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Research Article

Processing of Plural Marking in Nouns by German-Speaking Children With Normal Hearing and Children With Cochlear Implants: An Eye-Tracking Study

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ABSTRACT

Purpose: Our goal is to understand how the different types of plural marking are understood and processed by children with cochlear implants (CIs): (a) how does salience affect the processing of plural marking, (b) how is this processing affected by the incomplete signal provided by the CIs, and (c) is it linked to individual factors such as chronological age, vocabulary development, and phonological working memory?

Method: Sixteen children with CIs and 30 age-matched children with normal hearing (NH) participated in an eye-tracking study. Their task was to choose the corresponding picture to an auditorily presented singular or plural noun. Accuracy, reaction time, and gaze fixation were measured and analyzed with mixed-effect models.

Results: Group differences were found in accuracy but not in reaction time or gaze fixation. Plural processing is qualitatively similar in children with CIs and children with NH, with more difficulties in processing plurals involving stem-vowel changes and less with those involving suffixes. Age effects indicate that processing abilities still evolve between 5 and 11 years, and processing is further linked to lexical development.

Conclusions: Our results indicate that early implantation seems to be beneficial for the acquisition of plural as indicated by very small between-group differences in processing and comprehension. Processing is furthermore affected by the type of material (i.e., phonetic, phonological, or morphological) used to mark plural and less so by their segmental salience. Our study emphasizes the need to take into account the form of the linguistic material in future investigations at higher levels of processing.

The acquisition of a first language involves the simultaneous processing of information at several linguistics levels. This is especially the case for the production and processing of the morphosyntactic information such as inflectional morphology in general and of plural on nouns in particular. Plural markers can take different forms, which may not be equally salient. To understand

the possible effects of the markers' salience in language acquisition is especially relevant in the case of children who receive less or qualitatively different input, as is the case for children with hearing loss (HL). The complexity of the noun plural-marking system in German provides an excellent way to investigate the role of salience as it relies on different types of segments (i.e., both consonants and vowels) and type of processes (i.e., phonetic, phonological, and morphological).

Our study aims at understanding how children use the available information in the speech input when they

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process inflection. In particular, we aim at understanding the role of salience of the plural markers. Furthermore, we argue that, for children with cochlear implants (CIs), processing the linguistic information is influenced not only by the effects of HL (i.e., a later and/or lower quality of auditory input provided by the CIs) but also by the children's processing abilities in relation with their chronological age, vocabulary development, and phonological working memory.

The German Plural-Marking System

German has a complex noun plural-marking system relying on different plural types, resulting from different morphophonological processes and subsequent phonetic adaptation processes. Köpcke (1988) distinguishes eight different morphophonological formation processes for German, applying to all or only specific genders and relying on suffixation and vowel change, alone or in combination. Four different suffixes are available: segmental suffix /s/, syllabic suffixes /ə/ and /ɐ/, and /n/, which can be both segmental as [n] or syllabic as [ən]. Another type is formed by "umlaut," a vowel fronting of the back vowels /u/ and /o/, and the low vowel /a/, resulting in /y/, /ø/, and /ɛ/, respectively. It can occur as the sole plural marker or in

combination with the syllabic suffixes /ə/ and /ɐ/. Finally, a noun's singular and plural forms can also be identical: disambiguation of the noun number will then only be possible through the determiner, as in *das_{SG} Messer* [mɛsɐ]–*die_{PL} Messer* [mɛsɐ], the knife–the knives. Table 1 below, based on Köpcke (1988), summarizes all possible plural markings per gender.

As seen in Table 1, plural is not only marked by morphophonological material but also results in different phonetic changes located on the word's stem-final consonant. For example, in the *Kind_{SG}–Kinder_{PL}* pair, the stem-final consonant is the location of a voicing [d]–[t] alternation, following German's word-final devoicing rule (i.e., /d/ realized as [t] in word-final position).

Finally, not all plural markings are equally regular, productive, and frequent. Plural marked with -s is the most regular type overall, but -(e)n is most regular for feminine nouns (Clahsen et al., 1992). Plural marked with -s suffixes is the most productive, as it appears in all contexts and in loanwords. Plural types involving umlaut are the least productive (e.g., Laaha et al., 2006). Frequency varies across genders, but, overall, plural is most frequently marked with the -(e)n suffix, followed by the -e

Table 1. Plural marking in German (adapted from Köpcke, 1988; with the International Phonetic Alphabet [IPA] transcriptions of standard German pronunciation from Krech et al., 2009).

	Gender		
	Masculine	Feminine	Neuter
Def. article (sing./plur.)	der/die	die/die	das/die
Plural morpheme			
-e, [ə]	Fisch–Fische [fiʃ]–[fiʃə] fish	Kenntnis–Kenntnisse [kɛntnis]–[kɛntnisə] knowledge	Jahr–Jahre [ja:ʰ]–[ja:ʰə] year
-(e)n, [ən][n]	Bauer–Bauern [baʊɐ]–[baʊɐn] farmer	Tür–Türen [ty:ʰ]–[ty:ʰən] door	Auge–Augen [aʊgə]–[aʊgən] eye
-er, [ɐ]	Geist–Geister [gɛɪst]–[gɛɪstɐ] ghost	—	Kind–Kinder [kɪnt]–[kɪndɐ] child
-s, [s]	Park–Parks [pa:k]–[pa:ks] park	Mutti–Muttis [mʊti:]–[mʊti:s] mom	Auto–Autos [aʊto:]–[aʊto:s] auto
∅	Adler–Adler [a:dɐ]–[a:dɐ] eagle	—	Fenster–Fenster [fɛnstɐ]–[fɛnstɐ] window
umlaut	Bruder–Brüder [brʊ:dɐ]–[brʏ:dɐ] brother	Tochter–Töchter [tɔxtɐ]–[tœxtɐ] daughter	Kloster–Klöster [klo:stɐ]–[klø:stɐ] monastery
umlaut + -e, [ə]	Sohn–Söhne [zo:n]–[zø:nə] son	Kuh–Kühe [ku:]–[ky:ə] cow	Floß–Flöße [flo:s]–[flø:sə] raft
umlaut + -er, [ɐ]	Wald–Wälder [valt]–[vɛldɐ] wood	—	Volk–Völker [fɔlk]–[fœlke] people

Note. Em dashes indicate data not attested. Def. = definite; sing. = singular; plur. = plural.

suffix, no marking, and umlaut + -e suffix. It is less frequently marked with the -s suffix, -er suffix with or without umlaut, and umlaut alone (Zaretsky et al., 2013). So, what is most frequent is not necessarily most regular or most productive in German plural marking.

Acquisition of Inflectional Morphology in Children With Typical Development

The use of inflectional morphology in children has mainly been studied in production and less so in reception. The acquisition of inflectional morphology in general, and of nominal plural in particular, is a nonlinear process following a “U-shaped curve” developmental trajectory (e.g., English: Berko, 1958; Marcus, 1995; German: Behrens, 2002, 2011; Clahsen et al., 1992; Kauschke et al., 2011; Zaretsky et al., 2013, 2016). Following a stage where children produce plural nouns with great accuracy, there is then a stage of “overregularization” errors, in which children tend to apply generalized rules of plural marking using the language’s most frequent plural type as the rule to form all plurals. This is followed by a stabilization phase, where the production becomes adultlike.

Although the pattern of acquisition seems the same across languages, the time needed to reach adultlike production of plurals varies cross-linguistically, mainly due to different complexity levels of each language’s plural system. Production is adultlike approximately by the age of 6 years in English (Marcus, 1995) or 7 years in German (Kauschke et al., 2011) and still ongoing by the age of 7 years in Hebrew or Arabic (Hebrew: Ravid & Schiff, 2009; Palestinian Arabic: Saiegh-Haddad et al., 2012; Jordanian Arabic: Albirini, 2015). Furthermore, not all plural types are acquired simultaneously, and several factors influence accuracy in production of nominal plural in the course of its acquisition: frequency (Kauschke et al., 2011; Laaha et al., 2015), productivity (Laaha et al., 2006), and predictability (Albirini, 2015; Laaha et al., 2015; Saiegh-Haddad et al., 2012) of the plural markers.

The only receptive study in German (Korecky-Kröll et al., 2012) showed that German-speaking children are sensitive to the well-formedness of plural forms yet still not to the same extent as adults even at the age of 10 years. A series of studies in Australian English (Davies et al., 2017, 2019; Davies, Xu Rattanasone, & Demuth, 2020), using nonwords, showed that plural comprehension is an early acquired ability, with possible differences between allomorphs’ coming from their characteristics (e.g., segmental vs. syllabic). Taken together, these studies of plural comprehension and processing in English indicated effects of the type of allomorphs (segmental vs. syllabic) and, therefore, a possible role of their acoustic salience in plural comprehension and acquisition. The salience of

plural markers is, however, only briefly discussed as an explanation to the observed differences in processing the plural markers. Our study addresses this gap.

