosed as profoundly deaf (PTA > 91 dB) between birth and 28 months of age (mean \pm SD = 13 \pm 7.8 months). All children received a unilateral implant at the

TABLE 1 Individual data in children with CIs at 2 and 3 years of hearing age (HA)

CI device	Age at CI (months)	At 2 years of HA (months)	At 3 years of HA (months)	Sex	SES	MLU in words	MLU in morphemes
Nucleus	22	46	58	Female	Low	1.95	2.13
Nucleus	35	59	71	Female	Low	3.55	4.32
Nucleus	24	48	60	Female	Low	1.59	1.73
Nucleus	70	94	106	Male	Low	2.54	3.08
Nucleus	34	58	70	Male	Low	2.38	2.90
Nucleus	76	100	112	Female	Low	1.12	1.37
Nucleus	49	73	85	Male	Low	1.74	1.96
Nucleus	33	63	75	Female	Low	2.28	2.69
Nucleus	56	80	92	Male	Low	1.56	1.80
Nucleus	45	69	81	Male	High	3.71	4.33
Nucleus	28	52	64	Female	High	1.52	1.85
Nucleus	58	82	94	Male	Low	2.28	2.56
Digisonic	48	72	84	Female	High	1.70	2.01
Clarion	60	84	96	Female	High	3.20	3.76
Nucleus	39	63	75	Male	High	1.33	1.60
Clarion	45	69	81	Male	High	2.25	2.43
Nucleus	39	53	65	Male	High	2.68	3.25
Nucleus	48	72	84	Male	High	1.96	2.46
Clarion	38	62	74	Male	High	2.78	2.78
Nucleus	75	99	111	Female	High	4.08	4.75

time of evaluation, 16 wore a Nucleus CI24M (Cochlear Ltd), three a Clarion (Advanced Bionics AG), and one a Digisonic (Oticon Medical) device. Deafness was due to CMV infection ($n = 1$), bacterial meningitis ($n = 2$), hereditary factors ($n = 11$) or unknown causes ($n = 6$). Parents reported that, before implantation, their children were unable to produce intelligible speech sounds. All the participants had been receiving the same rehabilitation programme both before and after surgery according to the recommendations from the French National Authority for Health (André-Vert & Laurence, 2014) and were learning French as their first language. No children were reported as having an intellectual disability or autism spectrum disorder, according to the psychological assessment in the different clinical settings. The individual demographics of the children with CIs are presented in Table 1.

TD children

TD participants were recruited from their homes and from daycare centres in the Paris area, France. The natural speech of children interacting with their caregivers during a playtime session was collected. Inclusion criteria were (1) passing a bilateral hearing screening test, (2) scoring in the normal range on the Symbolic Play Test (Lowe & Costello,

1976), an age-appropriate non-verbal cognitive test and (3) being a French native speaker. The SES was assessed according to the Desrosières' classification (Desrosières et al., 1983), as indexed by parental occupation and education (mean of maternal and paternal school years). TD children were selected according to this SES index. A total of 38 were of high SES, that is, ranging from high school to postgraduate degree, and 38 were of low SES, that is, ranging from elementary school to high-school degree.

Procedure

A corpus-based design was adopted here to assess the extent of similarities and differences between CI and TD children. This corpus study was approved by the Institutional Review Board of the French National Health Institute (IRB No. 00000096). All participants' parents/legal guardians signed a written informed consent. This corpus included a total of 9,367 utterances and 27,945 words. An important property for clinical application is the availability of normative data and an empirically determined cut-off score for interpreting performance. For this study, 39 samples at 2 years of CA and 37 samples at 3 years of CA were extracted from our large dataset (315 samples) (Table 2).

TABLE 2 Descriptive summary of the corpus in children with CIs at 2–3 years of hearing age (HA) and in typically developing (TD) children at 2 and 3 years of chronological age (CA)

Total utterances	Group	N	HA versus CA	Mean	SE	90% Confidence intervals	
						Lower	Upper
Total utterances	CI	20	2 years of HA	74.65	13.47	48.25	101.05
	TD	39	2 years of CA	66.46	6.07	54.57	78.35
	CI	20	3 years of HA	63.55	8.68	46.54	80.56
	TD	37	3 years of CA	111.73	7.49	97.04	126.42
Number of words	CI	20	2 years of HA	196.45	53.29	92.00	300.90
	TD	39	2 years of CA	126.85	19.05	89.50	164.19
	CI	20	3 years of HA	197.85	30.48	138.10	257.60
	TD	37	3 years of CA	414.49	38.50	339.02	489.96
MLU in words	CI	20	2 years of HA	2.31	0.18	1.95	2.67
	TD	39	2 years of CA	1.60	0.09	1.43	1.78
	CI	20	3 years of HA	2.97	0.28	2.41	3.52
	TD	37	2 years of CA	3.38	0.15	3.09	3.68
MLU in morphemes	CI	20	2 years of HA	2.69	0.22	2.26	3.11
	TD	39	2 years of CA	1.86	0.11	1.65	2.08
	CI	20	3 years of HA	3.49	0.32	2.86	4.11
	TD	37	3 years of CA	4.09	0.19	3.72	4.46

Note: CI, cochlear implant; MLU, mean length of utterance.

