Chapter 1
General introduction
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"Perception is of definite and probable things."

(James, 1890, p. 82)

Communication is a continuous process in which mutual understanding must be reached to be called ‘effective’. On the recipient’s side of a spoken interaction, hearing impairment affects understanding and this may lead to communication breakdowns. If a breakdown is detected by the hearing-impaired recipient and/or their partner in conversation, various strategies can be used by both parties to either repair the interaction (e.g., Hallam & Corney, 2014) or to restrict the effect of the comprehension glitch on the unfolding conversation by concealing the problem (Skelt, 2007). Thus, uncertainties about the correct perception of spoken language by the hearing-impaired recipient enter the interaction, thereby influencing conversational fluency. Hearing impairment may also affect the sender’s side of the interaction: when congenital hearing impairment (CHI), i.e., hearing impairment from birth, has affected the acquisition of a spoken language, a hearing-impaired person may use linguistic forms that deviate from the norm (chapters 2 and 5 of this thesis). Despite the fact that language allows for variance in its use that is considered normal, deviations can be perceived as ‘errors’ by a conversational partner. According to the Language Expectancy Theory (Burgoon & Miller, 1985), the use of language that conflicts with societal expectancies may affect the persuasiveness of the communication. So, because CHI may have an impact on both sides of the interaction, the communication partner of a hearing-impaired person is likely to experience an interaction that does not evolve in a standard manner. In this thesis, we explore the consequences of moderate to severe CHI that may impact adults’ daily communication by examining their use of linguistic knowledge in language production and language reception. The studies focus on the deployment of morphosyntactic knowledge, as the area of morphosyntax is known to be specifically vulnerable when an oral language is acquired with degraded auditory input (e.g., Tomblin et al., 2015). Firstly, in the domain of language production, we examine whether adults who were born with moderate to severe hearing loss have problems with the correct use of morphosyntactic markers, as is observed in children with CHI (e.g., Hammer, 2010). Secondly, we examine whether the consequences of CHI on the acquisition of morphosyntax result in an impediment in the top-down use of morphosyntactic cues in language reception. To our knowledge, the studies in this thesis are the first to examine this latter possible consequence of CHI. Lastly, we extend the scope of our research by examining the relative contribution of bottom-up auditory abilities and top-down use of linguistic resources to auditory speech recognition in hearing-impaired individuals.
Chapter 1

The acquisition of language in children

When examining the long-term consequences of moderate to severe CHI on the linguistic abilities of adults, the focus of research is based on the available knowledge of how children acquire an oral language and how hearing loss affects this acquisition. For children acquiring a language, either an oral or a sign language, access to linguistic input is essential (Davidson et al., 2014). Within the context of this thesis, we focus on the role of auditory perception in language acquisition of an oral language.

Normal-hearing children start perceiving the language that is spoken in their environment when the auditory system becomes functional, at 25 to 29 weeks of gestation (Graven & Browne, 2008). This allows an early start of processing of auditory information, a process that continues after birth. Children learn to segment a continuous speech stream into words, based on their increasing abilities to discriminate between phonemes of the native language (Bertoncini & Cabrera, 2014). These abilities reflect development in the linguistic area of phonology. In addition, children segment the linguistic input by using prosodic stress cues (Johnson & Jusczyk, 2001) and statistical cues (Saffran et al., 1996). By combining verbal, nonverbal, and contextual information during meaningful interactions with people in their environment, children link words to referents in the real-world context. The development of word meaning, i.e., the linguistic area of semantics, and the building of a lexicon are hereby set off. Based on the linguistic input they perceive, combined with information from the context, children must induce the productive rules that allow users of the language to generate an infinite set of new sentences. In other words, children have to decode the morphosyntax of the language: structures within words (morphology) are discovered, as well as structures within sentences, between words or constituents (syntax). For the acquisition of morphosyntax, language learning processes are used based on statistics (i.e., on frequency and distribution of elements in a language) and grammatical processes (e.g., learning and deploying rules), though the boundary between these two learning mechanisms is not clear-cut (Saffran, 2003; Seidenberg et al., 2002). Lastly, when children discover the rules for appropriate and effective use of language, i.e., knowledge in the area of pragmatics (Ninio & Snow, 1996), all linguistic areas are covered. As language acquisition involves the discovering of regularities in the input, consistency in the input and in the perception of these regularities is a key factor. In the next paragraph, we discuss how hearing impairment affects this prerequisite for acquisition of an oral language.

