The Influence of Linguistic Proficiency on Masked Text Recognition Performance in Adults With and Without Congenital Hearing Impairment

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Objective: The authors first examined the influence of moderate to severe congenital hearing impairment (CHI) on the correctness of samples of elicited spoken language. Then, the authors used this measure as an indicator of linguistic proficiency and examined its effect on performance in language reception, independent of bottom-up auditory processing.

Design: In groups of adults with normal hearing (NH, n = 22), acquired hearing impairment (AHI, n = 22), and moderate to severe CHI (n = 21), the authors assessed linguistic proficiency by analyzing the morphosyntactic correctness of their spoken language production. Language reception skills were examined with a task for masked sentence recognition in the visual domain (text), at a readability level of 50%, using grammatically correct sentences and sentences with distorted morphosyntactic cues. The actual performance on the tasks was compared between groups.

Results: Adults with CHI made more morphosyntactic errors in spoken language production than adults with NH, while no differences were observed between the AHI and NH group. This outcome pattern sustained when comparisons were restricted to subgroups of AHI and CHI adults, matched for current auditory speech reception abilities. The data yielded no differences between groups in performance in masked text recognition of grammatically correct sentences in a test condition in which subjects could fully take advantage of their linguistic knowledge. Also, no difference between groups was found in the sensitivity to morphosyntactic distortions when processing short masked sentences, presented visually.

Conclusions: These data showed that problems with the correct use of specific morphosyntactic knowledge in spoken language production are a long-term effect of moderate to severe CHI, independent of current auditory processing abilities. However, moderate to severe CHI generally does not impede performance in masked language reception in the visual modality, as measured in this study with short, degraded sentences. Aspects of linguistic proficiency that are affected by CHI thus do not seem to play a role in masked sentence recognition in the visual modality.

Key words: Adults, Congenital hearing impairment, Long-term effects, Spoken language production, Visual language reception.

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INTRODUCTION

People with hearing impairment suffer from a reduced ability to understand speech in daily life situations (e.g., Plomp 1994). Rehabilitation with hearing aids or cochlear implants improves the abilities to understand speech in quiet environments, but understanding speech in more challenging acoustic environments, for example, in noise or reverberation, remains difficult (e.g., Cord et al. 2000). Abilities to understand speech in noise vary among persons with hearing impairment, even when individuals have similar pure-tone audiograms (e.g., Houtgast & Festen 2008). The ability to comprehend speech in challenging conditions depends on bottom-up peripheral auditory capacities and top-down cognitive abilities (Davis & Johnsrude 2007; Houtgast & Festen 2008; Pichora-Fuller 2008; Rönnberg et al. 2013). Audibility, determined by the ears' sensitivity, and spectral and temporal resolution affect bottom-up processing (Hopkins & Moore 2011). In top-down processing, working memory capacity, attention, speed of information processing, and the use of linguistic context play a role (see Akeroyd 2008 for a review). The relative contribution of bottom-up and top-down processing to speech recognition depends on the complexity of the acoustic scene and the cognitive and linguistic competencies of the listener (Avivi-Reich et al. 2014). Research into the specific contribution of linguistic factors to speech recognition has focused on linguistic characteristics of the speech material (e.g., Kalikow et al. 1977; Uslar et al. 2012) and the influence of linguistic proficiency on speech recognition, especially in nonnative listeners (see Garcia Lecumberri et al. 2010 for a review). However, less is known about how linguistic skills of hearing-impaired listeners impact their performance in language recognition, independent of bottom-up auditory processing. Specifically, in persons with congenital hearing impairment (henceforth CHI), this is an interesting question, because language acquisition with a degraded auditory input may lead to deficits in linguistic performance (Elfenbein et al. 1994; Delage & Tuller 2007; Moeller et al. 2007; Tuller & Delage 2014; Huysmans et al. 2014). As linguistic knowledge is also relevant for language reception (Cutler & Clifton 1999) and this knowledge may be affected by CHI, top-down processing in language *reception* may be disadvantaged by CHI as well. When language input is presented in the auditory modality, this linguistic disadvantage would be additional to the bottom-up degradation of the signal due to hearing loss in CHI persons. Therefore, to separately assess the influence of linguistic ability on language reception in CHI persons, language has to be presented in the visual modality.

Linguistic Proficiency in Individuals with CHI

Children born with a hearing impairment are known to be at risk for deficiencies in the acquisition of phonology (Elfenbein et al. 1994; Briscoe et al. 2001; Wake et al. 2004), lexicon (Davis et al. 1986; Wake et al. 2004; Moeller et al. 2007;

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Kiese-Himmel 2008), and pragmatics (Elfenbein et al. 1994). For CHI, the domain of morphosyntax is the most vulnerable linguistic area (Elfenbein et al. 1994; Norbury et al. 2001; McGuckian & Henry 2007), with the possibility of morphosyntactic weaknesses persisting into adolescence and adulthood (Delage & Tuller 2007; Huysmans et al. 2014; Tuller & Delage 2014). When acquiring grammatical skills, perceptual salience of the morphological markers (i.e., the relative amount of linguistic information present in the acoustic signal to be perceived) influences the order in which grammatical skills are established (Svirsky et al. 2002). Consequently, the acquisition of morphological markers with low saliency is at risk in subjects with CHI. In addition, 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). From their studies in children and adolescents with mild to moderate CHI (PTA between 21 and 70 dB HL), Tuller and Delage concluded that computational complexity was a central factor underlying poor performance on various morphosyntactic tasks. Besides this, their data showed that the specific linguistic aspects in which children and adolescents with mild to moderate hearing impairment showed difficulties were shared with atypical language learners like second language users (L2). The observed similarity between the CHI and L2 population suggests that degraded auditory input during the critical period for language acquisition has similar effects on morphosyntax as later onset of language acquisition.

The role of perceptual salience and relative syntactic complexity on the language performance in CHI subjects was reflected in the error patterns in the spoken language output of adults with moderate to severe CHI (i.e., pure-tone hearing thresholds between 35 and 95 dB HL) in a previous study (Huysmans et al. 2014). The significantly reduced spoken language production performance of adults with moderate to severe CHI in this earlier study indicated that their hearing impairment resulted in at least a vulnerability of, and possibly a deficit in, morphosyntactic knowledge. Among other linguistic information, listeners rely on their morphosyntactic knowledge to better understand speech in adverse conditions. The question we examine in the present study is whether moderate to severe CHI affects the use of morphosyntactic cues in the process of language reception, independent of low-level auditory abilities, as it does in spoken language production.

The Use of Linguistic Knowledge in Recognition of Spoken Language

Phonological, lexical, syntactic, and pragmatic knowledge of a language all contribute to the linguistic structures that a listener internally generates when processing incoming speech (Davis & Johnsrude 2007). When studying speech recognition in noise, linguistic factors are known to affect the signal to noise ratio (SNR) at which listeners correctly identify incoming speech. The SNR for word recognition is correlated with the frequency of occurrence of a word in the language, word familiarity, and the number of confusable words in the lexical network (Plomp 2001). When listening to sentences in noise, listeners benefit from linguistic redundancy: semantic, syntactic, and prosodic sources of information in a sentence increase the predictability of a single word, leading to better speech intelligibility (Kalikow et al. 1977). This benefit of linguistic redundancy is confirmed in listeners with impaired hearing (Most & Adi-Bensaid 2001; Benichov et al. 2012). However, little is known about the specific contribution of the use of morphosyntactic knowledge in the process of speech recognition in hearing-impaired individuals. Because the acquisition of morphosyntax is vulnerable in CHI, this aspect is of particular interest when studying the long-term consequences of CHI on speech recognition performance. Knowledge on the consequences of CHI for language reception in adults enhances our understanding of how CHI affects daily life communication at the long term. In addition, it may add focus to language rehabilitation in young CHI children to diminish the long-term effects of moderate to severe CHI on linguistic proficiency.

