

Links of Prosodic Stress Perception and Musical Activities to Language Skills of Children With Cochlear Implants and Normal Hearing

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Objectives: A major issue in the rehabilitation of children with cochlear implants (CIs) is unexplained variance in their language skills, where many of them lag behind children with normal hearing (NH). Here, we assess links between generative language skills and the perception of prosodic stress, and with musical and parental activities in children with CIs and NH. Understanding these links is expected to guide future research and toward supporting language development in children with a CI.

Design: Twenty-one unilaterally and early-implanted children and 31 children with NH, aged 5 to 13, were classified as musically active or non-active by a questionnaire recording regularity of musical activities, in particular singing, and reading and other activities shared with parents. Perception of word and sentence stress, performance in word finding, verbal intelligence (Wechsler Intelligence Scale for Children (WISC) vocabulary), and phonological awareness (production of rhymes) were measured in all children. Comparisons between children with a CI and NH were made against a subset of 21 of the children with NH who were matched to children with CIs by age, gender, socioeconomic background, and musical activity. Regression analyses, run separately for children with CIs and NH, assessed how much variance in each language task was shared with each of prosodic perception, the child's own music activity, and activities with parents, including singing and reading. All statistical analyses were conducted both with and without control for age and maternal education.

Results: Musically active children with CIs performed similarly to NH controls in all language tasks, while those who were not musically active performed more poorly. Only musically nonactive children with CIs made more phonological and semantic errors in word finding than NH controls, and word finding correlated with other language skills. Regression analysis results for word finding and VIQ were similar for children with CIs and NH. These language skills shared considerable variance with the perception of prosodic stress and musical activities. When age and maternal education were controlled for, strong links remained between perception of prosodic stress and VIQ (shared variance: CI, 32%/NH, 16%) and between musical activities and word finding (shared variance: CI, 53%/NH, 20%). Links were always stronger for children with CIs, for whom better phonological awareness was also linked to improved stress perception and more musical activity, and parental activities altogether shared significantly variance with word finding and VIQ.

Conclusions: For children with CIs and NH, better perception of prosodic stress and musical activities with singing are associated with improved generative language skills. In addition, for children with CIs, parental singing has a stronger positive association to word finding and VIQ than parental reading. These results cannot address causality, but they suggest that good perception of prosodic stress, musical activities involving singing, and parental singing and reading may all be beneficial for word finding and other generative language skills in implanted children.

Key words: Contrastive focus, Language skills, Music, Naming, Phonological awareness, Prosody: word stress and lexical stress, Rehabilitation, Sentence stress, Speech and language therapy, Verbal IQ, Vocabulary, Word finding.

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INTRODUCTION

The cochlear implant (CI) has proved very successful in allowing adults and children with profound hearing loss to communicate using speech. Nevertheless, children with CIs have difficulties in spoken language acquisition. For instance, many of them have more restricted receptive and expressive vocabularies than children with normal hearing (NH) (Percy-Smith et al. 2013; Lund 2016). At school age, compared with children with NH, about half of children with CIs have difficulties in expressive morphological and syntactic skills and in production of narratives (Boons et al. 2013), and many show poorer language abilities in general, including phonological awareness (PA) and verbal IQ. (Wu et al. 2008; Boons et al. 2012; Hashemi & Monshizadeh 2012; Geers & Nicholas 2013; Percy-Smith et al. 2013; Soleymani et al. 2016; for a review, van Wieringen & Wouters 2015). Up to 2011, approximately 80,000 children were able to compensate for their profound deafness with CIs (Boons et al. 2013), and the rate of implantation of young children is growing due to more efficient early diagnosis and clinical preference for implantation before 24 months of age (van Wieringen & Wouters 2015). From economic and ethical standpoints, good language abilities are crucial in everyday life, at school, and later for higher education and at work. From the perspective of families, good spoken language skills are essential because oral language is most often the family's mode of communication and parents prefer their children to be at mainstream schools (Vavatzanidis et al. 2018). Therefore, it is essential to seek improved rehabilitation methods that can help these children achieve language abilities closer to those expected of typically developing children.