The German plural system involves alternations of phonetic (i.e., stem-final consonant changes), phonological (i.e., stem-vowel changes), and morphological material (i.e., suffixation), which might differentially contribute to salience of the morphemes. This could lead to differences in processing: suffixes (i.e., suffixation is an addition of morphological material to the stem) should be the most salient materials, followed by stem-vowel changes (i.e., alternation of phonological material consisting of an internal modification of the stem without changing its structure) and then voicing alternation (i.e., phonetic adaptation to suffixation, which are a modification of a consonantal feature in word-final position), which should ease the processing of plurals, as it provides a supplementary cue but still be the least salient type of cue. Plurals formed by a suffixation result in a resyllabification when the suffix is syllabic (i.e., /ə/, /v/, /n/, or /ən/) as in the *Fisch_{SG}–Fi.sche_{PL}* pair but not when the suffix is segmental (i.e., /n/, or /s/) as in the *Pu.ppe_{SG}–Pu.ppen_{PL}* pair. This may contribute to making these plural markers more salient as the extra syllable in the plural form stands out next to the stem. Furthermore, salience can be understood as the intrinsic or systematic differences in the salience of individual speech sounds that compose the plural markers and that translate into differences in the respective salience of the individual morphemes. Theoretically, salience of speech sounds can be explained phonologically as the result of differences in sonority of the speech sounds within the phonological system (Clements, 1990; Selkirk, 1984) or phonetically as the correlates of the sound’s acoustic properties (e.g., “Phonetic Speech Power,” Fletcher, 1931; “perceived resonance of major classes of speech sounds,” Clements, 2005). Following these definitions, we expect vowels and therefore information carried by vowels (i.e., Umlaut), as well as syllabic suffixes (i.e., addition of a vowel after the stem: the *-ə/* and *-v/* suffixes) to be the most salient cues to plural, followed by sibilant suffixes (i.e., the *-s/* suffix) according to the sonority index or nasal suffixes (i.e., the *-n/* suffix) according to the Phonetic Speech Power hypothesis. Since voiced consonants are more sonorant, a singular–plural contrast including a voicing alternation (e.g., the [t]–[d] alternation in *Kind_{SG}–Kinder_{PL}*, [kɪnt]–[kɪndɐ]) should also contribute to higher salience and be easier to process than when there is no voicing alternation (e.g., the same [s] consonant in *Schloss_{SG}–Schlösser_{PL}*, [ʃlɔs]–[ʃlɛsɐ]), as the voicing contrast adds more information to the plural form. Taken together, we expect plural types involving morphological material to be the easiest to process: Among them, vocalic suffixes (i.e., addition of a syllable, with resyllabification of the stem) should be more salient than

consonantal suffixes (i.e., addition of a single segment, with no resyllabification of the stem). Then, plural types involving umlaut (i.e., a phonological process consisting of a change of the stem vowel) should be less salient than plural types involving suffixation only but more salient than those not involving umlaut. Finally, voicing alternation should be the least salient cue, as it is a phonetic adaptation that can occur following suffixation.

These expectations based on our definitions of salience are primarily proposed for children with NH. In the following section, we will focus on the processing of inflection in children with CIs and propose specific expectations regarding the influence of salience on noun plural processing in children who possibly had a delayed and partial access to the speech sounds due to a HL and the use of the CIs.

Processing of Inflection in Children With CIs

Although the use of CIs lead to improved perception of sounds, they transmit a poorer version of the speech signal to the inner ear (Drennan & Rubinstein, 2008), leading to persisting difficulties in processing certain speech sounds or features (Bouton et al., 2012; Giezen et al., 2010). This might result in further delays and difficulties in language development, both in production and comprehension (e.g., Boons et al., 2013; Geers & Nicholas, 2013).

Studies examining the morphosyntactic development of children with CIs have found poorer performances of children with CIs compared to peers with normal hearing (NH) matched in chronological age (Boons et al., 2013) or in vocabulary size (Jung & Ertmer, 2018) and contradictory effects of hearing age (e.g., no effect in Caselli et al., 2012; better performance with a higher hearing age in Schouwenaars et al., 2019). Furthermore, early implantation (i.e., before age 2 years) was a predictor of morphological and syntactic development for Dutch-speaking children (Faes et al., 2015). A high level of variability in morphosyntactic abilities has been observed in children with HL in general (e.g., Caselli et al., 2012; Ruigendijk & Friedmann, 2017; Tuller & Delage, 2014) and also in children with CIs (Boons et al., 2013; Duchesne et al., 2009; Szagun, 2000; Young & Killen, 2002).

Although the goal of a number of morphosyntactic studies was to assess the overall abilities of children with HL or with CIs, only few studies focused on one or several areas within this larger domain, connecting them to the hearing acuity with a CI. Morphosyntactic abilities were linked to the use of phonological information and cognitive abilities in children with HL: Both phonological short-term memory and wh-question processing were correlated to receptive abilities (Penke & Wimmer, 2018), and processing subject–verb (number) agreement improved

with better working memory abilities when more than one phonological cue to verb number marking was available (Schouwenaars et al., 2019).

Only few studies have studied plural marking in children with HL, and most of them in production. In a cross-linguistic study with Dutch- and German-speaking children with CIs and with NH, Laaha et al. (2015) showed that the most common error made by children with CIs was to use a singular form when a plural marking was needed and that Dutch-speaking children had less difficulties than German-speaking children, which they explain with the Dutch plural-marking system being more transparent (i.e., only marked by two possible suffixes and a limited number of exceptions) than the German system. To our knowledge, only two studies assessed the receptive abilities for plural marking in children with typical hearing and children with HL in English (Davies et al., 2023; Davies, Xu Rattanasone, Davis, & Demuth, 2020). The first study showed that accuracy was lower in children with HL using external hearing aids (HAs) or CIs than in children with NH. It also concluded that the children with HAs and the children with CIs showed qualitative differences: The children with HAs were able to identify the segmental [-s], as in [boks]–“books” and [-z] allomorphs, as in [dɔgz]–“dogs,” as plural markers, and, hence, had used morphology to build a representation of the plural derived from the singular. For children with CIs, however, syllabic suffixes [-ɪz], as in [haʊɪz]–“houses,” are more robust cues to identify plural novel words, and, hence, they seem to rely more on syllabic information to identify the singular or plural form of a word.

Only a small number of studies focus on German-speaking children with CIs and only in production. Szagun (2000, 2002) concludes that children with CIs are able to use at least several plural forms at 18 months following the cochlear implantation, yet with a high variability between children (Szagun, 2000). The most frequent error reported in Szagun (2002) is the absence of an expected plural marking in children with CIs, whereas for children with NH, it was the use of a partial marking (e.g., umlaut and no suffix when both should be used). These studies indicated that with regard to their use of plurals at 2 and a half years after the cochlear implantation of the children with a CI showed typical language development. These findings are consistent with Laaha et al. (2015), who showed that the most frequent error by both Dutch- and German-speaking children with CIs was the use of the item’s singular form, which is similar to errors made by younger children with NH, when they are matched in hearing age with the children with CIs.

Our literature review already gives some insight into the mechanisms at play when children acquire plural

marking and also in the possible challenges faced by children with HL and with CIs. However, it also shows that higher levels of language acquisition (i.e., morphosyntax) are most often treated independently from lower levels of processing (i.e., phonetic, phonological, or acoustic processing). The ability to use nominal plural marking is never studied by connecting the form of the plural markers to the types of processes that are involved (phonetic, phonological, and/or morphological, see above). It is, thus, not clear how the segmental information of the individual inflection markers is processed with a CI and what the effect is for acquisition.

Several differences have been observed in the processing of speech sounds between children with CIs and children with NH: For example, Bouton et al. (2012) observed similar abilities in the categorization of speech sounds by children with CIs and children with NH but less precision in processing both consonantal and vowel contrasts. Furthermore, perception and production of front, rounded vowels /y/, /ø/, and /æ/ have been found especially challenging for users of CIs (see, e.g., Verhoeven et al., 2016, for vowel production by children with CIs in Flemish Dutch). Therefore, between-group differences in processing plural markers might arise when these rely on an umlaut contrast, which corresponds to the fronting of back, rounded vowels /u/, /o/, and /ɔ/, resulting in /y/, /ø/, and /æ/, which is acoustically correlated to a higher second formant (F2). This is reinforced by articulatory properties of these vowels that makes them visually ambiguous with their back counterparts.

Research Questions and Expectations

Our study aims at understanding how phonetic, phonological, and morphological cues to plural marking are used for comprehension and processing by children with CIs. We aim at answering the following research questions: (1) What are the differences in processing noun plural marking between children with NH and children with CIs, with respect to (a) the type of information used to mark plural (i.e., phonetic, phonological, and morphological) and (b) the salience of the plural types and types of suffix? (2) How can these possible differences be explained by factors such as chronological age, vocabulary development, or phonological working memory?

Following our definition of salience, we first expect differences in understanding and processing the different plural types, suffixes, and types of cues under study. We further expect that the children with CIs will process specific types of information available in noun plural markers with a delay reflecting the specificities of perception and hearing with CIs. Finally, we expect that differences in processing might arise from the children's vocabulary development or phonological working memory (i.e., we

expect that the processing of the plural markers is facilitated with a larger vocabulary size and higher phonological working memory abilities), regardless of their hearing abilities.

To test these predictions and specificities of processing plural in children with CIs, we decided to focus on a group of children as homogeneous as possible, with early diagnosis of HL, a cochlear implantation before the age of 2 years and no known additional physical or cognitive impairments.

Method

Participants

Participants in this study were 16 children with CIs and 30 children with NH.¹ All were native speakers of standard German, spoken in the Northwest of Germany. Detailed information on the group of children with CIs is given in Table 2 below.

