Speech and sign perception in deaf children with cochlear implants

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7 EFFECTS OF BIMODAL INPUT ON SPEECH PERCEPTION

The comparison of perception abilities in the spoken and signed modality in Chapter 6 showed that the children with a CI, in general, performed at similar levels in both language modalities. In addition, contrary to what would be expected if signing experience had a direct negative impact on spoken language outcomes, performance in both language modalities correlated positively. In other words, relatively good performance in one modality does not generally imply relatively poor performance in the other modality. In this chapter, we will address more direct effects of signed input on speech perception. More specifically, we will report the results from an experiment that examined whether bimodal (i.e., simultaneously spoken and signed) input helps or hinders children with a CI to recognize and learn spoken words.

The data for this experiment were collected separately from the data presented in Chapters 4 to 6 and are available from a subset of the children with a CI that completed the other experiments. In §7.1 background information is provided on the role of the visual modality in language processing in general and in children with a CI in particular. In §7.2, the research methodology will be described and the results and discussion are presented in §7.3 and §7.4, respectively.

7.1 BACKGROUND

7.1.1 THE ROLE OF THE VISUAL MODALITY IN LANGUAGE PROCESSING

Although the primary sensory channel in spoken language processing is auditory, information is often reinforced and enriched by visual input, for instance, from the face and for sounds specifically visible, movements of the articulators. A famous example of such audiovisual integration is the 'McGurk' effect (McGurk & MacDonald, 1976). When people hear the syllable /ba/, but see a speaker producing the syllable /ga/, they often perceive the syllable /da/, where the consonant has a place of articulation between that of /b/ and /g/ and visually looks like /g/. Conversely, when they hear /ga/, but see /ba/, they often perceive /bagba/ or /gaba/ because they related the observed bilabial closure to a bilabial sound. Following this seminal work, a multitude of studies have shown that infants, children and adults are sensitive to visual speech information during spoken language processing, especially in unfavorable conditions such as in the presence of background noise or because of hearing impairment (for recent reviews, see e.g. Rosenblum, 2005, 2008; Woodhouse et al., 2009).

In addition to the face, however, auditory information is also enriched by visual input from the hands. Behavioral and neuro-imaging studies have shown that co-speech gestures, i.e., facial and hand movements that accompany speech, are tightly integrated with auditory input in language comprehension (Kelly et al., 2008; Skipper, Goldin-Meadow, Nusbaum, & Small, 2009). This is particularly striking when the information expressed in speech and gesture is incongruent. For instance, Kelly, Ozyurek and Maris (2010) recently showed that adults related short movies of someone performing a specific action (e.g., someone chopping vegetables) more quickly and accurately to bimodal speech-gesture targets when both speech and gesture matched the action (i.e., speech: “chop”, gesture: chop) than when one of them did not (e.g., speech: “chop”, gesture: twist). Importantly, participants were unable to ignore the gestures, even when explicitly instructed to do so, suggesting that the interaction between speech and gesture in language comprehension is mutual and automatic. Moreover, it is already present in early language development. For instance, the occurrence of word-gesture combinations predicts the onset of two-word combinations (e.g. Iverson & Goldin-Meadow, 2005). Conversely, delays in the early productive use of gestures are associated with delays in language development at a later age (e.g. Thal, Tobias, & Morrison, 1991). Most importantly for the present study, co-speech gestures have been found to support word learning in a foreign language in both children and adults (e.g. Kelly, McDevitt, & Esch, 2009; Tellier, 2008) and are used to support communication in children with language learning difficulties (Capone & McGregor, 2004).

Interaction between the oral-auditory and manual-visual modality in language processing is further illustrated by bimodal bilinguals, hearing people with one or two deaf parents who grew up learning both a spoken and a signed language. Although the spoken language is dominant in such bilinguals, they often also produce signs in their utterances. Interestingly, Emmorey et al. (2008) have shown that they prefer simultaneous productions of speech and sign (code-blending) over sequential switches between speech and sign (code-switching). The latter is a typical phenomenon in conversations between bilinguals who speak two spoken languages, i.e., unimodal bilinguals (see also Bishop, 2006b; Bishop & Hicks, 2005). Moreover, Emmorey, Petrich and Gollan (2010) found faster semantic decision times in bimodal bilinguals when they were presented with code-blends in comparison to words or signs alone. These results suggest that bimodality in language comprehension produces a processing advantage for hearing adults who are native speakers of a signed and a spoken language. The authors explain this result in terms of the Redundant Signals Effect (e.g. Miller & Ulrich, 2003): a combination of two redundant stimuli co-activates a response and results in a processing advantage. Although this effect has mainly been applied to the processing of nonverbal sensory signals, it might also apply to the combined activation of redundant lexical representations.

Importantly, the blending of spoken and signed utterances is also frequently observed in hearing and deaf children of deaf parents (Baker & Van den Bogaerde, 2008; Van den Bogaerde & Baker, 2005, 2008) and deaf children of hearing parents, including children with a CI (Klatter-Folmer et al., 2006). Emmorey et al.'s finding of processing advantages for bimodality in adult bimodal bilinguals might therefore also apply to children with a CI.

