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8 CONCLUSIONS

In the final chapter of this thesis we will summarize the main findings and their implications. This summary is divided into two parts: underlying processes in speech perception (§8.1) and interactions between language modalities (§8.2). In §8.3 we will briefly consider the role of age effects in explaining the performance of the children with a CI. Finally, in §8.4 we will discuss methodological considerations related to this research and make recommendations for future studies.

8.1 UNDERLYING PROCESSES IN SPEECH PERCEPTION

8.1.1 SUMMARY OF MAIN FINDINGS

Our first research question was whether children with a CI use acoustic cues differently in consonant and vowel perception from age-matched children with normal hearing. We found that the children with a CI used several acoustic cues less effectively than their peers with normal hearing, although it should be noted that some of these effects were only marginally significant after adjusting for multiple comparisons. The effect was most pronounced for the spectral cues in the fricative contrast /fu/-/su/, which also turned out to be the contrast that they discriminated most poorly in terms of identification of the endpoint stimuli and classification slope. However, we also found that both groups of children showed similar cue weighting patterns in sound categorization. They weighted the spectral cues as relatively stronger than other available cues such as duration in the vowel contrasts /ɑ/-/a/ and /ɪ/-/i/, and intensity in the consonant contrast /fu/-/su/.

Overall, the children with a CI were able to use acoustic cues quite similarly to their age-matched peers with normal hearing, although somewhat less effectively. The reduced spectrotemporal resolution of sound processing with a CI does not therefore appear to lead to different acoustic cue weighting patterns, at least not for the sound contrasts included in this thesis. Age at implantation was not significantly correlated with sound perception, but length of CI use was. That is, the longer a child had been using the CI the steeper the classification slopes, which means better discrimination of the contrasts.

Our overall finding that the children with a CI tended to discriminate particular vowel and consonant contrasts less well than the children with normal hearing suggests that their sound representations are poorly specified, i.e., are weak and fuzzy. This raises the question as to whether they are able to create new lexical representations on the basis of these sound representations. More generally, sound perception by six year-old typically developing children is not yet adult-like as evidenced by the performance differences between the children and adults on the sound categorization task in this thesis, and as shown in previous studies (e.g. Gerrits, 2001; Hazan & Barrett, 2000; Nittrouer & Miller, 1997). Furthermore, it has been suggested in the literature that typically developing children at this age are restructuring their lexical representations, creating greater phonetic detail under the influence of vocabulary growth (e.g. Garlock et al., 2001; Storkel, 2002, 2004). This suggests that they may have difficulties with learning similar sounding words in rapid word learning experiments. Hearing difficulties are likely to present an extra challenge in this respect. We therefore tested children and adults' ability to learn novel minimal word pairs, e.g., the word pair /tɑt/-/tat/, after a limited amount of exposures to the words and referents. Crucially, the sound contrasts that distinguished the minimal pairs were the same vowel and consonant contrasts as tested in the sound categorization task.

The results showed that whereas both child groups had problems with learning novel minimal pairs in a demanding task, only the children with a CI experienced similar problems with a less demanding and more ecologically valid task. As expected, the scores of the adults approached ceiling. The observed difficulties of the children with normal hearing in the demanding task might relate to the fragile nature of newly created lexical representations. In contrast, the problems for the children with a CI may be more directly related to their hearing difficulties and resulting problems in sound perception.

We found some relationship between the obtained measures: sound perception, as measured by the sound categorization task, correlated with rapid word learning for the children with normal hearing, but not for the children with a CI. Phonological short-term memory, as measured by a digit span task, did not correlate with rapid word learning for either group of children. However, digit span and sound categorization were correlated for the children with a CI, suggesting that limitations in phonological short-term memory may have contributed to their poorer sound perception. Age at implantation and length of CI use did not correlate with rapid word learning performance. Length of CI use correlated significantly with digit span, suggesting that auditory experience is an important factor in the development of phonological short-term memory.