Previous research has shown that several factors seem to be beneficial for speech perception and language development in children with CIs (Huang et al. 2017). Among these, language abilities are better in children implanted at an earlier age (Hayes et al. 2009; Niparko et al. 2010; Boons et al. 2012; Percy-Smith

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et al. 2013). Language abilities are also better in children who show no behavioral problems or other disabilities (Boons et al. 2013) and some studies have found benefits of bilateral over unilateral implantation (Boons et al. 2013; Sarant et al. 2014). Higher levels of language skills have also been found for children whose mothers have received higher education (Sarant et al. 2014) and whose mothers use only speech rather than total communication with their children (Boons et al. 2012; Percy-Smith et al. 2013). Furthermore, several perceptual and cognitive skills are connected to language abilities in children with CIs, including auditory working memory capacity (Pisoni & Cleary 2003, Pisoni et al. 2011) and nonlinguistic cognitive ability (Sarant et al. 2014).

However, there is still unexplained variance in the language skills of children with CIs, despite early implantation, suggesting that there may be other important predictors (Boons et al. 2013; van Wieringen & Wouters 2015; Moberly et al. 2016). Finding those would guide us toward more effective language rehabilitation of children with CIs, and in consequence to better communicative skills, academic performance, and well being.

Potential Predictors of Language Skills

Here, we introduce three potentially important predictors of language skills that have not as yet received much attention in studies of children with CIs: perception of prosodic stress, musical activities, and other activities undertaken with parents.

Perception of Prosody: Word and Sentence Stress • Prosody comprises the suprasegmental factors of intonation (the melody of speech) and rhythm. Intonation is conveyed by acoustic changes in pitch, while loudness, segment duration, and relative timing of segments represent speech rhythm. Prosody is multifunctional. It signals the emotional state of the speaker and also significant lexical, syntactic, and discourse structures of utterances (for a review, see Cole 2015). The ability to perceive the prosodic functions of sentence and word stress is thought to be particularly important for the development of spoken language.

Sentence stress (prosodic prominence) expresses the status of a word as new to the discourse (so-called broad or informational focus), or as having contrastive or narrow-scope focus (boy PAINTS a boat versus BOY paints a boat) (for a review, see Cole 2015). Parents typically speak to infants with an infant-directed style where they use much pitch variation, use high pitch and long segment durations, and in particular stress new or important words in sentences with these acoustic variations (Fernald 1991). This is thought to facilitate NH children's word learning by enhancing the recognition of new word forms and their phonological representations (the role of infant-directed speech in general: Thiessen et al. 2005; Singh et al. 2009; Estes & Hurley 2013; particularly sentence stress, Männel & Friederici 2013). Compared with sentences produced with adult-directed speech, infants with NH consistently learn word meanings from continuous speech, and from utterance of several clearly separated words, better when infant-directed style is used (Ma et al. 2011; Estes & Hurley 2013). Moreover, pitch variation in infant-directed speech and song aids the development of vowel categories and NH infants' perception of the phonetic content of speech (Trainor & Desjardins 2002; Lebedeva & Kuhl 2010). Furthermore, even adults with NH benefit from sentence stress in the learning of new words (Filippi et al. 2014)

and in sentence comprehension and recognition of phonemes (Cutler & Foss 1977).

Word stress (also called lexical stress) refers to the position of the strong stressed syllable of the word, which in English, as in Finnish (the native language of the children participating in the present study), is typically the first syllable of the word. English-speaking adults use strong syllables and word stress patterns to identify the beginnings of words in fluent speech (Cutler & Norris 1988; McQueen et al. 1994), and infants also do so (Morgan 1996; Echols et al. 1997; Curtin et al. 2005). Thus, the pattern of word stress is a cue for segmenting words from continuous speech (adults: Finnish and Dutch: Vroomen et al. 1998; British English: Mattys et al. 2005; children: Jusczyk et al. 1999; Mattys et al. 1999; Thiessen et al. 2005). Like sentence stress, the pattern of word stress (speech rhythm) aids the perception of phonemes, which is important for language learning (Mattys 1997; Bolger et al. 2014; Schön & Tillmann, 2015).

In line with the review earlier, access to word stress seems to be important for language acquisition. For instance, infants (aged 19 months) learn new word labels only if they are presented with word stress patterns familiar from their native language (Estes & Bowen 2013). For children with dyslexia and specific language impairment, sensitivity to word stress seems to be an important predictor of expressive and receptive language skills (for review, see Cumming et al. 2015). Further, there is direct evidence of beneficial effects of good perception of word stress for language skills: those children with NH who have better processing of word stress in infancy show better word and sentence production and comprehension later in childhood (Friedrich et al. 2009), while better ability to segment fluent speech at infancy is associated with better language abilities at age 4 to 6 years (Newman et al. 2006).