7.1.2 Children with a CI and the visual modality in language processing

The role of the visual modality in language processing by children with a CI has only recently received attention from researchers and most studies have been on the integration of auditory and visual speech information (for a review, see Mitchell & Maslin, 2007). Bergeson et al. (2005), for instance, studied the development of audiovisual comprehension abilities in 80 children with a CI that were followed for five years from pre-implantation. In addition to a sentence recognition test administered in auditory-alone, visual-alone and audiovisual format, they included a battery of standardized spoken language tests. In general, they found that over time the children's sentence recognition mostly improved in the auditory-alone and audiovisual format. However, complex interactions were observed between length of CI use, age at implantation, communication modality and improvement over time. Children in Oral Communication settings outperformed children in Total Communication settings in all three conditions before implantation, even the speech reading condition, but no longer so after five years of CI use. Furthermore, pre-implant scores in the visual-alone condition correlated strongly with speech perception, vocabulary knowledge and speech intelligibility three years after implantation. In other words, children that were better speech readers before implantation perceived and produced speech more accurately after implantation. According to the authors, children's success in combining auditory and visual cues in speech perception after implantation seems already to be reflected in their efficiency in using visual speech information before implantation.

Other studies have looked in more detail at the development of audiovisual integration abilities in young children with a CI. For instance, Bergeson, Houston and Miyamato (2010) showed that infants and young children with a CI between 16 and 39 months of age were not able to match silent video clips of a woman speaking the words 'judge' and 'back' to the respective sound tracks after three months of CI use, but succeeded after six months. Schorr, Fox, Van Wassenhove and Knudsen (2005) compared occurrence of the McGurk effect in a group of 5- to 14 year-old children with a CI and a group of age-matched children with normal hearing. The authors found that none of the children with a CI implanted after 2.5 years of age showed the McGurk effect (see §7.1.1), compared to 38% of the children implanted before that age and 57% of the children with normal hearing. When hearing the syllable /pa/ and seeing the syllable /ka/, they mostly reported having perceived /ka/ and not the syllable /ta/ where the consonant has a place of articulation between that of /p/ and /k/.

In contrast to the integration of auditory and visual *speech* information, the integration of auditory and visual input from the hands such as signs or co-speech gestures has to our knowledge not yet been studied in children with a CI. Bergeson et al. (2005) discuss possible negative consequences of simultaneously exposing children with a CI to speech and signs. They hypothesized that one of the possible explanations for poorer speech reading and spoken language outcomes in children with a CI from Total Communication settings is that they have to divide their visual attention between the hands (i.e., signs) and the face (i.e., speech reading). Such division of attention could create competition between limited processing resources in working memory and result in less efficient speech processing (see also Burkholder & Pisoni, 2006).

There is, however, evidence suggesting that exposing deaf or hard-of-hearing children and adults to speech and signs simultaneously may actually *enhance* spoken language processing. For instance, Hamilton and Holzman (1989) investigated modality effects on linguistic encoding in short-term memory in deaf and hearing adults varying in spoken and signed language experience. They found that subjects with both sign and speech experience recalled bimodal stimuli better than stimuli that were only spoken or signed[35]. More recently, Mollink et al. (2008) examined the effects of using signs in spoken vocabulary training for children with a mild-to-moderate hearing loss and found that signs had a positive effect on the learning and retention of new spoken vocabulary. In their study 14 children were exposed to a set of 64 pictures in four different naming conditions: with words, words and signs, words and colors, and no naming (only pictures). They were presented with the words three times in a period of three weeks: in each session the pictures were named twice by the experimenter and the child repeated the word on each occasion. Naming was tested one week and five weeks after the last session. At both test moments, the pictures that had been trained with words and signs combined received the highest percentage correct scores.

To summarize, although audiovisual integration is being considered in the pediatric CI literature, attention has only been paid to visual input from the face and not from the hands. On the one hand, simultaneous exposure to speech and signs might present a processing advantage for children with a CI compared to speech or sign alone, possibly because of the co-activation of redundant lexical representations as discussed above (cf. Hamilton & Holzman, 1989; Mollink et al., 2008). On the

[35] They had to remember lists of five items (words, signs or word-sign combinations); immediate recall was in written words.

other hand, such bimodal input might present a challenge because it can generate competition in working memory (Bergeson et al., 2005). To determine which of these alternative hypotheses is correct, we designed an experiment that tested the effects of bimodal input on spoken word recognition and learning. Here, we present preliminary results from a small sample of children with a CI. The children were a subset of those that participated in the experiments reported in Chapters 4 to 6.

7.2 Methodology

7.2.1 Participants

The participants were eight children with a CI (mean age at testing: 6;11, mean age at implantation: 1;10). Background information on the children is provided in Table 7.1 below (see also §3.1.1). They were a subset of the children that participated in the experiments reported in Chapters 4-6. At the time of testing, three of the children attended mainstream education and five children attended schools for the deaf. To ensure that the stimuli were clear and that the task was not too difficult for the children, data were also collected from ten adults (mean age 22;7), whose signing experience varied from null to two years in second language learning classes[36]. They were expected to perform at ceiling-level.

[36] Similar to the children, they were a subset of the adults that participated in the experiments reported in Chapters 4-6.

Table 7.1. Characteristics of the children with a CI ordered according to age at implantation.