Thirteen children have bilateral CIs, and three use a CI in combination with an HA and have, therefore, additional access to acoustic hearing. The age of the children with CIs ranged from 5;8 to 11;1 (years;months; $M = 8;4$, $SD = 1;10$); their age at implantation ranged from 0;5 to 1;10 ($M = 1;0$, $SD = 0;4$). Consequently, their hearing age ranged from 4;6 to 10;4 ($M = 7;1$, $SD = 2;1$), and their hearing age and chronological age were highly correlated, $r(14) = .92$, $p < .001$. The age of the children with NH ranged from 5;1 to 11;10 ($M = 8;3$, $SD = 2;0$). The two groups were matched in chronological age, $t(44) = 0.12$; $p = .905$. For this reason, and because we do not have enough information about the actual input received by the children with CIs before implantation, we chose to focus on chronological age and not hearing age for our analyses. All children with NH were screened for language delay by means of parental questionnaire and HL by means of an audiogram.

The recruitment and testing procedures were approved by the Ethical Commissions of the University of Oldenburg and of the Hannover Medical School and followed the COVID-19 guidelines for studies involving human participants in place at that time at the University of Oldenburg and at the Hannover Medical School. The children with NH were recruited through ads in the local newspaper and on the University's website and by word of mouth. The children with CIs were recruited through a collaboration with the Deutsches HörZentrum Hannover

¹Note that this group of children with NH is also part of a study using the same experimental protocol comparing their processing and comprehension abilities with adults with NH (Grandon et al., 2023).

Table 2. Individual information about the group of children with cochlear implants (CIs).

Participant	Number of CIs	Age at testing (years;months)	Age at implantation (years;months)	Device (right ear)	Device (left ear)
01	1	9;2	1;0	Medel	Hearing aid
02	2	6;1	0;8	Cochlear	Cochlear
03	1	9;8	0;5	Cochlear	Hearing aid
04	2	11;1	0;9	Cochlear	Cochlear
05	2	8;11	1;0	Cochlear	Cochlear
06	1	7;1	1;3	Hearing aid	Cochlear
07	2	9;6	1;8	Medel	Medel
08	2	11;0	0;8	Cochlear	Cochlear
09	2	11;2	1;1	Medel	Medel
10	2	8;11	0;11	Medel	Medel
11	2	6;11	1;10	Cochlear	Cochlear
12	2	6;1	0;11	Cochlear	Cochlear
13	2	5;8	1;1	Medel	Medel
14	2	8;0	1;0	Cochlear	Cochlear
15	2	8;10	1;0	Cochlear	Cochlear
16	2	6;1	1;5	Advanced bionics	Advanced bionics

(German Hearing Center Hannover) and Cochlear Implant Center Wilhelm Hirte in Hannover. Children were tested in one or two sessions (i.e., three of 16 children with CIs and 29 of 30 children with NH participated in two sessions) for a maximum of 2 hr in total, and they received a small present after each session for their participation.

Testing Procedure

Vocabulary development was assessed by means of the Peabody Picture Vocabulary Test (PPVT; German version: Lenhard et al., 2015). The PPVT is a standardized test in which children have to identify the corresponding picture to a word presented orally by an experimenter, out of a four-picture set. Mean PPVT scores (t value) are 54.8 (7.49) for the children with NH and 46.57 (7.21) for the children with CIs. The PPVT scores were significantly lower for the children with CIs, $t(42) = -3.36$; $p < .01$). Phonological working memory was assessed by means of the Language Impairment in the Multilingual Society non-word repetition test (Crosslinguistic Nonword Repetition [CL-NWR]; Chiat, 2015; Hinnerichs, 2016, for the German version), a nonstandardized test in which children have to repeat 16 items made of sequences of two to five consonant–vowel (CV) syllables: A two-syllable word is expected to be easier to recall than a five-syllable word, since it is less demanding in terms of phonological working memory. The child's production was recorded for later assessment. For our purposes, a whole-word accuracy was rated for each item. The scores of the children with NH ranged from 10 to 16 (total: 16 items, $M = 13.6$; $SD = 1.48$) and the scores of the children with CIs ranged from

5 to 16 ($M = 11.13$; $SD = 2.79$). The CL-NWR scores were significantly lower for the children with CIs, $t(44) = -4.03$; $p < .001$. In both groups of children, most errors were made for the items with five syllables.

Experimental Task

Plural Types and Word Selection

We used a picture-selection task with eye tracking to test the processing of nominal plural marking. We departed from the traditional classification of German plurals (e.g., Köpcke, 1988; Wiese, 2009), and we instead defined 10 categories. These vary in their combinations of material used to mark plural (i.e., phonetic, phonological, and morphological). This allows us to explore the effects of the segmental salience of the plural. Our categories are based on three types of cues to mark plural alone or in combination, namely, vowel change on the stem (i.e., umlaut), suffix addition to the singular form, and subsequent intervocalic voiced realization of the stem-final stop consonant. The details of these plural types are presented in Table 3 (plural types, types of cues to plural marking) with examples to illustrate them.

For each plural type, eight different words were chosen. These had to be singular-dominant (e.g., words such as eye were excluded), and they had to be depictable and understood easily by children (i.e., objects, animals, people, etc.). We also made sure that lemma frequency was as homogeneous as possible within and across categories. Lemma frequency was assessed using the Intellitext 2.6 database (Wilson et al., 2010): mean frequency (SD) across plural types was 43.40 (98.88) instances per million

Table 3. Plural types in our study.

Plural type	(SG–PL pairs)	Type of contrasting cues available		
		Phonological vowel change (umlaut)	Morphological suffix	Phonetic voicing contrast
No change	Kissen–Kissen [kɪsn]–[kɪsn], pillow	–	–	–
Vowel change: umlaut	Vogel–Vögel [fo:g]–[fø:g], bird	+	–	–
–/s/ suffix	Auto–Autos [aʔto:]–[aʔto:s], car	–	+	–
–/ə/ suffix	Tisch–Tische [tɪʃ]–[tɪʃə], table	–	+	–
–/n/ suffix	Katze–Katzen [katsə]–[katsən], cat	–	+	–
Umlaut + –/ə/ suffix	Ball–Bälle [bal]–[bələ], ball	+	+	–
Umlaut + –/ɐ/ suffix	Schloss–Schlösser [ʃlɔs]–[ʃlɔsɐ], castle	+	+	–
Voiced stem-final C + /ə/ suffix	Pferd–Pferde [pfe: ^h t]–[pfe: ^h də], horse	–	+	+
Voiced stem-final C + /ɐ/ suffix	Kleid–Kleider [klaɛt]–[klaɛdɐ], dress	–	+	+
Umlaut + voiced stem-final C + /ə/ or /ɐ/	Wald–Wälder [valt]–[vældɐ], forest	+	+	+

Note. SG–PL = singular–plural.

in four combined corpora. Details per plural type are given in the supplemental materials (<https://osf.io/jmvg6/>). The total number of items was: 10 plural types × 8 words × 2 numbers = 160 items. The items were presented in blocks of 20 items, balanced in number (10 plural and 10 singular targets), plural type (two of each type), randomized, and split into two testing sessions of 80 items each. Pauses were provided between blocks. Each testing session of 80 items took about 10–15 min to complete.

Material

All audio stimuli were recorded by a female native speaker of German. The recording took place in a sound-attenuated booth at the university. Recordings were made with a Neumann KM 184 cardioid Microphon, a Gina Echo 3G audio interface, and the Adobe Audition software (sampling frequency 44.1 kHz, mono, 32 bits, WAV format). The audio files were then cut and scaled in intensity (60 dB SPL) using Praat (Boersma & Weenink, 2020) to ensure constant volume of item presentation for the duration of the study. For each stimulus used, the time point when each item of a singular–plural pair starts to differ from the other member of the pair (e.g., the onset of the stem vowel in /fu:s/–/fy:sə/ <foot>) was extracted with a Praat script for data analyses.