Unfortunately, CIs cannot convey pitch well, which is likely to be problematic for the perception of intonation. However, the perception of intensity change and duration cues, and hence of speech rhythm, is generally good. Poor perception of pitch in adults and children with CIs appears to be responsible for their typically poor perception and production of prosody, including word and sentence stress (Torppa et al. 2014a; Chatterjee et al. 2015; Holt et al. 2016; Huang et al. 2017; Pettinato et al. 2017, among others). However, it seems that some early-implanted children have rather good ability to distinguish word stress patterns in infancy (at behavioral level, Segal et al. 2016; based on event-related potentials, Vavatzanidis et al. 2016). Little is known about the links between perception of word or sentence stress and language skills in children with CIs. One exception is a study by Carter et al. (2002) who found that in 8- to 10-year-old children with CIs, the accuracy of production of imitated word stress patterns of nonsense words correlated significantly with performance in word identification (Lexical Neighborhood Test), with language measures assessing receptive vocabulary, morphology and syntax, and with the intelligibility of the speech they produced. These findings indicate that the ability to recognize and imitate stress patterns is related not only to the ability to identify and learn words but also to language skills in general.

Access to stress cues might be expected to have an even stronger impact on speech and language development for children with CIs than for children with NH. It is known that if the listener cannot hear the phonotactic or acoustic-phonetic cues properly, as is the case for children with CIs (Geers et al. 2003; Donaldson & Krefl 2006; Johnson & Goswami 2010; Moberly

et al. 2016; Soleymani et al. 2016), or if language skills are only emerging or restricted, as they are for many children with CIs, the stress cues override the other cues in segmentation of words (Mattys et al. 2005). Thus, the ability to perceive word and sentence stress may be a stronger predictor of language skills in children with CIs than in children with NH. This predictive value of stress perception is also potentially greater in children with CIs simply because of the much greater range of stress perception abilities.

Musical Activities • Previously, we found better development of phonological auditory working memory, perception of word/sentence stress, and related auditory cues such as pitch and intensity in CI children who had participated from an early age in supervised singing and other musical activities compared with other children with CIs (Torppa et al. 2014a). While the musically nonactive children with CIs performed more poorly than NH control children, the musically active children with CIs performed similarly to NH controls in the perception of stress and underlying auditory cues. A controlled follow-up study in children with CIs has also shown that musical training enhances their perception of melodic contours, rhythm, and emotional prosody (Good et al. 2017), abilities which are likely to be related to the perception of prosodic stress (Hausen et al. 2013). Thus, if perception of stress is that important for language acquisition, children with CIs participating in musical activities with singing should have better language skills than other children with CIs.

There is plenty of evidence in NH children of links between musical training and language skills (for review, see Kraus & Chandrasekaran 2010). Musical training is associated with better preattentive processing of foreign language speech sounds (Intartaglia et al. 2017) and better word learning (Dittinger et al. 2017). There is also longitudinal evidence that musical activities benefit the perception of speech in background noise (Slater et al. 2015) and verbal memory (Ho et al. 2003). Randomized controlled trial (RCT) studies comparing musical training to training in arts or sport have shown that only musical training enhances reading skills and PA (sports versus music, PA, and reading, Degé & Schwarzer 2011; PA: Patscheke et al. 2016, 2018; painting versus music, PA, and reading, Flaunacco et al. 2015; for a meta-analysis, see Gordon et al. 2015). Further, RCT studies have shown that musical training but not visual art training enhances phoneme and speech segmentation (François et al. 2013). Moreover, verbal intelligence (VIQ) and executive function are enhanced by music training but not by visual art training (Moreno et al. 2011; Jaschke et al. 2018) nor by dancing training, which does not involve singing or playing musical instruments (Linnavalli et al. 2018). The benefits of musical training seem to extend to the development of the brain (Hyde et al. 2009; for reviews, see Münte et al. 2002; Herholz & Zatorre 2012), for example, in increasing gray matter volume in areas involved in auditory processing (Schneider et al. 2002) and speech perception (Gaser & Schlaug 2003), and strengthening connectivity between frontal and auditory areas (Halwani et al. 2011; Dittinger et al. 2018; Oechslin et al. 2018). The connections between these areas are important for speech perception, auditory working memory (Ylinen et al. 2015), perception of prosody (Sammler et al. 2015, 2018), and thus for language learning. These findings suggest that supervised musical activities could also enhance a wide range of language skills in children with CIs (see also Moreno & Bidelman 2014, for a review).