ID	Gender	Country of origin	Stimulation	Implant type	Educational setting at time of study	Age at implantation	Age at time of study
N7	F	NL	CI	Clarion (Platinum)	mainstream	0;7	6;6
A1	M	B	CI	Cochlear (Sprint)	mainstream	0;9	6;8
J3	M	B	CI	Cochlear (Sprint)	SimCom	0;10	5;9
S7	M	B	2CI	Cochlear (Sprint) / Digisonic (SP)	SimCom	1;2	6;7
L2	F	NL	CI	Clarion (Platinum)	bilingual	2;0	7;4
D8	M	NL	2CI	Cochlear (Sprint/Freedom)	mainstream	2;1	8;1
L4	M	NL	CI	Cochlear (Sprint)	bilingual	3;2	7;11
S5	M	NL	CI	Cochlear (Freedom)	bilingual	3;9	6;9
						M=1;10, sd=14 mo	**M=6;11, sd=9 mo**

Note. Ages are in years;months, M=mean, SD=standard deviation, mo=months

7.2.2 MATERIALS

7.2.2.1 TASK

Based on the picture-matching tasks discussed earlier in this thesis (§5.2.2.1 and §6.2.2.2), a new task was designed to measure word and sign recognition and learning. Recognition was tested with familiar items and learning with novel items. In addition, the role of phonological (dis)similarity was addressed by including both minimal and non-minimal pairs.

The experiment consisted of three conditions: speech, sign and bimodal. The experiment consisted of six blocks, two for each modality condition. In the first block the relatively easy non-minimal novel and familiar pairs were presented, followed by a block with the more difficult minimal novel and familiar pairs. Each block consisted of a familiarization and a testing phase. During familiarization, depending on the condition, participants were familiarized with one novel and one familiar pair of objects either in speech, sign or both, i.e., bimodal (see Figure 7.1 for instances of movie stills). The testing phase consisted of a set of two-alternative forced-choice identification trials. Crucially, after familiarization in the bimodal condition, participants were first tested on the words in the bimodal pairs and on the signs only after all word trials had been completed. In this way, the effects of *bimodal* input on *spoken* word recognition and learning could be examined. If the testing phase had also been bimodal, it would have been difficult, if not impossible, to establish whether the participants primarily responded to the words or the signs in the bimodal pairs. They could simply rely on their best modality during familiarization and testing, as was the case in the bimodal condition of the object-matching task discussed earlier (§6.2.2.3). The disadvantage of testing word before sign recognition and learning is that the familiarization-testing interval is longer for signs than for words. As a result, performance on the signs in the bimodal condition might be poorer than performance in the sign condition simply because more time had elapsed between familiarization and testing. However, the advantage of this design is that the word testing phase in the bimodal condition was identical to that in the speech condition. That is, the single difference between the conditions was the modality used during familiarization.

Figure 7.1. Example movie stills for the stimulus /tɑuw/ 'rope' from the familiarization phase in the speech (left), sign (middle) and bimodal (right) conditions. The stills represent the end of the stimulus.

During familiarization, a picture and a movie were presented next to each other in the center of the screen. The picture was always presented on the left side in this phase. Each stimulus was presented three times with inter-trial intervals of 500 milliseconds. Following familiarization, a black-and-white blocked flag was displayed in the center of the screen for 2000 milliseconds in order to fixate attention to the center. Next, 12 testing trials were presented in random order. In each trial a movie stimulus was played in the center of the screen, immediately followed by two pictures, one at the left and one at the right side of the screen. Left and right response keys on the laptop were indicated by stickers. The next movie stimulus was presented immediately following the participant's response. Participants responded to four *novel* (e.g., /tuk/ and /tik/*)*, four *familiar* (e.g., /mɑuw/ 'sleeve' and /dos/ 'box'), and four *filler* (e.g., /tuk/ and /dos/) trials. Side of presentation of the pictures on the screen in the testing phase was counterbalanced.

E-Prime 2.0® (Psychology Software Tools, Pittsburgh PA) was used to present the stimuli and record accuracy and reaction times. Accuracy was defined as the number of trials correctly answered. For each block, the minimum score that could be obtained was 0 and the maximum 12. Thus, the maximum score for the entire task was 6 blocks x 12 trials = 72. Reaction times were measured from the offset of the auditory stimulus to the overt response, i.e., the key press. Reaction times were analyzed separately for the three trial types. Only trials that were correctly answered were included and trials with reaction times more than 2.5 standard deviations above and below the mean reaction time for each participant were excluded from the analysis, resulting in the exclusion of 4.6% of the trials for the adults and 2.7% for the children with a CI.

7.2.2.2 STIMULI

The stimuli in the experiment consisted of video recordings of words and signs embedded in carrier phrases. For the words, the carrier phrases were ‘Kijk, een X!’ (*Look, a X!*) during familiarization, and ‘Waar is de X?’ (*Where is the X?*) during testing. For the signs, the carrier phrases were ‘*pointing to picture*[37] X!’ during familiarization, and ‘WAAR X?’ (*WHERE X ?*) during testing. The stimuli were spoken and signed by the same person who produced the stimuli reported in §4.2.2, §5.2.2 and §6.2.2. The stimuli were recorded against a blue background to optimize sign visibility using an external microphone attached to the video camera. The recorded stimuli were captured and digitalized using iMovie® and compressed to WMV format (440 kbps, 25 fps, 360x280 pixels) using Pinnacle® Studio 11[38]. They averaged about 3000 milliseconds in duration. The pictures that were presented together with the movie stimuli were black-and-white drawings of novel and familiar objects from the same picture databases as used for the picture-matching tasks (see §5.2.2.1).

