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CHAPTER THREE

EYE GAZE REVEALS THAT CHILDREN WITH COCHLEAR IMPLANTS HAVE DIFFICULTY PROCESSING SUBJECT-VERB AGREEMENT

ATTY SCHOUWENAARS, PETRA HENDRIKS,
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This study investigates comprehension of subject-verb agreement by German-speaking children with cochlear implants (CIs) (n=31, 7;1-12;4, mean: 9;6) and children with normal hearing (NH) (n=36, age 7;5-10;9, mean: 9;0). Previous research has shown that young children with NH have problems in the interpretation of verb inflection. For children with CIs, the subtle verb inflection information may be even harder to detect and comprehend. In a picture selection task with eye-tracking we found that children with CIs are less sensitive to number information provided by the verb (e.g., *Sie malt/malen die Prinzessin* 'she/they paint(s) the princess) than children with NH (CI: 85% correct, NH: 96% correct). Children with higher working memory scores are better in identifying the number of the subject. In contrast to children with NH, children with CIs identify the number of the subject earlier and better in sentences with strong verbs, where the singular and plural verb forms are perceptually more distinctive, than in sentences with weak verbs. Thus both cognitive and perceptual factors play a role in the processing of subject-verb agreement by children with CIs.

1. Introduction

Previous research has shown that young children (5-6 year olds) with normal hearing (NH) have difficulty identifying the number of the subject on the basis of verbal inflection and thus comprehending subject-verb agreement (Johnson, de Villiers, and Seymour 2005; Perez-Leroux 2006;

but see Brandt-Kobele and Höhle, 2010 for contradictory results). For children with cochlear implants (CIs), the subtle verbal inflection cues may be even harder to comprehend, as the speech input in CIs is degraded (Drennan and Rubinstein 2008). A cochlear implant is a surgically implanted device that provides a sense of sound to people with severe to profound hearing loss by bypassing the malfunctioning inner ear and stimulating the auditory nerve directly. For children with CIs, morphology and syntax are vulnerable language areas. The morphosyntactic development in this group of children is strongly influenced by the perceptual prominence of the morphological cues (Svirsky, Stallings, Lento, Ying, and Leonard, 2002). We therefore expect German-speaking children with CIs to have difficulty comprehending subject-verb agreement until an even later age than children with NH, as the cues to subject-verb agreement such as number information on the subject and the verb lack perceptual prominence in German. Language development in children with CI has also been argued to be related to cognitive development such as a lower working memory capacity (Pisoni, Kronenberger, Roman, and Geers, 2011).

In this paper we aim to find out (1) whether children with CIs use number information provided by verbal inflection in comprehension and (2) whether age, perceptual prominence of inflection and working memory play a role in their processing of subject-verb agreement.

2. The acquisition of subject-verb agreement in German

In German, the subject-verb agreement system is rather simple. The number and person of the finite verb agree with the number and person of the subject. However, subject-verb agreement is found to be difficult to acquire as children use it only at an older age as a cue for subject identification in comprehension (Clahsen 1986; Lindner 2003). In this study, we focus on the number distinction between singular and plural of third person in present tense. In German, the third person singular is formed by stem +*t* and the third person plural is formed by stem +*en* for weak verbs (*spielt* ‘plays’ vs. *spielen* ‘play’). For strong verbs, there is an additional vowel change in the third person singular, which makes the singular form more distinctive from the plural (*wäscht* ‘washes’ vs. *waschen* ‘wash’).