The musical activities in the studies earlier included playing instruments and singing. It is important to note that new words are learned better when embedded in songs than when spoken (Wallace 1994; Tamminen et al. 2017). The slower word rate and use of repetition in song compared with speech is likely to afford more time to process words (Patel 2014). The regular rhythm of song can also be beneficial for the development of perception of speech and with this, for language learning (Cason & Schön 2012; Cason et al. 2015; children with CIs, Torppa et al. 2018). We also have found that compared with other children with CIs, those who sing at home regularly have earlier and stronger P3a brain responses reflecting stronger attention shift toward changes in sounds (Torppa et al. 2014b) and better perception of speech in noise, which is important for language learning in noisy environments such as daycare or school (Torppa et al. 2018). Because singing captures the attention of young children and is thought to be beneficial for language learning, singing is frequently used in speech and language therapy (Manolson 1992, pp. 87–102; Estabrooks 1994, pp. 81–86; Ronkainen 2011). In sum, there are several reasons to expect that singing would be more important than playing musical instruments for language development, and therefore the emphasis on the supervised musical activities of the children in the present study was on singing.

Parental Activities • Data from children with NH indicate children's school performance and social and intellectual development are superior when parents spend more time in activities with their children (Kalb & Van Ours 2014). More specifically, Sylva et al. (2004) asked how much time parents had spent with their children in reading, teaching songs and nursery rhymes, painting and drawing, playing with letters and numbers, visiting the library, teaching the alphabet and numbers. All these activities were associated with higher intellectual, social and behavioral scores, this effect being stronger than those of parental education and occupation (see also Melhuish et al. 2008). Maternal participation in intervention and educational programs has been found to result in improved language skills in children with CIs (Sarant et al. 2014). Thus, the time that parents spend with their children in general might be important for the development of wide range of skills of children.

Of parental activities, reading to the child seems to be particularly important. More parental reading has been consistently shown to be related to better language outcomes in children with NH (receptive and expressive vocabulary, meta-analysis by Mol & Bus 2011; expressive vocabulary and reading comprehension, Klein & Kogan 2013; receptive vocabulary: Kalb & Van Ours 2014). Consistently, the more parents read for children with CIs, the better are their language skills (Sarant et al. 2014).

Parents and early childhood teachers all over the world comfort and entertain babies by singing to them (Custodero 2006; Ilari et al. 2011) and, by doing so, support language development, strengthen social bonding, and promote musical development (Trehub & Trainor 1998; Costa-Trehub 2001; Giomi & Ilari 2014). Parental singing seems to promote language development and auditory processing as early as infancy (Virtala & Partanen 2018). Furthermore, the more the parents sing for children with CIs, the better is their perception of word and sentence stress, and there is a similar but weaker connection in children with NH with perception of sentence stress (Torppa et al. 2010). Parental singing also leads to more singing of the

children themselves, and may partially underlie the finding on improved perception of speech in noise in those children with CIs who sing regularly compared with other children with CIs (Torppa et al. 2018). Furthermore, pitch patterns in songs facilitate infants' recognition of phonetic content of speech (Lebedeva & Kuhl 2010). Thus, parental singing may be as important as singing in day-care or rehabilitation settings for the language acquisition of children with CIs and NH.

The Present Study

The main goal of the present study was to investigate to what extent three factors—perception of prosodic stress, the child's musical activities, and parental activities—may explain the variability in language outcomes in children with CIs and children with NH. Understanding the possible causes of variation would allow therapists to create the best possible circumstances for children with a CI to acquire oral language. Specific focus was on three generative language skills—word finding, verbal I.Q., and PA, where children with CIs in general are expected to perform more poorly than children with NH (verbal I.Q., see earlier, Hashemi & Monshizadeh 2012; Geers & Nicholas 2013; PA: see earlier, adults: Lyxell et al. 2009; Moberly et al. 2016; children: Pisoni et al. 2011; Ambrose et al. 2012; Nitttrouer et al. 2012).