In total, four non-word pairs and four familiar word pairs were used in this experiment, half were minimal pairs and half were non-minimal pairs. The two non-minimal non-word pairs were selected from the set of non-words that was used in the picture-matching and object-matching tasks (see §5.2.2.1). Two new monosyllabic consonant-vowel-consonant minimal non-word pairs selected were distinguished by the vowels /u/ and /i/, a sound contrast with a strong visual correlate (lip rounding). Similar to the other non-words, they conformed to a monosyllabic consonant-vowel-consonant structure. Furthermore, we presented two familiar minimal and two familiar non-minimal word pairs that were judged to be known to typically developing six-year old children (Schaerlaekens et al., 1999), and for which pictures were available in the database (see §5.2.2.1). The selected novel and familiar word pairs are listed in Table 7.2.

Presentation of these word pairs in the speech and bimodal conditions was counterbalanced across participants. For instance, some participants were presented with the /tuk/-/tik/ and /kɔp/-/pɔp/ pairs in the speech condition and with the /fup/-/fip/

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[37] Pointing was preferred over the lexical sign KIJK (*LOOK*) that was used in the non-sign picture-matching task (see §6.2.2.2), because pointing establishes a more explicit relation between the following sign and the picture.

[38] This experiment was designed in the Laboratory for Language and Cognitive Neuroscience in San Diego during a 4-month visit in the Fulbright Visiting Scholar Program. Recorded stimuli were digitalized and compressed to QuickTime® format using iMovie®. Psyscope X (Cohen, MacWhinney, Flatt, & Provost, 1993) was used to present the stimuli. A pilot study with adults was completed with stimuli in English and American Sign Language. The experiment was later converted to E-Prime® 2.0 and the original video recordings compressed to WMV format.

and /tɑk/-/zɑk/ pairs as the auditory parts of the stimuli in the bimodal condition, whereas this was reversed for other participants.

Table 7.2. Minimal and non-minimal non-word pairs included in the experiment.

Novel word pairs		Familiar word pairs		
Orthographic form	**Phonological form**	**Orthographic form**	**Phonological form**	**English translation**
Miminal		**Minimal**		
toek - tiek	/tuk/ - /tik/	kop - pop	/kɔp/- /pɔp/	*mug - doll*
foep - fiep	/fup/ - /fip/	tak - zak	/tɑk/ - /zɑk/	*branch - sack*
Non-minimal		**Non-minimal**		
fuuk - soot	/fyk/ - /sot/	mouw - doos	/mɑuw/ - /dos/	*sleeve - box*
taat - peeg	/tat/ - /peχ/	touw - roos	/tɑuw/ - /ros/	*rope - rose*

The non-sign pairs included in the experiment came from the set of non-signs that was used in the picture-matching and object-matching tasks (see §6.2.2.2); illustrations are provided in Appendix D. These included both minimal and non-minimal non-sign pairs. Minimal *familiar* sign pairs were not included in the experiment because we were unable to find a stimulus pair for the bimodal condition that was a minimal pair in Dutch as well as in NGT and VGT. Presentation of the non-sign pairs in the sign and bimodal conditions was counterbalanced across participants. Given that the familiar word pairs in the speech and bimodal conditions were already counterbalanced, counterbalancing the familiar sign pairs in the sign and bimodal conditions would have resulted in the same pictures being presented twice to participants. Therefore, in addition to the familiar signs in the bimodal condition that matched the meaning of the familiar words in Table 7.2, two new familiar sign pairs that were the same in NGT and VGT were selected from NGT teaching material for young deaf children, and were only presented in the sign condition (BEER 'bear', BOEK 'book', BRIL 'glasses', PET 'cap').

7.2.3 PROCEDURE

Participants completed the experiment in one of two different orders: half completed the speech before the sign condition, and half completed the sign before the speech condition. All participants completed the bimodal condition last. This was done to make sure that participants were familiarized with both language modalities before completing the bimodal condition. The order of the speech and sign condition was counterbalanced to account for potential priming effects in the bimodal condition from the preceding modality. That is, participants who had just completed the speech condition might show a bias in relative attention towards that modality when processing the stimuli in the bimodal condition, and similarly for participants who had just completed the sign condition. These processing biases could affect the interaction between the two modalities in the bimodal condition and thus the results of the study, hence the counterbalancing of the speech and sign conditions.

Participants were told beforehand that they would see pictures of novel and familiar objects together with movies in which the objects were named. They were also told that they would see the task in speech, sign or both. Their task was to remember which word and/or sign was associated to which picture. In between blocks, they were reminded of the type of block that would follow (speech, sign or bimodal). Before the bimodal condition, they were told that the names of the objects would be both spoken and signed and that they would have to remember both, but that they would be tested on the words and signs separately. There was a pause between blocks, which was also used to provide non-specific feedback to stimulate the children. The experiment was preceded by a practice block in speech with two phonologically dissimilar non-words (/kaχ/ and /fet/) and two phonologically dissimilar familiar words (/døʀ/, 'door' and /bɑl/, 'ball'). Familiarization was identical to the experimental blocks, but testing was limited to six trials, two for each type of testing trials, presented in random order. The task took children approximately 25 minutes and adults 15 minutes.

