Speech and sign perception in deaf children with cochlear implants
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6 THE RELATIONSHIP BETWEEN SIGN AND SPEECH PERCEPTION

Until now we have only considered the spoken modality in relation to language processing by children with a CI. The experiments and findings discussed in Chapters 4 and 5 provided answers to the first two research questions posed in this thesis (§2.1). In Chapter 4 we saw that children with a CI used acoustic cues in the categorization of sound contrasts largely in the same way as their peers with normal hearing, although they showed a tendency towards poorer overall discrimination of most contrasts. In Chapter 5 we saw that they had substantial difficulties learning novel minimal pairs in rapid word learning tasks. Whereas reduced task demands and better sound categorization were associated with rapid word scores for the children with normal hearing, we were unable to establish such relationships for the children with a CI.

Chapters 6 and 7 will address the two remaining research questions, namely those that concern language processing in the signed modality in relation to language processing in the spoken modality (§2.2). More specifically, in this chapter we will examine how sign perception abilities relate to speech perception abilities in the same children with a CI (§2.2.2). To that end, the two modalities were independently assessed and related to one another. In Chapter 7 the focus will be on the interaction between the two modalities in a sign-supported speech context (§2.2.3). More specifically, we will investigate whether bimodal (i.e., simultaneously spoken and signed) input hampers or facilitates speech perception in children with a CI.

In order to relate sign perception abilities to speech perception abilities, the perception tasks in both modalities needed to be as similar as possible. Thus, we designed sign perception tasks that maximally resembled the speech perception tasks discussed in Chapters 4 and 5. Following an introduction to previous research on the relationship between spoken and signed language development in children with a CI (§6.1), the research methodology in the sign perception study is discussed in §6.2. In §6.3 the results from the sign perception tasks are compared to those of the speech perception tasks presented in the two previous chapters. Correlations between the two language modalities are presented in §6.4. In §6.5 performance in both language modalities is examined in relation to the children’s signing experience. The chapter ends with conclusions presented in §6.6.
Chapter 6

6.1 BACKGROUND

As mentioned in §1.4.2, many children with a CI receive some form of signed input before and, at least for some time, after implantation. This signed input can take several forms such as an artificial sign system, a sign language, cued speech (i.e., manual cues that complement lip gestures) or combinations thereof as in many Total Communication programs (Spencer & Tomblin, 2006). The role of signing in the education of deaf children has been and is still a question of debate and controversy with the debate impacting on educational programs available in different countries (Lynas, 2005; Marschark et al., 2005; Marschark & Spencer, 2006). Newborn hearing screening programs and cochlear implantation have had a profound impact on the deaf population, but the debate and controversy remain, perhaps even more strongly than before (Leigh, 2008). Although these developments have ensured early access to spoken language input for many deaf children, the diversity in reported outcomes makes it imperative that alternative educational approaches are available for deaf children and that these approaches match the needs of individual deaf children (Knoors, 2007; Leigh, 2008).

The crucial question in this debate is how signing affects spoken language development in deaf children, more specifically those with a CI. As discussed in §1.4.2, a large number of studies have addressed the question as to whether the communication modality used with the children affects spoken language outcomes, including speech production (e.g. Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Tobey, Rekart, Buckley, & Geers, 2004; Tobey et al., 2007), speech perception (e.g. Archbold et al., 2000; Bergeson et al., 2005; Geers et al., 2003a), vocabulary knowledge (e.g. Connor et al., 2000; El-Hakim et al., 2001; Kirk et al., 2003) and more general spoken language abilities (e.g. Geers et al., 2003b; Kirk et al., 2003; Svirsky et al., 2000). However, the findings in these studies have been contradictory and both advantages and disadvantages have been reported for children in Total Communication programs compared to children in Oral Communication settings (Geers, 2006). Recall that in the latter only spoken language is used, whereas in the former spoken language as well as some form of signed communication is used (§1.4.2). Furthermore, even if spoken language development might proceed somewhat more slowly in children with a CI that receive signed input as well, no strong evidence is available that signing prevents spoken language development in any way (Leigh, 2008). As rightly pointed out by Leigh, although the time and

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31 The situation of children with a CI learning a spoken language and a sign language might resemble bilingual spoken language development in children with normal hearing, who also show delays in some linguistic domains (e.g. Bialystok, 2001, 2009; Genesee, Paradis, & Crago, 2004). However, this comparison should be applied with caution. In contrast to children with normal hearing, deaf children have limited access to both languages because of
effort invested in stimulating spoken language development is justified, it remains unknown how much exposure to spoken language is necessary for children with a CI to gain optimal benefit from their implant.