We were especially interested in word finding which has been little studied in children with CIs. It reflects speed and efficiency in finding verbal names for familiar concepts (Newman et al. 2018). Its assessment involves words expected to be in the child's receptive vocabulary. We use word finding constantly when we speak or write. Thus, deficits in word finding can lead to severe difficulties in generating narratives, expressing feelings, answering questions and in everyday communication, leading further to negative long-term effects on self-esteem, social development, educational attainment, and well being (Best 2005; Messer & Dockrell 2006; Newman et al. 2018). Previous results from tasks requiring efficient word finding (measures of verbal I.Q. and PA, production of rhymes, production of narratives, word fluency, see earlier; Löfkvist et al. 2012; Wechsler-Kashi et al. 2014) give reason to expect that children with CIs have difficulties in word finding.

Word finding has several stages: At first, the stimulus (a picture or a sentence) activates the conceptual network related to the target word. The conceptual structure activates a set of lexical, semantically related candidates (lemmas), and leads to the selection of the target lemma (the semantic meaning of a target word). In the next stage, the syllabic and phonemic features (morpho-phonological format) of the word are selected and activated at the lexeme level. Finally, the motor plan is created and forwarded to articulation processes to produce the target word (Levelt 1989; Newman & German 2002; German & Newman 2004; Messer & Dockrell 2006; Newman et al. 2018). Here, we classified word finding errors as phonological or semantic to assess the stage at which word finding difficulties arise. We expected that compared with children with NH, children with CIs will make more phonological and semantic errors due to difficulties in identifying the phonemic content of words as a consequence of their problems in hearing.

Hypotheses

Based on the review earlier, we tested the following hypotheses: (1) Children with CIs perform more poorly than children

with NH in generative language skills, i.e., word finding, VIQ, and PA. (2) Impaired hearing is associated with a higher rate of both phonological and semantic errors in word finding. (3) All three generative language skills share a significant amount of variance in CI and NH children with the following three factors: (a) Perception of prosody (perception of word and sentence stress; a stronger link is expected for children with CIs than children with NH); (b) Children's musical activities; (c) Parental activities.

MATERIALS AND METHODS

Ethical Aspects

Parents gave written informed consent before the experiment and the participants gave their consent orally after the nature of the experiment was explained to them. The study was carried out in accordance with the Declaration of Helsinki and all procedures were approved by the local ethical committees of the participating hospitals.

Questionnaires

Information about musical and other activities was collected from questionnaires addressed to parents and to personnel in the daycare centers/schools 14 to 17 months before and also during the data collection period (Torppa et al. 2014a, b, 2018). In the questionnaires, we collected data on the type and regularity of informal musical activities of the children at home, and type, regularity and duration of formal musical activities of the children at daycare, school, music play school, etc. (e.g., music instrument or singing lessons, choir, music therapy etc.). See Torppa (Reference Note 3, Appendix 1) for the musical activity questions (<https://helda.helsinki.fi/bitstream/handle/10138/157046/Pitch-re.pdf;sequence=1>).

Parents also indicated how often they (1) read, (2) sang, and (3) engaged in other activities such as sports or handicrafts with their child using Likert scales (0 = never up to 5 = more than 3 to 4 times per week). Furthermore, parents indicated their level of education, their child's attendance in speech therapy, type of school education or daycare, and communication mode.

Participants

Children With CIs • The 21 participating children with unilateral CIs (9 male, 12 female) were aged 5 to 13 years when language skills and perception of prosodic stress were tested. All of them also participated in the study by Torppa et al. 2012, 2014a, b; Torppa, Reference Note 3), and the data for the present study were collected at the second time point of the studies by Torppa et al. 2014a, b; Torppa (Reference Note 3). They were native speakers of Finnish, and used primarily oral communication. According to the parents' answers in a background questionnaire, on average, the children signed less than once per week and their parents signed once per week. The children were in mainstream school or daycare and received standard speech and language therapy. The details of the participants are presented in Appendix A (supplementary material, Supplemental Digital Content 1, <http://links.lww.com/EANDH/A566>). The details of CI devices, aided thresholds, and dynamic ranges of the CI devices as fitted are shown in Torppa et al. (2012). Inclusion criteria were: early implant activation (before 3 years 1 month), no diagnosed additional developmental or linguistic

problems, and more than seven CI electrodes in use. All children had full insertion of the electrode array. Their thresholds of unaided hearing in the nonimplanted ear were too high to allow them to detect the free-field stimuli used in the present study without the CI.