7.2.4 Statistical analysis

Parametric statistical tests were used to analyze raw scores, expressed as percentage correct scores in the text, and reaction times. To compare performance in the speech, sign and bimodal conditions, we first performed a repeated measures ANOVA on overall scores and reaction times. In this analysis the bimodal condition was further divided in two "sub-conditions" according to the modality in which the participants were tested, namely speech or sign. These will be referred to here as $\text{bimodal}_{\text{speech}}$ and $\text{bimodal}_{\text{sign}}$, respectively (see Table 7.4). Paired samples *t*-tests were used for post hoc comparisons. Furthermore, to specifically compare the bimodal to the unimodal conditions, we ran a series of planned paired samples *t*-tests on scores and reaction times in the two bimodal conditions (i.e., $\text{bimodal}_{\text{speech}}$ and $\text{bimodal}_{\text{sign}}$) paired with those in the respective unimodal conditions (i.e., speech and sign) for the different types of stimulus pairs: novel or familiar, and minimally different or not minimally different. Bivariate Pearson product moment coefficients are reported in correlation analyses.

Table 7.4. Description of the four testing conditions and the labels used for reference in the text and figures.

Label	Description
Speech	Familiarized with words and tested on these words
Sign	Familiarized with signs and tested on these signs
Bimodal$_{speech}$	Familiarized with word-sign combinations and tested on the words
Bimodal$_{sign}$	Familiarized with word-sign combinations and tested on the signs

7.3 Results

Data were available from all participants. In this section, we will first report the results from the adults (§7.3.1), followed by the results from the children (§7.3.2). In §7.3.3 correlations with age at implantation, length of CI use and chronological age are presented (§7.3.3). Individual results for the children with a CI are presented in Appendix E.

7.3.1 Adults

Table 7.5 provides the descriptive statistics of the percentage correct scores and reaction times in the four conditions for the adults. As predicted, their scores were high overall and approached ceiling[39]. More specifically, they scored ≥90% correct on all stimulus pairs except for the novel word pairs in the bimodal$_{speech}$ condition (M=80.0% correct, highlighted in Table 7.5). A repeated measures ANOVA on overall scores in the four conditions revealed no significant effect of condition ($F(1,9)=1.11$, $p=.36$). Furthermore, none of the planned paired samples comparisons between scores in the two bimodal and respective unimodal testing conditions approached significance.

[39] Percentage correct scores approached ceiling for both the adults with signing experience and those without. Reaction times for the adults without signing experience were slower overall, but showed the same patterns across conditions as for the adults with signing experience. As a result, they are included as one group in the analyses presented below.

A repeated measures ANOVA on overall reaction times in the four conditions revealed a significant main effect of condition ($F(1,9)=7.37$, $p<.05$). Post hoc paired samples comparisons showed that the adults responded significantly faster in the bimodal$_{sign}$ condition compared to the bimodal$_{speech}$ condition (bimodal$_{sign}$: $M=537$ msec, bimodal$_{speech}$: $M=591$ msec; $t(9)=2.78$, $p<.05$). Furthermore, planned paired samples *t*-tests between the two bimodal and respective unimodal testing conditions showed that they responded significantly slower in the bimodal$_{sign}$ condition compared to the sign condition for novel minimal sign pairs (bimodal$_{sign}$: $M=654$ msec, sign: $M=490$ msec, $t(9)=-3.15$, $p<.05$). None of the other planned paired samples comparisons approached significance.

Table 7.5. Descriptive statistics of percentage correct scores (%) and reaction times (RT, msec) for the adults ($n=10$).

Stimulus type	**Trial type**		**Speech**	**Sign**	**Bimodal$_{speech}$**	**Bimodal$_{sign}$**
Minimal pairs	**Familiar**	**%**	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	97.5 (7.9)
		RT	472 (101)	489 (78)	489 (76)	505 (68)
	Novel	**%**	90.0 (17.5)	97.5 (7.9)	***80.0 (22.9)***	95 (10.5)
		RT	590 (148)	490 (111)	786 (337)	654 (210)
	Filler	**%**	100.0 (0.0)	100.0 (0.0)	97.5 (7.9)	97.5 (7.9)
		RT	541 (155)	511 (116)	579 (133)	507 (79)
Non-minimal pairs	**Familiar**	**%**	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	95.0 (10.5)
		RT	498 (74)	489 (61)	520 (122)	483 (83)
	Novel	**%**	92.5 (16.9)	90.0 (17.5)	92.5 (12.1)	95.0 (10.5)
		RT	596 (153)	620 (91)	632 (107)	579 (128)
	Filler	**%**	100.0 (0.0)	100.0 (0.0)	97.5 (7.9)	100.0 (0.0)
		RT	548 (117)	512 (60)	542 (104)	491 (72)

Note. Numbers represent means and standard deviations (between parentheses).