Outline of this Study

This study first describes morphosyntactic analysis of elicited spoken language samples in a group of normal-hearing (NH) adults and a group of adults with moderate to severe CHI. The outcomes on morphosyntactic correctness of the samples are used as a measure of the adults' linguistic proficiency. To examine the influence of current auditory reception abilities on language production, a second group of adults with hearing impairment is assessed, that is, adults who acquired their hearing loss after age 12*. In these adults with acquired hearing impairment (AHI), language was developed with NH abilities, as in the NH subjects. Our hypothesis is that auditory abilities during early language acquisition determine morphosyntactic correctness of spoken output, even in adulthood. This would be confirmed if the language samples of the CHI adults contained more morphosyntactic errors than the samples of both AHI and NH adults. In contrast, if current auditory limitations impede the perception, and thereby correction of morphosyntactic errors, both AHI and CHI participants would make more errors than NH adults. To test this hypothesis, we compare the number of morphosyntactic errors in the elicited spoken language samples between NH, AHI, and CHI adults. We further discern the influence of hearing impairment at the developmental stage from the influence of current hearing abilities on morphosyntactic correctness by making comparisons using subgroups of AHI and CHI subjects that are matched on current auditory reception performance.

As a next step, this study examines the impact of differences in one aspect of linguistic proficiency (i.e., morphosyntactic correctness of an elicited sample of spoken language) on sentence recognition performance in the three groups. To avoid confounding in performance by auditory limitations in the listeners with impaired hearing, language reception is assessed in the visual modality by using the Text Reception Threshold (TRT) test (Zekveld et al. 2007). Research has shown that sentence recognition in the auditory and visual modality share common processes (Humes et al. 2007). The TRT test (Zekveld

*Although substantial growth in various domains of language is still observed after primary school age (Nippold 2007), the aspects of morphosyntax that are studied in this article are considered to be acquired in the critical period for language acquisition, which, according to Lenneberg (1967), extends until the age of 12 years (but see, e.g., Singleton 2005, for a critical analysis of the so-called critical period hypothesis). For participants in the AHI group, hearing loss had to be acquired after the age of 12 years to ensure this morphosyntactic knowledge was acquired while being normally hearing.

et al. 2007) is a visual proxy of the auditory Speech Reception Threshold (SRT) test (Kramer et al. 2009). The TRT test measures a subject's ability to read visually presented sentences, masked by a pattern of vertical bars. In NH subjects, about 30% of the variance in TRT is shared with variance in SRT in stationary noise (Zekveld et al. 2007). This indicates that modality independent cognitive and linguistic abilities are involved in both tests to construct meaningful wholes of sentence fragments. For adults with hearing impairment, combining the outcomes of TRT and SRT in modulated noise allows an estimation of the relative contribution of nonauditory and auditory factors to speech recognition in noise (George et al. 2007). Until now, little research has examined the relation between TRT performance and specific measures of linguistic proficiency. In a study with subjects with normal and impaired hearing, TRT performance was not associated with word vocabulary scores (Zekveld et al. 2011). In another study, no specific measures of linguistic proficiency were used, but TRT performance was shown to be related to (non-) nativeness in the tested language (Goverts et al. 2011). Obviously, native and nonnative users of a language differ in the quality of the linguistic knowledge used in sentence recognition, which evokes a possible analogy with adults with CHI, compared with adults who acquired spoken language with NH. For the present study, we hypothesize that the effect of moderate to severe CHI on the use of morphosyntactic knowledge results in poorer visual language reception, like it results in poorer spoken language production.

To study the relation between aspects of linguistic proficiency that are affected by CHI and performance in masked sentence recognition, we examine the correlation between errors in the use of a specific morphosyntactic cue in spoken language production and the use of this cue in the perception of a masked sentence. Based on the "distortion sensitivity approach" (van Schijndel et al. 2001; Goverts & Houtgast 2010; Goverts et al. 2011), the TRT task is administered with grammatically correct sentences and sentences in which a morphosyntactic distortion is applied. The introduced morphosyntactic error types are based on the common errors in the spoken language output of adults with moderate to severe CHI, as identified in our earlier study (Huysmans et al. 2014). If TRT performance decreases when sentences are ungrammatical, this implies that the morphosyntactic information that is distorted in the sentence is normally used in sentence recognition. Assuming that NH and AHI adults are equal in their use of morphosyntactic knowledge, we expect TRT performance in both groups to be sensitive to the introduced morphosyntactic distortions. This is reflected in a decrease of TRT scores for the recognition of ungrammatical sentences, compared with the recognition of grammatical sentences. Assuming that CHI has affected the use of morphosyntactic knowledge in language reception, we already hypothesized poor performance for the CHI group in visual speech recognition of grammatical sentences. With regard to their sensitivity to morphosyntactic distortions in sentence recognition, we expect the CHI group to be less sensitive than the NH and AHI groups. If the CHI adults' sentence recognition performance is less disturbed by a morphosyntactic distortion in a sentence, this would indicate that CHI adults do not (fully) use the information contained by the cue when it is not distorted in the task with grammatically correct sentences. Poorer masked text recognition of grammatically correct sentences would then (partly) be due to a deficit in the use of the specific cue. This performance pattern would confirm the hypothesis that CHI affects the use of morphosyntactic knowledge in visual language reception, as it does in spoken language production. For individuals within the CHI group, we additionally expect a relation between the occurrence of specific morphosyntactic errors in their elicited spoken output and the sensitivity to the corresponding morphosyntactic distortions in masked text recognition: More errors in a specific category in the spoken output are expected to relate to a lower sensitivity to this distortion in the sentence recognition task (TRT).

In summary, the first aim of this study is to assess the effect of perceptual limitations during early language acquisition on the morphosyntactic correctness of elicited spoken language samples in adults. Second, the relation between linguistic proficiency, as assessed by analyzing the samples from the spoken language production task, and the use of morphosyntactic cues in language reception in the visual modality is studied.

MATERIALS AND METHODS

Participants

An overview of the participant characteristics is given in Supplemental Digital Content 1 (http://links.lww.com/EANDH/A260). In the NH group, 22 adults (15 females and 7 males) participated, with a mean age of 34 years (range 18 to 57 years, SD = 13.4 years). They were recruited through advertisements on posters, in emails, and on a website for recruiting participants for scientific research. In all NH participants, the mean pure-tone hearing threshold at 0.5, 1, and 2 kHz did not exceed 15 dB HL at the best ear. Participants with impaired hearing were recruited through audiological diagnostic centers in the region, hearing aid dispensers, and advertisements on hearing loss-related websites. The group of participants with CHI consisted of 21 adults (13 females and 8 males), with a mean age of 36 years (range 19 to 56 years, SD = 11.4 years). To be included in the CHI group, anamnestic or audiometric indications were required to support the assumption that a participant was born with bilateral moderate to severe hearing impairment. All CHI participants reported to be diagnosed with hearing impairment in the first years of life, between 3 months and 4 years old, and all reported that their hearing was not better before diagnosis. Oldest PTA of the best ear† ranged from 35 to 100 dB HL, with a group mean of 71 dB HL (SD = 15.2 dB HL). All CHI participants received hearing aids between 10 months and 6 years old and thereby acquired their language under circumstances of unaided and later aided bilateral hearing loss. All CHI participants but one received speech and language therapy to support language development in childhood. Educational setting in primary and secondary school varied between participants (see Supplemental Digital Content 1 for details; http://links.lww.com/EANDH/A260). At the time of this study, 6 CHI participants were fitted with a cochlear implant and 15 used a hearing

†Given the age of several participants, collection of audiometric data to define the level of hearing impairment early in life was not always successful. For 14 of 21 participants, audiometric data were available to define their level of hearing impairment early in life. For the other 7 participants, data for the level of hearing impairment at a young age were derived from either information of their parents (in 4 participants) or from more recent audiometric data if participants indicated their hearing loss had not changed since childhood (in the last 3 participants). The variable "oldest PTA of the best ear" (pure-tone average, i.e., mean threshold at 0.5, 1, and 2 kHz) in the CHI group therefore reflects oldest available (n = 14) or derived (n = 7) data.