In spontaneous speech, German children produce verbal inflection correctly already around the age of 2 (Poeppel and Wexler 1993; Rice, Noll, and Grimm 1997). However, it is unclear at what age children use verbal inflection to identify the number of the subject in comprehension. For English and Spanish, it is found that children show comprehension problems until the age of 5-6 (Johnson et al. 2005; Perez-Leroux 2006), whereas French children already show good comprehension of subject-verb agreement at the age of 2.5 (Legendre et al. 2014). For German, several studies have investigated the production of subject-verb agreement. Many of these have focused on children with specific language impairment, for which subject-verb agreement is found to be impaired (Hamann, Penner, and Lindner 1998; Clahsen, Rothweiler, Sterner, and Chilla 2014; among others). Fewer studies have studied the comprehension of subject-verb agreement in German; moreover, contradictory results are reported. For example, Brandt-Kobele and Höhle (2010) argue that 3 and 4 year olds are sensitive to verbal inflection based on their behavior in a preferential looking paradigm without any explicit comprehension task. However, these children were not able to point towards the correct interpretation above chance level in a separate picture selection task. In a next study, Brandt-Kobele and Höhle (2014) found that German 5-year-olds are able to detect agreement violations in an online sentence comprehension task. So it seems that children acquiring German are able to detect agreement violations and are sensitive to the number of verbal inflection by the age of 5, but might not be able to identify the number of the subject on the basis of verbal inflection until the age of 6 (see also similar results on Dutch in Schouwenaars, van Hout, and Hendriks 2014).

3. Language development in children with cochlear implants

Language development in children with CIs proceeds faster than language development in children with profound hearing loss using conventional hearing aids (Geers and Moog 1994; Tomblin, Spencer, Flock, Tyler, and Gantz 1999; Svirsky, Robbins, Iler-Kirk, Pisoni, and Miyamoto 2000). At the same time, there is much individual variability in language development in children with CIs (e.g., Lesinksi-Schiedat, Illg, Heermann, Bertram, and Lenarz 2004; Schouwenaars, Finke, Hendriks, and Ruigendijk, in press). Some of this variability is explained by age at implantation: children who are implanted at an earlier age have better language outcomes (o.a., Sharma, Dorman, and Spahr 2002; Harrison, Gordon, and Mount 2005). Another explanation for the observed individual variability is the cognitive variation among individuals. Children with CIs often score lower on cognitive tasks such as working memory than their normal hearing peers (van Wieringen, and Wouters, 2014), and those children with CIs with higher working memory, fluency-speed, inhibition and sequence learning skills, also have better language outcomes (Pisoni, Conway, Kronenberger, Henning, and Anaya, 2012).

Vocabulary scores of children with CIs are often similar to those of children with NH. However, their development of syntax and morphology are often delayed (Geers, Nicholas, and Sedey 2003; Caselli et al. 2012; Boons et al. 2013). This delay might be caused by a poorer language input on a qualitative and quantitative level. Instead of perceiving speech sound through thousands of hear cells that correspond to different frequencies, CI users perceive sound through at most 22 electrodes. The effective number of channels is even less due to neighboring channel interaction (Fu and Nogaki 2005). Moreover, the sound quality is further decreased due to frequency-to-place misalignments (e.g., Wilson and Dorman 2008). Thus, CIs provide qualitatively inferior language input. In addition, before implantation children may have had only little to no language input in their first year(s) of life. This might have a great impact on their language development.

As mentioned above, perceptual prominence is found to play an important role in morphosyntactic development in children with cochlear implants. For example, perceptually more salient copula such as ‘is’ and ‘are’ are produced correctly before plural forms of nouns by English children with CIs (Svirsky, Stallings, Lento, Ying, and Leonard 2002). Likewise, noun and verb inflectional forms are produced correctly before unstressed articles by German children with CIs (Szagun 2000). Furthermore, Dutch children with CIs make more errors on the inflection of finite verbs in their spontaneous speech than children with NH (Hammer and Coene 2016). Moreover, the third person singular marker *–s* has been argued to be difficult to discriminate for German children with hearing loss (Hennies, Penke, Rothweiler, Wimmer, and Henn, 2012). Taken together these results from different studies and languages suggest that perceptual prominence plays a role in comprehension as well. In the current study, German is used as the language of investigation as it enables testable predictions due to the perceptually prominent distinction between singular and plural strong verbs. We hypothesize that number is easier to distinguish and faster to identify for strong verbs that have an additional vowel change than for weak verbs for children with CIs. This is expected to show in fewer comprehension errors and earlier looks towards the target interpretation which can be detected with eye-tracking. Based on previous research, we hypothesize that demographic factors such as hearing age, as well as cognitive factors such as working memory play a role in processing subject-verb agreement.

