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Author M.R. Giezen
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SUMMARY IN ENGLISH

PEDIATRIC COCHLEAR IMPLANTATION

A cochlear implant (CI) is an electronic ear prosthesis that directly stimulates the auditory nerve and partially restores access to sound and speech for profoundly deaf children and adults. The last decade has witnessed a substantial increase in the number of implantations in deaf children. At the same time, a rapid decrease of the age at implantation to below 12 months and advances in design and speech processors have increased the benefit children can obtain from the CI. Bilateral implantation and the combination of acoustic hearing aids and CIs can even further increase the benefit, especially in noisy environments (Chapter 1).

Although the potential and success of CIs has far exceeded expectations, they do not restore normal hearing. Compared to the human ear, sound processing with a CI is characterized by poor spectral, and to a lesser extent temporal, resolution. Recent studies with large samples of children have indicated that many continue to be delayed in their spoken language development compared to their peers with normal hearing, even after several years of CI use. However, there is substantial inter-individual variation in outcomes (Chapter 1).

Standardized speech perception, speech production and expressive and receptive vocabulary and language tests are typically used for assessing spoken language outcomes in children with a CI. Relevant as these may be in the clinical setting, they tell us little about actual performance with the CI and underlying processes in speech perception that may help to explain the observed large inter-individual variation in outcomes. For this reason, the first goal of this thesis was to study the perception of sounds and words and their interrelationship (Chapter 2).

The observed delays in spoken language development further suggest that children with a CI may benefit from having access to alternative modes of communication such as sign language. However, the role of signed input in the education of children with a CI is much debated (Chapter 1). Instead of supporting spoken language development it has been suggested that any form of signed input impedes spoken language development. Typically these studies have compared two groups of children from different educational settings, usually Oral Communication settings (i.e., only spoken language) and Total Communication settings (i.e., both spoken language and some form of signed communication). By contrast, only a few studies have assessed both language modalities in the same children. Furthermore, no systematic study has yet been done on the effects of using sign-supported speech on spoken language processing in children with a CI. The second goal of this thesis was therefore to obtain further insight into the effects of signed input on spoken language abilities, in particular speech perception (Chapter 2).

STUDY DESIGN

This thesis has accomplished these goals by examining the use of acoustic cues in sound perception and the representation of sound contrasts in novel words, by interrelating similar performance measures in both language modalities, and by investigating the effects of bimodal (i.e., simultaneously spoken and signed) input on speech perception. Specifically, we assessed speech and sign perception abilities in a sample of 15 5-to 6-year-old children with a CI who varied in the extent and nature of signed input received at home and school. Half were educated a spoken language, supported with signs, and the other half were also educated in a sign language. Average age at implantation in the sample was 1;8 and average length of CI use four years. Their performance was compared to that of 20 age-matched children with normal hearing and 21 young adults with normal hearing. The administered tasks included sound and sign categorization, rapid word and sign learning and phonological short-term memory in both modalities. In addition, an extra task designed to investigate the effects of bimodal input on spoken word recognition and learning was administered to a subset of the children with a CI (Chapter 3).

THE PERCEPTION OF SOUNDS AND WORDS

Listeners discriminate and identify speech sounds on the basis of language-specific combinations of acoustic cues present in the speech input, such as spectral and temporal cues. The development of adult-like cue weighting continues until later childhood and likely presents an extra challenge for children with a CI given their limitations with sound processing. We therefore investigated the use of acoustic cues in vowel and consonant contrasts with a sound categorization task (Chapter 4). In each contrast, different acoustic cues were manipulated, such as spectrum and duration for the vowel contrasts. Results showed that the children with a CI used some acoustic cues less effectively than their peers with normal hearing, resulting in shallower discrimination functions. The place of articulation contrast /fʌ/-/sʌ/ presented them with the most difficulties. Importantly, however, both groups of children and the adults showed similar perceptual cue weighting patterns for the vowel and consonant contrasts. For instance, they all weighted the spectral cue as relatively stronger than the durational cue in categorizing the vowel contrasts. That is, despite poor spectral resolution of the implant, children with a CI appear to show typical language-specific cue weighting patterns. Finally, the children with normal hearing did not yet exhibit adult-like use of acoustic cues and categorized contrasts less consistently than the adults, consistent with previous reports in the literature on the continuing development of sound perception into childhood.