In contrast to spoken language outcomes, very few studies have examined sign language development in children with a CI (Knoors, 2006; Thoutenhoofd et al., 2005). Moreover, the few available studies are mainly limited to case descriptions of a few children (Cassandro et al., 2003; Coerts et al., 1994; Nordqvist & Nelfelt, 2004; Yoshinaga-Itano, 2006). The only exception is De Raeve et al. (2009; see also Wiefferink et al., 2008), who reported data from a longitudinal study on the influence of linguistic environment on language outcomes in a group of 22 children with a CI educated in either a spoken language (supported with signs) plus a sign language \((n=7)\) or sign-supported speech only \((n=15)\). In addition to the spoken modality, the children educated in sign-supported speech plus a sign language and a subset of the children educated in sign-supported speech only were also assessed in the signed modality. The authors concluded that speech perception, speech production and spoken language abilities developed more rapidly in the children without a sign language in their input. However, they noted that the children without a sign language had been diagnosed and implanted at an earlier age than the children with a sign language, and that this could also explain their findings. Spoken and signed language abilities were only directly compared in the children educated in sign-supported speech plus a sign language. The obtained measures included mean length of utterance, number of spoken and signed utterances, and number of words and signs used in spontaneous language samples. The number of words and spoken utterances as well as the number of signs and signed utterances increased in the course of the study, but slightly faster for the spoken modality. Initially mean length of utterance was longer in signed utterances than in spoken utterances, but by the end of the study it was the opposite.

Klatter-Folmer et al. (2006) followed six deaf children of deaf and hearing parents longitudinally over a period of three years from 3;5. They analyzed lexical richness, syntactic complexity, language dominance and interactional participation in semi-structured conversations. Three children received a CI in the course of the study. The authors concluded that the development in both language modalities was intertwined in these children and that signing did not have a negative effect on their spoken language development (cf. Coerts et al., 1994). In fact, syntactic complexity was highest for mixed utterances, i.e., utterances with both speech and signs.

This latter finding raises an interesting question, namely whether using speech and signs simultaneously might have an additive advantage to using either of them separately. Being bilingual in a spoken language and a sign language, i.e., bimodal

their hearing difficulties and because most of them have hearing parents and receive non-native signed input (see §2.2.1).
bilingualism, offers a unique opportunity to produce two languages at the same time, which is physically impossible for bilinguals in two spoken languages, i.e., unimodal bilinguals. Simultaneous production of words and signs is called code-blending and occurs quite frequently in conversations among bimodal bilinguals (Bishop, 2006a; Emmorey, Borinstein, Thompson, & Gollan, 2008), sometimes even in conversations between bimodal bilinguals and non-signers (Casey & Emmorey, 2009). Hearing children from deaf parents have also been found to frequently produce code-blended utterances, more so than deaf children from deaf parents (Baker & Van den Bogaerde, 2008; Van den Bogaerde & Baker, 2005, 2008). The study of bimodal bilingualism and possible implications for children with a CI will be further considered in Chapter 7, which will examine bimodal perception in children with a CI.

Here, we will focus on how sign and speech perception interrelate in children with a CI. Speech perception in this population has been discussed in detail in §2.1, but practically nothing is known about their sign perception. In fact, very few studies have examined sign perception in deaf children (e.g. Ormel et al., 2009). In addition, two studies investigated sign perception by hearing non-signing infants (Baker, Golinkoff, & Petitto, 2006; Krentz & Corina, 2008). Lederberg and colleagues have investigated rapid word and sign learning in deaf children with acoustic hearing aids or CIs, but did not explicitly distinguish between both language modalities (Lederberg & Spencer, 2009; Lederberg et al., 2000).

The rationale behind the comparison between sign and speech perception abilities in the present chapter is as follows. If signing experience had a direct negative impact on spoken language outcomes in children with a CI, relatively high sign perception abilities would result in relatively low speech perception abilities and vice versa. For such a direct comparison, it is imperative that the tasks in both modalities measure the same underlying constructs and are as similar as possible. As already described in §2.2, studies with deaf signing adults have shown that many processes involved in speech and sign perception are comparable, including pre-lexical perception, lexical processing and phonological storage (for a review, see Emmorey, 2007). To further facilitate the comparison between the two modalities, we designed a sign categorization task, two rapid sign learning tasks and a phonological short-term memory task for signs that maximally resembled the auditory counterparts described in Chapters 4 and 5. Similar to the speech perception tasks, the same phonetic contrasts, namely a hand configuration and a location contrast, were tested in the sign categorization and the rapid sign learning tasks.

Performance on the speech and sign perception tasks will be compared for children with a CI, age-matched children with normal hearing with no signing experience and young adult second language learners of Sign Language of the Netherlands (NGT, Nederlandse Gebarentaal). This first analysis will show the
relative performance levels in both modalities across groups. In addition, correlation analyses between both modalities will be performed for the children with a CI. Finally, a comparison of two subgroups of the children with a CI, divided according to their signing experience, will be presented.

6.2 METHODOLOGY

6.2.1 PARTICIPANTS

Participants were 15 children with a CI (mean age: 5;8), 10 children with normal hearing with no signing experience (mean age: 6;0) and 11 young adult second language learners of NGT with 1-2 years of signing experience (mean age: 21;7). The children with normal hearing and the adults were subsets of those reported for the speech perception experiments in Chapters 4 and 5 (see also §3.1).