8.1.2 Implications

Spoken word recognition is characterized by competition between word candidates with overlapping phonological representations (Magnuson et al., 2007; see also

§2.1.2). Poor perception of sound contrasts and a lack of phonetic detail in newly created lexical representations can be predicted to increase lexical competition during spoken word recognition. When children with a CI are uncertain about which sounds and words they hear, co-activated word candidates will compete more strongly and/or for a longer time than in children with normal hearing. For instance, if they have difficulty distinguishing between /f/ and /s/, and they hear the sentence 'It's a funny day', they will initially activate all word candidates starting with both /f/ and /s/ instead of only words starting with /f/. Furthermore, if the words *funny* and *sunny* are not clearly distinguished in their mental lexicon, both will remain equally activated until the semantic or pragmatic context decides on the correct interpretation. Word recognition and sentence processing may thus cause a greater cognitive load.

In this respect, the problems children with a CI experience during spoken word recognition may be similar to those experienced in second language (L2) listening. Because languages differ in their sound inventories, L2 learners may initially treat two different L2 sounds as belonging to one category because their first language does not distinguish between them (e.g. Best, McRoberts, & Goodell, 2001; Escudero et al., 2009; Escudero & Boersma, 2004; MacKay, Flege, Piske, & Schirru, 2001). Such inaccurate categorization of L2 phonemes can cause word recognition problems for L2 learners (Cutler, 2005). For instance, there is an increase of pseudo-homophones in their mental lexicon, i.e., words that sound alike but have different meanings. For Dutch learners of English, *cattle* may be activated when hearing *kettle* since they have difficulties distinguishing the vowel contrast /ɛ/-/æ/. In addition, they may experience spurious lexical activation from non-words embedded in longer words or phrases that they confuse with real words as in *chess* in *chastise*. Finally, they have to resolve temporary ambiguity. For instance, upon hearing the first syllable of the word *pencil*, the word *panda* will also remain active. Each of these problems results in a (temporary) increase in lexical competition during spoken word recognition and slower lexical access. Children with a CI may therefore experience a similar increase in lexical competition during spoken word recognition because of inaccurate sound categorization. Indeed, two recent studies have found less efficient lexical access in children with a CI compared to their peers with normal hearing (Wass et al., 2009; Wechsler-Kashi, Schwartz, Cleary, & Madell, 2009).

In addition, our findings help to explain the recurrent finding that children with a CI have difficulties in learning novel words in rapid word learning tasks (Houston et al., 2005; Tomblin et al., 2007; Willstedt-Svensson et al., 2004). As explained in §2.1.2, when children hear novel words, they will initially try to match the input to words in their mental lexicon. Only when recognition fails will they form a new lexical representation. Competition between a novel word and familiar words in the mental lexicon thus makes it more difficult to detect the novelty status of the word (Hoover et al., 2010; Jarvis, Merriman, Barnett, Hanba, & Van Haitsma, 2004; Storkel et al., 2006; Swingley & Aslin, 2007). Our results suggest that phonological neighborhoods in children with a CI might be larger than those of children with normal hearing. They might therefore experience more competition when encountering novel words.

Our results also have implications for the development of phonological awareness, an important precursor to reading. Several studies have reported poorer phonological awareness and/or word reading ability in children with a CI compared to their peers with normal hearing (e.g. Geers, 2003; James, Rajput, Brinton, & Goswami, 2008; James et al., 2005; Spencer & Tomblin, 2009). Metsala, Stavrinos and Walley (2009) recently showed that in typically developing children performance on a speech gating task[44] predicted the development of phonological awareness across a one-year span; phonological awareness in turn predicted word reading ability (see also Walley et al., 2003). The difficulties in learning to read that many children with a CI experience may thus be related to poor phonological specificity in their lexical representations.

Finally, poorly specified representations of speech sounds and words may negatively affect verbal working memory processes if phonological information is poorly encoded in short-term memory (e.g. Burkholder-Juhasz et al., 2007; Pisoni et al., 1999). Indeed, our results showed a trend towards smaller digit spans in the children with a CI than their peers with normal hearing. Additionally, sound perception correlated positively with phonological short-term memory. It should be mentioned, however, that this relation may also be in the opposite direction (see §4.4.1). Most importantly, less efficient processing in verbal working memory has been associated with poorer spoken language outcomes in children with a CI (e.g. Dawson et al., 2002; Pisoni et al., 1999; Willstedt-Svensson et al., 2004).