The influence of congenital hearing impairment on the acquisition of an oral language

Studies on the outcomes of newborn hearing screening programs report a prevalence of moderate to profound bilateral hearing loss of around 1 per thousand (Wood et al., 2015;
Van der Ploeg et al., 2012). In more than 70% of the newborns identified with bilateral hearing impairment, hearing loss is caused by a problem in the inner ear or beyond, thereby categorized as sensorineural hearing impairment. In the rest of the children, bilateral hearing impairment is conductive, i.e., caused by a problem in the outer or middle ear, or mixed in nature (Davis & Davis, 2016). All types of hearing impairment affect the audibility of auditory signals, while speech recognition is additionally hindered by suprathreshold distortions when hearing impairment is sensorineural (Plomp, 1986). Though conductive or mixed hearing impairment also may affect language acquisition in children, the studies in this thesis focus on the consequences of bilateral sensorineural hearing impairment on linguistic abilities.

For children who are born with a hearing impairment, access to linguistic input is less evident than for normal-hearing children. When discussing spoken language acquisition in children with CHI, a distinction is made between input and uptake (Harris, 1993; Moeller & Tomblin, 2015). Input represents all the speech that is directed to or spoken in the environment of the child, while uptake is the language that has actually been perceived and processed, and hence can be used in grammar-building. Congenital hearing impairment has a clear effect on the uptake of spoken language: hearing loss induces a significant reduction of the audibility of the speech signal and may also cause a degradation of its fine details. The use of hearing aids or a cochlear implant decreases these effects, but does not neutralize them (Coene et al., 2010; Stelmachowicz et al., 2001). Thus, the uptake of language in children with CHI is based on degraded auditory perception of the speech signal. Besides this direct effect of CHI on the perception of spoken language, hearing loss exerts an indirect influence on the probability that linguistic input leads to uptake (Moeller & Tomblin, 2015). Children with hearing loss have greater difficulty recognizing speech in noisy conditions than normal-hearing children (Caldwell & Nittrouer, 2013), so a smaller part of the available linguistic input is accessible to them. Thus, CHI affects the uptake of available linguistic input due to a reduction in the quality of the acoustic signal and a reduction in the amount of input that is accessible. The linguistic input, on the other hand, may also be affected when a child has a hearing loss. Parents may offer their hearing-impaired child less complex input than is offered to normal-hearing peers (Ambrose et al., 2015; Gallaway et al., 1990; Nittrouer, 2010). This may reduce the language learning opportunities of the hearing-impaired child. Though the adaptations in the input could be well adjusted to the language level of the child (Gallaway et al., 1990), it is yet unclear whether this facilitates or hinders language development in the long term (Ambrose et al., 2015).

The impact of CHI on the input and uptake of spoken language forms the root of the ‘inconsistent access account’ (Moeller & Tomblin, 2015), which states that CHI children’s limitations in the access to and the perception of linguistic input decrease their instantaneous

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1 In chapter 2, based on an article by Kumaravadivelu (1994), the term ‘intake’ is used for what is defined as ‘uptake’ in this introduction.
uptake of language. Over time, hearing-impaired children’s cumulative language experience is thereby reduced. Following the inconsistent access account, the consequences of CHI for the linguistic abilities of an individual depend on factors that define the extent to which the access is affected. One factor perturbing the consistency of the linguistic access is the degree of severity of the hearing impairment, categorized as mild (hearing thresholds between 20 and 40 dB HL), moderate (between 40 and 70 dB HL), severe (between 70 and 95 dB HL), and profound (over 95 dB HL) (European Group on Genetics of Hearing Impairment, 1996). Hearing impairment affects people’s hearing acuity, but it also affects the quality of the perceived auditory signals via supra-threshold effects (Moore, 1995). The relationship between degree of hearing impairment and a child’s linguistic abilities is shown to be significantly moderated by the effectiveness of rehabilitation services: aided audibility, hearing aid use (age at fitting, duration, and consistency of use), and characteristics of the caregiver input influence the linguistic outcomes to a considerable extent (Moeller & Tomblin, 2015; Tomblin et al., 2015). This latter finding supports the inconsistent access account and yields more insight in which factors impose a risk and which factors provide protection for CHI-induced language delays.