In this corpus, all spoken words produced by the children were transcribed by an experienced research assistant trained to transcribe the data using the Child Language Data Exchange System (CHILDES) CHAT format (MacWhinney, 2000). For details regarding the operation of the taggers, disambiguators and dependency analysers, see MacWhinney (2008) and, more recently, Finestack et al. (2020). A second research assistant reviewed each media file with its transcript and made corrections when necessary. The interrater agreement of the transcribed material was 95%. Word combinations were considered as utterances separated by a pause or a change in intonation: for example, ‘I want to go to bed’ (= 1 utterance) versus ‘I want ... I want ... I want to go to bed’ (= 3 utterances). The Computerized Language Analysis (CLAN) utilities of the CHILDES tools, including the KidEval program which extracts all word forms and morphemes, were used for the statistical analyses. The program allowed us to identify and count all parts of speech, including all French morphemes. A French script for KidEval was used and the transcripts were entered directly into an Excel spreadsheet. In this study, the most frequent and predictable FWs ($n = 19$) were examined (Table 3).

Dependency grammar analysis was also used to compare the developmental profile of FWs between children with CIs and TD in the learning process of multiword utterances involving determiner/nouns, prepositions/nouns, subject/verbs, object pronoun/verbs and

verb/determiner/nouns. These are of great use to clinicians in tracking GRs and syntactic dependencies. This may provide a relevant framework for assessment and early intervention after cochlear implantation.

Statistical analyses

Two multivariate analyses of variance (MANOVA) were first performed to evaluate an effect of group, age (i.e., HA versus CA) and family SES on FWs and AGRs. To examine the contribution of each of these variables to MLU_{word} between children with CIs and TD, a stepwise multiple regression analysis was also run: MLU_{word} was the dependent variable and each of the 19 variables served as covariation factors or predictors. Finally, structural equation models (SEM), a combination of confirmatory factor analysis (CFA) and path analysis, were used to capture the relationships between all observed variables for characterizing their grammatical complexity. By assigning a hierarchical rank to each variable, it is possible to estimate their degree of complexity with a better level of granularity than MLU_{word} . Similar to regression analyses but more powerful, SEMs examine linear causal relationships between observed variables, while accounting for measurement error (Bollen & Noble, 2011). SEMs were performed using JAMOVI version 1.6 (<https://www.jamovi.org/>) and path analysis was drawn using *Onyx* software

TABLE 3 Annotations of grammatical categories according to the Child Language Data Exchange System (CHILDES) codes

CHILDES code	Grammatical categories	Function words (FWs) and agreement features (AGRs)
det	Articles	<i>le la, les, l', un, une</i> (the, a)
det:poss	Possessive determiners	<i>son, sa</i> (his, her)
prep	Prepositions	<i>dans, sur</i> (in, on)
pro	Tonic pronouns	<i>moi, lui, elle</i> (me, him, her)
pro:dem	Demonstrative pronouns	<i>c'est</i> (it is)
pro:int	Interrogative pronouns	<i>où, qu'est ce que</i> (Wh tag)
pro:obj	Object pronouns	<i>le, la, les</i> (him, her, them)
pro:refl	Reflexive pronouns	<i>me, se</i> (myself, him/herself)
pro:rel	Relative pronouns	<i>qui, que</i> (who, that)
pro:subj	Subject pronouns	<i>il/elle, ils/elles</i> (he/she, they)
pro:y/en	Specific pronouns-y/en	<i>y'en a</i> (there are)
v:aux	Auxiliary verbs	<i>a pris</i> (has taken), <i>est tombé</i> (has fallen)
v:exist	Copula	<i>est belle</i> (is pretty)
v:mdl	Modal verbs	<i>falloir, pouvoir</i> (must, can)
v:poss	Possessive verbs	<i>a un livre</i> (has a book)
v:pp	Past participles	<i>a pris</i> (has taken)
3s	Third-person singular	<i>il dort</i> (he sleeps)
PL	Plural forms in nominal, adjectival and verbal contexts	<i>les voitures</i> (the cars) <i>les voitures rouges</i> (the red cars) <i>ils dorment</i> (they sleep)
&f	Feminine forms in nominal, adjectival and verbal contexts	<i>la voiture</i> (the car) <i>la petite voiture</i> (the tiny car) <i>elle conduit</i> (she drives)

(<http://onyx.brandmaier.de>) This modelling approach has been described previously (Le Normand & Thai-Van, 2022).