Summarizing, increased lexical competition as a result of poor sound discrimination and a lack of phonetic detail in lexical representations can lead to a bottleneck in spoken language processing (see McMurray et al., 2010 for discussion). Language development starts with perceiving sounds and words and if these two processes are disturbed, spoken language acquisition will present a greater challenge, as illustrated by recent studies on the predictive powers of early speech perception abilities for later language development (e.g. Kuhl et al., 2005; Marchman & Fernald, 2008; Newman et al., 2006). Although advances in CI technology and newborn hearing screening have created opportunities for many deaf

[44] In a speech gating task participants are presented with word fragments of increasing duration and they have to guess the word after each fragment. This task can be used as a measure for the specificity of lexical representations (e.g. Mainela-Arnold, Evans, & Coady, 2008; Metsala et al., 2009).

children to acquire a spoken language and achieve near-to-age-equivalent scores on standardized spoken language tests, CIs do not restore normal hearing, as is also underlined by our results[45]. Spoken communication remains effortful for children with a CI, especially in noisy environments that, unfortunately, characterize many situations in daily life. In addition, despite the fact that many children perform incredibly well with their implants, many others obtain much less or even minimal benefit from it. These children continue to show substantial delays in spoken language development after implantation and may never achieve the means for successful spoken communication. To reduce effortful spoken communication and to allow for alternative means of communication when the CI provides only limited benefits, it would seem important to also provide input in and access to another language modality, namely the signed modality.

8.2 INTERACTIONS BETWEEN LANGUAGE MODALITIES

8.2.1 SUMMARY OF MAIN FINDINGS

Whereas in Chapters 4 and 5 the focus was on the spoken modality and more specifically on speech perception in children with a CI, in Chapters 6 and 7 it was on the relationship between the spoken and the signed modality. The role of signed input in the education of children with a CI is strongly debated in the literature, with some studies reporting that it has profound negative effects on spoken language outcomes, while others report neutral or even positive effects (see §1.4.2 for detailed discussion). Our approach differed from these previous studies, however, because instead of comparing children from different educational settings, we assessed and related both language modalities in the same sample of children. A within-subject approach is less sensitive to confounding variables than a between-subjects approach, because in the latter approach the two groups of subjects may differ in aspects other than the variable of interest alone.

In addition to adopting a within-subject approach, a major difference between the research reported here and previous research is that we used experimental tasks as outcome measures instead of standardized tests. We did not include standardized

[45] It remains to be seen to which extent poor sound discrimination abilities in children with a CI can be improved by discrimination training and to which extent such training may generalize to phonological processing abilities (see e.g. Moore, Rosenberg, & Coleman, 2005 on typically developing children). Unfortunately, available training studies so far have focused on adult implant users (e.g. Fu & Galvin III, 2008; Loebach, Pisoni, & Svirsky, 2009; Stacey & Summerfield, 2008).

speech perception tests and vocabulary measures because we were interested precisely in the underlying processes that characterize performance on such tests. In addition, standardized speech perception and especially vocabulary tests are highly dependent on previous language experience. Studies with child and adult bilinguals have consistently shown smaller vocabularies in each of their languages than their monolingual counterparts (Bialystok, 2009). Smaller receptive and expressive spoken language vocabularies in children with a CI who receive signed input in addition to spoken input are therefore not unexpected. When spoken and signed vocabulary are considered together, these children may have equal or in fact larger vocabularies than those who receive only spoken input (see e.g. Connor et al., 2000).

To facilitate the comparison between the two language modalities, we assessed performance on a sign categorization task, two rapid sign learning tasks and a phonological short-term memory task for signed digits that were similar in design to their auditory counterparts. The performance of the children with a CI on the sign perception tasks was compared with that of children with normal hearing and no signing experience and adults with 1-2 years of signing experience as second language learners.

Comparison of both language modalities for the three groups of participants showed that the children with a CI performed similarly in both modalities on the picture-matching, object-matching and digit span tasks, while the other two groups, which had no or limited signing experience, were significantly less accurate in the signed modality (except for the adults in the digit span task due to a ceiling-effect). The children with a CI performed more poorly in the signed than the spoken modality on the categorization task in terms of their classification slopes. As we argued in §6.3.1, their relative difficulties with this task may not have been due to a lack of signing experience, but to the particular design of the task.