4. Method

Participants

Thirty-one children with cochlear implants participated in this study (14 male, 16 female, age range: 7;1-12;4, mean: 9;6 years, SD: 1;6 years). These children were monolingual German, prelingually deaf, bilaterally implanted, with the first implantation before the age of 3;3 and had no additional disorders according to their medical file. As a control group, 36 typically developing monolingual German children with normal hearing participated (22 male, 14 female, age range: 7;5-10;9, mean: 9;0 years, SD: 1;1 years). All children with normal hearing were tested at the University of Oldenburg, as well as a few children with CIs, but most of the children with CIs were tested at the Cochlear Implant Center Wilhelm Hirte in Hannover. Prior to the experiment, the children's legal representatives gave written informed consent and after the experiment children received thank-you gifts for their participation. The study was approved by the Ethics Committee of the University of Oldenburg and the Hannover Medical School and in accordance with the declaration of Helsinki.

Stimuli

To examine children's comprehension of subject-verb agreement we conducted a *picture selection task with eye-tracking*. In this task two pictures were presented on the screen and a pre-recorded sentence was played via two loudspeakers (Genelec at 65 dBA). The task was to select the picture that best matched the sentence. We used declarative sentences with the ambiguous pronoun *sie*, like (1).

(1) *Sie malt/malen die Prinzessin.*
pronoun$_{SG/PL}$ paint$_{SG}$/paint$_{PL}$ the princess.
'She/They paint(s) the princess'

The German pronoun *sie* can refer either to a singular feminine referent ('she') or a plural referent ('they')[1]. In sentence (1), the number of the subject referent is therefore only identifiable by the number marking on the finite verb. Of each picture pair, one picture corresponded to the singular subject interpretation and the other to the plural subject interpretation (see

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[1] Or in fact to the formal form of the second person both singular and plural, this is not relevant for this study though.

Figure 3-1). The position of the target picture on the screen and the position of the subject referent in the pictures were balanced over four lists. Four reversible transitive verbs were used, of which two were weak verbs (*filmen* ‘to film’ and *malen* ‘to paint’) having a stem +t form for third person singular, and two were strong verbs (*fangen* ‘to catch’ and *waschen* ‘to wash’) having a stem +t and a vowel change form for third person singular. In total there were 16 items, eight in the singular and eight in the plural condition.

Figure 3-1. Example of a picture pair, one picture matching the singular interpretation of sentence (1) (left), and the other the plural interpretation (right)

Procedure

First, children’s working memory was assessed in a *digit span test* (HAWIK-IV; Petermann and Petermann, 2007). Sequences of digits were read out loud by the experimenter and the children were asked to repeat the sequence in the presented order (forward) or in the reversed order (backward). The first item of the forward session contained a sequence of three digits and the first item of the backward session a sequence of two digits. After two items with the same sequence length, the sequence length increased with one digit. The test session ended when both items of the same sequence length were recalled incorrectly. In the analyses, the total number of correct repetitions for both sessions together was taken as a measure of working memory.

The eye-tracking experiment started with a nine-point calibration, followed by two practice trials. In the practice trials, number was not contrasted in the picture pair. Instead, sentences such as *The mailman is sitting on the swing* were used with, in addition to a matching picture, a non-matching picture in which a mailman is standing next to a bike. Each item started with a familiarization phase in which the picture pair was displayed for 2500 ms. Then a fixation cross appeared on the screen and the eye-tracker had to detect a 500 ms long fixation to the cross before continuing with the item, this to ensure that participants' gaze started at the centre of the screen and was calibrated accurately. After the fixation cross, the picture pair reappeared on the screen and 50 ms later the sentence was presented. Participants had to press the button corresponding to the picture they thought best matched the sentence. Eye movements were collected at a sample rate of 300 Hz with a Tobii TX300 eye tracker in a two-computer setup. On one computer the experiment was run and behavioural data was collected with the E-Prime 2.0 software (Psychological Software Tools, Inc.). With the use of E-prime Extensions for Tobii (TET calls) eye movements were collected from the second computer. Together, the digit span task and the picture selection task took about 20 minutes.