6.2.2 MATERIALS

6.2.2.1 SIGN CATEGORIZATION

To measure pre-lexical sign perception, a sign categorization task was designed using E-Prime® v2.0 software (Psychology Software Tools, Pittsburgh PA). Similar to the sound categorization task discussed in §4.2.3, the task was designed according to an XAB format. Two phonetic contrasts were included in the task: a hand configuration and a location contrast. The stimuli were still images that represented a continuum between two endpoint hand configurations or locations in signing space. These stimuli had previously been used by Emmorey et al. (2003) and permission was obtained from the first author to use their stimuli. The stimuli series had been created with 3-D animation software (Poser from MetaCreations) by linear interpolation from the two endpoints in ten steps, resulting in 11 stimuli for each contrast (for details, see Emmorey et al., 2003). The stimuli series for the hand configuration and location contrasts are shown in Figure 6.1 and 6.2, respectively and will further be referred to as /open/-/closed/ (hand configuration) and /eye/-/chin/ (location). The stimuli were projected directly above animation monkey pictures, associated with X, A and B. An example of what a categorization trial looked like is provided in Figure 6.3. We chose to use the animation monkey pictures to increase similarity to the sound categorization task. If we had directly asked the participants to choose between the two endpoint stimuli images (the
stimuli associated with A and B in Figure 6.3), the endpoint stimuli would have been perceptually available to participants when they had to indicate their choice for A or B, which was not the case in the sound categorization task.

Figure 6.1. Stimuli series for the hand configuration contrast representing a gradual change from an open flat hand (referred to in the text as open) to a closed fist (referred to in the text as closed).

Figure 6.2. Stimuli series of for the location contrast representing a gradual change from a location near the eye (referred to in the text as eye) to a location near the chin (referred to in the text as chin).
Inter-stimulus and inter-trial intervals were the same as in the sound categorization task, as was randomization of stimuli presentation. Children performed on one contrast only in order to reduce the length of testing (cf. §4.2.3), while adults performed on both contrasts and had a brief pause between contrasts. Presentation of contrasts was counterbalanced across viewers. Prior to the test session, children completed a practice session consisting of four trials using the contrast they were not tested on. For adults, the practice session consisted by necessity of trials from a contrast they were also tested on. The task took between 5 and 10 minutes for children and 10 and 15 minutes for adults. Participants were told that two monkeys would try to imitate the signs of a third monkey and that they had to decide which of the two succeeded best. Data analysis proceeded in the same way as for the sound categorization task reported in §4.2.4. However, given that a single visual cue was manipulated in both phonetic contrasts, the dependent variables were only phoneme endpoint identification (§4.2.4.1) and classification slope (§4.2.4.2).

6.2.2.2 PICTURE-MATCHING

E-Prime® v2.0 software (Psychology Software Tools, Pittsburgh PA) was used to create a non-sign picture-matching task similar in design to the non-word picture matching task discussed in §5.2.2.1. Instead of auditory stimuli, video stimuli were presented, consisting of a target sign (either a non-sign or a familiar sign) embedded in a carrier phrase: “KIJK, X!” (LOOK, X!) during familiarization, and “WAAR X?”

Figure 6.3. Example of a trial in the sign categorization task. Presentation of stimulus X (1) was followed by presentation of stimuli A and B (2). X, A, and B were presented together with animation monkey pictures. In their response, participants had to choose between the two animation monkey pictures associated with the A and B stimulus (3).
(WHERE X?) during testing. The video stimuli were recorded against a blue-grey background to optimize visibility of the signs. Because the experimenter, a second language learner of NGT, administered the signed object-matching task (§6.2.2.3), he also signed the stimuli for the picture-matching task. The recorded stimuli were captured, digitized and compressed to WMV format (440 kbps, 25 fps, 360x280 pixels) using Pinnacle® Studio 11. They averaged about 3000 milliseconds in duration.

Minimal non-sign pairs were created by the experimenter and non-sign status was checked by native signers of NGT and Flemish Sign Language (VGT, Vlaamse Gebarentaal). The non-signs included both one-handed and two-handed signs. The minimal non-sign pairs were distinguished by hand configuration (open-closed) or location (eye-chin), as in the sign categorization task. In total, six non-sign pairs were formed; three pairs for each phonological contrast (illustrated in Appendix D). One pair for each contrast was presented in the picture-matching task, the other two in the object-matching task (see §6.2.2.3). In addition, two familiar signs that were the same for NGT and VGT were selected as filler stimuli from NGT teaching material for young deaf children because ratings of signs for age of acquisition are not available for NGT or VGT (RIEM, ‘belt’ and SCHAAR, ‘scissors’). Finally, drawings of novel and familiar objects were selected from the same databases as for the non-word picture-matching task (§5.2.2.1).

The experiment was divided into two blocks, corresponding to two stimulus sets of one minimal non-sign pair and one familiar sign. Familiarization and testing phase were as in the non-word picture-matching task, i.e., nine familiarization trials followed by ten two-alternative forced choice identification trials including two incongruent trials. In the familiarization trials and the testing trials, the novel objects were presented 25% upwards from the center of the screen and the video stimuli 25% downwards.