aid, either unilateral or bilateral. Current auditory characteristics of the participants are described with unaided pure-tone average thresholds (PTA, i.e., mean threshold at 0.5, 1, and 2 kHz) and maximum aided speech recognition score of CVC words in quiet, presented with a loudspeaker at an intensity of 60 to 80 dB SPL. Mean PTA in a subgroup of 15 not implanted CHI participants‡ was 82 dB HL (SD = 12.8 dB HL), ranging from 55 to 98 dB HL. Maximum aided word recognition scores for all CHI participants ranged from 73 to 100%, with a mean of 85.3% (SD = 8.7%). The group of participants with AHI consisted of 22 adults (15 females and 7 males), with a mean age of 52 years (range 34 to 59 years, SD = 7.3 years). In all AHI participants, hearing impairment was acquired after the age of 12, which means that spoken language had been acquired with NH abilities. The AHI group consisted of 17 participants using hearing aids, either unilateral or bilateral, with moderate to severe hearing impairment in the best ear, and 5 participants who used a cochlear implant. The distribution of hearing aid users and cochlear implant users is thus comparable in the AHI group and the CHI group. Data on PTA thresholds of the AHI group are thus based on a subgroup of 17 not implanted participants (see footnote ‡): Mean PTA in these participants was 67 dB HL (SD = 15.9 dB HL), ranging from 48 to 97 dB HL. For all AHI participants, the maximum aided speech recognition score of CVC words in quiet, presented with a loudspeaker at an intensity of 60 to 80 dB SPL, ranged from 61 to 100%, with a mean of 90.6% (SD = 9.3%). All NH, AHI, and CHI participants were native Dutch speakers, used spoken language to communicate in daily life and reported not to have been in contact with users of a sign language§ before the age of 12 years. Additional criteria were normal or corrected-to-normal vision, no diagnosis of color blindness, no attentional deficits, no cognitive disorders, and no dyslexia. The ethics committee of the VU University Medical Center Amsterdam approved the study. All participants provided written informed consent.

Materials and Test Procedures

Tests were administered in 2 sessions of approximately 2.5 hr each. In the first test session, assessment included filling out a questionnaire regarding hearing and educational history, pure-tone audiometry (unaided), recognition of monosyllabic words in quiet (only for the hearing-impaired participants, aided; Bosman & Smoorenburg 1995), a task to elicit spoken language (i.e., favorite game or sports task, FGST; Nippold et al. 2005), tests of sentence recognition with grammatical and ungrammatical sentences, in noise for the NH subjects and in quiet for the AHI and CHI subjects (aided)¶, and a digit-triplets in noise test (only in the hearing-impaired participants, aided; Smits et al. 2013). In the second session, participants were assessed with the WAIS-III-NL nonverbal subtest Block Design‖ and verbal subtest Similarities (Wechsler 2000), tests of masked text recognition (TRT with grammatical and ungrammatical sentences), and a word naming task (based on de Groot et al. 2002, described below). Correctness of the elicited spoken language samples and performance in visual sentence recognition serve as outcome measures to compare between groups. The other outcome measures are used to describe group characteristics and examine possible confounding variables.

- Naming Task

A word naming task was used to measure the participants' lexical access ability (based on de Groot et al. 2002). Thirty words were simultaneously presented on a screen and participants were instructed to read the words out loud as fast as possible. Time needed to read out loud all words was measured by either using a stopwatch (in 3 participants) or by marking the beginning and ending of the spoken sequence in a digital recording (in all others). The outcome of a naming task is a good indicator of decoding ability and correlates with reading fluency (Katz et al. 2012). The naming task was added to the test battery after the first 9 NH participants were already assessed. Consequently, naming data were available for 13 out of 22 NH participants and for all AHI and CHI participants.

- Digit Triplets in Noise Test (DIN)

Digits in noise are widely used in a speech in noise screening test by telephone (e.g., Smits et al. 2004; Jansen et al. 2010; Watson et al. 2012). For diagnostics, the DIN test was developed and shown to be valid (Smits et al. 2013; Moore et al. 2014; Kaandorp et al. 2015). In this study, the Dutch version of the DIN test (Smits et al. 2013) was used to assess current auditory reception in the hearing-impaired participants while using their own rehabilitation device. In short, 3 trials of 24 digit triplets were presented to each participant, with digits between 0 and 9, pronounced by a male speaker. Participants were asked to repeat the triplets in the correct order. Overall intensity level of the speech and noise was kept at 65 dB(A), while the SNR varied according to an adaptive procedure depending on the correctness of the response. The outcome of the DIN test is the SNR at which 50% of the digit triplets is repeated correctly. This SRT is calculated by taking the average SNR of triplets 5 to 25. Note that triplet 25 was not actually presented, but its SNR is defined by the SNR of triplet 24 and the correctness of the participant's response. The test is assumed to mainly reflect bottom-up speech recognition abilities, with relatively small influence of top-down linguistic abilities (Smits et al. 2013). Auditory signals for the DIN test were generated using the PC's internal soundcard (RME HDSP 9632), an amplifier (Samson Servo 4060 quad), and a loudspeaker (Tannoy Reveal) at a distance of 1.5 m and 0 degree azimuth.

- Assessment of Morphosyntactic Correctness of Spoken Language Production

The FGST (Nippold et al. 2005) was used to elicit a spoken language sample in expository discourse, that is, a discourse genre in which a person uses language to convey

‡Pure-tone average (current or preimplantation) of the best ear is less relevant in implanted participants, because their current auditory abilities are mostly defined by the fitting of the cochlear implant. For implanted subjects, aided word recognition scores are thus sufficient to give an indication of their current auditory speech reception abilities.

§In the period in which the CHI participants of this study attended primary and secondary school, sign language was not used in Dutch schools for the hearing-impaired to interact with children who did not have profound hearing impairment.

¶Data with regard to recognition of sentences in the auditory modality will be presented in a subsequent article. Note that the sentence material used in the auditory modality was different from the sentences in the TRT task presented in this article, but had the same linguistic characteristics.

‖The Block Design score of participant CHI03 is based on a short assessment of the subtest. This assessment was done as part of another study, in which the subject participated earlier on the day of testing. Therefore, the test could not be repeated for our study.

information. Samples were recorded, transcribed, and segmented into utterances, that is, T-units (1 independent clause and all attached subordinate clauses; Hunt 1970). Details of the elicitation procedure, transcription, and segmentation are given in Supplemental Digital Content 2 (http://links.lww.com/EANDH/A261). Following the method of Van den Dungen and Verbeek (1999), morphosyntactic correctness was judged and expressed in two general measures, that is, number of ungrammatical utterances and number of morphosyntactic errors. All morphosyntactic errors were categorized into 6 specific error categories and a residual category: (1) article deletion in an obligatory context, (2) subject–verb agreement error in the present tense, (3) preposition error, (4) incorrect determiner (i.e., incorrect gender of article or demonstrative pronoun), (5) other suffix error, (6) adverb error, and (7) other morphosyntactic errors. The specific error categories follow the results of earlier research on the morphosyntactic correctness in the spoken output of adults with moderate to severe CHI (Huysmans et al. 2014), where significant weaknesses were found for categories 1, 2, and 6, and weaknesses were expected for the other categories. To allow comparisons between subjects and groups, the count value of each morphosyntactic parameter was rescaled to a ratio using sample size (i.e., number of errors/number of utterances in the sample × 100), which is a common procedure in sample analysis (e.g., Scott & Windsor 2000). To examine the reliability of the analyses, 10% of the samples (as in Hammer 2010) was reanalyzed by a second experienced clinical linguist. The judgments of the two coders were compared for each utterance and dissimilarities were discussed. After discussion, the mean percentage agreement for all morphosyntactic parameters was 99.44%, ranging from 97.97 to 100%. The reliability of the analyses was thereby judged as satisfactory and the outcomes of the analysis of the single coder were used for further analysis.