5. Results

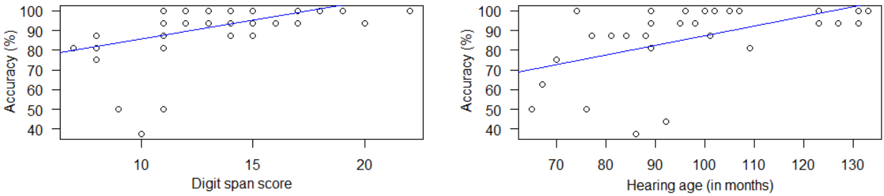
Accuracy

The mean accuracy scores by children with CIs was 85% correct (SD: 35.6) and 96% correct (SD: 19.6) by children with NH. The accuracy data was analysed by generalized linear mixed-effects regression modelling (GLMER) using lme4:glmer (Bates et al. 2015) with the software R (version 3.5.0). A first model was built to see whether there were differences between the two groups of children and between singular and plural inflection on the verb. This model contained a binomial dependent variable of item ACCURACY and random intercepts for PARTICIPANT and ITEM. The fixed factor of GROUP (CI vs. NH) was significant and improved the model ($\beta = 1.48$, $z = 3.542$, $p < .001$) based on comparisons of Akaike-Information-Criterion scores (AIC; Akaike 1974). Children with CIs scored significantly lower than children with NH. The fixed factor of CONDITION (singular vs. plural) was not significant and was therefore excluded from the model. So no difference in accuracy was found between items with a third person singular verb form and items with a third person plural verb form.

There was a lot of individual variation within the group of children with CIs, which we tried to explain in a second model. In this model, only the ACCURACY scores of the children with CIs were taken as a binomial dependent variable. Again random intercepts for PARTICIPANT and ITEM were included. Continuous variables that improved the model were DIGIT SPAN SCORE ($\beta = 0.34$, $z = 2.676$, $p < .01$) and HEARING AGE ($\beta = 0.04$, $z = 3.049$, $p < .01$), see Figure 3-2. Hearing age is the chronological age minus the age at first implantation. Note that chronological age -which was also significant- and hearing age strongly correlate (r(28)=.91, p < .001) and therefore cannot both be included in the model. Hearing age was included in the model as it was a better predictor. Not the factor of verb type, but the fixed factor of VERB showed a significant difference between the four verbs used. Scores on items with the weak verb *filmen* ‘to film’ were significantly lower than scores on items with the weak verb *malen* ‘to paint’ (β =1.12, z = 2.090, p < .05) and the strong verb *fangen* ‘to catch’ (β =1.12, z = 2.089, p < .05). To summarize, this model shows that children with a higher digit span score and children with an older hearing age have a better understanding of subject-verb agreement compared to children with a lower digit span score and children with a younger hearing age. Furthermore, the model shows that the verb used plays a role in the understanding of subject-verb agreement by children with CIs.

Figure 3-2. Mean accuracy scores in percentages per participant with CIs on the picture selection task compared to their digit span score (left) and their hearing age in months (right)

(Each dot represents one or more children with a particular score and the blue line represents the correlation)



Gaze data

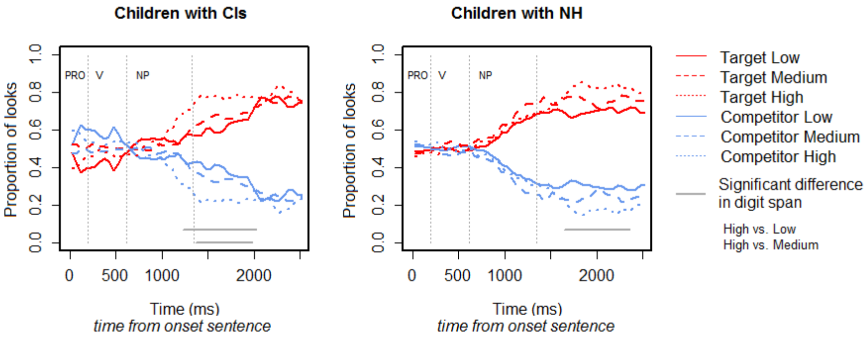
The eye movement data was analysed by generalized additive mixed modeling (GAMM) using the packages *mgcv* 1.8.4 (Wood 2006) and *itsadug* (van Rij, Wieling, Baayen, and van Rijn, 2015) in R. As GAMMs fit nonlinear trends over time, they are particularly useful for analyzing eye movements (e.g., Nixon, van Rij, Mok, Baayen, and Chen, 2016; Schouwenaars, Hendriks, and Ruigendijk, 2018). Two GAMM models were made: one to investigate the gaze patterns with regard to different digit span scores and the other with regard to different verb types. Both models contained a dependent variable that was calculated by subtracting the looks to the competitor from the looks to the competitor for timebins of 200 ms. Only the gaze data of accurate items were included and subject was included as a random effect factor. Furthermore, a 99% confidence interval was used.