For the picture stimuli, we used black-and-white drawings of objects, animals, or people retrieved from the Pixabay (<https://pixabay.com>) and Shutterstock (<https://www.shutterstock.com>) databases. We used one item for pictures depicting the singular form of the word and two copies of the exact same item (same drawing, same size) for pictures of the corresponding plural form of the word. The position on the screen (left–right) for singular and plurals was balanced, 50% singular on the left side and 50% on the

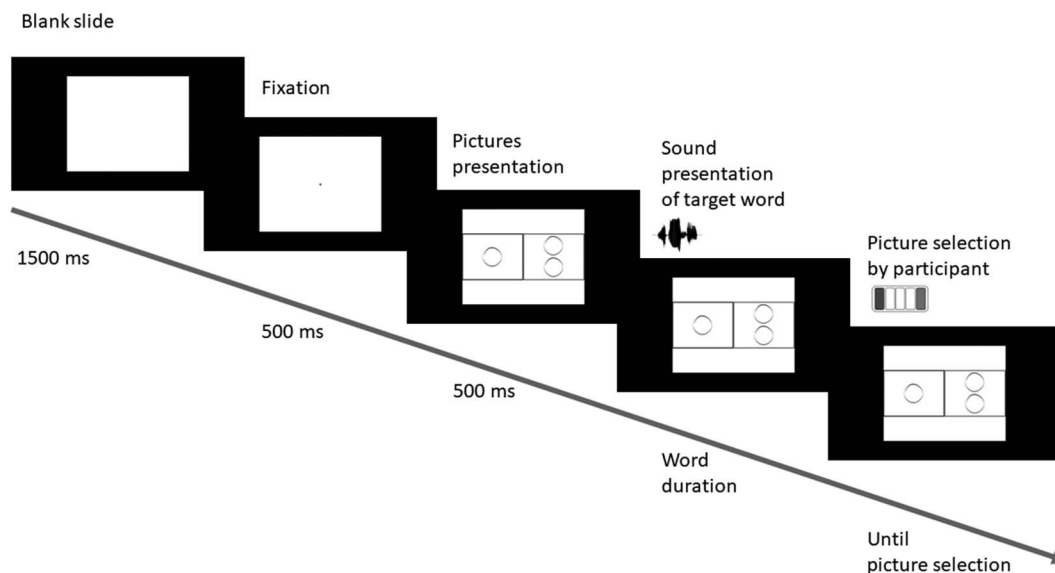
right side. The two areas of interest (AOIs) were two white 512 × 384 pixel (127.09 mm × 95.56 mm) rectangles with a colored frame placed next to each other at the center of the screen; the singular and the plural version of the item were placed in the center of each AOI. Figure 1 illustrates the visual and audio presentation of the stimuli with an example (i.e., Kreis–Kreise, circle–circles).

Procedure and Data Recording

Each child could participate in one or two testing sessions. Each testing session consisted of 80 trials: one singular and one plural version of four items per category that correspond to 10 different plural types. Before starting each 80-item testing session, a 5-point calibration was conducted to ensure appropriate detection of the participant’s eye gaze.

A blank slide was presented for 1,500 ms before each item. To start the procedure (see Figure 1), we first presented a fixation cross in the middle of the screen on a white background. After 500 ms of cross fixation, two pictures depicting the singular and the plural version of the item were presented. After 500 ms, the prerecorded audio target word was played in isolation through two speakers placed on each side of the monitor and set at a comfortable level. After hearing the word (singular or plural version), participants were asked to select the picture matching that word in pushing the left or right button on a Chronos response box. They were instructed to answer as soon as they could after the word ended. Before the testing phase, a training phase with six items was run to ensure understanding of the task and familiarity with the response device by the participants. If necessary, the training phase could be repeated several times before starting the testing phase.

Figure 1. Experimental design, with the example of a visual stimulus presentation on the screen (e.g., Kreis_{SG}–Kreise_{PL}, circle–circles).



A Tobii Pro Fusion eyetracker was used with a laptop and an external screen (size: 21.5 in., 476.57 mm × 268.76 mm) on a one-computer setting. We ran the experiment and collected behavioral data with Eprime 3.0 (Psychology Software Tools). We recorded eye movements with the Eprime Extensions for Tobii (TET Package) with a 250 Hz sampling frequency.

Data Analyses

Data Preprocessing

Accuracy was measured as the correct or incorrect identification of the target item presented orally. Reaction time (RT) corresponds to the time between the word offset and the participant’s response and log-transformed to reduce the influence of potential outliers.

For the gaze fixation analyses, we first calculated the number of fixations toward two AOIs, namely, the target picture and the competitor, in 100-ms timebins centered on the item’s first singular–plural formal divergence. We excluded fixations to the other areas of the screen from this count. We then calculated a percentage of fixations toward the target (vs. competitor) for each 100-ms timebin. We chose 100 ms over smaller timebins to have more possible data points per timebin, thus, giving as a more reliable picture of the fixation evolution.

Items for the “No Change” category were excluded from further analyses, since they do not provide differences between singular and plural forms. No accuracy can be computed, and gaze data could not be aligned to a specific time point.

Statistical Modeling

Accuracy: Generalized linear mixed-effect model. The dependent variable for the analyses of accuracy is a binomial (0/1) response accuracy. Therefore, it was analyzed with a generalized linear mixed-effect model. We used the *glmer()* function from the *lme4* package (Bates et al., 2015) on the R Software, Version 4.0.3 (R Core Team, 2020). A first model was created, and one by one, the following independent variables were added: Group (i.e., children with NH vs. children with CIs) and Plural Type (nine levels, see Table 3 above). Number (i.e., plural vs. singular targets) was added, as a systematically varied variable that could have an effect on the processing of the items. Model improvement was assessed through step-by-step model comparisons of a reference model and a more complex model based on the Akaike information criterion (AIC; Akaike, 1974) scores. For categorical predictors such as Group (children with CIs vs. children with NH), Number (plural vs. singular), and Plural Types (nine levels), we used a deviation coding that allows each level of a predictor to be compared to the mean accuracy of all other levels. Details of model-building and corresponding outputs are given in the supplemental materials (<https://osf.io/jmvg6/>), and best-fitted models are presented in the Results section.

RT: Linear mixed-effect model. The dependent variable of our analyses of log-transformed RT is a continuous variable and was thus analyzed by means of a linear mixed-effect model using the *lmer()* function from the *lme4* package (Bates et al., 2015) on the R software. Whereas accuracy gives information about the knowledge of plural marking, RT gives information regarding the

certainty of the children's decision. Therefore, for RT analyses, in addition to Group (children with NH vs. children with CIs) and Number (plural vs. singular targets, included as it systematically varies in the material), we chose to focus on the individual factors that might influence the measurements (chronological age, CL-NWR, and PPVT). We analyze RT for all items, regardless of the response accuracy. By keeping all RTs for the analyses, we avoid excluding guessed answers, both accurate and inaccurate: By only considering accurate answers, we would include all guessed but correct answers but would exclude all guessed but incorrect answers. Contrast coding for the analyses of RT for categorical predictors is similar as for the analyses of accuracy.

Gaze data: Generalized additive mixed-effect model.

Since we are interested in the processing of short words, we focused our analyses on the time frame comprising fixations from 200 ms before the onset of the singular–plural difference to 1,500 ms after this point. Fixation toward the target is the dependent variable for gaze data analyses, ranging from 0 (i.e., no fixation toward the target in a 100-ms time-bin) to 1 (i.e., fixation only to the target in a 100-ms time-bin) evolving over time. To model this nonlinear evolution of fixation toward the target over time, we used generalized additive mixed-effect models (GAMMs), with the *bam()* function, working with the *mgcv* (Wood, 2011) and *itsadug* (van Rij et al., 2020) packages on R. As for accuracy and RT, models were built step by step by adding factors to the simplest model. By-participant and by-item random smooths were added to the model.

To address our first research question that focuses on the processing of plural marking by the two groups of children, we first considered Group (children with NH and children with CIs) as variable of interest in the first analyses (again Number [singular vs. plural] was included, as it systematically varies in the material). Then, we conducted separate types of analyses: (a) We first compare the processing of the three types of contrasting cues (binary variables: Umlaut Contrast, Suffix Contrast, Voicing Contrast; see Table 3), and (b) we then test the effects of the markers' salience by focusing on the Plural Types (nine different levels combining different phonetic, phonological, and morphological information; see Table 3), and on comparing the individual suffixes (-/s/, -/n/, -/t/, and -/ɔ/).

To address our second research question that explores the individual factors influencing the processing of plural marking, we finally considered the possible effects of Chronological Age, Vocabulary Development, and Phonological Working Memory. For each of these analyses, we go from the first model including Number only, to which we add separate composite smooths created to model the interactions of factors. For example, Group

and individual Plural Types were combined into separate predictors to explore the singular–plural difference in gaze fixation for each Plural Type. To build the models for gaze fixation, we add each variable one by one to a simple model. We assess the improvement of the new model by comparing it to the previous model without the new, added variable of interest using (a) the “deviance explained” index given by the summary output, and (b) the comparison of the AIC and fREML scores through the *compareML()* function of the *itsadug* package. As for RT analyses, we consider gaze fixation data for all items, regardless of the accuracy of picture selection. This allows us to consider gaze fixation as informative of the whole comprehension process.

Results

To ensure readability of this section, details of each model building steps for accuracy, RT, and gaze data and model outputs are provided in the supplemental materials (<https://osf.io/jmvg6/>).

Picture Selection

Accuracy of Picture Selection

Mean accuracy of picture selection is provided for each group and each plural type in Table 4. It was very high for both groups of children (children with CIs: $M = 92.36\%$, $SD = 26.57\%$; children with NH: $M = 94.76\%$, $SD = 22.29\%$).

A first model was built to study the effects of the Plural Types on accuracy. It only included Group (children with NH: -1 vs. children with CIs: 1) as a fixed-effect factor, which had a significant effect on the dependent variable ($\beta = -0.54$, $z = -2.20$, $p < .05$). Number (singular: -1 vs. plural: 1) and Plural Type (nine levels) did not improve the fit of the model; we therefore assumed that neither variable had a significant effect on accuracy. A second model was built to study the effects of individual factors on the accuracy of picture selection. This model included Group and Age as fixed-effect factors. Group had a significant effect on Accuracy ($\beta = -0.59$, $z = -2.72$, $p < .01$), as well as Age (higher in older children, $\beta = 0.03$, $z = 3.73$, $p < .001$). Neither the Group \times Age Interaction nor PPVT and CL-NWR Scores improved the fit of the model. These factors were therefore not included.