RESULTS

Multivariate ANOVA (MANOVA)

The first MANOVA run on each variable showed group differences (Wilks' Lambda = 0.59, $F(19, 108) = 3.41$, $p < 0.001$) as well as age-related differences (Wilks' Lambda = 0.50, $F(19, 108) = 5.05$, $p < 0.001$). Two-way group \times age interactions were significant (Wilks' Lambda = 0.65, $F(19, 108) = 2.64$, $p = 0.001$), indicating that children with CIs differed from TD children in the productive use of FWs and AGR at 3 years of HA. A total of 18 out of 19 variables scored significantly lower in the CI compared with the TD group. Significant differences were found for all variables, except for the copula (for detailed results, see Table S1 in the additional supporting information).

The second MANOVA controlling socio-family factors showed no difference for SES index (Wilks' Lambda = 0.78,

$F(19, 108) = 1.35$, $p = 0.16$), no interaction for age \times SES (Wilks' Lambda = 0.78, $F(19, 108) = 1.37$, $p = 0.16$), no interaction for group \times SES (Wilks' Lambda = 0.76, $F(19, 108) = 1.47$, $p = 0.12$) no interaction for age \times group \times SES Wilks' Lambda = 0.85, $F(19, 108) = 0.84$, $p = 0.65$). These findings indicated that SES did not play a role in the productive use of FWs and AGRs. However, significant differences remained in TD children at 3 years of CA for plurals and for seven FWs (prepositions and possessive determiners, modal verbs, subject pronouns, object pronouns, interrogative pronouns and tonic pronouns) in TD children at 3 years of CA (see Table S2 in the additional supporting information).

Stepwise regression analysis

Stepwise regression analysis, in which 19 variables were entered as independent variables to predict MLU_{words} , showed that plurals and determiners predicted MLU_{words} for children with CIs at 2 and 3 years of HA, whereas feminine marker and subject pronouns predicted MLU_{words} for TD at 2 and 3 years of CA (Table 4 and Figure 2).

TABLE 4 Stepwise multiple regression analysis predicting mean length of utterance (MLU) from 16 function words (FWs) and three agreement features (AGRs) in children with cochlear implants (CIs) at 2 and 3 years of hearing age (HA) and in typically developing (TD) children, and at 2 and 3 years of chronological age (CA)

Model	Predictors	β	SE(β)	<i>t</i>	Partial r^2
<i>CI at 2 years of HA</i>					
1	Plurals	0.038	0.014	2.77**	0.547**
2	Plurals	0.053	0.014	3.77**	0.671**
	Modal verbs	-0.015	0.007	-2.27	-0.404
3	Plurals	0.030	0.014	2.14*	0.315*
	Modal verbs	-0.045	0.011	-3.95**	-0.580**
	Past participles	0.047	0.016	2.99**	0.439**
<i>TD at 2 years of CA</i>					
1	Feminine agreements	0.029	0.002	13.87***	0.918***
2	Feminine agreements	0.019	0.002	8.53***	0.398***
	Third-person singular	0.018	0.003	6.10***	0.285***
3	Feminine-agreements	0.013	0.002	6.20***	0.233***
	Third-person singular	0.016	0.002	6.62***	0.249***
	Modal verbs	0.031	0.007	4.48***	0.168***
<i>CI at 3 years of HA</i>					
1	Determiners-articles	0.022	0.008	2.70**	0.536**
<i>TD at 3 years of CA</i>					
1	Subject pronouns	0.022	0.004	5.41***	0.680***
2	Subject pronouns	0.016	0.004	3.78***	0.550***
	Possessive determiners	0.081	0.027	2.96**	0.458**
3	Subject pronouns	0.024	0.005	4.56***	0.628***
	Possessive determiners	0.077	0.026	3.00**	0.469**
	Specific pronouns- y	-0.039	0.017	-2.32*	-0.380*

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

SEM analysis

The SEM analysis examined the loading factor of all variables (β cut-off value = 10) from the CFA analysis and is provided as Materials S5 and S6 in the additional supporting information. Figures 3 and 4 present four path diagrams showing the different degrees of grammatical complexity in children with CIs and TD at two crucial periods in their grammatical development. Four FWs did not fit the model for children with CIs (tonic pronouns, determiner-possessives, reflexive and relative pronouns) at 2 years of HA. Seven FWs did not fit the model for children with CIs (tonic pronouns, past participles, object pronouns, reflexive pronouns, relative pronouns, specific pronoun 'y' and possessive verbs) at 3 years of HA, indicating heterochrony of performance between the two groups.

Dependency grammar analysis

Dependency grammar analysis showed that children with CIs at 2 and 3 years of HA and TD children at 2 and 3 years of CA used similar syntactic dependencies related to

determiners/nouns but not related to prepositions/nouns, subjects/verbs and verbs/determiners/nouns (Table 5).