For the first model, equally divided groups of digit span scores (low vs. medium vs. high) were made based on the median digit span score per group of children (CI vs. NH). The groups of digit span scores (low vs. medium vs. high) and the groups of children (CI vs. NH) were combined into one predictor with six levels. For the second model, the levels of verb type (weak vs. strong) and its interactions with group (CI vs. NH) were combined into one predictor with four levels.

Working memory

With the first GAMM model, significant differences were found in the gaze patterns of children with CIs with a high digit span score versus children with a low or medium digit span score. Figure 3-3 shows that children with CIs with a higher digit span score identify the number of the subject on the basis of the finite verb earlier and with more certainty than children with a low or medium digit span score, as the proportion of looks to the target picture shows an earlier and steeper rise in children with a higher digit span score. For children with NH significant differences are found between the high digit span group and the low digit span group after 300 ms from the offset of the sentence. For these children, looks to the target picture are higher for the high digit span group compared to the low digit span group, indicating that the high digit span group is more certain of the identification.

Figure 3-3. Eye movements in proportion of looks for children with CIs (left) and children with NH (right) from the onset of the sentence

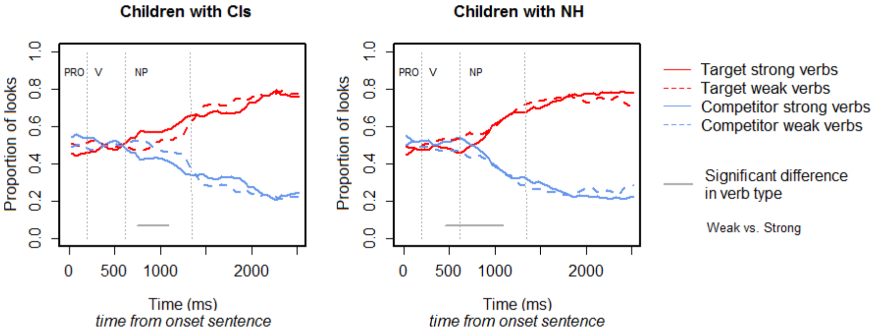


(The red lines are looks towards the target picture and the blue lines are looks towards the competitor picture of children with Low digit span (solid line), Medium digit span (dashed line) and High digit span (dotted line). A horizontal grey line indicates a significant difference between gaze patterns of the different levels of digit span, as analysed with GAMMs. The vertical dashed lines indicate the onset of the verb, the onset of the full NP and the offset of the sentence).

Weak and strong verbs

With the second GAMM model, significant differences were found between the weak and strong verbs. Figure 3-4 shows that for children with CIs looks towards the target picture increase earlier for strong verbs than for weak verbs, whereas for children with NH looks towards the target picture increase earlier for weak verbs than for strong verbs. This indicates that for children with CIs number identification of strong verbs is easier, as opposed to children with NH, for whom number identification of weak verbs is easier.

Figure 3-4. Eye movements in proportion of looks for children with CIs (left) and children with NH (right) from the onset of the sentence



(The red lines are looks towards the target picture and the blue lines are looks towards the competitor picture for items with strong verbs (solid line) and weak verbs (dashed line). A horizontal grey line indicates a significant difference between gaze patterns of the weak versus strong verbs, as analysed with GAMMs. The vertical dashed lines indicate the onset of the verb, the onset of the full NP and the offset of the sentence).

