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3 METHODOLOGY

This chapter presents the methods used to answer the four research questions of this thesis that are restated below. More detailed information on the methodology is presented in the individual chapters.

RQ 1. Do children with a CI use acoustic cues differently in consonant and vowel perception from children with normal hearing of the same age? More specifically, do they use the same cues and if so, do they use such cues as effectively? (Chapter 4)

RQ 2. Are they able to learn novel minimal word pairs after a limited amount of exposure to the novel words and their referents? Furthermore, how do their sound perception and phonological short-term memory relate to their rapid word learning? (Chapter 5)

RQ 3. How do their sign and speech perception abilities compare to one another? (Chapter 6)

RQ 4. Does bimodal input hamper or facilitate their speech perception? (Chapter 7)

3.1 PARTICIPANTS

A group of 15 children with a CI, 20 age-matched children with normal hearing and 21 young adults with normal hearing participated in the series of experiments targeting (pre)lexical perception in speech and sign. By comparing the two groups of children it will be possible to establish whether children with a CI exhibit delays. The results from the adults will be used to determine how close children's performance is to the adult target.

3.1.1 CHILDREN WITH A CI

The children with a CI were 15 pre-lingually deaf 4- to 6-year old children (4 girls, 11 boys). Individual background information for the children is provided in Table 3.1. Their mean age was 5;9 (4;4 – 6;7, SD=10 mo). The majority (12) of these children were part of a group of children from the Netherlands and Flanders[15] that had been followed longitudinally from shortly before implantation until three years post-implantation. The goal of this longitudinal project was to examine the effect of linguistic environment on spoken language development. The project was carried

[15] Flanders refers to the Dutch-speaking part of Belgium; the adjectival form is 'Flemish'.

out by the Dutch Foundation for the Deaf and Hard of Hearing Child (Amsterdam, The Netherlands) and the Royal Institute for the Deaf (Hasselt, Belgium). De Raeve et al. (2009) present a summary of the most important results from this longitudinal project (see also Wiefferink, Spaai, Uilenburg, Vermeij, & De Raeve, 2008)[16]. Importantly, these children formed a relatively homogeneous group with respect to several variables known to affect spoken language outcomes in this population (see §1.3). None of the children in this group were known to have additional disabilities. For all children the surgery was uneventful and the implants were fully inserted. The children were fitted with the latest speech processing algorithm available at the time. For one child programming of the device had been problematic due to behavioral difficulties. For another child, initial problems in programming were solved within three months time. All children wore their implant for the greater part of the day. Parent involvement was overall average to high. All children had Dutch as their native language. Three Dutch children with a CI were added to the sample of 12 children to make the Dutch and Flemish group more comparable in number[17]. They were all pre-lingually deaf and further matched the other children.

All children had received their implant before their fourth birthday and the mean age at implantation in the sample was 1;8 (0;7 – 3;9, SD=11 mo). Six of the 15 children had received their implants before 12 months of age and ten of the 15 children had received their implants before 24 months of age. That is, the majority of the children with a CI included in the sample were implanted relatively early. Importantly, all except two of the children in the sample had received a CI before three years of age (the other two received a CI at 3;2 and 3;9). As a result, almost all children fell below the age cut-off reported in neurophysiological studies to be at risk for atypical (sub)cortical auditory processing (see §1.4.1). This allows us to look for behavioral effects of age at implantation within a narrow and early window. Given that there is substantial variation in age at implantation in the sample and all children were approximately between five and six years old when they were tested for the first time, they differed substantially in the length of time they had been using their implant. On average, they had been using their CI for four years (1 yr/7 mo – 5 yrs/11 mo; SD=14 mo). Thus, age at implantation and length of CI use are

[16] The final report of this project can be downloaded from the website of ONICI (*Onafhankelijk Instituut voor Cochleaire Implantatie*, www.onici.be). The report is in Dutch, but includes a summary in English.

[17] Initially, the parents of 15 children with a CI (7 Dutch, 8 Flemish) from the longitudinal study were asked by letter for their consent to include their child in the study. The parents of 12 children (5 Dutch, 7 Flemish) consented. Subsequently, the parents of six other Dutch children with a CI (from the same school as three of the five Dutch children in the sample) were asked by letter for their consent to include their child in the study; the parents of three children consented.

confounded in our sample. This will be taken into account when interpreting any effects of age at implantation on performance.