DISCUSSION

Since little research has been conducted on French-speaking children with CIs, the main objective of this corpus study was to compare the productive use of 16 FWs and three AGRs (third-person singular, feminine and plural markers) using an automatic Part of Speech Tagger (POS-T) available in CHILDES. Four important results were found in the CI group: (1) a contrasting developmental profile at 3 years of HA, (2) different predictors of MLU_{words} , (3) an atypical hierarchy of GRs between words and (4) a disrupted architecture of adjacent syntactic dependencies in the production of verbal clitics and other pronominal forms.

A contrasting developmental profile

By 2 years of HA and CA, MANOVA revealed no significant interaction between family SES and group on GCs.

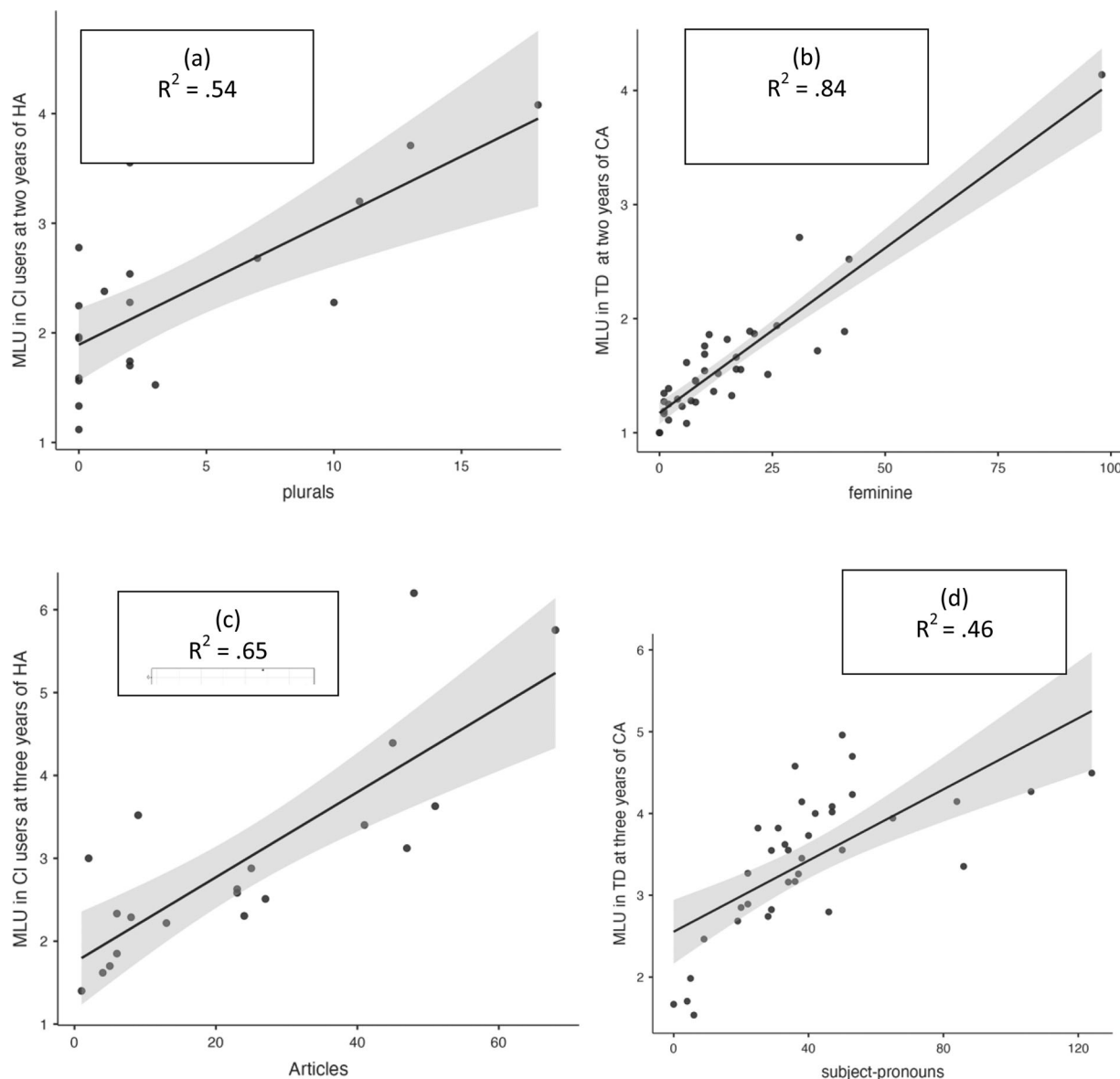


FIGURE 2 Scatterplots between predictors and mean length of utterance in words (MLU_{words}) (a) in children with cochlear implants (CIs) at 2 years of hearing age (HA); (b) in typically developing (TD) children at 2 years of chronological age (CA); (c) in children with CIs at 3 years of HA; and (d) in TD children at 3 years of CA

This means that GCs were not significantly influenced by SES at this age. This result is important as it confirms an excellent MLU_{words} match between the two groups of children. However, the post-hoc comparison revealed a contrasting developmental profile between children with CIs and TD children, indicating that at age 3 of HA and CA, early grammatical development is strongly associated with the family environment. Children with responsive caregivers, and those in more stimulating environments, are more cognitively advanced than children in less stimulating environments. Caregivers who interact frequently with children promote their language development, as many researchers have already shown, finding a strong corre-

lation between children's language level and family SES (Peyre et al., 2014).