7.3.2 CHILDREN WITH A CI

Table 7.6 provides the descriptive statistics of the percentage correct scores and reaction times in the four conditions for the children with a CI. Figure 7.2 illustrates their mean percentage correct scores in the four conditions according to stimulus type (familiar or novel, and phonologically similar or different). A repeated measures ANOVA on overall scores in the four conditions revealed no significant effect of modality ($F(1,7)=.44$, $p=.66$). Furthermore, none of the planned paired samples comparisons between scores in the two bimodal and respective unimodal testing conditions approached significance.

Table 7.6. Descriptive statistics of percentage correct scores (%) and reaction times (RT, msec) for the children with a CI (n=8).

Stimulus type	Trial type		Speech	Sign-alone	$\text{Bimodal}_{\text{speech}}$	$\text{Bimodal}_{\text{sign}}$
Minimal pairs	**Familiar**	**%**	90.6 (18.6)	96.9 (8.8)	96.9 (8.8)	96.9 (8.8)
		RT	1409 (571)	1173 (365)	1142 (377)	1726 (516)
	Novel	**%**	84.4 (12.9)	78.1 (20.9)	93.8 (11.6)	71.9 (20.9)
		RT	1585 (501)	2235 (910)	1566 (475)	2079 (553)
	Filler	**%**	96.9 (8.8)	96.9 (8.8)	93.8 (11.6)	96.9 (8.8)
		RT	1524 (502)	1289 (663)	1305 (403)	1663 (370)
Non-minimal pairs	**Familiar**	**%**	100.0 (0.0)	93.8 (11.6)	100.0 (0.0)	100.0 (0.0)
		RT	1551 (935)	1165 (236)	1018 (333)	1268 (530)
	Novel	**%**	78.1 (24.8)	93.8 (11.6)	62.5 (37.8)	84.4 (18.6)
		RT	2101 (1126)	1453 (501)	2086 (1196)	2006 (595)
	Filler	**%**	93.8 (17.7)	100.0 (0.0)	96.9 (8.8)	96.9 (8.8)
		RT	1356 (563)	1335 (394)	1425 (352)	1608 (448)

Note. Numbers represent means and standard deviations (between parentheses).

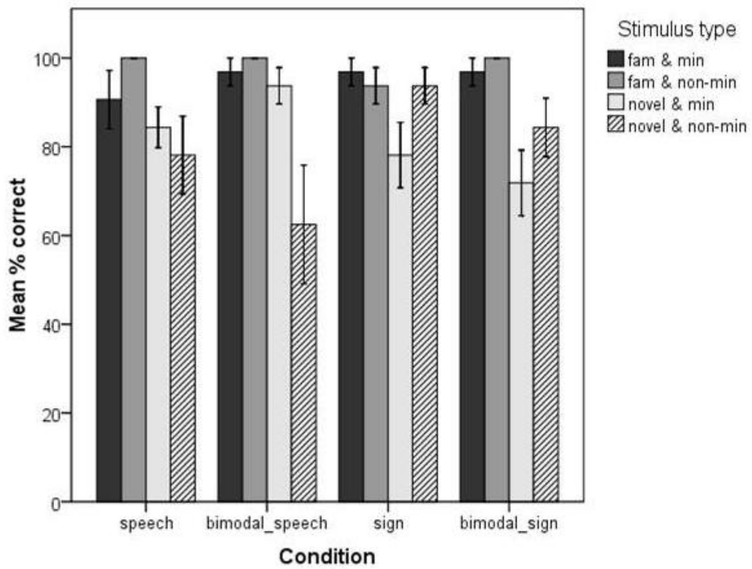

Figure 7.2. Mean % correct scores for the children with a CI in the four conditions according to stimulus type: familiar (fam) or novel, and minimal pairs similar (min) or non-minimal pairs (non-min).

Figure 7.3 illustrates the children's mean reaction times in the four conditions according to stimulus type (familiar or novel, and phonologically similar or different). A repeated measures ANOVA on overall reaction times in the four conditions revealed no significant effect of condition ($F(1,7)=4.56$, $p=.07$). However, planned paired samples comparisons between reaction times in the two bimodal and respective unimodal testing conditions showed that the children responded marginally significantly faster in the $\text{bimodal}_{\text{speech}}$ condition compared to the speech condition for familiar minimal word pairs ($\text{bimodal}_{\text{audiovisual}}$: $M=1142$ msec, speech: $M=1409$ msec, $t(7)=2.24$, $p=.06$). Furthermore, they responded significantly slower in the $\text{bimodal}_{\text{sign}}$ condition compared to the sign condition for familiar sign pairs in the block with minimal novel sign pairs[40] ($\text{bimodal}_{\text{sign}}$: $M=1726$ msec, sign: $M=1173$ msec, $t(7)=-2.87$, $p<.05$). None of the other planned paired samples comparisons approached significance.