6. Discussion

Based on the results of our experiment we can conclude that children with CIs can interpret number information provided by verbal inflection relatively well. However, overall their performance is significantly lower than that of children with NH. Furthermore, there is a lot of variability in the group of children with CIs. Different eye-movement patterns were observed between the two groups of children, indicating that they process subject-verb agreement differently. In the following, we will discuss the factors explaining the variance in performance and the differences in processing.

The correct identification of subject-verb agreement was affected by *hearing age*, which is the time between first implantation and children's chronological age. The older the children's hearing age, the better their performance on the comprehension task. So especially children with a younger hearing age had problems identifying the number of the subject on the basis of inflection on the finite verb. Presumably, the younger children catch up as a result of more language experience. This observed effect of hearing age implies that children's problems with subject-verb agreement should be seen as a delay rather than an impairment. Unlike in previous studies, no effect of age at implantation was found (cf. Nicholas and Geers, 2007; Hammer and Coene, 2016). The children in the current study were all implanted before the age of 3;3, and the majority even in their first year of life. An effect of age at implantation may not have been found due to the lack of variance within the group with respect to age at implantation. Alternatively, the sensitive period for optimal cochlear implantation may be within the first 3 and a half to 4 years of life (Kral and Sharma 2012).

This study confirms that working memory capacity is associated not only with children's performance in terms of their final interpretation of the sentence, as found in previous studies (e.g., van Wieringen and Wouters 2014), but also with their processing of the sentence. The link between working memory capacity and sentence processing has found previously in reading studies with eye-tracking (Just and Carpenter 1992) and is now nicely illustrated with the use of a picture selection task in our gaze data. Especially for the group of children with CIs working memory capacity seems to matter. The gaze patterns show that children with a high working memory identify number of the subject based on verbal inflection earlier and with more certainty than children with a medium or lower working memory.

Children with CIs made significantly more errors on items with the verb *filmen* 'to film' compared to *fangen* 'to catch'. Both verbs start with a high frequency fricative which is known to be difficult to perceive by populations with hearing impairments (e.g., Elfenbein, Hardin-Jones and Davis 1994). But whereas the distinction between singular and plural for the verb *filmen* 'to film' is only present in the last morpheme (*filmt* vs. *filmen*), the distinction for the verb *fangen* 'to catch' is also present in the first morpheme due to the vowel change (*fängt* vs. *fangen*) and is therefore perceptually more prominent.[2] The vowel change may make it easier to distinguish the singular from the plural form, which could help children with CIs to identify the number of the subject through verbal inflection. In addition to the end-of-sentence interpretations, also the eye movements revealed this group difference with respect to weak versus strong verbs. For children with NH, number marking on weak verbs was identified earlier than on strong verbs. For children with NH, acquisition of subject-verb agreement in weak verbs might be easier than in strong verbs as the latter are considered part of the mental lexicon with underspecified representations (Clahsen, Prüfert, Eisenbeiss, and Cholin 2002) for which lexical retrieval processes are required that become more efficient when children get older (Clahsen and Fleischhauer 2014). For children with CIs the opposite pattern was found. Number identification was earlier for strong verbs than for weak verbs. As mentioned above, a possible explanation for the observed pattern can be found in the perceptual prominence of strong verb forms. If true, this would imply that perceptual prominence is an important factor in the morphosyntactic development of children with CIs not only in production (as found by, e.g., Svirsky et al. 2002), but also in comprehension.

In clinical practice, performance on morphosyntax and especially subject-verb agreement could be used as a diagnostic tool to detect problems in language development in children with cochlear implants.

7. Conclusion

Most 7- to 12-year-old children with cochlear implants understand subject-verb agreement, but nevertheless do so less well than their hearing peers. The longer the children have had their cochlear implant and the larger their working memory capacity, the better they are in identifying the number of the subject. In contrast to children with normal hearing, children with cochlear implants identify the number of the subject earlier and better in sentences with strong verbs, where the singular and plural verb forms are

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[2] Note that for the verb *waschen* no significant differences were found in the end-of-sentences interpretations.

perceptually more distinctive, than in sentences with weak verbs. Even though children with cochlear implants are overall less sensitive to verbal inflection than children with normal hearing when interpreting subject-verb agreement, our study suggests that their development of subject-verb agreement is merely delayed and not necessarily impaired.

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