Different predictors of MLU_{words}

When examining the contribution of FWs to MLU_{words} to assess grammatical complexity, plurals and determiners were found to predict MLU_{words} in children with CIs, while feminine markers and subject pronouns best predicted MLU_{words} in TD children at 2 and 3 years of CA, respectively. Although the CI and TD groups of children were matched for MLU_{words} , they did not share the same

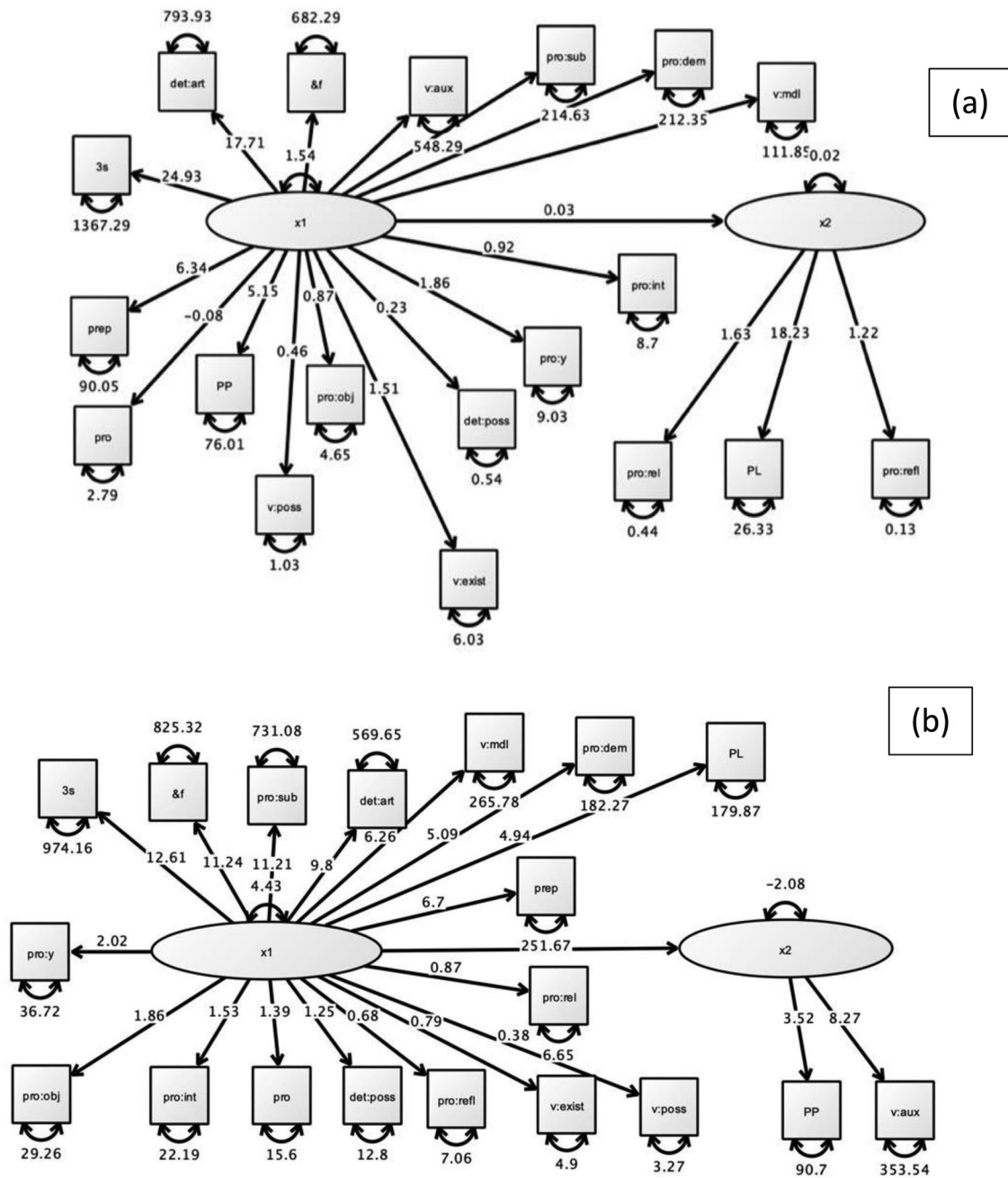


FIGURE 3 Path diagram of function words (FWs) and agreement features (AGRs) (a) in children with cochlear implants (CIs) at 2 years of hearing age (HA) and (b) in typically developing (TD) children at 2 years of CA

predictors of MLU_{words} . Despite advances in CI technology, children with CIs still have difficulties perceiving and encoding FWs due to low perceptual salience of grammatical forms (Guo et al., 2013; Kronenberger & Pisoni, 2019; Leonard & Finneran, 2003; Svirsky et al., 2002).