- Test of Masked Text Recognition (TRT test)

To assess the participants' abilities to read visually masked sentences, the TRT center test was applied (Zekveld et al. 2007; Besser et al. 2012). Each TRT test list consisted of 13 sentences, presented one by one in a red font (letter size 26) on a computer screen at a distance of 70 cm, masked with a black vertical bar pattern of fixed spacing and variable width. Depending on the width of the bars, which was adaptively varied, letters were not, partially, or fully covered. Bar periodicity was slightly less than two characters. The words of each sentence appeared in the centre of the screen. Presentation time of each word corresponded to the duration of the word in the audio recording of the sentence, multiplied with factor 1.8, after a pilot study with 2 CHI adults had established that this time duration allowed enough time to read each word, even if the sentence was ungrammatical. Participants were asked to read and repeat each sentence as accurately as possible. The first sentence of each list was presented with a level of 72% masked text, which is below threshold, and repeated with 12% less masking on subsequent presentations until it was read correctly. After the first sentence of the list, all subsequent sentences were presented only once. A 1-up-1-down adaptive procedure was used in which the percentage of masking was increased with 6% after a correct response and decreased with 6% after an incorrect response. The outcome TRT is the percentage of *un*masked text at which a person is able to read 50% of the presented sentences correctly, calculated as the mean percentage of unmasked text of sentences 5 to 14. Note that the 14th sentence is not actually presented, but its level of masking is defined by the masking percentage of sentence 13 and the correctness of the participant's response. Lower TRT scores indicate better test performance. TRT tests were administered using a PC and a Dell 1703 FP1 monitor.

Lists with grammatically correct Dutch sentences and lists with ungrammatical Dutch sentences were used for TRT assessment. A selection of original sentences from the TRT test, derived from the SRT stimuli corpus of Versfeld et al. (2000), was used to create lists with grammatically correct stimuli. Other sentences were morphosyntactically distorted to create ungrammatical sentences in six categories. As for the original grammatical sentences, all morphosyntactically distorted sentences were aimed to contain eight or nine syllables. Distortions were applied in six categories, based on the error patterns in the spoken language production of CHI adults in a previous study (Huysmans et al. 2014) and on expectations of possible other morphosyntactic weaknesses in CHI language production. Each sentence contained one morphosyntactic error. Four lists of 13 sentences were created for each of the following six morphosyntactic distortion categories: (a) article deletion, (b) subject–verb agreement error, (c) preposition error, (d) article substitution, (e) suffix error, (f) adverb error. Examples for all distortion categories are given in Supplemental Digital Content 3 (http://links.lww.com/EANDH/A262).

Before the TRT test trials, a TRT practice session with original grammatical sentences was conducted. After this, participants were additionally trained in reading aloud a mix of 30 grammatical and ungrammatical unmasked sentences. Note that participants were instructed to read each sentence the way it was presented, so morphosyntactic errors had to be repeated as such. Following these two practice sessions, the actual TRT assessment was conducted.

When assessing TRT with ungrammatical sentences, participants should not be able to predict whether a sentence is grammatically correct or not, and which type of morphosyntactic error is introduced in a sentence. Therefore, 8 test blocks of 52 sentences were created by mixing 3 lists of 13 grammatically distorted sentences each with 1 list of 13 grammatically correct sentences. In 4 of these 8 test blocks, distortions a, b, and c were mixed with one list of original, grammatical sentences (a-b-c-orig), while in the other 4 blocks, distortions d, e, and f were mixed with one grammatical list (d-e-f-orig). In a ninth test block, 4 lists of original, grammatical sentences were mixed (orig4). When presenting the 52 sentences of each test block, an interleaved adaptive TRT procedure was applied: The first 4 sentences (one of each list) were repeatedly presented with gradually decreasing percentage of masking until the sentence was repeated correctly. All subsequent sentences were presented only once, with the masking percentage of each sentence depending on the masking level of the preceding sentence of that list and the correctness of the participant's response to that sentence. This means that the presentation of sentences of each list followed its own adaptive procedure. In all participants, the orig4-test block was administered fifth in line, while the order of the mixed test blocks was balanced over subjects. After the first 4 blocks, a 15-min break was offered**. Before each block, participants were informed what to expect: They were either reminded that some sentences in the upcoming test block were grammatically correct and others were ungrammatical, or were told that all sentences in the test block were grammatically correct. For each test block, four TRTs were calculated, based on the results of the adaptive procedure of the four lists in the block. Outcome measures for the TRT test thus were TRTorig (TRT for original grammatical sentences from four lists in the orig4-block), TRTorig-mixed (TRT for original grammatical sentences from eight lists, mixed in a block with ungrammatical sentences), and TRTdistA till TRTdistF (TRT for sentences in each distortion condition, from four lists). Performance in the TRTorig condition was expected to best reflect language recognition in daily life: To fully rely on their linguistic knowledge, it was required that participants knew that all presented sentences in a test block were grammatical. In daily life, perceived utterances are assumed to be grammatically correct as well. In the TRTorig-mixed condition, performance was presupposed to be influenced by the uncertainty about the grammaticality of the sentence. In the TRTdist conditions, performance was presupposed to be influenced by both the uncertainty about the grammaticality and the introduced morphosyntactic distortion. To examine the participants' sensitivity to the applied distortion, distortion sensitivity (DSdist) values were calculated as the difference in percentage points between the TRT in a specific distortion condition and the TRTorig-mixed. By using the TRTorig-mixed performance as the reference for recognition of grammatically correct sentences, the influence of introduced uncertainty about grammaticality of the sentence was eliminated from the DSdist score. The DSdist scores thus only reflect the effect of the morphosyntactic distortion on masked sentence recognition performance.

RESULTS

Inspection of the test results in the reference group (NH) revealed that the scores of 1 participant (NH18) deviated more than 1½ times of the interquartile range of the NH group on the nonverbal Block Design test, the general measures for morphosyntactic correctness of the spoken language sample, and 7 out of 8 TRTs. Because this participant was part of the reference group and the outcomes on morphosyntactic correctness and TRT are central in the present study, all his/her data were excluded from further analysis. This resulted in a group size of 21 NH participants for all further analyses.

Independent Auditory and Nonauditory Measures

For the SRT values of the DIN test, intraclass correlation coefficients (ICCs) for consistency were calculated within each group with a two-way mixed alpha model for the outcomes of all three measurements and for the second and third measurement. ICCs for the average of 3 measurements were high (ICC = 0.975 for the AHI group and ICC = 0.932 for the CHI group). The average of three measurements was taken as the outcome value for the DIN test in further analyses.

The SRTDIN values showed a normal distribution within each group (AHI, $\bar{x} = -1.5$ dB(SNR), SD = 4.1 dB(SNR); CHI, $\bar{x} = +1.1$ dB(SNR), SD = 3.9 dB(SNR)). An independent samples t test showed the AHI and CHI group to differ significantly in SRTDIN scores ($t = -2.08$; $p < 0.05$), indicating that the AHI subjects generally had better current aided speech reception abilities than the CHI subjects.

The outcomes on Block Design, Similarities, and Naming were not normally distributed in each of the groups. Table 1 shows the median scores and interquartile levels for these tests for the three groups.

Nonparametric testing showed no group differences in Block Design scores. Significant group differences were found between the NH and CHI groups on Similarities (Mann–Whitney $U = 100{,}000$; $n_{NH} = 21$, $n_{CHI} = 21$; $p < 0.01$) and Naming (Mann–Whitney $U = 189{,}500$; $n_{NH} = 12$, $n_{CHI} = 21$; $p < 0.05$). The AHI group did not differ from the NH or the CHI group on any measure.

Morphosyntactic Correctness of the Elicited Spoken Language Samples (FGST)

The number of utterances in the elicited spoken language sample ("sample size") varied between participants (NH, Mdn = 77, range from 45 to 176; CHI, Mdn = 74, range from 42 to 122; AHI, Mdn = 78.5, range from 39 to 223). Nonparametric testing yielded no significant group differences in sample size. Spearman's correlation analysis showed no significant correlations between sample size and scores on the morphosyntactic error measures within groups, except for a positive correlation between preposition error and sample size in the CHI group ($p < 0.01$). Because groups did not differ significantly in sample size and the morphosyntactic outcome measures were generally not related to sample size, rescaling of the parameter values for differences in sample size (i.e., number of errors/sample size × 100) allowed for group comparisons.

Figure 1 shows the group data for all morphosyntactic outcome measures, that is, number of ungrammatical utterances, number of morphosyntactic errors, and number of errors in seven error categories.