The task took children approximately ten minutes and adults five minutes. They were told that they would be presented with novel and familiar signs together with pictures of novel and familiar objects, and that they had to remember which sign was associated to which object. Presentation of the two blocks was counterbalanced across participants within each group. The blocks were separated by a brief pause to prepare the participants for the next block and to provide non-specific feedback to motivate the children. The task was preceded by a practice block with two phonologically dissimilar non-signs (see Appendix D) and a familiar sign.

Accuracy and reaction times were automatically recorded within the program. Accuracy was defined as the number of trials correctly answered (maximum score was 2 blocks x 8 trials = 16). Reaction times were measured from the offset of the

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The common practice of representing glosses of signs in small capitals is followed here (Baker, Van den Bogaerde, & Woll, 2005a).
The relationship between sign and speech perception

video stimulus to the overt response, i.e., the key press. As in the non-word picture
matching task, reaction times were analyzed separately for the trials with two novel
objects, the congruent filler trials and the incongruent filler trials. Furthermore, only
trials correctly answered were analyzed and trials with reaction times more than 2.5
standard deviations above and below the mean reaction time for each participant
were excluded, resulting in the exclusion of 4.0% of the trials for the children with a
CI, 1.4% for the children with normal hearing and 2.9% for the adults. The
difference in reaction times for the congruent and incongruent filler trials was used
as an index of sensitivity to a switch in sign-object mappings.

6.2.2.3 OBJECT-MATCHING

The object-matching task discussed in §5.2.2.2 was also administered in a sign
condition (see §3.1). Similar to the speech condition, it consisted of three subtests: a
novel sign learning test, a generalization test and a rapid sign learning test. The only
difference with the speech condition was that minimal non-sign pairs and familiar
signs were presented together with novel and familiar objects.

In the rapid sign learning test, the objects were placed in random order on the
table in front of the child and were labeled once from left to right with the phrase
'KJK, X!' (LOOK, X!), accompanied by pointing to the objects. The three objects were
then labeled again from left to right, accompanied by pointing. As in the speech
condition, familiarization was followed by three test trials in which the children
were asked to point to one of the three objects in response to the question 'WAAR X?'
(WHERE X?). The same procedure as for the speech condition was adopted here, i.e.,
the experimenter asked for both novel objects or for a single novel object twice. The
non-signs originated from the set of non-signs mentioned above (§6.2.2.2). In
addition, two familiar signs that were the same for NGT and VGT were selected as
filler stimuli from NGT teaching material for young deaf children (PET ‘cap’ and
BRIL ‘glasses’). Similar to the speech condition, uncommonly and frequently used
objects such as different types of kitchen utensils were used as novel objects and
familiar objects, respectively.

Two blocks, corresponding to two stimulus sets, were administered in a fixed
order (hand configuration contrast followed by location contrast). The task took
approximately five minutes. The children were told that they would be presented
with novel and familiar signs together with novel and familiar objects, and that they
had to remember which sign belonged to which object. The number of trials in
which a child correctly associated the non-sign with the correct novel object was
used as the dependent variable in the analysis. Presentation of the non-sign pairs for
each contrast in the two rapid sign learning tasks was counterbalanced across
participants such that subsets of participants were presented with different non-sign
pairs in the same task, but they were never presented with the same non-sign pair twice across tasks.

Importantly, this task was also administered to the children with a CI in a speech plus sign (i.e., bimodal) condition. The bimodal condition was included as a preliminary investigation of the effects of bimodal input as compared to spoken or signed input alone, a topic that will be addressed in more detail in Chapter 7. Familiarization and testing phases were presented simultaneously in speech and sign to the child. Four stimulus sets were created by arbitrarily pairing a non-word pair with a non-sign pair. These had not yet been presented to the child in the speech or sign condition. The four stimulus sets, corresponding to four blocks, were administered in the following order for all participants: /ɑ/-/a/ + /open/-/closedl → /bl/-/p/ + /leyel/-/chinl → /d/-/l/ + /open/-/closedl → /f/-/s/ + /eye/-/chinl. The task took approximately ten minutes to complete. Children were told that, this time, they would be presented with novel and familiar words and signs at the same time and that they had to remember which words and signs belonged to which object. Scoring proceeded in the same way as for the other conditions.

6.2.2.4 DIGIT SPAN

A signed digit span was created in the same way as the auditory digit span task discussed in §5.2.2.3. It consisted of 15 sequences of five different lengths (i.e., three sequences for each length), ranging from two to six digits. As in the auditory digit span task, inter-stimulus interval was set at 2000 milliseconds. To allow comparison with the spoken version the digits 7 and 9 were also excluded. The video stimuli for the digit span task were signed by the experimenter using the same recording equipment and background as for the non-sign picture matching task (§6.2.2.2). The digits were produced in neutral signing space and only the torso of the signer was visible in the recordings. The signer’s hands returned to rest position (off screen) between subsequent digits. Presentation and scoring was equal to the spoken version, including the presentation of a two-digit practice sequence at the beginning. The task took approximately five minutes for children and adults. They were told that they would see sequences of signed digits that they had to memorize and then recall in the same order as they were presented.