Children with CIs struggled to produce complex FWs such as subject, object, reflexive, relative pronouns and possessive verbs but also more salient and frequent FWs such as tonic pronouns, demonstrative pronouns, prepositions and modal verbs. The latter are weak monosyllabic grammatical forms and, as has been suggested, CI users

tend to store lexical (Le Normand & Moreno-Torres, 2014; Ouellet et al., 2000) rather than phonological representations. By 2 years of HA, children with CIs tended to use plural forms, while at 3 years of HA they used determiners. Not surprisingly, the CI group used mainly determiners rather than subject pronouns as they tended to rely more on nominal rather than verbal morphology, thus avoiding more complex constructions. It should be noted, however, that the children with CIs made many gender errors, consisting mainly of substitutions—use of *le* instead of *la* ‘the’—rather than omissions. These results are in line with

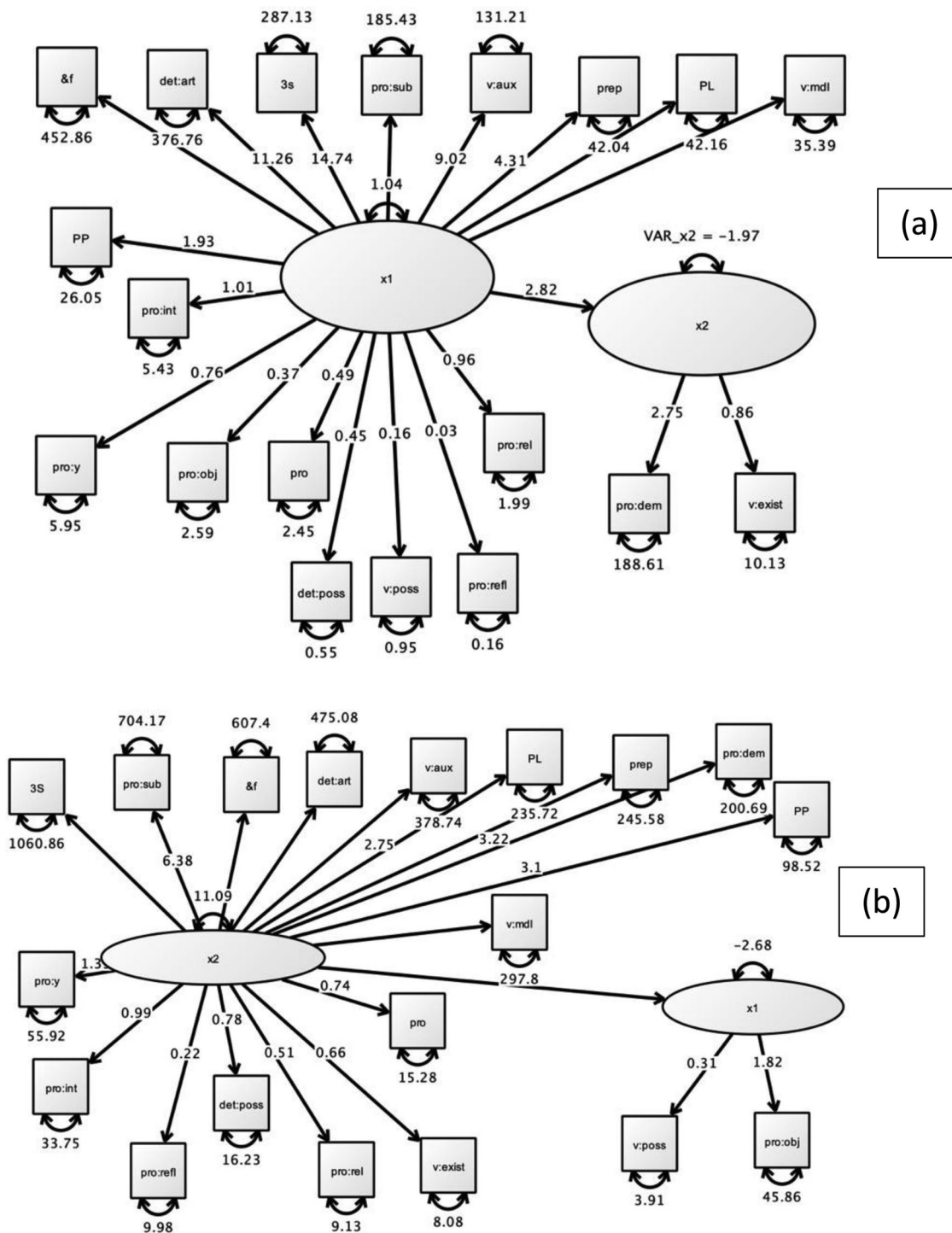


FIGURE 4 Path diagram of function words (FWs) and agreement features (AGRs) (a) in children with cochlear implants (CIs) at 3 years of hearing age (HA); and (b) in typically developing (TD) children at 3 years of chronological age (CA). Single-headed arrows represent variance while double-headed arrows represent covariance

other studies conducted in German and Spanish, which also described similar patterns in young children with CIs (Moreno-Torres & Torres, 2008; Szagun, 2004). According to these authors, omissions of determiners could be associated with prosody, while substitution errors in noun agreement or verb agreement could indicate grammatical

and/or processing deficits, suggesting that children with CI do not show uniform grammatical profiles. This particular difficulty in grammatical morphology in children with CIs has also been examined using natural speech samples in Italian (Caselli et al., 2012; Chilosi et al., 2013), Dutch (Faes et al., 2015; Hammer & Coene, 2016), Swedish

TABLE 5 Post-hoc comparisons of syntactic dependencies governing multiword utterances in children with cochlear implants (CIs) at 2 and 3 years of hearing age (HA) and in typically developing (TD) children at 2 and 3 years of chronological age (CA)