RT in Picture Selection

Mean RT (in ms) for each group and each plural type are provided in Table 4. RT values were log-transformed to reduce the effects of outliers. Our best-fitted model included Group (children with NH: -1 vs.

Table 4. Mean accuracy (in %) and reaction times (in ms) for children with normal hearing (NH) and children with cochlear implants (CIs).

Plural type	Accuracy (in %)		Reaction time (in ms)	
	Children with NH	Children with CIs	Children with NH	Children with CIs
No change	NA	NA	NA	NA
Vowel change: umlaut	92.67 (26.09)	90.28 (29.73)	864.01 (873.05)	1118.90 (1007.07)
-/s/ suffix	93.75 (24.23)	92.36 (26.65)	885.29 (868.97)	967.03 (751.08)
-/ə/ suffix	94.18 (23.43)	93.75 (24.29)	808.44 (986.48)	941.76 (801.56)
-/n/ suffix	94.18 (23.43)	90.97 (28.76)	837.40 (1043.65)	938.18 (750.40)
Umlaut + /ə/ suffix	96.55 (18.27)	92.36 (26.65)	767.04 (744.35)	924.54 (852.69)
Umlaut + /v/ suffix	95.69 (20.33)	93.06 (25.51)	898.32 (821.16)	1082.04 (1012.14)
Voiced stem-final C + /ə/ suffix	95.04 (21.73)	93.06 (25.51)	849.48 (803.16)	1074.03 (1183.17)
Voiced stem-final C + /v/ suffix	96.12 (19.33)	93.75 (24.29)	787.75 (768.13)	929.66 (671.18)
Umlaut + voiced stem-final C + /ə/ or /v/	94.61 (22.60)	91.67 (27.74)	794.01 (782.88)	907.85 (820.86)

Note. NA = not available.

children with CIs: 1), Number (singular: -1 vs. plural: 1), and Age (in months). The results first showed that RT was similar in both Groups of children ($\beta = 0.10$, $z = 1.96$, $p = .057$). They further indicated an effect of Number ($\beta = -0.05$, $z = -3.10$, $p < .01$): RT was shorter, meaning reaction was quicker with a plural target than with a singular target. The decision was also quicker in older children, as seen in the effect of Age ($\beta = -0.01$, $z = -6.55$, $p < .001$). Finally, there was neither an effect of Phonological Working Memory nor of Vocabulary Development (CL-NWR and PPVT scores not included in the model).

Gaze Fixation

As shown in the previous sections describing the method and procedure to the experiment, participants were presented two pictures and an audio token of the target word, which was either plural or singular. When the first cue to plural marking started,² which corresponded to either a stem-vowel change, the onset of a contrasting voiced or voiceless stem-final consonant, or the onset of a suffix, participants started to direct their gaze toward one of the two pictures. The time between the first cue and the end of the word was very brief (between 118 ms and 632 ms for plural items). Very quickly and before the word offset, the gaze fixation was oriented toward one picture, then reached a plateau until the end of gaze recording (which corresponded to the time when the participant clicked on the chosen picture). In the following sections, our analyses of gaze fixation data will aim at examining what picture was being fixated when and what it meant for the processing of plural marking.

²Indicated as the 0-point on our plots and analyses: see Figures 2 and 3 below and the supplemental materials: <https://osf.io/jmvg6/>.

- Effects of Group (children with NH vs. children with CIs) on gaze fixation

We built a first GAMM to study the effects of Group (children with NH and children with CIs) on the fixation toward the target picture. Number (plural vs. singular targets) is also included as a fixed-effect factor. The best-fitted model included Participant and Item as random effect factors, and difference smooths for Number (plural vs. singular target), modeling the nonlinear difference of both factors. Group did not improve the model fit and was, therefore, not included (see the supplemental materials: <https://osf.io/jmvg6/>). The difference between singular and plural targets is significant ($p < .001$), and indicates that the children direct their gaze earlier and with more amplitude when the target is a plural word. Group was neither included as a factor alone or in interaction with Number, which leads us to assume that the groups of children do not differ with respect to gaze fixation patterns.

In the next steps, we present the analyses and results on our first research question: (a) Types of Cues used in plural marking and (b) Plural Types and type of suffix. In a further step, we address our second research question by presenting the results of individual factors influencing gaze fixation. To this end, we started from the first model including Number only and added possible fixed-effect factors one by one.

- Processing of the Types of Cues to plural marking

Since we aimed at understanding the role of each Type of Cue (i.e., phonetic vs. phonological vs. morphological) available to mark plural, we first analyzed vowel change (i.e., umlaut), voicing contrast, and suffix as binary variables as presented in Table 2 above: plural marking relied on vowel change for four Plural Types, on suffixation for eight Plural Types and on voicing for three Plural

Types (several Plural Types relying on more than one Type of Cue). For example, plural marked with “-n/ suffix” was described as [-umlaut], [-voicing], and [+suffix]. We started from the model presented in the previous section and added these possible binary fixed-effect factors one by one. Main effect of Number was still present but will not be discussed further in this section. The best-fitted model for these analyses included Participant and Item as random-effect factors, and difference smooths for Number (plural vs. singular target), Umlaut (contrast vs. no contrast), and Suffix (contrast vs. no contrast), modeling the nonlinear difference of these factors. Voicing (contrast vs. no contrast) did not improve the model and was therefore not included. Figure 2 presents the evolution of the fixation toward the target when plural was marked with umlaut (e.g., Wald–Walder, forest) or without umlaut contrast (e.g., Auto–Autos, car) and when plural was marked with a suffix (e.g., Wald–Walder, forest) or without a suffix (e.g., Vogel–Vogel, bird).

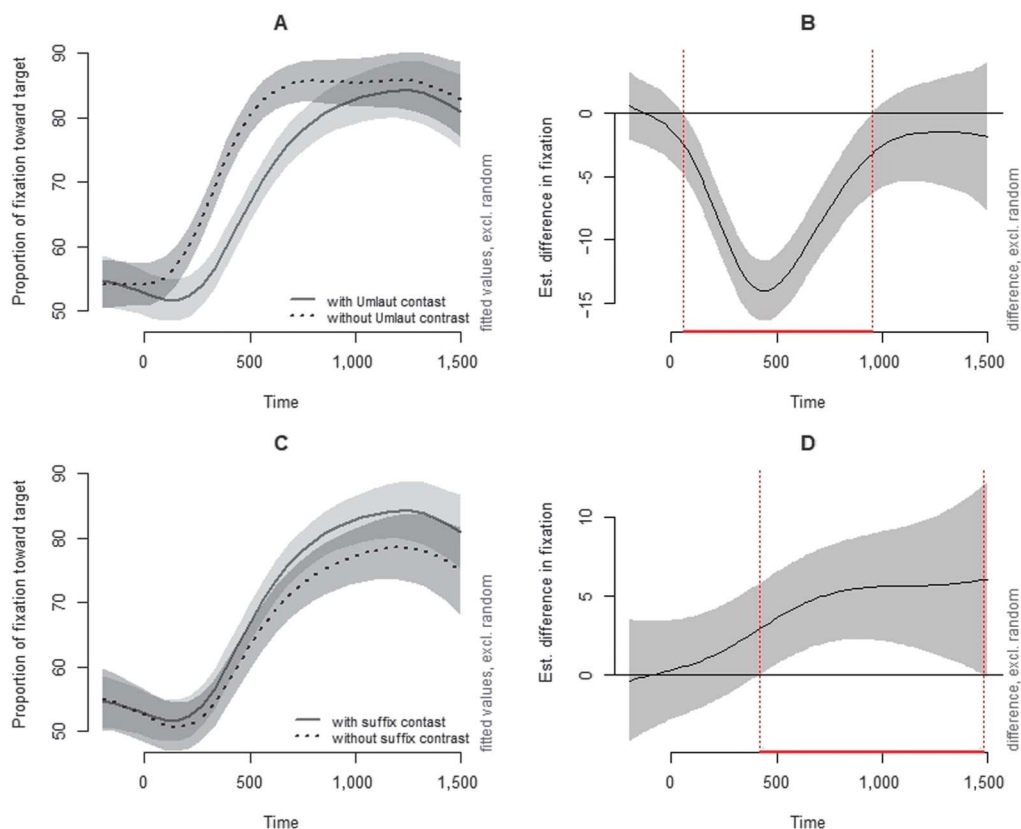
A visual inspection of the smooths for the presence or absence of an umlaut contrast and the corresponding difference of smooths (Figures 2A and 2B) indicated that

gaze fixation toward the target occurred later when plural was marked with an umlaut contrast than when it did not include an umlaut, indicating a quicker access when the word stem was identical in singular and plural forms. In contrast, the smooths corresponding to gaze fixation when plural was marked with a suffix or without a suffix and their corresponding difference of smooths (Figures 2C and 2D) show that Plural Types involving a suffix were processed quicker than the Plural Types not involving suffixes. The use of a voicing contrast to mark plural did not improve the model, meaning that at this point we do not have results that show it had an effect in plural processing.