Despite as a group performing at equal levels in both modalities, inter-individual variation among the children with a CI in the signed modality was relatively large. Importantly, we showed that the observed variation in their sign perception abilities was positively associated with variation in their speech perception abilities. More specifically, we observed significant *positive* correlations between phoneme endpoint identification scores in the sound categorization task and classification slopes in the sign categorization task, between scores in the spoken and signed picture-matching tasks, and between reaction times in the spoken and signed picture-matching tasks. Furthermore, chronological age and length of CI use correlated positively with picture-matching scores in the signed modality. These positive correlations clearly show that relatively good performance in the signed modality does not preclude relatively good performance in the spoken modality. On the contrary, the children that had good speech perception abilities also had good sign perception abilities.

In order to further investigate the relationship between the two language modalities in children with a CI, we examined the interaction between both modalities when children are simultaneously exposed to speech and sign. Does exposing children with a CI to such bimodal input negatively affect speech perception, as suggested by Bergeson et al. (2005), or positively, as observed by Mollink et al. (2008) for hard-of-hearing children? To examine this children were familiarized with and tested on words, signs or simultaneously produced word-sign combinations that were either familiar or novel, and phonologically dissimilar or similar. We were unable to find negative effects of bimodal exposure on spoken word recognition and learning. In fact, for familiar minimal pairs, information from both modalities was beneficial because it resulted in faster reaction times compared to the speech condition.

8.2.2 Implications

Although it cannot be said that signing experience leads to improved speech perception, we were unable to find negative effects. In fact, we obtained positive correlations between performances in both language modalities for the children. Negative effects of signed input have been suggested in several studies comparing speech perception in children in Oral and Total Communication settings (Archbold et al., 2000; Geers et al., 2003a; Kirk et al., 2003; Pisoni et al., 1999; Svirsky et al., 2000). As discussed in §1.4.2, the findings from these studies were difficult to interpret for several reasons: 1) the variation in educational practices subsumed under the label Total Communication; 2) Oral Communication and Total Communication children may have differed in other respects than just communication modality; and 3) specifically those children who are showing less than expected progress may be more prone to end up in Total Communication settings and/or remain there for a longer time.

In Chapter 7, we specifically addressed one account of how simultaneously exposing children with a CI to speech and signs might negatively affect spoken language outcomes, namely the 'division of visual attention' account by Bergeson et al. (2005). Our results show, however, that it is very unlikely that bimodal input creates competition in visual attention between the face, for speech reading, and the hands, for sign recognition. If anything, the effect that we observed was positive and suggested cross-modal facilitation, not interference. We caution against generalization of these results, however, because the sample size and observed effects were small, and because we only examined the effects of bimodal input on the recognition and learning of isolated spoken words. Replication and extension of our findings is therefore warranted. Nevertheless, the results are suggestive and in line with those from Chapter 6, namely that exposure to and use of the signed as well as the spoken modality does not impede development in children with a CI.

On the basis of our findings, we therefore argue in favor of signed input for children with a CI. Signed input before and for at least some time after implantation can provide the means for effective early parent-child interaction and can provide important foundations for cognitive, linguistic and social development (Marschark, 2007). Given that the majority of deaf children are born to hearing parents, achieving natural and effective communication in the signed modality is only possible with substantial effort from parents and encouragement from professionals. However, access to the signed modality will provide the children with the opportunity to use communicative means other than spoken language whenever needed to, for instance, in challenging listening environments, in the case of device malfunctioning or when interacting with deaf peers without a CI. Indeed, many parents think signing support is useful after implantation (Archbold et al., 2006; Christiansen & Leigh, 2004; Watson et al., 2008).

How long parents should provide signed input to their children at home and school and how much input there should be has to be considered for each child individually, but ensuring successful communication should be the main driving force in this decision. Creating access to the spoken modality may be the ultimate goal of cochlear implantation, but this does not necessarily imply that alternative means of communication cannot play a role in the lives of these children, or that speech-sign bilingualism should be discouraged. Regardless of whether a particular child with a CI will go through life relying solely on spoken communication, or will also use signed communication, the opportunities for development in both language modalities should be offered and this can only be achieved by providing input in both modalities from the outset and at least throughout a substantial part of childhood.

On a final note, we would like to mention the possibility that any delays in spoken language development in children with a CI that also receive signed input may not be permanent. Although opinions will surely differ on this matter, temporary delays in spoken language development might be justified in order to stimulate sign language development. More longitudinal studies are needed to determine whether differences in spoken language abilities between children with and without signed input decrease over time and may eventually disappear (see e.g. Bergeson et al., 2005).