TABLE 1. Group outcomes for independent nonauditory measures

	Block Design	Similarities	Naming
NH			
Median	11.00	12.00	13.00
1st quartile	10.00	11.50	11.25
3rd quartile	13.50	14.00	15.75
AHI			
Median	10.50	12.00	14.00
1st quartile	9.75	9.00	12.00
3rd quartile	13.25	14.25	18.25
CHI			
Median	12.00	10.00	16.00
1st quartile	8.50	9.00	13.50
3rd quartile	13.50	11.50	19.00

Group median and interquartile levels for norm scores ($\bar{x} = 10$, SD = 3, min = 1, max = 19) of the WAIS-III-NL subtests Block Design and Similarities and for speed scores (in seconds) for the naming task; for the NH group, values are based on n = 21 (except for the naming task, where n = 12), for the AHI group on n= 22, and for the CHI group on n = 21.
AHI, acquired hearing impairment; CHI, congenital hearing impairment; NH, normal hearing.

**For practical reasons, TRT assessment in 1 participant (CHI15) was carried out on two different days. For technical reasons, the order of the test blocks differed from standard procedure in 2 participants (AHI13 and CHI12).

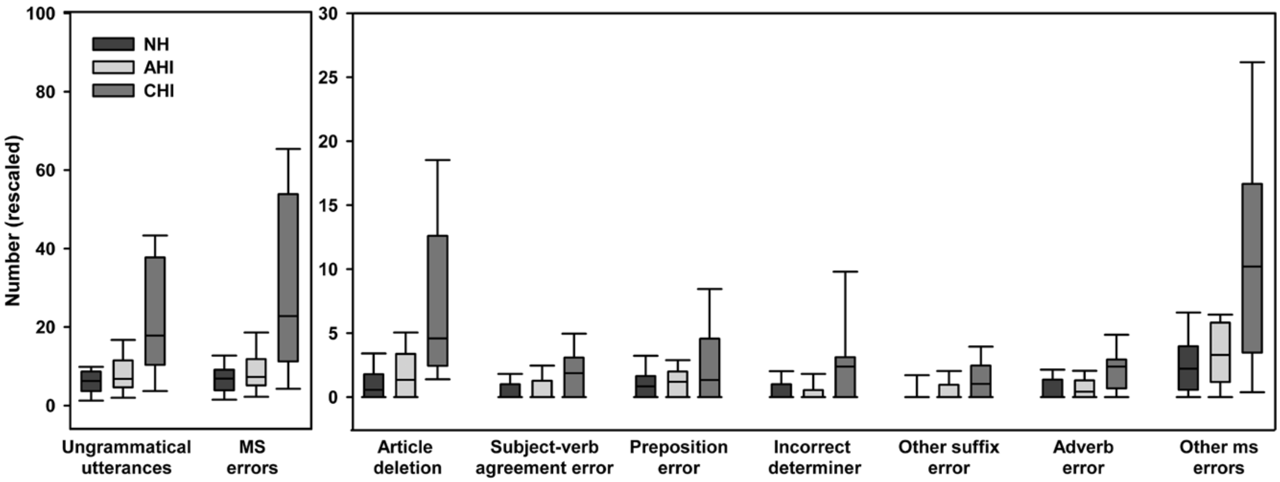

Fig. 1. Group scores for number of ungrammatical utterances, number of morphosyntactic errors, and number of errors in seven error categories; individual variable values were rescaled relative to the sample size (i.e., number of errors/sample size × 100); group median, interquartile levels, and 10% and 90% intervals are indicated ($n_{NH} = 21$, $n_{AHI} = 22$, $n_{CHI} = 21$).

Because the morphosyntactic measures had a positively skewed distribution, nonparametric tests were used for group comparisons. Using Bonferroni adjusted alpha levels of 0.007 per test (0.05/7), for none of the morphosyntactic measures a group difference between NH and AHI was found. However, CHI participants made significantly more errors than NH participants in their elicited spoken language sample in nearly all morphosyntactic categories, that is, in all but the categories “preposition error” and “incorrect determiner.” Details of these statistical analyses are given in Table 2.

Morphosyntactic Correctness in Subgroups Matched for Current Auditory Reception Abilities • To control for the influence of current aided auditory reception abilities on morphosyntactic correctness of the spoken output, nonparametric group comparisons were repeated with 2 subgroups of AHI and CHI participants (both n = 15), matched for SRTDIN scores. In Supplemental Digital Content 1 (http://links.lww.com/EANDH/A260), the SRTDIN scores of participants included in these subgroups are presented in italics. Nonparametric testing confirmed the subgroups not to differ in distribution of SRTDIN scores (Mann–Whitney $U = 112{,}500$; $n_{AHIDIN} = 15$, $n_{CHIDIN} = 15$; $p = 1.0$).

The last two columns of Table 2 show the outcomes of nonparametric tests for group differences, comparing the NH reference group with the AHI_{DIN} and CHI_{DIN} group for all morphosyntactic measures. No group differences were found between the NH and AHI_{DIN} groups, while the subjects in the CHI_{DIN} group showed significantly poorer performance than the reference group on several morphosyntactic parameters.

Masked Text Recognition

- Exploration of the Data

Table 3 shows descriptive data of the outcomes in each TRT condition, based on eight measurements in the TRTorig-mixed condition and on four measurements in all other categories. ICCs for consistency were calculated for all measurements in each condition, within each group, with a two-way mixed alpha model. Standard error of measurement was calculated for each TRT condition within each group. Likewise, ICCs were calculated for three measurements in each TRT condition within each group (seven measurements in TRTorig-mixed), to explore consistency when excluding the first measurement. This yielded ICCs that were generally lower than the ICCs of 4/8 measurements. Therefore, no data were excluded from analysis. For each condition, the average TRT of all measurements was used as the outcome score for further analysis.

TABLE 2. Results of nonparametric tests for group comparisons for all morphosyntactic measures

	NH vs. AHI	NH vs. CHI	NH vs. AHI_{DIN}	NH vs. CHI_{DIN}
Total ungrammatical utterances				
U	287.5	377.0	206.0	260.0
p	0.170	0.000*	0.125	0.001*
Total morphosyntactic errors				
U	281.0	377.5	205.5	262.0
p	0.224	0.000*	0.125	0.000*
Article deletion				
U	283.0	390.0	206.0	288.0
p	0.189	0.000*	0.125	0.000*
Subject–verb agreement error				
U	242.5	330.0	180.5	223.0
p	0.731	0.003*	0.465	0.036
Preposition error				
U	240.0	273.0	177.0	203.0
p	0.823	0.180	0.547	0.150
Incorrect determiner				
U	226.0	315.5	143.0	232.0
p	0.878	0.008	0.657	0.016
Other suffix error				
U	269.5	341.0	187.5	257.0
p	0.206	0.001*	0.340	0.001*
Adverb error				
U	227.0	352.0	152.5	232.0
p	0.917	0.001*	0.874	0.016
Other morphosyntactic errors				
U	271.0	364.0	190.5	241.5
p	0.329	0.000*	0.294	0.006*

Mann–Whitney U and p values for nonparametric group comparisons between various groups ($n_{NH} = 21$, $n_{AHI} = 22$, $n_{CHI} = 21$, $n_{AHIDIN} = 15$, $n_{CHIDIN} = 15$) for all morphosyntactic measures.

**Bonferroni corrected $p < 0.05$, two-tailed.*

AHI, acquired hearing impairment; CHI, congenital hearing impairment; NH, normal hearing.