- Processing of the different plural types and types of suffix

Starting again from the model built in the first subsection for the analysis of the effect of the Group, we added Plural Types (nine levels) from Table 2 as the next factor to create a new model. We then added separate composite smooths to model the interactions of Plural Type with Group and Number (singular vs. plural targets). The best-fitted model included Participant and Item as random effect factors, and smooths for each Group ×

Figure 2. Gaze fixation toward targets (A) and difference in fixation with or without umlaut contrast (B) and gaze fixation toward targets (C) and difference in fixation with or without suffix contrast (D). Excl. = excluding; Est. = estimated.



Plural Type and each Number \times Plural Type interaction. This allowed us to explore the significance of the between-group and singular–plural differences in gaze fixation for each plural type. Interaction smooths, difference plots for both interactions, and a table summarizing all differences for the Number \times Plural Type interaction are presented in the supplemental materials (<https://osf.io/jmvg6/>): Even though separate smooths for each Group \times Plural Types interaction contributed to the best-fitted model, we found no between-group difference for any of the Plural Types under consideration.

To further compare the role of the segmental cues in processing, we then focused on plurals involving suffix as the single cue to plural marking, namely, *-ə/*, *-n/*, and *-s/*, and excluded all other plural types. For these suffix comparisons, our best-fitted model included all Suffixes alone and in interaction with Number (plural vs. singular) as separate composite smooths. As seen in Figure 3, gaze directed earlier to plural targets marked with the *-ə/* suffix, followed by the *-n/* suffix and the *-s/* suffix.

The differences between smooths on Figure 3 further indicate that these delays were significant for *-ə/* versus *-n/* and *-ə/* versus *-s/*, starting around the time the suffixes were heard (at the 0 mark on the difference plots), and a little later for the *-s/* versus *-n/* difference (around 240 ms after suffix onset), that is, after the entire suffix had been heard. For these analyses, Group was not included in the corresponding GAMMs, as it did not lead to model improvement.

- Effect of chronological age, vocabulary development, and phonological development on gaze fixation

In order to understand which individual factors (Chronological Age, Vocabulary Development, and Phonological Working Memory) influence processing of plural in the children, we built a separate model with these individual factors. The best-fitted model included Participant and Item as random-effect factors and Number (singular vs. plural), Age, and PPVT score (i.e., Vocabulary

Development Score) as fixed-effect factors. Our variable selection procedure led us to leave out the CL-NWR score (i.e., Phonological Working Memory score). The results indicated that (a) chronological age had a significant effect on both singular ($p < .001$) and plural targets ($p < .05$) processing and (b) vocabulary development (i.e., PPVT score) also had a significant effect on singular ($p < .001$) but not on plural targets ($p = .596$). Table 5 summarizes all results presented in this section and reflects a contrasted picture in response to our two main research questions.

Research Question 1: Processing is mostly similar for the two groups, plural targets are processed quicker than singular targets and the Type of Cues available affect processing the most, in the sense that suffixes result in earlier fixation of the target than umlaut.

Research Question 2: An older chronological age and a more advanced vocabulary development (i.e., PPVT score) are predictors of more efficient processing.

Discussion

This study examined the factors influencing comprehension and processing of nominal plural in children with NH and a specific and homogeneous group of children with CIs who all had an early identification of HL, an early cochlear implantation, and no further known physical or cognitive impairments. The factors under study are of linguistic nature (phonetic, phonological, and morphological cues) and of individual nature (chronological age, vocabulary development, phonological working memory). We argued (a) that cues relying on phonetic, phonological, and morphological materials, which are not equally salient, lead to differential processing when children are not provided full acoustic characteristics of speech sounds, as is the case with CIs, but also (b) that individual factors such as chronological age, vocabulary development, and phonological working memory can contribute to explain possible processing differences.

Figure 3. Gaze fixation toward the target for each suffix type (A) and between-category fixation differences between plural types marked with suffixes only: *-e* versus *-n* (B), *-e* versus *-s* (C), and *-s* versus *-n* (D).

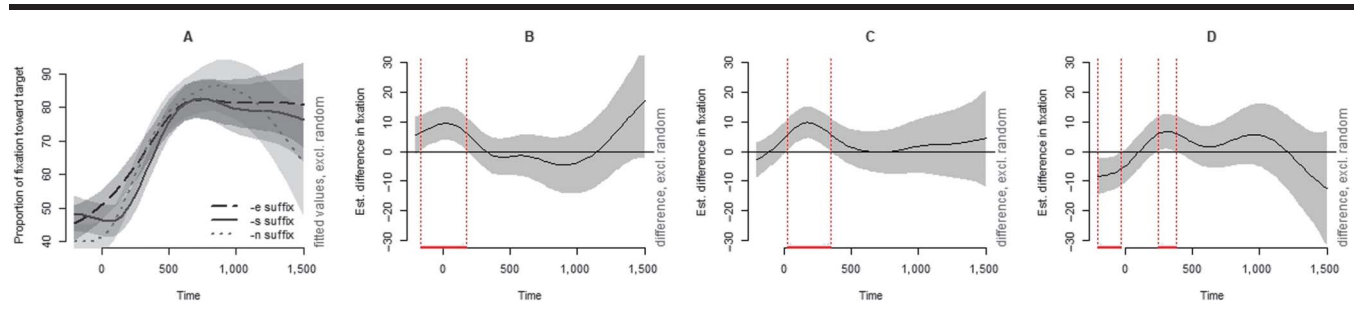


Table 5. Summary of all the results (accuracy, reaction time [RT], and gaze fixation).

Research question	Fixed-effect factor	Accuracy	RT (log)	Gaze fixation
RQ1: Group and linguistic factors	Group	Higher accuracy in children with NH, $p < .01$	n.s.	n.s.
	Number	n.s.	Shorter RT with plural targets, $p < .01$	Earlier fixation toward plural targets (main effect)
	Plural Type	n.s.	Not tested	n.s.
	Type of Cues	n.s.		Later fixation with umlaut contrasts (vs. without umlaut contrast) Earlier fixation with suffix contrasts (vs. without suffix contrast) No effect of voicing on fixation
	Suffix Type	not tested		Earlier fixation with $-/ə/$, then $-/n/$, then $-/s/$
RQ2: Individual factors	Chronological Age	Higher accuracy in older children, $p < .001$	Longer RT for younger children, $p < .001$	Earlier fixation for older children
	Vocabulary Development (PPVT)	n.s.	n.s.	Earlier fixation for children with higher PPVT
	Phonological Working Memory (CL-NWR)	n.s.	n.s.	n.s.

Note. RQ = research question; NH = normal hearing; n.s. = not significant; PPVT = Peabody Picture Vocabulary Test; CL-NWR = Crosslinguistic Nonword Repetition.

Our first expectation based on the difference in levels of processing (i.e., phonetic, phonological, and morphological) was that suffixation would be the most salient cue since it consists in adding material after the stem, followed by umlaut, which is a change in a stem-medial vowel and that voicing alternation would be the least salient cue as it is a phonetic alternation in a stem-final consonant following a suffixation. Our second expectation was that the plural markers involving vowels (i.e., umlaut, $-/ə/$ and $-/e/$ suffixes) would be more salient than those involving consonants (i.e., voicing of stem-final consonant, $-/s/$ and $-/n/$ suffixes): From a phonetic perspective, vowels are produced with more energy than consonants, and from a phonological perspective, they are also more sonorant than consonants; for the same reasons, we were expecting that voicing of the stem-final consonant would facilitate processing by providing additional information about the word's number.

These two expectations were, however, different for both groups due to the children's hearing abilities and the use of CIs specifically: Between-group differences in processing plural markers coming would arise from difficulties for the children with CIs to process certain speech sounds and specific phonological features (e.g., Bouton et al., 2012; Giezen et al., 2010), specifically those related to the umlaut plural. Identifying changes on the vowels' front-back dimension, which is necessary for perceiving the umlaut, strongly relies on a difference in F2 for segments that are otherwise visually ambiguously articulated. The combination of its acoustic characteristics and visual

ambiguity makes the fronting contrast especially difficult for children with CIs to process and, consequently, to produce, as evidenced by a more centralized production of front vowels than in children with NH (e.g., Verhoeven et al., 2016). Therefore, our strongest expectation was that processing vowels (i.e., umlaut) would be more challenging for the children with CIs, since the fronting of the stem-medial vowel in plural forms has been found challenging for users of CIs.

Below, we provide a step-by-step discussion of how all these expectations were met in our study for all three measurements (accuracy, RT, and gaze fixation): We first discuss the use of different linguistic processes (i.e., phonetic, phonological, and morphological), we then turn to between-group differences in processing the plural types and their segmental information, and, finally, we address how individual factors affect these three measurements.