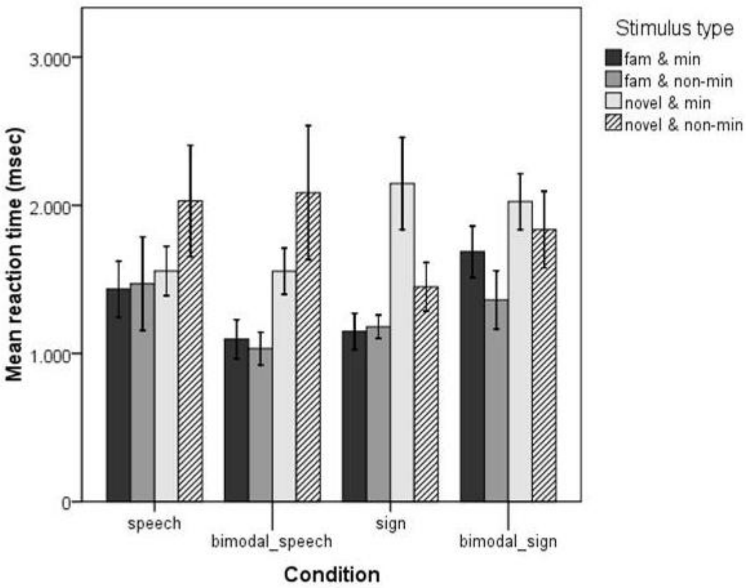

Figure 7.3. Mean reaction times for the children with a CI in the four conditions according to stimulus type: familiar (fam) or novel, and minimal pairs (min) or non-minimal pairs (non-min).

As in the studies reported in Chapters 4-6, our sample of children with a CI in this study included both Dutch children and Flemish children and that the former received more signed input than the latter an may be considered to have more

[40] Recall that the familiar sign pairs in the experiment were all non-minimal sign pairs (see §7.2.2).

signing experience (see §3.1.1). It is therefore possible that especially the Dutch children experienced positive effects from bimodal exposure. In order to examine this possibility, we analyzed the reaction time data on the familiar minimal pair in the bimodal_{speech} and speech conditions for the Dutch (n=5) and Flemish (n=3) children separately. Indeed, whereas the Dutch children responded significantly faster in the bimodal_{speech} condition compared to the speech condition for familiar minimal word pairs (bimodal_{speech}: M=1040 msec, speech: M=1602 msec, $t(4)=-3.75$, $p<.05$), the Flemish children did not (bimodal_{speech}: M=1190 msec, speech: M=1155 msec, $t(2)=-.21$, $p=.85$). Importantly, although the Flemish children with a CI did not experience facilitation from the bimodal exposure, they also did not experience interference from it. These results therefore suggest that bimodal input does not interfere with speech perception in children with a CI and can even facilitate speech perception in those children with relatively much signing experience[41].

7.3.3 Correlations

For the children with a CI, correlations of age at implantation, length of CI use and chronological age with scores and reaction times in the four different test conditions were examined. As in previous chapters, longer CI use was associated with earlier implantation ($r=.75$, $p<.05$). In addition, longer CI use was associated with higher scores in the bimodal_{sign} condition ($r=.91$, $p<.01$), and faster reaction times in the speech ($r=-.89$, $p<.01$), the sign ($r=-.74$, $p<.05$) and the bimodal_{speech} conditions ($r=-.81$, $p<.05$). Neither age at implantation nor chronological age correlated with scores or reaction times in any of the four testing conditions.

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[41] In order to examine the possibility that a similar bimodal distribution in the data between the Dutch and Flemish children had cancelled out any positive or negative effects of bimodal exposure, we reanalyzed all accuracy and reaction time data separately for the Dutch and Flemish children. In addition to the difference with respect to the familiar minimal word pairs reported in the text, the Dutch and Flemish children also appeared to respond differently to the familiar sign pairs in the block with novel minimal sign pairs. Whereas the Dutch children responded significantly slower in the bimodal_{sign} condition compared to the sign condition (sign: M=1083 msec, bimodal_{sign}: M=1594 msec, $t(4)=-3.15$, $p<.05$), the Flemish children did not (sign: M=1257 msec, bimodal_{sign}: M=1843 msec, $t(2)=-1.20$, $p=.35$). However, given that the absolute difference in reaction times between the two conditions is quite similar for the Flemish and Dutch children (586 msec and 511 msec, respectively), this apparent difference in performance between the two groups more likely reflects a difference in statistical power.

7.4 DISCUSSION

In this chapter, we have directly assessed the effects of bimodal (i.e., speech and sign) input on speech perception in children with a CI. The results clearly show that bimodality in the input had no negative effects on the processing of words, regardless of whether they were phonologically similar or dissimilar, and novel or familiar. Crucially, the fact that we did not find evidence for negative effects of bimodal exposure on speech perception cannot be accounted for by a lack of attention to the signs in the bimodal condition. The absence of significant differences between scores and reaction times in the $\text{bimodal}_{\text{sign}}$ and sign conditions for all except one stimulus pair shows that the children had looked at the signs during familiarization.

Apparently the children with a CI had no difficulty distributing their visual attention over the speaker's hands and face. In fact, for one stimulus type, bimodal exposure had a positive effect on the creation or retrieval of spoken lexical representations. Reaction times were faster when familiarization of familiar minimal word pairs had been bimodal compared to only spoken, which suggests that they experienced cross-modal facilitation. Mollink et al. (2008) found positive effects of bimodal exposure on word learning in children with a mild-to-moderate hearing loss wearing acoustic hearing aids (see §7.1.2.). Our results suggest that deaf children with a CI may experience similar positive effects from bimodal exposure.