Despite the relative homogeneity of the sample, the Dutch and Flemish children differ in several respects. Firstly, in Flanders newborn hearing screening was introduced earlier than in the Netherlands. As a result, the age at diagnosis and first intervention for deaf and hard-of-hearing children in Flanders is on average earlier than in the Netherlands, and thus age at implantation is lower on average, that is, between 18 and 24 months in the Netherlands and between 11 and 17 in Flanders (De Raeve et al., 2009). Secondly, bilateral implantation as well as the use of CIs in combination with acoustic hearing aids is more common in Flanders than in the Netherlands. The mean age at implantation for the Dutch children in the sample was 2;2, whereas for the Flemish children it was 1;4. This difference was significant ($t(13)=2.36$, $p<.05$). In addition, at the time of study, three Flemish children had received a second CI and one had been fitted with an acoustic hearing aid for the non-implanted ear. One Dutch child had received a second CI, but wore it infrequently.

Table 3.1. 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)	bilingual	0;7	5;1
X5	M	B	CI+HA	Cochlear (Sprint)	SimCom	0;7	6;7
J8	M	B	CI	Cochlear (Sprint)	SimCom	0;8	4;10
A1	M	B	CI	Cochlear (Sprint)	mainstream	0;9	5;3
J3	M	B	CI	Cochlear (Sprint)	SimCom	0;10	4;4
V4	M	B	2CI	Cochlear (Freedom, 2x)	SimCom	0;11	6;7
S7	M	B	2CI	Cochlear (Sprint) / Digisonic (SP)	SimCom	1;2	5;2
S6	F	NL	CI	Cochlear (Sprint)	bilingual	1;8	4;10
T1	M	NL	CI	Cochlear (Sprint)	sign supported speech	1;11	4;10
L2	F	NL	CI	Clarion (Platinum)	bilingual	2;0	6;0
D8	M	NL	2CI	Cochlear (Sprint/Freedom)	mainstream	2;1	6;7
K3	M	NL	CI	Clarion (Platinum)	bilingual	2;1	6;4
L6	F	B	2CI	Digisonic SP (2x)	SimCom	2;9	6;7
L4	M	NL	CI	Cochlear (Sprint)	bilingual	3;2	6;7
S5	M	NL	CI	Cochlear (Freedom)	bilingual	3;9	5;4
						M=1;9, SD=11 mo	**M=5;8, SD=10 mo**

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

Crucially, the Dutch and Flemish children also differed in the type of educational setting, due to different perspectives on the role of sign language in education between the countries. The Dutch children were mainly educated in spoken Dutch (supported with signs) and Sign Language of the Netherlands, i.e., a bilingual approach. In contrast, the Flemish children were mainly educated in spoken Dutch, supported with signs (referred to as 'Simultaneous Communication' in Table 3.1)[18]. Furthermore, the parents of the Dutch children had followed courses in Sign Language of the Netherlands (NGT, *Nederlandse Gebarentaal*) and were encouraged to provide signed input to their child, whereas most Flemish parents had not followed courses and were encouraged to use only spoken language with their child. Importantly, this situation provides variation in the amount of signed input at home and school and thus in any effects of signing experience on their speech perception. It should be noted, however, that two children in this group already attended mainstream education at the time of this study. These children evidently no longer received signed input at school.

3.1.2 Children with normal hearing

The children with normal hearing were 20 Dutch children (14 girls, 6 boys) with no known history of speech, language or hearing difficulties (as reported by the school). Their mean age was 5;11 (5;2 – 6;6, SD=4 mo), which matched the chronological age of the children with a CI. Half of the children came from a middle class school in the central region of the Netherlands (The Hague) and half from a middle class school in the central region of Flanders (Hasselt). This was done in order to match the children with normal hearing and the children with a CI with respect to their native regional variety of Dutch (i.e., Northern Standard Dutch versus Southern Standard Dutch). A subset of the sample of children with normal hearing (10) also completed the sign perception tasks in this study, even though they had no signing experience, to compare their performance to that of the children with a CI.

3.1.3 Adults with normal hearing

In order to have an adult control for some of the tasks, 21 Dutch young adults (19 female, 2 male), 20 of who reported no history of speech, language or hearing

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[18] The signs in sign-supported communication are adopted from the surrounding sign languages, Sign Language of the Netherlands (NGT, *Nederlandse Gebarentaal*) in the Netherlands and Flemish Sign Language (VGT, *Vlaamse Gebarentaal*) in Flanders.

impairments, participated in this study[19]. Their mean age was 22;3 (19;0 – 26;3, SD=29 months). They were undergraduate students at the University of Amsterdam. They had Dutch as their native language. Even though they originally came from different parts in the Netherlands, all reported to use the regional variety of Dutch spoken in the central region of the Netherlands. A subset of the adults (11), second-year students in Sign Linguistics from the University of Amsterdam with 1-2 years of signing experience, completed also the sign perception tasks to compare their performance to that of the children with a CI. The others were mostly students in English Language and Culture from the University of Amsterdam.