Most stimuli presented in the bimodal condition originated from the larger set of (non-)words and (non-)signs referred to in §5.2.2.1 and §6.2.2.2, respectively. However, because only two phonetic contrasts were included in the rapid sign learning tasks, as opposed to four in the rapid word learning tasks, two additional non-sign pairs were created and presented in this condition. These non-sign pairs contrasted minimally in the same hand configuration or location as the larger set of non-sign pairs and are also included in Appendix D). Non-sign status was checked by native NGT and VGT signers.
Importantly, it has been observed that digit spans differ across languages due to cross-linguistic differences in the number of syllables in words for digits (e.g., Olazaran, Jacobs, & Stern, 1996). Such cross-linguistic differences are not relevant here, however, because the digits included were monosyllabic in both language modalities (but see Bavelier et al., 2006; Boutla et al., 2004; Emmorey & Wilson, 2005; Wilson & Emmorey, 2006 and also §2.2.2 for discussion on possible cross-modality differences in digit spans).

6.2.3 Statistical Analysis

The non-parametric Wilcoxon Signed Rank test was used to compare performance on the sound and sign categorization tasks. The parametric repeated measures ANOVA was used to compare performance in the two modalities on the other tasks. Independent and paired samples t-tests were used for post hoc comparisons, where the t statistic for unequal variances was adopted in case of a significant Levene’s test for equality of variances. In all group wise post hoc comparisons, a correction was applied to adjust for multiple comparisons and the significance cut-off was .02 (α/n=.05/3=.02). Only participants that completed a task in both modalities were included in the analyses. As in Chapter 5, in correlation analyses Pearson product moment correlation coefficients are reported when two normally-distributed variables were correlated, while Spearman rho rank-based coefficients are reported when at least one of the two variables was non-normally distributed.

The results are discussed in three sections. First, we compare relative performance in both language modalities across groups (§6.3.1). Next, we present the correlation analyses (§6.3.2). Finally, we compare results from two subgroups of children with a CI formed on the basis of their signing experience (§6.3.3). Individual results for the children with a CI are provided in Appendix C.

6.3 Relative Performance in Both Language Modalities

The analyses were based on different numbers of participants for each task due to missing data. These numbers are mentioned when discussing the results for a particular task. One child with a CI (J8 in Table 3.1) was excluded from all analyses because he failed to complete any of the four tasks. He had also been excluded from the analyses presented in Chapters 4 and 5 because of inattentiveness during testing. In this section, results for sign and sound categorization are presented first (§6.3.1), followed by rapid sign and word learning (§6.3.2 and §6.3.3) and phonological short-term memory (§6.3.4).
6.3.1 SIGN AND SOUND CATEGORIZATION

Data from both the sound and sign categorization tasks were available from 9 children with a CI, 10 children with normal hearing and 11 adults. Figure 6.4 illustrates the mean phoneme endpoint identification scores in both language modalities for all three groups. Because of small sample sizes, phoneme identification scores were averaged across phonetic contrasts in the statistical analysis. Separate Wilcoxon Signed Rank Tests revealed no significant difference between the two language modalities for the children with a CI ($Z=-.850, p=.40$), significantly higher scores in the spoken modality for the children with normal hearing ($Z=-2.38, p<.05$), and significantly higher scores in the signed modality for the adults ($Z=-3.04, p<.01$). Higher endpoint identification scores in the signed modality for the adults, who had only limited signing experience, were unexpected. However, it should be noted that they performed near-ceiling on this measure in both language modalities. We will therefore not further interpret this modality effect.

![Figure 6.4](Image)

**Figure 6.4.** Mean phoneme endpoint identification scores in both language modalities for the children with a CI (CI), the children with normal hearing (NH) and the adults (A).

Separate Wilcoxon Signed Rank Tests were also performed on the classification slopes for both language modalities across contrasts. Significantly steeper classification slopes were observed in the spoken modality for all three groups.
The relationship between sign and speech perception

(children with a CI: $Z=-2.67, p<.01$; children with normal hearing: $Z=-2.67, p<.01$; adults: $Z=-2.85, p<.01$). Classification slopes for the hand configuration contrast and the location contrast for the three groups of participants are illustrated in Figures 6.5 and 6.6.
Figure 6.5. Classification slopes for the hand configuration contrast for the children with a CI (left panel), the children with normal hearing (middle panel) and the adults (right panel). Stimulus number is presented on the horizontal axis. % open responses are presented on the vertical axis.
Figure 6.6. Classification slopes for the location contrast for the children with a CI (left panel), the children with normal hearing (middle panel) and the adults (right panel). Stimulus number is presented on the horizontal axis. % /eye/ responses are presented on the vertical axis.
The results from the sign categorization task show that the adult second language learners of NGT had no difficulty identifying the phoneme endpoints and had relatively steep classification slopes. By contrast, mean phoneme endpoint identification scores for both child groups generally did not exceed chance-level (50%). Furthermore, as Figure 6.5 and 6.6 illustrate, there is no evidence that the children discriminated the phonetic contrasts. The sigmoidal function (S-curve) that is typically observed in categorization tasks and is clearly visible in the figures for the adults, is absent in the figures for the children. One possible explanation for the difficulties experienced by the children is that they had insufficient signing experience to do the task. Recall that the children with normal hearing had no signing experience at all. The children with a CI did have signing experience, but the extent and nature of signing experience varied substantially between them (see §3.1.1). Perhaps their signing experience was insufficient to consistently discriminate these phonetic contrasts. This explanation is somewhat unlikely, however, because the adult second language learners of NGT also had limited signing experience, but clearly did discriminate the contrasts. In addition, as we will see below, many of the children with a CI were able to learn novel minimal pairs that differed in these contrasts. Moreover, previous studies have shown that adults with no signing experience could discriminate similar contrasts (Baker et al., 2005b; Best et al., 2010; Emmorey et al., 2003).