8.3 AGE EFFECTS

Throughout Chapters 4 until 7, we have considered the role of age at implantation, length of CI use and chronological age in explaining the performance of the children with a CI. Especially age at implantation has often been found to affect spoken language outcomes in this population (see §1.4.1 for a detailed discussion). However, it did not correlate significantly with any of the outcome measures included in the present thesis. In §5.4.2 it was suggested that this may have been due to the small sample size in combination with the restricted range in age at implantation in our sample and the fact that most children in our sample were implanted in the first two years of life. Most available studies on the role of age at implantation investigated samples with a wider range in age at implantation and thus also included children who were implanted after two years of age (e.g. Anderson et al., 2004; Artieres et al., 2009; Chin et al., 2007; Geers et al., 2003b; Kirk et al., 2003; Nicholas & Geers, 2007; Svirsky et al., 2004; Zwolan et al., 2004).

Although age at implantation and length of CI use were to some extent confounded in our sample (see §3.1.1), we did observe a significant positive correlation between length of CI use and several outcome measures (see §5.3.4, §6.4 and §7.3.3). That is, the longer the child was using the device, the better he or she performed on the tasks, in the spoken as well as the signed modality. These correlations with length of CI use suggest an important role for language input after implantation in the development of speech and sign perception abilities.

To summarize, although age effects only weakly influenced performance on our outcome measures, they suggest that length of CI use is a more important factor than age at implantation in explaining speech perception abilities in a sample of children with a CI that were implanted relatively early. Moreover, length of CI use positively impacted on both speech and sign perception abilities. It is possible that age at implantation is more important in predicting early spoken language development, whereas later outcomes are affected relatively more by length of CI use (see e.g. Artieres et al., 2009; Geers et al., 2009). Alternatively, age at implantation may mainly be found to be an influencing factor in samples that include a wider range in ages at implantation and thus also a substantial number of children that are implanted after two years of age (see e.g. Nicholas & Geers, 2007)[46].

[46] However, Coene et al. (in press) recently showed effects of age at implantation on a variety of linguistic measures in a sample of 9 children with a CI implanted between 5 and 19 months of age.

8.4 METHODOLOGICAL CONSIDERATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

In the concluding section of this thesis, we would like to discuss a few methodological considerations regarding generalization of our findings and future research.

8.4.1 SAMPLE REPRESENTATIVENESS

Our sample of children with a CI was relatively small, especially given the large inter-individual variation in this population (§1.3.1). As a consequence, the statistical power in the analyses was low. A larger sample may therefore have revealed further differences between children with a CI and children with normal hearing that we were unable to detect in the present study. It should be noted, however, that despite small numbers the sample was relatively homogenous (§3.1.1). The children were all pre-lingual profoundly deaf and ten out of 15 children had been implanted in the first two years of life. The surgery had been uneventful and the implants fully inserted for all children. They were also fitted with the latest speech processing algorithm available at the time. Parent involvement was overall average to high and at the time of study all children wore their implant for at least the greater part of the day. All children had at least one hearing parent and Dutch was the only spoken language used at home. Furthermore, at the time of testing no additional disabilities had been diagnosed for any of the children. Because of the relative homogeneity of our sample, several sources of inter-individual variation known to affect outcomes in this population had largely been controlled for, such as the age at onset and severity of hearing loss, the number of languages spoken at home and the presence of any additional disabilities. Especially for small samples, homogeneity can thus be considered an advantage. Evidently many other sources of variation remain that we were unable to control for, such as type of CI, etiology of hearing loss, and frequency and intensity of speech-language therapy.

Homogeneity of a sample can also be considered a disadvantage, however, because it limits the sample representativeness. That is, whereas our sample may have been quite homogenous, the wider population of children with a CI is not and includes children varying widely in age at onset and severity of hearing loss, age at diagnosis, age at implantation, success of the surgery, nonverbal IQ, family support, classroom placement and so on (Geers et al., 2007). Ideally, outcome studies should include all children consecutively implanted at an implant center in a specific time period, regardless of background, success of the surgery and fitting, consistency of CI use or educational setting. Only few studies so far have accomplished that, however (Marschark et al., 2007). In addition, there is a need for research projects involving multiple CI centers, allowing for large representative samples (e.g. Fink et al., 2007). In the European context, this may also be achieved with collaborations between centers from different countries and support from supranational funding agencies. Such international studies may also allow more fine-grained distinctions in assessing effects of communication modality and educational approaches than has hitherto been possible (e.g., distinguishing between Auditory-Verbal, Bilingual-Bicultural, Simultaneous Communication, and Total Communication approaches).