Syntactic dependencies	HA and CA	Group	Mean	SE	95% Confidence intervals		t (1, 112)
					Lower	Higher	
Determiner/nouns	2 years of HA	CI	17.2	6.25	4.93	29.46	
	2 years of CA	TD	8.2	2.51	3.27	13.13	1.62 n.s.
	3 years of HA	CI	21.8	3.92	14.15	29.55	
	3 years of CA	TD	35.7	3.49	28.89	42.6	2.46 n.s.
Preposition/nouns	2 years of HA	CI	2.00	0.78	0.46	3.54	
	2 years of CA	TD	2.00	0.65	0.71	3.29	1.00 n.s.
	3 years of HA	CI	1.75	0.50	0.76	2.73	
	3 years of CA	TD	8.86	1.08	6.72	10.99	5.40***
Subject/verbs	2 years of HA	CI	6.35	2.41	1.62	11.08	
	2 years of CA	TD	6.75	2.17	2.49	11.01	0.099 n.s.
	3 years of HA	CI	9.75	2.65	4.54	14.96	
	3 years of CA	TD	31.33	3.56	24.33	38.33	4.86***
Verb/determiner/nouns	2 years of HA	CI	2.45	1.03	0.42	4.48	
	2 years of CA	TD	1.05	0.39	0.26	1.83	0.94 n.s.
	3 years of HA	CI	4.10	0.91	2.31	5.89	
	3 years of CA	TD	10.67	1.36	7.99	13.34	4.33***

ns $p > 0.05$; *** $p \leq 0.001$

(Hansson et al., 2017) and Hebrew (Adi-Bensaid & Greenstein, 2020). The question of the cross-linguistic nature of grammatical difficulties in children with CIs should be addressed in the light of research on the cross-linguistic nature of typical language development in several structurally different languages. Understanding the form that disability takes in a particular language would improve the possibilities for assessment and treatment in that language.

An alternative explanation for these grammatical deficits could be related to memory circuits associated with language. In this sense, a dual system of language learning, called declarative-procedural, has been proposed (Ullman, 2004). In this system, the declarative part, underpinned by declarative memory (explicit and depending mainly on medial temporal lobe neurological structures), is responsible for semantic learning and irregular grammatical morphology. The procedural part, related to implicit procedural memory (dependent on a series of subcortical structures, mainly the basal ganglia, part of the parietal cortex, the superior temporal cortex and the cerebellum), is responsible for syntactic learning, regular grammatical morphology and phonology.

Atypical hierarchical GRs between words

The analysis of the contribution of FWs and AGRs to MLU_{words} in children with CIs mainly provides insight into the mechanisms that potentially differentiate chil-