In studies examining linguistic outcomes in children with various degrees of hearing impairment, the areas of phonology, lexicon, and pragmatics are shown to be at risk (see Moeller et al., 2007, for an overview). The linguistic area of morphosyntax, however, appears to be most vulnerable when oral language is acquired with degraded auditory input (Elfenbein et al., 1994; Hammer, 2010; McGuckian & Henry, 2007; Norbury et al., 2001; Tomblin et al., 2015). Specifically, morphosyntactic markers that are perceptually subtle, i.e., low in perceptual salience, are vulnerable when acquired with impaired hearing (Svirsky et al., 2002). Additionally, in general, the relative complexity of the linguistic computation that is needed to derive specific morphosyntactic constructions is relevant and may overrule the influence of perceptual salience (Tuller & Delage, 2014). Despite the fact that various factors interact to moderate the relationship between childhood hearing impairment and language outcomes (Moeller & Tomblin, 2015), data of a study in adolescents with mild to moderate CHI (Delage & Tuller, 2007) suggested that the degree of CHI is a source of inter-individual variation in linguistic abilities that surfaces at an age beyond the developmental stage. This suggestion followed the observation that variance in the linguistic abilities of adolescents (aged 11 to 15) was related to the severity of the adolescents’ hearing impairment, while age did not exert an influence on the outcomes in this group (Delage & Tuller, 2007). This pattern in factors underlying the performance of adolescents was opposite to the pattern underlying performance in younger children with CHI, where age was a determining factor in the variation (Davis et al., 1986; Gilbertson & Kamhi, 1995; Hansson et al., 2004; Norbury et al., 2001; Stelmachowicz et al., 2004). Thus, it seems that in mature language users, i.e., at an age at which normal variation in developmental rhythm no longer exerts an influence on linguistic abilities, the specific impact of perceptual limitations during language acquisition is more distinct. Therefore, the studies in this thesis examine the linguistic performance of adults who were born with a bilateral moderate to severe sensorineural hearing
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loss and who acquired their oral language while using hearing aids. The outcomes of these studies provide valuable information about the long-term effects of moderate to severe CHI on linguistic abilities. In addition, these studies identify the linguistic structures of Dutch that are particularly vulnerable when acquired with impaired hearing.

The use of morphosyntactic knowledge in language production and reception

In interactions between people, language is produced by the sender to convey a message, while the recipient processes the perceived signal to understand what has been said. “Perception is of definite and probable things”, (James, 1890, p. 82), was quoted at the beginning of this introduction. According to James (1890), the general law of perception is that “whilst part of what we perceive comes through our sense of the object before us, another part always comes… out of our own head” (p. 103). Within the context of perception of a language, these quotes describe the process that recipients go through when perceiving incoming linguistic information: recipients process bottom-up information from the acoustic or visual signal and feed their interpretation of this input with predictions from higher-level top-down resources like knowledge of the world, context information, and knowledge of the language that is used (Pichora-Fuller, 2008; Davis & Johnsrude, 2007; Houtgast & Festen, 2008; Norris et al., 2015; Rönnberg et al., 2013). The more probable the stimulus is, the less information within the stimulus is needed to recognize it. Thus, besides using other sources of knowledge to recognize linguistic input, the use of knowledge of specific regularities in the language limits the array of possible interpretations and thereby facilitates interpretation, even when sole bottom-up processing of the signal is inconclusive. Hence, it is clear that acquired linguistic knowledge is not only deployed in the process of language production, but is also used in language reception.

In people with CHI, the impact of perceptual limitations on the acquisition of morphosyntax is hypothesized to surface in their performance in both domains of language processing, independently of the modality: in spoken and written language production, adults with CHI are hypothesized to make more morphosyntactic errors than adults who acquired their language with normal hearing. This hypothesis is examined in chapter 2 for spoken language production and in chapter 3 for written language production. In auditory and visual language reception, on the other hand, consequences of CHI on the acquisition of morphosyntax are hypothesized to be reflected in poorer use of morphosyntactic cues when processing linguistic input. This hypothesis is examined in chapter 5 for visual language recognition and in chapter 6 for auditory language recognition. If this hypothesis for language reception holds, this would imply that adults with CHI are not only hindered by bottom-up auditory limitations in auditory speech recognition, but also by a CHI-induced impediment in the top-down use of morphosyntactic knowledge.
Chapter 1

Outline of this thesis

This thesis describes studies that examine possible consequences of moderate to severe sensorineural CHI in two domains of linguistic processing, i.e., in language production and language reception, and in two modalities, i.e., in the auditory (spoken) and visual (written) modality. To assess adults’ abilities in language reception, we use a sentence repetition task. This task does not necessarily require comprehension of the content of the sentences, so we further use the term ‘recognition’ to describe the assessed ability in the domain of language reception. The studies in this thesis thus concern four quadrants of a matrix: spoken language production, written language production, auditory language recognition, and visual language recognition.