8.4.2 ECOLOGICAL VALIDITY

The outcome measures included in this thesis were all experimental tasks specifically designed to answer our research questions. The advantage of using experimental measures is that it allows for methodological control of variables. For instance, in order to exclude the role of previous language experience, we opted for rapid word learning tasks instead of standardized vocabulary tests to examine lexical learning in this thesis. However, an increase in methodological control usually comes at the cost of a decrease in *ecological validity*. That is, the participants had to perform tasks that were not necessarily representative of natural behavior. Although children, and to a lesser extent adults, are frequently exposed to novel words, these are usually not minimal pairs and they are usually not produced in the absence of semantic context that provides clues as to their meaning.

This concern applies to much experimental research in general, but in the case of children with a CI two additional concerns should be noted. Assessing children in quiet testing rooms under laboratory-like experimental conditions does not reflect their performance in more naturalistic, noisy environments (see also §1.3.1). Moreover, neither experimental sound perception or word learning tasks nor standardized spoken language tests reflect their communicative functioning (Beadle et al., 2005; Lin et al., 2008). There is therefore a strong need for studies that examine the functional listening performance of children with a CI in more natural environments, e.g., at home or in their classrooms, and for the development of measures of communicative functioning specifically targeted to this population (e.g. Lin et al., 2007).

8.4.3 MOVING TARGETS

The rapidly changing face of cochlear implantation and thus also of the population of children with a CI (see also §1.2) is a major challenge for research. The continuing technological improvement of the CI and the processing algorithms provides children implanted today with a better starting position than those implanted six years ago, such as the children in this thesis. In addition, more children with a CI receive bilateral implants now than six years ago, either sequentially or simultaneously[47]. Furthermore, children with severe hearing loss and not only profound hearing loss are now also implanted (e.g. Fitzpatrick et al., 2009). Finally, although the children in our sample were implanted relatively early (1;8 on average), this can still be considered fairly late according to today's standards (e.g. Archbold & O'Donoghue, 2009; Eter & Balkany, 2009; Holt & Svirsky, 2008; Papsin & Gordon, 2007). The results we have presented here might therefore not apply to children that have been implanted more recently. As discussed by Geers (2006), children with a CI form a rapidly moving target and outcome research is soon outdated. However, we should not forget that the children who received their implants six years ago have to learn to read today and present their teachers with challenges on how to best help them in this process. These children should therefore not be neglected in pediatric CI research.

8.4.4 Inter-individual variation in performance

A final issue concerns inter-individual variation. Large inter-individual variation has been reported often in the pediatric CI literature (Belzner & Seal, 2009; Bond et al., 2009; Peterson et al., 2010; Schauwers et al., 2005; Thoutenhoofd et al., 2005), and the research presented here is no exception. All analyses presented in Chapters 4 to 7 involved group results and comparisons. However, as can be judged from the standard errors in the bar charts and the individual results listed in Appendices C and E, performance by the children with a CI was characterized by substantial inter-individual variation. To illustrate this point, we will review the performance of three children in some detail here, relative to that as a group[48].

For instance, child *A1*, a Flemish child implanted at 0;9, was in a mainstream school at the time of study. His performance in the spoken modality resembled that of the group (e.g., 63% correct for sound categorization, 75% for picture-matching and 50% for object-matching). As expected given his limited signing experience, he performed relatively poorly in the signed modality (e.g., 25% correct for sign categorization, 69% for picture-matching task and only 25% for object-matching). In the study from Chapter 7, he was one of the children that benefited most from the bimodal input. His overall percentage correct scores were 79% in the speech

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[47] In our sample three children had received a second implant. In addition, one child used an implant on one side and an acoustic hearing aid on the other; this has also become more common in recent years and is called electric-acoustic or bimodal hearing (for reviews, see Ching et al., 2007; Firszt et al., 2008; Nittrouer & Chapman, 2009; Schafer et al., 2007).