dren with CIs from TD children. SEMs analysis is best able to capture the grammatical complexity underlying the syntactic knowledge architecture. Grammatical complexity was different between children with CIs and TD, as demonstrated by a difference in the hierarchical modelling approach from the CFA data. Four FWs were highly loaded for both groups: namely, (1) third-person singular, (2) subject pronouns *il/elle/on* 'he/she/it', (3) articles and (4) auxiliaries *avoir/être* 'to have/to be'. This suggests that these four simple FWs are easy to learn because they are highly predictable and frequent. The subject pronouns (*je* 'I', *tu* 'you', *il* 'he', *elle* 'she', *nous* 'we', *vous* 'you', *ils/elles* 'they'), which are placed next to the verb (usually before it), are sufficient to illustrate the decisive role played by GRs. This is not the case for other pronouns requiring multi-word utterances such as object pronouns which are placed before the verb, and reflexive, relative, interrogative pronouns which are organized in different structures according to their GRs with the transitive or intransitive verb. Even for TD children, these complex FWs are left unspecified, resulting in an incomplete grammar. SEMs analysis from the CFA allowed a status to be assigned to each FW. This modelling approach represents the different hierarchies of GRs in language learners with predictions about how the child produces simple and complex sentences. The different patterns underlying the grammatical complexity of FWs found in children with CIs and TD can also be interpreted as an atypical learning process due to differences in perceptual and production processing.

A disrupted architecture of adjacent syntactic dependencies

The multi-word utterances underlying adjacent and non-adjacent syntactic dependencies in children with CIs reflect a specific architecture of FWs syntactic dependencies. Although the issue of grammatical complexity in young TD children remains an ongoing debate in the literature (Braginsky et al., 2015; Dye et al., 2019; Szagun & Schramm, 2019), young children with CIs very often fail to cope with obligatory GR contexts not only at the level of inflectional verbal morphology (AGRs and tense) but also at the level underlying adjacent and non-adjacent syntactic dependencies. French clitics like determiners or subject pronouns, for example, require the child to use them in an obligatory nominal or verbal context. Thus, children with CIs at 2 and 3 years of implant use compared with TD children at age two and three used similar adjacent syntactic dependencies related to determiners/nouns but not related to prepositions/nouns, subjects/verbs, and verbs/determiners/nouns. A possible explanation for these results could be a deficit in verbal clitics rather than in nominal clitics. One interpretation could be that a specific architecture of syntactic dependencies is disrupted at an early age, due to low perceptual saliency of FWs. This is consistent with the distributional learning hypothesis of language acquisition, according to which infants and toddlers are sensitive to FWs early in life. Newborns aged 1–3 days can categorize FWs versus content words using their distinct phonological and acoustic cues (Shi et al., 2006; Shi and Gauthier, 2005).

Infants' processing of FWs and AGRs like gender and number is surprisingly robust and tailored to the distributional structure of syntactic categories and the properties of native language input (Morgan et al., 1987; Xanthos et al., 2011). When toddlers produce short utterances, both child-directed input and the child's ability to process that input are likely to have an impact on early grammar-building.

Results showed that children with CIs continue to lag in their development of grammatical abilities, despite the technological advances in CI processors implemented in recent years. FWs are so easy to learn for TD children because they are distributionally restricted, highly predictable and frequent. In contrast, they are difficult to learn for children with CIs because they lack perceptual salience. The assessment of input–output language processing will help to answer key questions such as the role of language processing deficits affecting children with CIs.

A strength of this corpus study is the size of the dataset, which allowed the screening and identification of grammatical difficulties in French-speaking children with CIs. A corpus-based design using computational tools, such as the one used herein, could also increase the oppor-

tunities for clinicians and researchers to make detailed assessments of developmental grammatical trajectories in different languages. However, the findings from this corpus study should be interpreted with some caution. Although the CI dataset was designed longitudinally, it was obtained in a group of children implanted unilaterally somewhat later than current recommendations, which call for intervention to begin as early as 6 months of age (Awad et al., 2019) and implantation as early as 1 year (Heman-Ackah et al., 2012).

It is conceivable that participants with earlier bilateral implantation may have performed differently from those reported in the current study. Further studies with earlier implanted children, using a similar corpus-based design, should refine the assessment of differences in early grammar-building between children with CIs and TD.

CONCLUSIONS

Data from this corpus study can be used to support the implementation of evidence-based grammatical interventions in profoundly deaf children at 2 and 3 years of CI use. For example, the different profiles observed between children with CIs and their CA-matched 2–3-year-old peers provide evidence that FWs and AGRs are organized as a specific network in terms of syntactic dependencies governing both simple and complex adjacent or non-adjacent GRs. Therefore, a general approach to the development of clinical practice guidelines can be outlined with the goal of improving the outcomes of grammar interventions. Our findings support indeed new strategies for evaluation, remediation and follow-up that focus on four targets: (1) developmental profiling, (2) relationships between MLU and FWs, (3) the existence of an atypical GR hierarchy between words and (4) the disrupted architecture of adjacent syntactic dependencies in the production of verbal clitics and other pronominal forms. Identifying atypical patterns of grammatical development is crucial for speech–language pathologists working with French children with CIs, as it allows for the development of new intervention strategies and programmes.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest. The authors alone are responsible for the content and writing of the paper.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within the article and its Supplementary Materials (S1–S6).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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