TABLE 3. Group outcomes for eight conditions of the TRT test

	NH				AHI				CHI			
	$\bar{x}$	SD	ICC	SEM	$\bar{x}$	SD	ICC	SEM	$\bar{x}$	SD	ICC	SEM
TRTorig	52.7	2.6	0.436	4.0	53.9	3.9	0.768	3.8	54.3	4.9	0.799	4.4
TRTorig-mixed	54.6	3.1	0.780	4.2	56.6	3.4	0.775	4.5	56.9	4.7	0.855	5.1
TRTdistA	61.4	5.1	0.824	4.3	62.9	4.6	0.764	4.4	63.9	6.3	0.823	5.3
TRTdistB	64.1	4.4	0.619	5.4	68.4	7.1	0.823	6.0	67.0	6.3	0.776	5.9
TRTdistC	62.5	3.0	0.280	5.1	66.6	6.4	0.775	6.1	64.5	6.3	0.870	4.0
TRTdistD	58.8	4.0	0.717	4.3	63.5	5.5	0.769	5.2	60.8	3.8	0.590	4.8
TRTdistE	63.0	5.2	0.754	5.2	65.1	6.2	0.845	4.9	66.6	6.6	0.858	5.0
TRTdistF	60.8	4.1	0.656	4.8	64.0	6.0	0.795	5.4	64.5	6.1	0.786	5.8

Group scores for eight TRT outcome measures: mean values, standard deviations, intraclass correlation coefficients, and standard errors of measurement are given, based on four measurements in all conditions, except for the TRTorig-mixed condition, in which eight measurements were used (n_{NH} = 21, n_{AHI} = 22, n_{CHI} = 21).
TRT, text reception threshold.

• TRT for Grammatical Sentences

Figure 2 shows the group data for TRTorig and TRTorig-mixed scores.

Given the small sample sizes of the groups, normality was assessed by examining skewness and kurtosis values, with values between −1 and +1 considered to reflect normal distribution (Twisk 2010). The TRTorig and TRTorig-mixed data showed normal distribution in the NH and AHI groups, but not in the CHI group. Therefore, either parametric or nonparametric tests were used to test whether TRTs for grammatical sentences in a grammatical test condition (TRTorig) and in a mixed test condition (TRTorig-mixed) differed within groups. In each group, significant differences were found (NH: paired samples t test $t = -3.327$, $p < 0.01$; AHI: paired samples t test $t = -5.172$, $p < 0.01$; CHI: Wilcoxon signed ranks test $Z = -3.181$, $p < 0.01$). These differences reflect better text recognition of grammatical sentences when presented in a block with only grammatical sentences (TRTorig).

When comparing the TRTorig outcomes between groups, no differences were found (NH versus CHI: Mann–Whitney U = 279,500; n_{NH} = 21, n_{CHI} = 21, $p > 0.05$; NH versus AHI: independent samples t test $t = -1.225$; n_{NH} = 21, n_{AHI} = 22; $p > 0.05$; AHI versus CHI: Mann–Whitney U = 240,000; n_{AHI} = 22, n_{CHI} = 21; $p > 0.05$). This indicates that the group of CHI adults processed the masked grammatical sentences in a similar way as the NH and AHI adults. However, when comparing the groups' performance in the TRTorig-mixed condition, the AHI and CHI group both showed poorer performance than the NH group (NH versus CHI: Mann–Whitney U = 305,000; n_{NH} = 21, n_{CHI} = 21, $p < 0.05$; NH versus AHI: independent samples t test $t = -2.061$; n_{NH} = 21, n_{AHI} = 22, $p < 0.05$; AHI versus CHI: Mann–Whitney U = 238,500; n_{AHI} = 22, n_{CHI} = 21, $p > 0.05$].

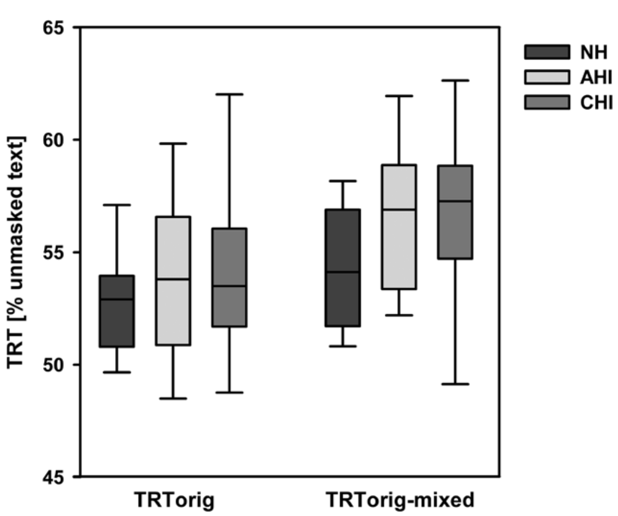

Fig. 2. Group scores for TRTorig and TRTorig-mixed, measures of masked text recognition of grammatical sentences, either in a test block with only grammatical sentences (TRTorig) or in a test block mixed with distorted sentences (TRTorig-mixed). TRT is the mean percentage of unmasked text at which 50% of the sentences is read correctly; group median, interquartile levels, and 10% and 90% intervals are indicated (n_{NH} = 21, n_{AHI} = 22, n_{CHI} = 21). TRT indicates text reception threshold.

• Sensitivity to Morphosyntactic Distortions in the TRT Task

Following the distortion sensitivity approach, the participants' sensitivity to specific morphosyntactic distortions in the processing of masked sentences was studied by comparing their TRT scores for the various categories of distortion with their TRTorig-mixed score. Figure 3 shows group data†† for TRT performance with grammatical sentences (TRTorig-mixed) and with sentences from each of six morphosyntactic distortion categories (TRTdistA: article deletion, TRTdistB: subject–verb agreement error, TRTdistC: preposition error, TRTdistD: article substitution, TRTdistE: suffix error, and TRTdistF: adverb error).

Group Comparisons for Distortion Sensitivity (DSdist) Values • The participant's sensitivity to an applied distortion was quantified by the distortion sensitivity (DSdist) value, calculated as the difference between the TRT in a specific distortion condition and the TRTorig-mixed score in percentage points. Nonparametric tests were performed on the DSdist values to examine group differences in sensitivity to morphosyntactic distortions, using Bonferroni adjusted alpha levels of 0.008 per test (0.05/6). No significant group differences were found for any of the distortion conditions.

Associations Between Morphosyntactic Errors in Language Production (FGST) and Distortion Sensitivity (DSdist) Values • Within the CHI group, nonparametric correlation analysis was performed to examine associations between the

††In 3 participants (AHI22, CHI15, and CHI21), in several of the TRTdist trials, a sentence was not correctly recognized even when presented without any (0%) masking, probably due to the presentation rate that was still too high. If this happened more than once in a list (CHI15, n = 6 and CHI21, n = 5), the results for that list were omitted from analyses. If this occurred in more than one list of a certain condition, no TRT was calculated (for two distortion conditions in CHI 15 and in CHI21).

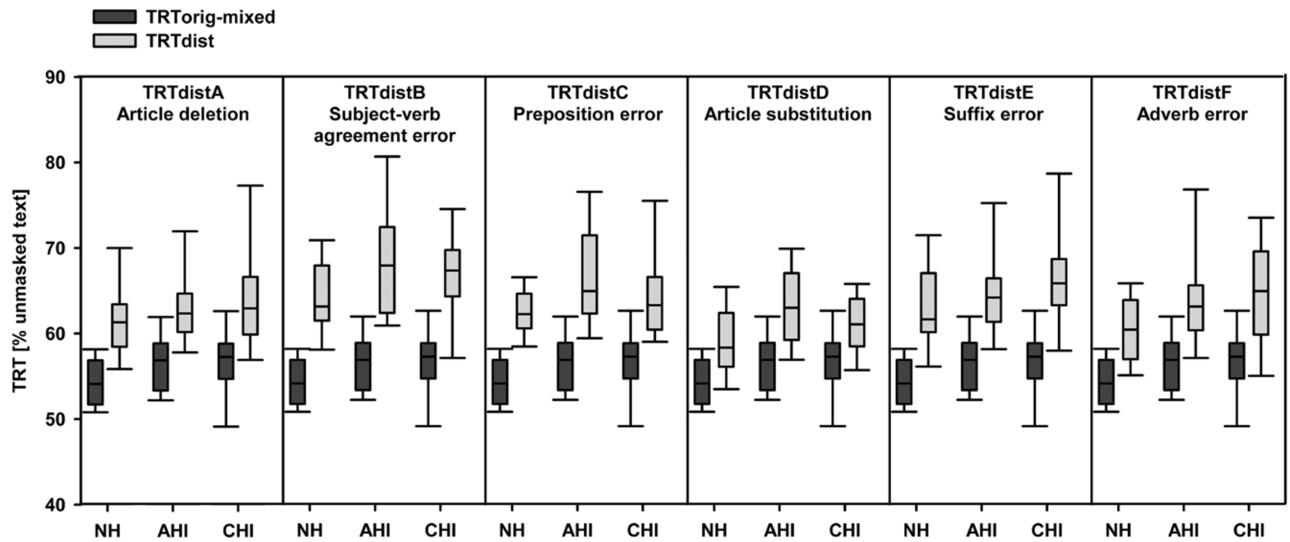

Fig. 3. Group scores for masked text recognition of grammatical sentences (TRTorig-mixed) and sentences with a morphosyntactic distortion (TRTdistA: article deletion, TRTdistB: subject–verb agreement error, TRTdistC: preposition error, TRTdistD: article substitution, TRTdistE: suffix error, and TRTdistF: adverb error). TRT is the mean percentage of unmasked text at which 50% of the sentences is read correctly; group median, interquartile levels, and 10% and 90% intervals are indicated (n_{NH} = 21, n_{AHI} = 22, n_{CHI} = 21, except for TRTdistA and TRTdistC (n_{CHI} = 20) and for TRTdistB (n_{CHI} = 19)). TRT indicates text reception threshold.