Alternatively, the task might have been too complex for the children. As explained in §6.2.1, we had tried to make the sign categorization task as similar to the sound categorization task as possible. However, our efforts to make the two tasks comparable might have increased cognitive demands. Particularly, the combined use of stills of signs and animation monkey pictures might have confused the children because they had to make a categorization decision on one type of visual stimuli (i.e., the stills), while they had to give a response using the other type of visual stimuli (i.e., the monkey pictures).

In order to disentangle these two alternative explanations, we administered the sign categorization task to four deaf children without a CI (5-6 years of age) who were acquiring NGT from birth, and four hearing adults with no signing experience. If the reason for the difficulties that the children in our study experienced were insufficient signing experience, then children acquiring NGT from birth should not have as much difficulty with the task, whereas adults with no signing experience should have great difficulty. If task complexity were the reason, the deaf children without a CI should also perform poorly, whereas the hearing adults might show less difficulty with the task. A third alternative is that both explanations are correct, in which case both deaf children and hearing adults would show difficulty.

The outcomes clearly supported the second explanation. Similar to the children with a CI, phoneme endpoint identification scores of the deaf children without a CI
The relationship between sign and speech perception

did not exceed chance-level and they had shallow classification slopes. By contrast, identification scores of the adult non-signers were at ceiling-level and they had classification slopes in between those of the children and the adult second language learners. The poor performance by the children with a CI therefore appears to be due to the complexity of the task and not to insufficient signing experience. Moreover, the results from the adult non-signers confirm findings from previous studies that, in addition to a linguistic basis, at least some phonological contrasts in sign languages have also a perceptual basis that is common to signers and non-signers (Baker et al., 2005b; Best et al., 2010; Emmorey et al., 2003).

6.3.2 Picture-matching

Data from the picture-matching tasks in both language modalities were available from 13 children with a CI, 9 children with normal hearing and 10 adults. Figure 6.7 shows the mean overall percentage correct scores in both language modalities across contrasts for the three groups of participants. A 3 (Group) x 2 (Modality) x 2 (Trial type) repeated measures ANOVA with Group as a between-subjects variable and Modality and Trial type as within-subjects variable revealed a main effect of Group ($F(2,29)=14.34$, $p<.01$), Modality ($F(1,29)=5.20$, $p<.05$) and Trial type ($F(1,29)=86.74$, $p<.01$). Importantly, these main effects were qualified by a Group x Modality interaction ($F(2,29)=7.82$, $p<.01$) and a Group x Trial type interaction ($F(2,29)=4.67$, $p<.05$).

Paired samples $t$-tests were performed to further interpret the two significant interactions. Scores were significantly higher in the spoken modality than the signed modality for the children with normal hearing ($t(8)=-4.32$, $p<.01$) and the adults ($t(9)=-2.76$, $p<.05$), but not for the children with a CI ($t(12)=1.27$, $p=.23$). Furthermore, the adults obtained significantly higher scores on target trials than the children (children with a CI: $t(18)=-10.34$, $p<.01$; children with normal hearing: $t(17)=-7.91$, $p<.01$), who did not differ significantly from one another ($t(20)=.38$, $p=.71$). No significant differences between the three groups of participants were observed for scores on filler trials.
In the analysis of overall reaction times the incongruent trials were excluded and will be discussed separately below. Figure 6.8 shows the mean reaction times across contrasts for the three groups of participants. A 3 (Group) x 2 (Modality) x 2 (Trial type) repeated measures ANOVA with Group as a between-subjects variable and Modality and Trial type as within-subjects variable revealed a main effect of Group ($F(2,29)=10.17, p<.01$) and Trial type ($F(2,29)=17.75, p<.01$). Independent samples $t$-tests showed that the adults responded significantly faster than the children (children with a CI: $t(12)=3.87, p<.01$; children with normal hearing: $t(24)=12.86, p<.01$). The reaction times for the two child groups did not differ significantly ($t(33)=.90, p=.37$). Furthermore, across groups responses were faster on filler than target trials ($t(31)=4.21, p<.01$).
The relationship between sign and speech perception