In our study, we used three different measures, proposing a broad picture on the mechanisms at play in comprehension of plural: accuracy of picture selection, RT as an indicator of certainty of decision, and fixation toward target as an index of information processing. The main motivation behind our study was to understand the use of different phonetic, phonological, and morphological cues in children with CIs and children with NH (Research Question 1): We hypothesized that the processing of a speech sound or of a morpheme was directly related to their salience, which would be reflected in a delayed processing pattern for the children with CIs when compared

to their peers with NH. On the one hand, not all three measurements (accuracy, RT, and gaze fixation) are affected in the same way by the factors of interest, and we do not find a clear and general preference for one plural type in our measurements. Accuracy is not different across plural types, and we did not find an effect of the type of cues that mark the plural. However, the analyses of gaze fixation show a clear effect for suffix as the easiest cue to process, stem vowel (i.e., umlaut) as the most difficult cue to process, and voicing as nonrelevant for comprehension and processing. This suggests that indeed not all cues to plural are processed similarly, with morphological material (i.e., suffixes) being easier to process than phonological material (i.e., umlaut) and, finally, phonetic information (i.e., voicing). This is in contradiction with our expectation that all vowel cues are more salient than consonantal cues but consistent with the study by Saiegh-Haddad et al. (2012) on Palestinian Arabic that found differential processing of the different types of material used in plural marking, namely, better accuracy with suffixation than with stem changes. Finally, the syllabic *-ə/* suffix is processed faster than the segmental *-n/* and *-s/* suffixes. This is in line with the better accuracy found for syllabic than segmental suffixes in the study by Davies, Xu Rattanasone, Davis, and Demuth (2020) in English and supports our argumentation that syllabic suffixes are more salient than segmental suffixes, due in part to a higher salience of cues realized by vowel material and the subsequent resyllabification of the stem.

On the other hand, our results only showed a between-group difference for accuracy (i.e., lower for children with CIs) but not one for RTs or gaze fixation. This does not support our overall expectation related to the children's hearing abilities: The processing abilities of this specific group of children with CIs have indeed been developed and caught up with their age-matched peers and only minor difficulties remain in identifying the accurate target number, which is possibly linked to the quality of the signal provided by the CIs. This is consistent with the production study by Penke and Wimmer (2018), in which children with CIs had caught up with their peers with NH at the age of 6 years, and with the study by Faes et al. (2015) that showed that the morphological development of children with CIs had reached that of children with NH by the age of 5 years. However, our results contrast with the comprehension study by Davies et al. (2023), which found that processing singular versus plural auxiliary led to delayed processing in 8- to 12-year-old children with HL when compared with age-matched peers with NH. Note that in that specific study and unlike our present study, the group of children with HL was quite heterogeneous as far as hearing devices were concerned (types of devices, age at first fitting, and duration of device use). Our next result indicated that processing is

different for singular and plural targets, as evidenced by quicker response times and earlier fixation to plural target pictures, whereas accuracy is similar for singular and plurals. For plural items, pictures contain more visual information (i.e., for plural items, two objects of the same size are presented in the same space as for the singular items) and could, therefore, gain more attention from the children. Furthermore, this preferential fixation toward plural targets is consistent with the studies by Davies et al. (2019) in 3- and 4-year-old children with typical development and Davies et al. (2023) in school-age children with and without HL. When it comes to processing phonetic, phonological, and morphological material, we expected the two groups of children of our study to show different processing patterns (Research Question 1), coming from their different hearing abilities, especially when plural markers include a vowel change (i.e., umlaut). This is not the case, as evidenced by the similarity in processing by the two groups: The difference in the plural markers' salience that is coming from their different speech sounds did not result in a different processing pattern in the two groups of children.

Finally, our study was also interested in the effects of individual factors on the development of processing (Research Question 2). All the three measurements (i.e., accuracy, RT, and gaze) proved to be affected by chronological age, indicating that even though the two groups of children process plural marking in a similar way, it still evolves and has not fully stabilized by the age of 11 years: Accuracy is higher in older children, almost reaching ceiling, RT decreases with age, and gaze fixation is also affected by age. More specifically for gaze fixation, specific effects of individual factors on the processing of plural versus singular target were found in the form of different effects of vocabulary development on gaze fixation toward singular and plural targets (i.e., only singular targets are affected by vocabulary development); this might indicate a difference in certain lexical representations that is not fully stabilized up to the age of 11 years. Note that we chose not to analyze possible effects of hearing age in the group of children with CIs: Since the group is very homogeneous as they all had early implantation between 0;5 and 1;10 years, their hearing age is strongly correlated with their chronological age, and any findings for hearing age might prove to be a hidden effect of chronological age. In this study, we chose to consider chronological age over hearing age: All of the children with CIs in this study had early diagnoses of HL along with early age at implantation; however, due to this fact, we do not have enough information about the quality of the input they had received prior to implantation, both with and without HAs. For this reason, both groups were matched in chronological age, not in hearing age. Taken together, the absence of a group effect and the presence of an age effect

indicate that despite a later access to input, and despite input that is qualitatively different as provided by CIs, these children with CIs seem able to catch up with their peers with NH and follow the same developmental trajectory.

Conclusions

This study's contribution is to question the role of the intrinsic phonetic, phonological, and morphological characteristics of plural marking in its processing and the influence of their segmental salience on the processing of plural in children with CIs, who only receive an incomplete (and later) input through their CIs. We were able to show that not all cues are processed equally, specifically suffixes in German seem easier to process than stem-vowel changes, although they are not necessarily more salient. Importantly, the differences in salience of the cues to plural do not prevent this homogeneous group of children with CIs with early identification of HL and early cochlear implantation before the age of 2 years to develop processing abilities that appear comparable to those of their peers with NH.

Data Availability Statement

The data are available from the first author upon request.

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References

- Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19(6), 716–723. <https://doi.org/10.1109/TAC.1974.1100705>
- Albirini, A. (2015). Factors affecting the acquisition of plural morphology in Jordanian Arabic. *Journal of Child Language*, 42(4), 734–762. <https://doi.org/10.1017/S0305000914000270>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>
- Behrens, H. (2002). Learning multiple regularities: Evidence from overgeneralization errors in the German plural. In A. H.-J. Do, L. Domínguez, & A. Johansen (Eds.), *Proceedings of the 26th Annual Boston University Conference on Language Development* (Vol 1., pp. 72–83). Cascadilla Press.
- Behrens, H. (2011). Cues to form and function in the acquisition of German number and case inflection. In E. V. Clark & I. Arnon (Eds.), *Experience, variation, and generalization: Learning a first language* (pp. 35–51). Benjamins. <https://doi.org/10.1075/tilar.7.03beh>
- Berko, J. (1958). The child's learning of English morphology. *Word*, 14(2–3), 150–177. <https://doi.org/10.1080/00437956.1958.11659661>
- Boersma, P., & Weenink, D. (2020). *Praat: Doing phonetics by computer* (Version 6.1.23) [Computer software]. Retrieved September 28, 2020, from <http://www.praat.org/>
- Boons, T., De Raeye, L., Langereis, M., Peeraer, L., Wouters, J., & Van Wieringen, A. (2013). Expressive vocabulary, morphology, syntax and narrative skills in profoundly deaf children after early cochlear implantation. *Research in Developmental Disabilities*, 34(6), 2008–2022. <https://doi.org/10.1016/j.ridd.2013.03.003>
- Bouton, S., Serniclaes, W., Bertocini, J., & Cole, P. (2012). Perception of speech features by French-speaking children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, 55(1), 139–153. [https://doi.org/10.1044/1092-4388\(2011/10-0330\)](https://doi.org/10.1044/1092-4388(2011/10-0330))
- Caselli, M. C., Rinaldi, P., Varuzza, C., Giuliani, A., & Burdod, S. (2012). Cochlear implant in the second year of life: Lexical and grammatical outcomes. *Journal of Speech, Language, and Hearing Research*, 55(2), 382–394. [https://doi.org/10.1044/1092-4388\(2011/10-0248\)](https://doi.org/10.1044/1092-4388(2011/10-0248))
- Chiat, S. (2015). Non-word repetition. In S. Armon-Lotem, J. de Jong, & N. Meir (Eds.), *Methods for assessing multilingual children: Disentangling bilingualism from language impairment* (pp. 125–150). Multilingual Matters. <https://doi.org/10.21832/9781783093137-008>
- Clahsen, H., Rothweiler, M., Woest, A., & Marcus, G. F. (1992). Regular and irregular inflection in the acquisition of German noun plurals. *Cognition*, 45(3), 225–255. [https://doi.org/10.1016/0010-0277\(92\)90018-D](https://doi.org/10.1016/0010-0277(92)90018-D)
- Clements, G. N. (1990). The role of the sonority cycle in core syllabification. *Papers in Laboratory Phonology*, 1, 283–333. <https://doi.org/10.1017/CBO9780511627736.017>
- Clements, N. (2005). Does sonority have a phonetic basis? Comments on the chapter by Vaux. In E. Raimy & C. Cairns (Eds.), *Contemporary views on architecture and representations in phonological theory*. MIT Press.
- Davies, B., Holt, R., & Demuth, K. (2023). Children with hearing loss can use subject-verb agreement to predict during spoken language processing. *Journal of Experimental Child Psychology*, 226, Article 105545. <https://doi.org/10.1016/j.jecp.2022.105545>
- Davies, B., Xu Rattanasone, N., Davis, A., & Demuth, K. (2020). The acquisition of productive plural morphology by children with hearing loss. *Journal of Speech, Language, and Hearing Research*, 63(2), 552–568. https://doi.org/10.1044/2019_JSLHR-19-00208
- Davies, B., Xu Rattanasone, N., & Demuth, K. (2017). Two-year-olds' sensitivity to inflectional plural morphology: Allomorphic effects. *Language Learning and Development*, 13(1), 38–53. <https://doi.org/10.1080/15475441.2016.1219257>
- Davies, B., Xu Rattanasone, N., & Demuth, K. (2020). Acquiring the last plural: Morphophonological effects on the comprehension of /-əz/. *Language Learning and Development*, 16(2), 161–179. <https://doi.org/10.1080/15475441.2020.1717956>
- Davies, B., Xu Rattanasone, N., Schembri, T., & Demuth, K. (2019). Preschoolers' developing comprehension of the plural:

- The effects of number and allomorphic variation. *Journal of Experimental Child Psychology*, 185, 95–108. <https://doi.org/10.1016/j.jecp.2019.04.015>
- Drennan, W. R., & Rubinstein, J. T.** (2008). Music perception in cochlear implant users and its relationship with psychophysical capabilities. *Journal of Rehabilitation Research and Development*, 45(5), 779–790. <https://doi.org/10.1682/JRRD.2007.08.0118>
- Duchesne, L., Sutton, A., & Bergeron, F.** (2009). Language achievement in children who received cochlear implants between 1 and 2 years of age: Group trends and individual patterns. *Journal of Deaf Studies and Deaf Education*, 14(4), 465–485. <https://doi.org/10.1093/deafed/enp010>
- Faes, J., Gillis, J., & Gillis, S.** (2015). Syntagmatic and paradigmatic development of cochlear implanted children in comparison with normally hearing peers up to age 7. *International Journal of Pediatric Otorhinolaryngology*, 79(9), 1533–1540. <https://doi.org/10.1016/j.ijporl.2015.07.005>
- Fletcher, H.** (1931). Some physical characteristics of speech and music. *Bell System Technical Journal*, 10(3), 349–373. <https://doi.org/10.1002/j.1538-7305.1931.tb01281.x>
- Geers, A. E., & Nicholas, J. G.** (2013). Enduring advantages of early cochlear implantation for spoken language development. *Journal of Speech, Language, and Hearing Research*, 56(2), 643–655. [https://doi.org/10.1044/1092-4388\(2012/11-0347\)](https://doi.org/10.1044/1092-4388(2012/11-0347))
- Giezen, M. R., Escudero, P., & Baker, A.** (2010). Use of acoustic cues by children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, 53(6), 1440–1457. [https://doi.org/10.1044/1092-4388\(2010/09-0252\)](https://doi.org/10.1044/1092-4388(2010/09-0252))
- Grandon, B., Schlechtweg, M., & Ruigendijk, E.** (2023). Processing of noun plural marking in German-speaking children: An eye-tracking study. *Journal of Child Language*. <https://doi.org/10.1017/S0305000923000521>
- Hinnerichs, J.** (2016). *Spezifische Sprachentwicklungsstörungen bei Kindern mit Deutsch als Zweitsprache. Zur Eignung des Nachsprechens von quasi-universalen Nichtwörtern als Differentialdiagnostik* [Specific language development disorders in children with German as a second language. On the suitability of repeating quasi-universal non-words as a differential diagnosis] [Unpublished master's thesis].
- Jung, J., & Ertmer, D. J.** (2018). Grammatical abilities in young cochlear implant recipients and children with normal hearing matched by vocabulary size. *American Journal of Speech-Language Pathology*, 27(2), 751–764. https://doi.org/10.1044/2018_AJSLP-16-0164
- Kauschke, C., Kurth, A., & Domahs, U.** (2011). Acquisition of German noun plurals in typically developing children and children with specific language impairment. *Child Development Research*, 2011, Article 718925. <https://doi.org/10.1155/2011/718925>
- Köpcke, K.-M.** (1988). Schemas in German plural formation. *Lingua*, 74(4), 303–335. [https://doi.org/10.1016/0024-3841\(88\)90064-2](https://doi.org/10.1016/0024-3841(88)90064-2)
- Korecky-Kröll, K., Libben, G., Stempfer, W. N., Wiesinger, J., Reinisch, E., Bertl, J., & Dressler, W. U.** (2012). Helping a crocodile to learn German plurals: Children's online judgment of actual, potential and illegal plural forms. *Morphology*, 22(1), 35–65. <https://doi.org/10.1007/s11525-011-9191-8>
- Krech, E.-M., Stock, E., Hirschfeld, U., & Anders, L.-C.** (2009). *Deutsches Aussprachewörterbuch* [German pronunciation dictionary]. De Gruyter Mouton. <https://doi.org/10.1515/9783110215564>
- Laaha, S., Blineder, M., & Gillis, S.** (2015). Noun plural production in preschoolers with early cochlear implantation: An experimental study of Dutch and German. *International Journal of Pediatric Otorhinolaryngology*, 79(4), 561–569. <https://doi.org/10.1016/j.ijporl.2015.01.029>
- Laaha, S., Ravid, D., Korecky-Kröll, K., Laaha, G., & Dressler, W. U.** (2006). Early noun plurals in German: Regularity, productivity or default? *Journal of Child Language*, 33(2), 271–302. <https://doi.org/10.1017/S0305000906007379>
- Lenhard, A., Lenhard, W., Segerer, R., & Suggate, S.** (2015). *Peabody Picture Vocabulary Test-4. Ausgabe*. Pearson.
- Marcus, G. F.** (1995). Children's overregularization of English plurals: A quantitative analysis. *Journal of Child Language*, 22(2), 447–459. <https://doi.org/10.1017/S0305000900009879>
- Penke, M., & Wimmer, E.** (2018). Deficits in comprehending wh-questions in children with hearing loss—The contribution of phonological short-term memory and syntactic complexity. *Clinical Linguistics & Phonetics*, 32(3), 267–284. <https://doi.org/10.1080/02699206.2017.1350883>
- Ravid, D., & Schiff, R.** (2009). Morphophonological categories of noun plurals in Hebrew: A developmental study. *Linguistics*, 47(1), 45–63. <https://doi.org/10.1515/LING.2009.002>
- R Core Team.** (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Ruigendijk, E., & Friedmann, N.** (2017). A deficit in movement-derived sentences in German-speaking hearing-impaired children. *Frontiers in Psychology*, 8, Article 689. <https://doi.org/10.3389/fpsyg.2017.00689>
- Saiegh-Haddad, E., Hadieh, A., & Ravid, D.** (2012). Acquiring noun plurals in Palestinian Arabic: Morphology, familiarity, and pattern frequency. *Language Learning*, 62(4), 1079–1109. <https://doi.org/10.1111/j.1467-9922.2012.00727.x>
- Schouwenaars, A., Finke, M., Hendriks, P., & Ruigendijk, E.** (2019). Which questions do children with cochlear implants understand? An eye-tracking study. *Journal of Speech, Language, and Hearing Research*, 62(2), 387–409. https://doi.org/10.1044/2018_JSLHR-H-17-0310
- Selkirk, E.** (1984) On the major class features and syllable theory. *Language Sound Structure*, 107–136.
- Szagan, G.** (2000). The acquisition of grammatical and lexical structures in children with cochlear implants: A developmental psycholinguistic approach. *Audiology and Neurotology*, 5(1), 39–47. <https://doi.org/10.1159/000013864>
- Szagan, G.** (2002). The acquisition of grammar in young German-speaking children with cochlear implants and with normal hearing. In K. Schauwers, P. Govaerts, & S. Gillis (Eds.), *Language acquisition in young children with cochlear implant (Antwerp Papers in Linguistics 102)* (pp. 40–60). University of Antwerp.
- Tuller, L., & Delage, H.** (2014). Mild-to-moderate hearing loss and language impairment: How are they linked? *Lingua*, 139, 80–101. <https://doi.org/10.1016/j.lingua.2013.10.009>
- van Rij, J., Wieling, M., Baayen, R., & van Rijn, H.** (2020). *Itsa-dug: Interpreting time series and autocorrelated data using GAMMs* (R package Version 2.4).
- Verhoeven, J., Hide, O., De Maeyer, S., Gillis, S., & Gillis, S.** (2016). Hearing impairment and vowel production. A comparison between normally hearing, hearing-aided and cochlear implanted Dutch children. *Journal of Communication Disorders*, 59, 24–39. <https://doi.org/10.1016/j.jcomdis.2015.10.007>
- Wiese, R.** (2009). The grammar and typology of plural noun inflection in varieties of German. *The Journal of Comparative Germanic Linguistics*, 12(2), 137–173. <https://doi.org/10.1007/s10828-009-9030-z>
- Wilson, J., Hartley, A., Sharoff, S., & Stephenson, P.** (2010). Advanced corpus solutions for humanities researchers. *Proceedings of PACLIC 24, Sendai, Japan*, 769–778. <https://aclanthology.org/Y10-1089>

-
- Wood, S. N.** (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 73(1), 3–36. <https://doi.org/10.1111/j.1467-9868.2010.00749.x>
- Young, G. A., & Killen, D. H.** (2002). Receptive and expressive language skills of children with five years of experience using a cochlear implant. *Annals of Otology, Rhinology & Laryngology*, 111(9), 802–810. <https://doi.org/10.1177/000348940211100908>
- Zaretsky, E., Lange, B. P., Euler, H. A., & Neumann, K.** (2013). Acquisition of German pluralization rules in monolingual and multilingual children. *Studies in Second Language Learning and Teaching*, 3(4), 551–580. <https://doi.org/10.14746/ssl.2013.3.4.6>
- Zaretsky, E., Lange, B. P., Euler, H. A., & Neumann, K.** (2016). Factors considered and ignored in plural acquisition: Frequency rules? *Language and Cognition*, 8(2), 283–313. <https://doi.org/10.1017/langcog.2014.51>