number of morphosyntactic errors in a specific error category in a subject's spoken language sample, elicited with the FGST, and the subject's sensitivity to that morphosyntactic distortion in the TRT task, expressed with the DSdist value. No significant correlations were found. The occurrence of errors in spoken language thus did not predict sensitivity to morphosyntactic distortions in text reception.

DISCUSSION

Moderate to severe CHI affects spoken language acquisition in children, but little research has been done on its effect on language production and language reception in adults. This study examined the reproducibility of the authors' earlier finding that adults with moderate to severe CHI display problems in the correct use of morphosyntax in spoken language production. As a second step, the study evaluated whether current hearing abilities could explain these problems in CHI adults' spoken language production. This evaluation was done by investigating the performance of adults with a comparable hearing loss, but that developed after the age of 12 years (so-called AHI). Furthermore, this study examined whether CHI affects language recognition in the visual domain, thus independent of bottom-up auditory processing. In brief, the data indicate that CHI affects the correctness of spoken language production, elicited in expository discourse. No problems with morphosyntactic correctness were found in the AHI group, which implies that deviancies in the performance of the CHI adults are likely to be caused by reduced hearing in early life. In text reception, in contrast, the groups did not differ in performance. This implies that CHI did not affect visual recognition of short, degraded sentences.

The first aim of this study was to evaluate the influence of CHI on correctness of spoken language production in adults. The data confirm and extend our earlier findings (Huysmans et al. 2014): Again, adults with moderate to severe CHI made more morphosyntactic errors in their spoken language sample, elicited with the FGST, than adults with NH. One could hypothesize that these errors occur because hearing impaired subjects do not perceive their own speech well. However, the current data show that adults with AHI do not make more errors than the NH adults, which contrasts with the CHI group, despite similar current auditory reception abilities. This observation sustained when comparisons were restricted to subgroups of AHI and CHI adults, matched for current auditory speech reception abilities. By using the digits in noise test, auditory speech reception was assessed with minimal influence of top-down linguistic abilities (Smits et al. 2013; Kaandorp et al. 2016). Performance was thus not confounded by differences between subjects in linguistic proficiency. The AHI and CHI adults differ in age, with the AHI subjects generally being older than the CHI subjects. However, research has shown that age does not exert an influence on morphosyntactic correctness in a spoken language task (Mulder & Hulstijn 2011). All potentially relevant factors considered being equal, the AHI and CHI adults only differ in the circumstances in which spoken language was acquired, that is, with normal versus degraded auditory input. This study thus confirms the effect of moderate to severe auditory perceptual limitations during language acquisition on morphosyntactic correctness of spoken output, even at an adult age.

In their spoken language output, adults with moderate to severe CHI made more errors in three categories that were also affected in the participant sample of our earlier study (Huysmans et al. 2014): article deletion in an obligatory context, adverb error, and subject–verb agreement error in the present tense. In addition, the present CHI sample made more errors than NH adults in the use of suffixes for noun plural marking and adjectival inflexion. Theories of how CHI may affect specific aspects of spoken language acquisition, as discussed in the "Introduction," give an explanation for the occurrence of problems in each of these four affected categories. Given the error patterns, perceptual salience (i.e., the relative amount of linguistic information present in the acoustic signal to be perceived) is a likely factor underlying errors in bound morpheme use (subject–verb agreement errors and other suffix errors) and errors in the use of determiners (article deletion in an obligatory context). The use of pronominal adverbs is considered a complex issue in Germanic languages (Belz 2005; Van Canegem-Ardijns & Van Belle 2005), so relative grammatical complexity is likely to be a key factor in part of the adverb errors. A more detailed explanation of the role of CHI in these errors is given in our earlier publication (Huysmans et al. 2014). The data of this study thus identify morphosyntactic aspects of Dutch that are vulnerable when acquired with degraded auditory input. Note that all subjects in our study showed variability in the morphosyntactic correctness of their spoken output: Errors did not occur in every instance when a specific morphosyntactic paradigm was used (e.g., not every verb in the present tense in a sample was conjugated incorrectly). Adults with CHI showed a significantly larger variability in correctness than the adults in the NH and AHI group. The implications of this finding are discussed later.

The second aim of this study was to evaluate the influence of linguistic proficiency, assessed with morphosyntactic correctness of the elicited spoken language sample, on performance in masked sentence recognition, which was operationalized by measuring the TRT test. We chose a test for masked sentence recognition in the visual modality to exclude the influence of current auditory perceptual limitations as a confounder in language reception. In the three groups, the use of morphosyntactic knowledge in sentence processing was reflected in poorer text recognition of grammatical sentences in test blocks mixed with ungrammatical sentences (i.e., in the TRTorig-mixed condition) than in a test block with exclusively grammatical sentences (i.e., in the TRTorig condition). In the mixed condition, where uncertainty about grammaticality was introduced, subjects could be less confident to use their morphosyntactic knowledge when constructing a sentence from text fragments. If participants would not use their morphosyntactic knowledge to compensate for the incompleteness of the visual linguistic input, the introduced uncertainty about the effectiveness of using this knowledge would not affect performance. The reduced TRT performance for grammatical sentences in the TRTorig-mixed condition thus illustrates that participants actually use their morphosyntactic knowledge when constructing meaningful wholes of text fragments.

At a group level, our results indicate that moderate to severe CHI did not affect sentence recognition performance in the visual modality in a test condition in which subjects could rely on and take advantage of their morphosyntactic knowledge (TRTorig). This result is not in line with the earlier introduced hypothesis that we expected poorer performance in visual language reception in the CHI subjects, resulting from CHI-induced difficulties in the use of morphosyntactic knowledge in language reception, as in language production. To further explore this finding, we examined associations between various independent measures (i.e., age and outcomes for Block Design, Similarities, Naming, SRTDIN, and number of morphosyntactic errors) and the individuals' TRTs for grammatically correct sentences (TRTorig). In Supplemental Digital Content 4 (http://links.lww.com/EANDH/A263), details of this nonparametric correlation analysis are given. Analysis showed that the variable "number of morphosyntactic errors in spoken language production," measuring one aspect of linguistic proficiency, was related to TRTorig scores in the CHI group (Spearman's rho correlation coefficient = 0.57; $n_{CHI} = 21$; Bonferroni corrected $p < 0.05$). In the CHI group, making more morphosyntactic errors in spoken language production was associated with poorer TRTorig performance. In the NH and AHI group, however, an association between TRTorig performance and this measure was not found, nor was an association found between TRTorig performance and any other independent measure. This finding for the NH and AHI group is in line with a study of Zekveld et al. (2011), in which a measure of linguistic proficiency (i.e., vocabulary size) was not associated with TRT performance for NH and AHI listeners. Furthermore, the absence of group differences in TRTorig performance in the present study in spite of clear group differences in one particular aspect of linguistic proficiency indicates that other factors account for variance in the TRTorig outcomes, for instance differences in verbal processing capacity (Besser et al. 2012; Koelewijn et al. 2012). Such aspects were not assessed in the present study.