Our finding that the adults with normal hearing did not show cross-modal facilitation is not surprising given their already near-ceiling performance in the speech condition (see Table 7.3). However, for them bimodal exposure actually appeared to hamper speech processing to some extent. Unexpectedly, they responded significantly faster in the $\text{bimodal}_{\text{sign}}$ condition compared to the $\text{bimodal}_{\text{speech}}$ condition, although the former had a longer interval between familiarization and testing (see §7.2.2.1). Bimodal exposure thus appeared to interfere with their processing of the spoken words in the bimodal condition. We will now discuss possible explanations for the observed cross-modal facilitation (§7.4.1) and interference (§7.4.2) effects.

7.4.1 CROSS-MODAL FACILITATION

One possible explanation for the observed processing advantage in the bimodal condition is the more general *redundant signals* effect, according to which combined information from two redundant stimuli co-activates a response and results in a processing advantage (e.g. Miller & Ulrich, 2003). That is, the processing advantage in the bimodal condition may have resulted from the co-activation of spoken and signed lexical representations during encoding or retrieval (see also Emmorey et al., 2010; Hamilton & Holzman, 1989). More specifically, the co-activation of spoken and signed lexical representations during familiarization in the bimodal condition may have resulted in increased lexical activation and subsequent faster retrieval of the spoken lexical representations during testing. A similar explanation has been put forward with respect to nonverbal multisensory learning, namely that multisensory input creates or changes multisensory neural representations that are subsequently also activated by unisensory stimulation, providing a richer representation that can be used in sensory processing (for a review, see Shams & Seitz, 2008).

It remains to be explained, however, why cross-modal facilitation effects were only observed for minimally different word pairs and not for word pairs that were phonologically dissimilar (see Table 7.3). One possible, but speculative, answer to this question is that the encoding or retrieval of phonologically similar words might benefit more from increased lexical activation than phonologically dissimilar words because the former compete more with each other during spoken word recognition (see §2.1.2).

7.4.2 CROSS-MODAL INTERFERENCE

In contrast to the children with a CI, the adults with normal hearing appeared to experience cross-modal interference in the bimodal condition. This may be explained by their limited signing experience and/or lack of familiarity with bimodal language processing. Some of the adults had had no signing exposure at all. Moreover, although some adults had two years of signing experience as second language learners of NGT, it is likely that they were less often exposed to speech-sign combinations as the children with a CI. Processing of the signs in the bimodal stimuli may have been particularly effortful for them and may have interfered with processing of the spoken words in the same stimuli, perhaps due to competition between limited processing resources along the lines of Bergeson et al. (2005).

Furthermore, besides positively or negatively affecting speech perception, bimodal exposure also affected sign perception. More specifically, the children's responses on the familiar "minimal"[42] sign pairs were slower when familiarization had been bimodal compared to only signed, and the same pattern was observed for the novel minimal sign pairs in the adults. These negative effects could be due to the longer interval between familiarization and testing for the sign pairs in the bimodal condition, or to a form of competition between processing resources in the bimodal condition, as discussed above. Either way, however, it remains unclear why only these specific stimulus pairs were affected.

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[42] Recall that the familiar sign pairs in the experiment were all non-minimal sign pairs (see §7.2.2).

7.4.3 CONCLUSION

To summarize, the results showed that bimodal input does not negatively affect speech perception in children with a CI. In fact, we found that bimodal input appeared to have a *positive* effect on their processing of familiar phonologically similar word pairs. It should be stressed that the sample size was small and that the results should therefore be interpreted with caution, especially because these concern null effects. However, if we visually compare the scores and reaction times in the speech and $\text{bimodal}_{\text{speech}}$ conditions in Figures 7.2 and 7.3, we see that, if anything, scores in the latter condition tend to be higher (except for novel non-minimal pairs) and reaction times faster. This supports our conclusion that bimodal exposure does not negatively affect speech perception and even suggests that a larger sample size may reveal further evidence for cross-modal facilitation in lexical processing.

Further (longitudinal) studies with larger samples are needed to examine the role of the two language modalities, preferably over time. It is not unlikely, for instance, that the benefit from the signed modality is especially pronounced in the first few years following implantation and becomes smaller over time when children gain more experience with the CI and become more proficient in the spoken modality. Importantly, even when children perform age-appropriately on standardized spoken language tests and accurately perceive speech in quiet one-to-one situations, the signed modality may provide useful and much-needed support in more challenging conditions, such as during classroom discussions, playground activities and birthday parties[43]. Future studies should also investigate whether the results obtained here with the presentation of isolated words and signs extend to sentences.

Nevertheless, the results reported in this chapter clearly show that exposing children with a CI to speech and sign at the same time does not necessarily negatively affect their speech perception and does not appear to create competition between limited processing resources. In fact, under some circumstances, namely when the auditory information that needs to be processed is particularly challenging, bimodal exposure may be beneficial, for instance, in retrieving lexical representations of phonologically similar words. These findings further our understanding of the effects of signed input on spoken language processing in children with a CI, although evidently much work remains to be done in this area (cf. Leigh, 2008).

[43] Research into the benefits that children with a CI can obtain from multimodal information in challenging listening conditions of course should not only concern the benefits of access to manual-visual information, but also of access to audiovisual information (see also §7.1.2). For instance, in collaboration with the Leiden University Medical Center we are currently involved in a study that investigates the relative benefit of visual speech information for speech perception in quiet and in noise in children with a CI and children with normal hearing (Beers & Giezen, in preparation).