3.2 TASKS

Several tasks were designed to answer the research questions posed in this thesis. Each task is briefly introduced in this section as related to the four research questions presented at the beginning of this chapter. Each task will be discussed in more detail in the chapter presenting its results.

3.2.1 THE PERCEPTION OF SPEECH SOUNDS: ACOUSTIC CUE WEIGHTING

In order to examine the perception of speech sounds, a speech sound categorization task was designed. This task was designed according to an XAB format, where participants have to decide whether stimulus X is more like A or B, where X is a randomly chosen stimulus from a stimulus series and A and B are the two endpoint stimuli of the series. The XAB categorization task has previously been used by Escudero, Benders and Lipski (2009) and Escudero and Wanrooij (2010), for instance, to examine acoustic cue weighting in adult native listeners and second language learners. In addition, an adapted version has been used by Brasileiro (2009) to examine acoustic cue weighting in young monolingual and bilingual 3- to 7-year-old children. The task allows to determine how effectively specific acoustic cues are used in phonetic categorization of speech sounds and whether specific cues are more important than others. Four speech sound contrasts were tested: two vowel contrasts and two consonant contrasts. The stimulus series for each contrast were created by modifying specific acoustic characteristics such as formant values and duration in naturally recorded speech sound tokens. E-Prime 2.0® (Psychology Software Tools, Pittsburgh PA) was used to present the stimuli and record

[19] One adult reported a history of stuttering. Given that stuttering affects speech production but not speech perception, this participant completed only the tasks that did not require a spoken output (i.e. all tasks except the phonological short-term memory task).

responses. The speech sound categorization task will be explained in more detail in §4.2.3.

3.2.2 THE RELATIONSHIP BETWEEN SOUND PERCEPTION AND RAPID WORD LEARNING

Rapid word learning was assessed in two ways, namely with an on-line picture-matching task (§3.2.2.1) and with an off-line object-matching task (§3.2.2.2). An on-line as well as an off-line task were designed to consider the effects of task demands on the performance of children with a CI, given that previous research has shown that they have smaller verbal working memory capacity than their peers with normal hearing and may have problems with sustained visual attention (Burkholder & Pisoni, 2006; Horn et al., 2005). In addition, phonological short-term memory was independently assessed by means of a digit span task (§3.2.2.3).

The use of word learning tasks was preferred to the use of expressive or receptive vocabulary measures because the former are less dependent on language experience and directly assess word learning abilities, whereas vocabulary measures only assess how many words a child has already learned at a particular age (cf. Hwa-Froelich & Matsuo, 2005; Kan & Kohnert, 2008; Prezbindowski & Lederberg, 2003; Tomblin et al., 2007). Of course, both types of measures are related in the sense that the effectiveness of word learning abilities will partially determine how many words the child has learned at a particular age.

3.2.2.1 PICTURE-MATCHING

In order to assess on-line rapid word learning, a non-word picture-matching task was designed. Non-words are words that do not exist in a particular language (in this case Dutch), but do meet the phonotactic constraints of that language and therefore are possible words in that language (e.g., 'bliek' /blik/ in Dutch). That is, they consist of native sounds and sound sequences.

The non-words used in this task formed minimal pairs, meaning that they only differed from each other in one phonemic segment. Crucially, in order to facilitate comparison between the speech sound categorization and word learning tasks, the phonetic contrasts that distinguished the minimal pairs were exactly the same as those used in the sound categorization task. The pictures used in this task were drawings of novel objects. The participants were familiarized with the word-object pairings preceding a set of two-alternative forced choice test trials in which participants had to match words with pictures. Some of the test trials were incongruent trials, in which the non-word that was presented did not match the novel object shown on the screen. These trials were included as an additional measure of word learning based on reaction times, adapted from infant word learning studies.

E-Prime 2.0® (Psychology Software Tools, Pittsburgh PA) was used to present the stimuli and record responses. Both accuracy (number of trials correctly answered) and reaction times were recorded and analyzed. Reaction times were analyzed because, even if children with a CI are able to learn novel minimal pairs, they might encode, store and/or retrieve them less efficiently than children with normal hearing and thus show slower reaction times. The picture-matching task is explained in more detail in §5.2.2.1.