In Chapter 5, we examined the interrelationship between sounds and words by testing children and adults' ability to learn novel minimal pairs (e.g., /tat/-/tat/) in

rapid word learning tasks. Their scores in these tasks were related to their sound perception and phonological short-term memory. The latter was measured with a digit span task. The same consonant and vowel contrasts included in the sound categorization task distinguished the minimal pairs in the rapid word learning tasks. 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. Age at implantation did not correlate with sound categorization, rapid word learning or phonological short-term memory. However, the latter correlated significantly with length of CI use, highlighting the importance of auditory experience in the development of phonological short-term memory. Phonological short-term memory further correlated significantly with sound categorization for the children with a CI. A significant correlation between sound categorization and rapid word learning was found for the children with normal hearing but not for the children with a CI, and for only one of the two rapid word learning tasks. This correlation suggests that the construction of novel lexical representations is affected by the stability of phonetic category boundaries, consistent with existing literature on the continuing development of both phonological and lexical representations into childhood.

SPEECH AND SIGN PERCEPTION: RELATIONS AND INTERACTIONS

Chapters 6 and 7 investigated the relationship and interaction between sign and speech perception in children with a CI. In Chapter 6 we showed that they obtained equal levels of performance in the spoken and signed modality on the two rapid word and sign learning tasks and on the phonological short-term memory tasks. However, on the categorization task they performed more poorly in the signed modality. Correlations between the two modalities for each task showed significant *positive* correlations for several measures, whereas negative correlations would have been expected in case of a direct negative influence of signing experience on speech perception. That is, in our sample the children with higher sign perception scores also obtained higher speech perception scores. Moreover, length of CI use correlated with scores in both language modalities, underlining the importance of language input following implantation for the development of speech and sign perception abilities. These findings suggest that spoken and sign language development are not mutually exclusive for children with a CI and that other factors such as early language stimulation, cognitive development and efficient parent-child interaction may be more important in determining language outcomes in both modalities.

In Chapter 7 we extended our investigation of the relationship between the two language modalities to real-time interaction in a sign-supported speech context. That is, we wanted to determine whether exposing children with a CI to bimodal input facilitated or hampered their speech perception. For that reason, we compared spoken word recognition and learning in speech-only and bimodal conditions. The

stimuli consisted of familiar and novel word and sign pairs, both phonologically similar (i.e., minimal pairs) and dissimilar. Crucially, although familiarization in the bimodal condition was in speech and sign, testing was only in speech, allowing us to directly investigate the effects of bimodal input on speech perception. The results revealed no negative effects of bimodal exposure on spoken word recognition and learning and in fact suggested positive effects on the recognition of phonologically similar familiar words, such as /kɒp/ and /pɒp/. These results are consistent with the positive correlations reported in Chapter 6 and further indicate that the two modalities can actually complement each other in language processing.

IMPLICATIONS

The discussion of our findings (Chapter 8) focused on the increase in lexical competition that is likely to result from less sharp boundaries between phonetic categories and a lack of phonetic detail in newly created lexical representations. Furthermore, we argued that increased competition in the mental lexicon will likely negatively impact the speed and efficacy of spoken word recognition and verbal working memory processes, and slow down vocabulary acquisition and the development of phonological awareness. Additionally, our findings from Chapters 6 and 7 showed that signed and spoken language development are not mutually exclusive for children with a CI and that bimodal input may even facilitate their spoken word recognition. Signed input therefore does not appear to have negative effects on spoken language processing. Thus, it is argued that signed input should not be withheld from children with a CI, especially given its importance in stimulating early social and cognitive development, in the case of implant malfunctioning and in facilitating interactions with deaf peers without a CI. In fact, this speaks for bilingualism in a spoken and a signed language as the ultimate goal in the rehabilitation and education of children with a CI. Evidently, to achieve this goal considerable effort and support is required from all those involved in pediatric cochlear implantation, including parents, clinicians, speech-language therapists and teachers, and last but not least, researchers, who need to provide a stronger evidence base regarding the effects of signed input on social, cognitive and language development in children with a CI.