[48] Background characteristics of these children can be found in §3.1 (Table 3.1).

condition, 88% in the sign condition and 96% for the words in the bimodal condition.

Child *D8*, a Dutch child implanted at 2;1, was also in a mainstream school at the time of study. He performed relatively well in the spoken modality (e.g., 63% correct for sound categorization, 72% for picture-matching and 88% for object-matching) and also in the signed modality (e.g., 100% correct for sign categorization, 100% for picture-matching and 75% for object-matching). His overall percentage correct scores in study from Chapter 7 approached ceiling (96% correct in the speech condition, 92% in the sign condition and 96% for the words in the bimodal condition).

Child *S5*, a Dutch child implanted at a relatively late age, namely 3;9, was at a school of the deaf at the time of the study. He performed relatively poorly in the spoken modality (e.g., 50% correct for sound categorization, 53% for picture-matching, but surprisingly, 100% for object-matching) as well as the signed modality (e.g., 50% correct for sign categorization, 38% for picture-matching, but again surprisingly, 75% for object-matching). His overall percentage correct scores in the study from Chapter 7 were relatively low and he did not appear to benefit much from bimodal input (83% correct in the speech condition, 88% in the sign condition and 83% for the words in the bimodal condition).

The observed variation in performance among these three children underlines that any conclusions based on group results should be interpreted with caution and should take into account the inter-individual variation in the group. Moreover, there is the issue of incomplete or missing data. Not all children completed each of our tasks and a few children failed to complete some tasks in their entirety. This is not very surprising given that experimental data from young children, typically or atypically developing, is often characterized by missing data. However, the children with a CI in our sample more often did not complete a task than the age-matched children with normal hearing, suggesting that there is more to the problem than just chronological age or general cognitive ability. Unfortunately, incomplete data is very difficult to interpret. For instance, it may be that, because they are generally more often tested than children with normal hearing, they felt less constrained in indicating that they did not want to continue anymore. Alternatively, it may be that they got tired earlier than their peers with normal hearing because attentive listening is more difficult for them.

More importantly, however, two children had to be excluded from all analyses in Chapters 4 to 6 because they failed to complete *several* of the tasks. As such, they did not contribute to the group results and the variation in those results, but they are relevant to the present discussion. For one of these children, implanted at 1;8, fitting and programming of the CI had been problematic. In general, she was considered a low performer with the implant and mainly communicated in sign language. These circumstances likely contributed to her difficulties with completing the speech perception tasks. She was however able to complete the sign perception tasks. The second child, implanted at 0;8, was very inattentive on both testing days, resulting in difficulties in completing our tasks. This child was generally considered a good performer with the implant. It is possible that we simply tested the child at an unfavorable moment. Alternatively, this child may have clinically relevant attention difficulties. For instance, Pisoni et al. (2008) discuss preliminary results showing that children with a CI are rated more poorly than children with normal hearing on several scales of executive functioning, including attention and behavioral regulation (see also Barker et al., 2009).

Large inter-individual variation in outcomes among children with a CI stresses the need for individually based intervention. More specifically, the population of children with a CI includes children who rapidly catch up with their peers with normal hearing, children who develop their spoken language with the same rate and therefore maintain a constant language delay, and children whose language delay increases over time (see e.g. Nicholas & Geers, 2007). Thus, varied educational choices have to be made regarding special education or mainstreaming in terms of the type and amount of additional support a child should receive. More specifically, some children may do very well in mainstream settings and not need additional signed support, while others may need such support. The problem with waiting until it becomes clear that a child does not make sufficient progress and therefore needs additional support is that a delay in social-emotional, cognitive and linguistic development might already have occurred (Leigh, 2008).

This thesis has provided evidence that the spoken and the signed modality do not interfere with each other and that they may even enhance one another under specific circumstances. Clearly, further research that examines the relation and interaction between both modalities in this population is needed before the debate on the effects of signed input on spoken language outcomes can be settled. However, if future studies corroborate the findings presented here, we see no reason why children with a CI should not receive signed input in addition to spoken input. This would ensure successful communication at all times and give them the opportunity to profit from the best of both modalities as they become successful speech-sign bilinguals.