In all our studies but one, the performance of adults with moderate to severe CHI is compared to the performance of normal-hearing adults (NH), who thus acquired their oral language (Dutch) without auditory perceptual limitations. This group is used as a reference to examine possible consequences of auditory limitations during the acquisition of language on linguistic performance in adulthood. However, the CHI adults’ auditory abilities at the moment of testing may also compromise their performance on the various tasks. Therefore, in some of the studies in this thesis, a reference group of adults who acquired bilateral sensorineural hearing impairment after the age of 12 years (AHI) was included for assessment. Because the AHI adults differ from the CHI adults with regard to their hearing abilities during language acquisition but can be matched to the CHI adults for their current hearing abilities, these two possible sources of variance in outcomes can be disentangled.

This thesis aims to answer the following research question:

‘Does moderate to severe congenital hearing impairment (CHI) affect the use of morphosyntactic knowledge in spoken language production, written language production, visual sentence recognition, and auditory sentence recognition?’

Chapter 2 discusses a study on the spoken language production of 20 adults with moderate to severe CHI and 10 NH adults. Spoken language samples, elicited in expository discourse, are analyzed with regard to morphosyntactic correctness and syntactic complexity. This study identifies specific categories of morphosyntactic errors that are made more frequently by the group of adults with moderate to severe CHI, compared to the group of NH adults.

Chapter 3 describes the performance of the same study population as in chapter 2, i.e., adults with moderate to severe CHI and NH adults, in written language production. Analysis is done on samples of written language, elicited in expository discourse, assessing the morphosyntactic correctness and syntactic complexity of the adults’ written utterances. This study examines whether the specific morphosyntactic difficulties that were observed in the spoken language production of the adults with moderate to severe CHI in chapter 2 are also apparent in their written language production.
Chapter 4 introduces the *distortion-sensitivity approach* as a method to assess the use of linguistic cues in sentence recognition. Within the outline of this thesis, this chapter offers additional information on the research method used in the subsequent chapters, but does not answer a specific part of the research question. The applicability of the distortion-sensitivity method is examined in two groups of adults who differ evidently in their linguistic abilities, i.e., in 13 native and 10 non-native users of Dutch. In these groups, auditory sentence recognition in noise and visual sentence recognition with masked text are assessed. In the visual modality, sentence recognition is studied in two conditions, i.e., with grammatically correct Dutch sentences and with sentences in which syntactic, lexical, or semantic cues are distorted. The sensitivity to these distortions, reflected in the decrease in performance between the original and distorted condition, yields information about whether the distorted cue is actually used when performing the task. This study shows that the distortion-sensitivity approach is applicable to assess the use of linguistic cues in sentence recognition.

Chapter 5 discusses a study of the performance of adults in *visual sentence recognition*, combined with analysis of their *spoken language production*. The study is performed in 21 adults with moderate to severe CHI, 22 adults with AHI, and 22 NH adults. As in the study of chapter 2, an elicited spoken language sample from each adult is analyzed for morphosyntactic correctness. Next, the distortion-sensitivity approach is deployed to examine the use of specific morphosyntactic cues in visual sentence recognition. Within this approach, visual sentence recognition is assessed with grammatically correct Dutch sentences and with sentences in which errors were introduced from the specific error categories that were observed in the spoken language production of adults with moderate to severe CHI (chapter 2). Groups are compared for their recognition of grammatically correct sentences and for their sensitivity to the morphosyntactic distortions. Lastly, this study examines whether there is an association between the adults’ incorrect use of morphosyntactic markers in spoken language production and their use of comparable morphosyntactic cues in visual sentence recognition.

Chapter 6 discusses the performance of the adults of the hearing-impaired groups of the study in chapter 5 (i.e., the group of adults with moderate to severe CHI and the group of adults with AHI) in tasks for *auditory sentence recognition*. As in the study described in chapter 5, the distortion-sensitivity approach is used to examine the use of specific morphosyntactic cues in sentence recognition. In addition, this chapter discusses the relative contribution of bottom-up auditory abilities and top-down linguistic abilities to auditory sentence recognition in the hearing-impaired adults.

The final chapter (chapter 7) summarizes and discusses the most important results of the studies in this thesis. Furthermore, clinical implications are discussed.

Chapters 2 to 6 of this thesis have been published or submitted for publication as a research paper. As a consequence, there is some overlap in the content of the chapters.