3.2.2.2 Object-matching

A non-word object-matching task was designed as a measure of off-line rapid word learning to control for performance differences related to some of the task demands of on-line picture matching. The object-matching task was an interactive rapid word learning task presented live to the child by the experimenter and consisted of three subtests: a novel word learning test, a generalization test and a rapid word learning test (Lederberg & Spencer, 2009; Lederberg et al., 2000). The novel word learning test examined whether the children could associate a novel word with an unfamiliar object without explicitly labeling the novel object. The generalization test examined whether the children could generalize a novel word to different exemplars of the same object. The rapid word learning test examined whether the children could learn novel words for novel objects with a limited amount of exposure to both the words and the objects.

Similar to the on-line picture-matching task, the novel words formed minimal pairs. The objects used in the task were mainly kitchen utensils for which it was unlikely that the young children knew the names. Given that adults would likely be able to name the majority of the objects, the object-matching task was only administered to the children. The children were familiarized with the word-object pairings and receptive knowledge of the novel words was tested immediately afterwards. Performance was scored on-site, but also recorded on video for off-site reviewing of the session and initial scoring. The object-matching task is explained in more detail in §5.2.2.2.

3.2.2.3 Phonological short-term memory

As mentioned in §2.1.2, phonological short-term memory capacity has been associated with vocabulary acquisition, as novel sound sequences need to be temporarily stored before they can be integrated in long-term memory. Because of this association and given reports of poorer phonological short-term memory in children with a CI relative to children with normal hearing (Burkholder-Juhasz et al., 2007; Dawson et al., 2002; Pisoni et al., 1999; Willstedt-Svensson et al., 2004), we included a phonological short-term memory task in this study. Phonological short-term memory is usually tested by recalling sequences of digits, letters or (non-)words that increase in length as the test progresses (Gathercole, 1999). Digits were used in this thesis because these are less language experience-dependent than real words or non-words. In addition, it can be assumed that young children are familiar with the words for the digits. The sequences ranged from two to six digits, with three different sequences at each list length. Recall was in fixed, forward, order. That is, if the digit sequence was *5 3 2*, the three digits had to be recalled in that order. The forward digit span task has been used extensively with young typically as well as atypically developing children, including children with a CI (e.g. Gathercole, 1999; Gray, 2003a; Pisoni et al., 1999). The digit span task is explained in more detail in §5.2.2.3.

3.2.3 THE RELATIONSHIP BETWEEN SIGN AND SPEECH PERCEPTION

In order to facilitate the comparison between perception in the signed and spoken modalities, we attempted to keep the tasks and the tested abilities as similar as possible. Thus, a sign categorization task, two rapid sign learning tasks and a signed phonological short-term memory task were designed that matched the designs of those described in §3.2.1 and §3.2.2.

Similar to the sound categorization task, the signed version was designed according to an XAB format. Two phonetic contrasts were included: a hand configuration and a location contrast. The stimulus series for both contrasts consisted of linearly interpolated still images of hand configurations and locations in signing space created in a 3-D animation program, which had been used before by Emmorey et al. (2003).

Two rapid sign learning tasks were designed to match the rapid word learning tasks. Non-signs were created that fulfilled the phonotactic constraints of NGT and VGT. In the picture matching task, video recordings were used to present the novel signs. In the object-matching task, the novel signs were presented by the experimenter. For the remainder, the design of the picture-matching and object-matching tasks were exactly the same as that of their auditory counterparts. It is important to note that in addition to a spoken and signed version, the object-matching task was administered in a bimodal condition to the children with a CI. In this condition, novel words and signs were presented simultaneously. It was added as a preliminary investigation of the effects of bimodal input compared to either spoken or signed input alone (see also §3.2.4).

Finally, a phonological short-term memory task for signs was designed in which participants had to repeat sequences of signed digits of increasing length. The children were free to recall the sequences in their preferred modality (speech or sign) to avoid an effect of production difficulties during recall. As mentioned in §2.2.2, ordered recall might be particularly difficult for deaf signers and a task with free recall might therefore be more suited to measure their phonological short-term memory (Bavelier et al., 2008). However, because the goal was to keep the tasks as similar as possible in both modalities, and because the auditory forward digit span task has been used before in studies of children with a CI, phonological short-term memory for signs was also measured with a forward digit span task.