To examine the subjects' sensitivity to morphosyntactic distortions in the sentences used in the masked text recognition task, TRTs were assessed with grammatically correct and incorrect sentences. When test blocks contained incorrect sentences, this inevitably introduced uncertainty about the grammaticality of the sentences. For the recognition of grammatical sentences in a condition with introduced uncertainty (TRTorig-mixed), our data show that both groups with hearing-impaired subjects performed poorer than the subjects in the NH group. This is an interesting finding that came up as a consequence of the study design and was not part of the rationale behind this study. The fact that this group difference was not found in the TRTorig condition indicates that the poorer performance of both the AHI and CHI group is not likely to be related to differences in the use of linguistic knowledge. This conclusion is supported by the fact that there is no difference between groups in their sensitivity for morphosyntactic distortions when processing masked sentences, as expressed in the DSdist values. In both the AHI and CHI group, one or more other factors must account for poorer performance in the visual processing of grammatically correct sentences with uncertainty about grammaticality. As the AHI and NH group only differ in age range, and not in any other independent measure, we tested the association between age and TRTorig-mixed outcomes. No association was found, leading to the conclusion that the performance pattern of the AHI group in the TRTorig-mixed condition cannot be explained by the factors assessed in this study. Within the CHI group, no associations between TRTorig-mixed scores and any assessed variable were found. The only aspect that the adults in the AHI and CHI group have in common is their current status of hearing impairment. In daily life, people with hearing impairment often experience discrepancies between what they understand and what was actually said. This might create an elevated consciousness in HI adults of the possibility that their perception deviates from reality. As a result, HI individuals might be more susceptible to introduced uncertainty about the grammaticality of a sentence, even in the visual modality. In contrast, NH adults have less reason to doubt their perception in daily life, which might result in lower susceptibility for possible ungrammaticalities in the reception task of this study. To our knowledge, increased susceptibility to uncertainties in the linguistic input, as we hypothesize here, would be an unknown relevant consequence of hearing impairment.

A major finding of this study is that CHI affects performance on the task for production of spoken language in expository discourse, while no effect is observed on performance on the task for visual language reception. One factor that could underlie this contrast between language production and language reception performance is the difference in complexity of the linguistic units involved in the tasks. In the spoken language production task, utterances were generally more complex than the simple sentences used in the language reception task. Earlier research suggests that errors in spoken language production are more likely to occur in longer, complex utterances than in short, simple utterances (Bishop 1994; Franck et al. 2002). As morphosyntactic knowledge is used less intensively when recognizing simple sentences than when producing complex utterances, our reception task could be not sensitive enough to assess a possible long-term effect of moderate to severe CHI. In daily life, language reception concerns longer linguistic units, which are perceived auditorily and are often more complex than the sentences used in the current TRT tests. Therefore, our results leave open the possibility that consequences of moderate to severe CHI on the linguistic proficiency of adults do impede language reception in daily life, additional to the impediment due to current perceptual limitations. Further research is needed to examine how the linguistic system of adults with moderate to severe CHI processes more complex input in language reception. It would also be interesting to assess CHI adults' language recognition with utterances from their own language sample of the production task. This way, the use of a morphosyntactic cue in sentence recognition would be assessed in utterances of a length in which an error may occur, and the error would reflect the participant's own specific weakness in the use of morphosyntactic knowledge in spoken language production. In addition, a more detailed analysis of participants' response errors in the sentence recognition task could yield insight in possible differences in individuals' strategies in the use of linguistic knowledge when performing the task.

Another factor that could underlie the observed differences in performance between language production and language reception is related to differences in processing between the two modalities. Reception and production models show that both systems tap into the same morphosyntactic knowledge (Levelt 1993), but the mechanisms for using this knowledge in language production and reception differ (Matthei & Roeper 1983). In a language reception task, subjects repeat the presented sentence, so the correct response is fully or partially given. Linguistic knowledge is thus used to complete missing information if needed and then to repeat the sentence. In the language production task, in contrast, produced utterances completely depend on the subjects' active use of available linguistic knowledge. This could imply that language reception is less sensitive for differences in available linguistic resources to show up in performance, compared with language production. In addition, earlier research has shown that the task we used to elicit language in expository discourse requires a considerable amount of cognitive resources (Nippold et al. 2005): the open ended questions posed to a participant ask for a structured response, in which cause-and-effect, procedural reasoning, precise vocabulary, and the use of accurate information and appropriate grammar have to be combined in a clear and organized matter. Subjects have to exploit their cognitive resources to coherently formulate a structured response, leaving fewer resources for applying the correct linguistic form. This allocation of resources may result in a decrease in performance (referred to as "resource limited processing"; Norman & Bobrow 1975), that is, in the occurrence of ungrammaticalities in spoken language production in the current task. Earlier research has shown, like the present study, that even NH adults make errors in spoken language production (Mulder & Hulstijn 2011). The data of the present study, however, showed that the performance decrease in the spoken language production of CHI adults was more substantial than in NH and AHI adults, and that this decrease in performance concerned specific aspects of morphosyntax. Given the considerable task demands of the language production task, a possible difference in available cognitive resources between the CHI adults and the NH and AHI adults could explain the CHI adults' more substantial decrease in performance. This explanation of our results would be in line with results of research in children using a cochlear implant (Kronenberger et al. 2013), showing that the development of executive functioning (i.e., processes used to regulate thought and behavior) is at risk when auditory signals are perceived with limitations. The hypothesis that the substantial decrease in language production performance in the CHI adults is due to limitations in allocation of cognitive resources could also explain the adults' performance pattern: CHI adults did not make specific errors consequently in all utterances but showed a variable performance instead. They correctly applied the morphosyntactic knowledge in their spoken language production regularly. This implies that the errors in spoken language production do not reflect impaired competence, but are performance problems. The nature of the observed errors, however, suggests an association with perceptual limitations during early language acquisition: Errors specifically occur when morphosyntactic knowledge needs to be applied that relatively highly depends on perceptual salience or on efficient use of a critical time window in its acquisition. Hearing impairment during early language acquisition seems to have affected automatisation in the use of this specific morphosyntactic knowledge. This observation is in line with the vulnerable marker hypothesis (Bishop 1994), which states that performance problems in the use of morphosyntactic paradigms that are vulnerable in their acquisition may occur when the processing capacity of the production system is strained, despite an adequate level of competence. Thus, our data on spoken language production may suggest that CHI affects the use of cognitive resources and leads to increased vulnerability in the application of specific morphosyntactic paradigms. Since relevant aspects of cognitive functioning were not assessed in the present study, further research is needed to examine this hypothesis.

Summarizing, differences in complexity of the linguistic units involved in the two tasks and differences in processing between modalities could have affected the sensitivity of the language reception task to examine the relation between the use of linguistic resources and language reception performance. Furthermore, it might be questioned whether measuring sentence reception at a level of 50% intelligibility, which is common when using an adaptive procedure like the TRT as used in the present study, is the most appropriate level to study this relation. Norman and Bobrow (1975) state that the profitability of using additional cognitive resources when performing a task depends on the quality of the information available in the stimulus. When the quality of the available information is too low, the deployment of cognitive resources may not lead to better performance (referred to as "data limited processing"). It therefore would be interesting to systematically examine which level of intelligibility, and thus which quality of the available linguistic input, would be most sensitive to assess the effect of differences in linguistic resources on sentence recognition performance.

Problems with morphosyntax in spoken language production have clear clinically relevant implications for CHI adults. In everyday communication, errors in spoken language are apparent, which might influence the interaction of CHI adults with other people. In this study, specific morphosyntactic aspects of Dutch were identified as weak spots for adults with moderate to severe CHI, indicating that these aspects are vulnerable when acquired with degraded auditory input. Speech and language therapy in young hearing-impaired children, either using hearing aids or cochlear implants, should focus on these aspects of morphosyntax to possibly prevent long-term weaknesses in their use in spoken language.

In conclusion, the present study shows that moderate to severe CHI affects language production in adulthood, but generally does not impede performance in masked language reception in the visual modality, as measured in this study with short, degraded sentences. Aspects of linguistic proficiency that are affected by CHI thus do not seem to play a role in masked visual sentence recognition.

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