Finally, sensitivity to a switch in word- or sign-object mappings was compared between the two language modalities for each group of participants. Recall that absolute differences between reaction times in congruent and incongruent trials were expressed as a difference ratio by dividing the reaction times in the incongruent trials by the sum of the reaction times in the congruent and incongruent trials. A 3 (Group) x 2 (Modality) repeated measures ANOVA with Group as between-subjects variable and Modality as within-subjects variable only revealed a main effect of Group ($F(2,29)=5.90$, $p<.01$). Independent samples $t$-tests indicated that the adults learners were more sensitive in their reaction times to a switch in word- or sign-object mappings than the children (children with a CI: $t(21)=-2.79$, $p<.05$; children with normal hearing: $t(17)=-4.36$, $p<.01$), who did not differ significantly from each other ($t(20)=-1.57$, $p=.13$). Separate one-sample $t$-tests on the difference ratios in the signed modality for each group of participants showed that the difference ratio was significantly higher than 0.5 for the adults (.59, $t(9)=6.29$, $p<.01$), but not for the children with a CI (.56, $t(9)=1.33$, $p=.22$) and the children with normal hearing (.50, $t(6)=.53$, $p=.61$). In other words, only the adults showed clear sensitivity to a switch in sign-object mappings.
Figure 6.9. Mean difference ratios in the picture-matching tasks in both language modalities for the children with a CI (CI), the children with normal hearing (NH) and the adults (A). The horizontal reference line indicates the 0.5 cut-off point for sensitivity to the switch in sign-object mappings (< 0.5 = insensitive; > 0.5 = sensitive).

6.3.3 OBJECT-MATCHING

Data from the object-matching task in the speech and sign conditions were available from 11 children with a CI and 10 children with normal hearing. Figure 6.10 shows the mean percentage correct scores in both language modalities across phonetic contrasts for the children with a CI and the children with normal hearing. A 2 (Group) x 2 (Modality) repeated measures ANOVA with Group as a between-subjects variable and Modality as a within-subjects variable only revealed a significant Group x Modality interaction ($F(1,19)=7.35$, $p<.05$). Paired samples t-tests showed that scores in the speech condition were significantly higher than scores in the sign condition for the children with normal hearing ($t(8)=3.02$, $p<.05$), but not for the children with a CI ($t(10)=-.75$, $p=.47$).
The relationship between sign and speech perception

Figure 6.10. Mean percentage correct scores in the speech and sign condition of the object-matching task for the children with a CI (CI) and the children with normal hearing (NH).

Figure 6.11 illustrates the mean percentage correct scores in the three conditions (i.e., speech, sign and bimodal) in the object-matching task for the children with a CI. A one-way repeated measures ANOVA revealed no significant differences between the three conditions \((F(2,20)=.30, p=.75)\). That is, in this preliminary investigation we were unable to find either positive or negative effects of bimodal input on lexical learning. However, it should be noted that both familiarization and testing were in speech and sign in the bimodal condition (§6.2.2.3) and the children therefore could have used either modality to learn the labels for the novel objects in this condition. The children may have predominantly attended to the words during familiarization, to the signs or to both. Therefore, the results tell us little about the effects of bimodal input on language processing in the spoken modality specifically. We will address this limitation in Chapter 7 that investigates in more detail the effects of bimodal input on speech perception.
6.3.4 DIGIT SPAN

Data from the digit span tasks in both language modalities were available for 9 children with a CI, 10 children with normal hearing and 9 adults. Figure 6.12 shows the mean digit span in both modalities for the three groups. A 2 (Group) x 2 (Modality) repeated measures ANOVA revealed a main effect of Group ($F(2,28)=127.64, p<.01$) and Modality ($F(1,25)=30.44, p<.01$), as well as a significant Group x Modality interaction ($F(1,25)=17.93, p<.01$). Paired samples $t$-tests showed that digit spans were significantly greater in the spoken than in the signed modality for the children with normal hearing ($t(9)=8.14, p<.01$), but not for the children with a CI ($t(8)=1.64, p=.14$) or the adults ($t(8)=-1.00, p=.35$).
Figure 6.12. Mean digit spans in both language modalities for the children with a CI (CI), the children with normal hearing (NH) and the adults (A).

6.3.5 Summary

The analyses in this section show that performance in the signed modality did not differ from performance in the spoken modality for the children with a CI on the picture-matching, object-matching and digit span tasks, whereas as expected the children with normal hearing and the adults mostly performed better in the spoken modality. The children with a CI performed more poorly in the signed than the spoken modality on the categorization task as measured by classification slopes (no modality effect was found for phoneme endpoint identification). However, as already discussed in §6.3.1, this could very well have been due to the higher cognitive demands of the sign categorization task compared to the sound categorization task.

This first analysis of the relationship between the two language modalities in children with a CI thus shows that speech and sign perception abilities of children with a CI tend to be at the same level. However, as judged from the greater error bars for the signed compared to the spoken modality in Figures 6.4-6.12, inter-individual variation in performance on the tasks in the signed modality was relatively large (see also Appendix C). In the next section, we will examine whether this observed inter-individual variation in sign perception abilities is associated with variation in performance in the spoken modality.
6.4 **Correlations Between Language Modalities**

To further examine the relationship between speech perception abilities and sign perception abilities among the children with a CI, a correlation analysis was performed between outcome measures in the two modalities: between sound and sign categorization, between rapid word and sign learning, and between phonological short-term memory for spoken and signed digits. The outcome measures included in the correlation analyses were phoneme endpoint identification and classification slope for sign categorization; scores, reaction times and difference ratio for picture-matching; scores for object-matching; and digit span for phonological short-term memory. In addition, chronological age, length of CI use, and age at implantation were included as variables in the correlation analysis to determine their effects on performance in the signed modality.