3.2.4 The effects of bimodal input on speech perception

To address the question whether bimodal input facilitates or hampers speech perception, we designed a task in which participants were familiarized with and tested on phonologically similar or dissimilar names of familiar and novel objects. The task was administered in three conditions: speech, sign and bimodal. Crucially, in the bimodal condition, the word components of the bimodal stimuli were tested separately from the sign components. This was done to directly compare spoken word recognition and learning in the speech and bimodal condition, which only differed in whether or not the words were presented in combination with signs during familiarization. The design of the task further resembled the picture-matching task discussed in §3.2.2.1. E-Prime 2.0® (Psychology Software Tools, Pittsburgh PA) was used to present the stimuli and record responses. Both accuracy (number of trials correctly answered) and reaction times were recorded and analyzed.

The data for this task were collected after the initial set of data (the tasks presented in §3.2.1-3) had been collected. The task was administered to a subset of the children with a CI and the adults that had completed the earlier tasks. Further details on the task and the participants will be given in §7.2.2.

3.3 Procedure

Administration of the first set of tasks (§3.2.1-3) took place individually in quiet testing rooms in the different schools and in a quiet testing room at the University of Amsterdam for the adults. The categorization, picture-matching and digit span tasks were administered on a Dell® Latitude D630 (Intel® Core™ 2 Duo T7250, 14” display, 1280x800 resolution) laptop using two external speakers for the tasks that involved presentation of auditory stimuli (Trust® SP-2310). The object-matching tasks were administered live by the experimenter.

The tasks were administered on two separate days for the children. On the first day, the speech categorization task, the sign categorization tasks (if applicable), the non-word picture-matching task and the non-sign picture-matching task were administered in that order; on the second day, the object-matching task and the digit span task were administered. The speech condition of the object-matching task was administered first, followed by the spoken digit span task, the signed condition of the object-matching task, the signed digit span task and the bimodal condition of the object-matching task. On both days, testing took approximately 45 minutes for the children that completed both the speech and sign perception tasks and 30 minutes for the children who only completed the speech perception tasks. At the end of each session, the children received a small gift. The adults completed all tasks in a single session of approximately one hour if they completed the speech and sign tasks, and approximately 45 minutes if they only completed the speech tasks. The adults received a small payment for their participation.

The picture-matching task investigating the effects of bimodal input on speech perception (§3.2.4) was administered separately after the initial set of data had been collected. It was administered on a Dell® Inspiron 1525 (Intel® Core™ 2 Duo T7250, 15.4 display, 1280x800 resolution) laptop using two external Trust® SP-2200 speakers. Administration took place individually in quiet testing rooms in the different schools and in a quiet testing room at the University of Amsterdam for the adults. Testing took approximately 25 minutes for the children and 20 minutes for the adults.

Given different testing environments, as well as probable inter-individual variation in post-implant hearing thresholds for the children with a CI, the sound volume level was not set at a fixed level, but at the participant's own range of comfort. The sound level was set during the practice sets for each task. Instructions for the children with normal hearing and the adults were in spoken Dutch and for all children with a CI in spoken Dutch supported with signs. Each task was preceded by a practice set, except for the object-matching task that was preceded by a novel word learning test and a generalization test. During practice sets, additional instructions were given when the experimenter felt that it was necessary.

After data collection and analysis, a written summary of the results and conclusions was sent to the schools, parents or caretakers of the child participants, and to the adult participants. Individual results were not provided in the summary, but were available on request.

3.4 STATISTICAL ANALYSES

The SPSS® 15, PASW® 17 and SPSS® 18 software packages were used for statistical analyses. Parametric statistical techniques were used to analyze the data from the picture-matching, object-matching and digit span tasks. More specifically, univariate analyses of variance were used to examine main effects and independent and paired samples *t*-tests were used for post hoc comparisons. In independent samples *t*-tests, the *t* statistic for unequal variances was adopted in case of a significant Levene's test for equality of variances.

The analysis of the results from the categorization tasks required the use of non-parametric statistics because the data were non-normally distributed. More specifically, the rank-based Kruskal-Wallis H test was used to examine main effects and the rank-based Mann-Whitney U test was used for post hoc comparisons. For the statistical interpretation of the Mann-Whitney U test, two-tailed exact significance was adopted to adjust for small and unbalanced samples. The Wilcoxon Signed Rank test was used for non-parametric paired samples comparisons.

In correlation analyses comparing performance in the spoken and signed modalities and investigating effects of age at implantation and length of CI use, Pearson product moment correlation coefficients are reported when the two correlated variables were both normally-distributed and Spearman rho rank-based coefficients when at least one variable was non-normally distributed.

In all analyses, significance is reported as $<.05$ or $<.01$. In all group post hoc comparisons, a correction was applied to adjust for multiple comparisons and the significance cut-off was .02 ($\alpha/n=.05/3=.02$). In all graphs reported in this thesis, the error bars represent one standard error from the mean.