This analysis revealed significant correlations between phoneme endpoint identification scores in the sound categorization task and classification slopes in the sign categorization task ($r=.71$, $p<.05$), reaction times in the non-word and picture-matching tasks ($r=.82$, $p<.01$), and scores in the non-word and non-sign picture-matching tasks ($r=.67$, $p<.05$). In addition, chronological age and length of CI use both correlated significantly with scores in the non-sign picture matching task (chronological age: $r=.70$, $p<.01$; length of CI use: $r=.67$, $p<.05$). These age effects might have resulted from an increase in signing experience through the years after implantation for the children who continue to receive signed input.

This correlation analysis shows that in contrast to what would be expected if signing experience had a direct negative effect on speech perception abilities, both language modalities correlated positively with each other. That is, children that had higher phoneme endpoint identification scores in the sound categorization task, showed relatively better discrimination of the signed phonetic contrasts. In addition, the children who obtained higher scores and responded faster in the non-word picture matching task were the same children who obtained higher scores and responded faster in the non-sign picture-matching task. It is important to note that these positive correlations between the two language modalities do not imply a causal relationship between the abilities involved. That is, it is not the case that good sign perception abilities cause good speech perception abilities or vice versa. Rather, the relevant message here is that relatively good sign perception abilities do not exclude relatively good speech perception abilities.

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34 Correlations of these factors with performance in the spoken modality were discussed in §5.3.4 (see Table 5.4).
6.5 The role of signing experience

As a final step in the investigation of the relationship between sign and speech perception abilities, the sample of children with a CI was divided into two groups according to signing experience. As explained in §3.1, half of the children with a CI in the sample, namely the Dutch children, had received a considerable amount of signed input over the years, whereas the other half, namely the Flemish children, had received only limited signed input. Figures 6.13-6.16 show the performance of the Dutch and Flemish children with a CI on the different outcome measures in both modalities: sound and sign categorization (Figure 6.13), rapid word and sign learning (Figures 6.14 and 6.15) and phonological short-term memory (Figure 6.16).

Figure 6.13. Mean phoneme endpoint identification scores in the sound (speech) and sign (sign) categorization tasks for the Flemish (FL) and Dutch (NL) children with a CI.
Figure 6.14. Mean percentage correct scores in the non-word picture matching task (speech) and the non-sign picture matching task (sign) for the Flemish (FL) and Dutch (NL) children with a CI.

Figure 6.15. Mean percentage correct scores in the speech, sign and bimodal condition of the object-matching task for the Flemish (FL) and Dutch (NL) children with a CI.
Figure 6.16. Mean digit spans in the spoken and signed modality for the Flemish (FL) and Dutch (NL) children with a CI.

Although the respective sample sizes in both groups are too small for statistical comparison, the figures show by inspection that the Dutch children with a CI, as expected, generally obtain higher scores on the sign perception tasks than the Flemish children with a CI (most notably on the categorization and object-matching tasks). Importantly, however, except for phonological short-term memory, their higher sign perception scores are not associated with lower speech perception scores. The considerable difference in spoken digit spans between the Dutch and Flemish children is remarkable and might indeed be the result of their respective linguistic environments. Consistent with this idea, Pisoni et al. (1999) found smaller digit spans for children in Total Communication settings compared to children in Oral communication settings. They suggested that reduced amounts of exposure to speech following implantation might lead to less efficient processing of auditory information in verbal short-term memory. The different linguistic environment is not the only possible explanation for the observed difference in spoken digit spans, however. Recall that a significant positive correlation was observed between length of CI use and spoken digit span scores (see §5.3.4). On average, the Flemish children were implanted earlier than the Dutch children; as a result, they were using
their CI for a longer time when tested (§3.1). The difference in spoken digit spans could therefore also be an effect of “hearing” experience with the CI.

6.6 CONCLUSION

In this chapter we have shown that, in general, the sign perception abilities of the children with a CI are on the same level as their speech perception abilities. However, the range in observed sign perception abilities is large due to substantial inter-individual variation in the amount of signed input received by the child and thus their signing experience. Crucially, we found no evidence that better sign perception abilities led to poorer speech perception abilities in the same children. In contrast, on three outcome measures we observed positive correlations between the two language modalities. Our results thus suggest that relatively good signing and speech perception abilities are not mutually exclusive for children with a CI (cf. De Raeve et al., 2009; Klatter-Folmer et al., 2006; Preisler et al., 2001). Evidence from correlations should be interpreted with caution, however, because they do not imply causality. In addition, the results from the bimodal condition of the object-matching task warrant further research into the interaction between both modalities during language processing. In Chapter 7, therefore, an experiment will be reported that more directly examined the effects of signed input on speech perception.