To study whether supervised musical activities predicted language skills, we categorized the CI children as musically active or nonactive using reports from the parental questionnaires (Torppa et al. 2014a). Children were considered musically active when the following criteria were met: participation in music or dance for more than 1 year, and engagement in musical activities involving singing. Eight children with CIs fulfilled these criteria and were hence called CIm children. The other CI children (CIn children, $n = 13$) engaged in nonmusical activities 1 to 2 times a week, which matched the frequency of musical activities in the CIm children. Analysis of variance (ANOVA) and analysis of covariances (ANCOVAs) (age controlled) showed that CIm and CIn children did not differ in age, duration of implant use, age at switch-on, aided thresholds, dynamic range of fittings, or nonverbal intelligence (block design subtest of Wechsler Intelligence Scale for Children (WISC)-IV, Wechsler 2010). Chi-square tests confirmed that they did not differ in gender, coding strategy, or device type (MED-EL, Cochlear) (Torppa et al. 2014a; Torppa, Reference Note 3). Maternal education was higher in CIm children (Fisher exact test, two-sided $p = 0.008$), and they engaged more in informal musical activities at home than CIn children (Torppa et al. 2014a; Torppa, Reference Note 3). For example, parents of CIm children sang more often for their children than parents of CIn children (ANCOVA, age controlled, $F_{1,18} = 9.93$, $p = 0.006$).

Children With NH • The 31 NH children (14 male, 17 female) were aged 5 to 13 years when language skills and perception of prosodic stress were tested. They were all native speakers of Finnish. None had any diagnosed developmental or linguistic problems and all had NH, as confirmed by child welfare clinics. The details of the participants are presented in Appendix A.

For studying the possible predictors of language skills, we included all NH children in the analysis, and designated them the NH_{all} group. Children in the NH_{all} group were also categorized as musically active (NHm, $n = 16$) or minimally/nonactive (NHn, $n = 15$) based on parental questionnaires, and were matched on the group level by age and gender (Appendix A).

Musically active children had been undergoing weekly individual or group music training such as music play school (Linnavalli et al. 2018), Lindfors Foundation speech-music groups or school classes with an emphasis on music for a minimum of 12 consecutive months in the case of preschoolers or 3 years for school-aged children older than 7 years. These criteria are similar to those used by Strait et al. (2012, 2014), and for the school-aged children with NH, were more strict than the criteria for children with CIs. As shown in Appendix A the duration of musical activities was longer for the NHm children (and thus for the NH_{all} group) than for the CIm children and the CI group. Few Finnish children with CIs are able to attend long-term music activities because the criteria for acceptance to affordable state-supported music education are based on tasks where good pitch perception is required. Therefore, it was impossible to use the same criteria for CIm versus CIn classification as for NHm versus NHn classification. Although the style of training varied across musically active children (Appendix A), all training included singing and all but 2 children were attending training at the time of testing. These children had discontinued

musical training just before the present study began. Eight NHn children had received some short term music instruction (Appendix A). In general, NHn children participated in activities other than music 1 to 2 times a week. Maternal education was slightly higher in NHm children (Fisher exact test, two-sided $p = 0.066$) and they engaged in more musical activity at home (Torppa et al. 2014a; Torppa, Reference Note 3) than NHn children (ANCOVA, age controlled, $F_{1,28} = 7.18$, $p = 0.012$), although these activities did not include more parental singing.

Because the musically active NHm children and NH_{all} group were more involved in musical activities than the CIm children and CI group, a subset of 21 NH children were selected as individual matches to the CI children, based on musical activity, age, and gender. This matched group is termed the NH_{control} group, and marked as Con in Appendix A. They participated in the studies by Torppa et al. (2012, 2014a, b; Torppa, Reference Note 3) and the data for the present study were collected at the second time point of the studies by Torppa et al. (2014a, b), Torppa (Reference Note 3). The data from the rest of the NH children was not used in the previous studies.

General Procedure

Every child took part in two test sessions in which tests were administered in random order. One session, lasting about 1 hr, included the WISC-IV Vocabulary subtest as a measure of VIQ, and the block design subtest as a measure of nonverbal or performance intelligence quotient (PIQ) (Wechsler 2010). The other session, lasting around 2 hr (with breaks, juice, and biscuits), included assessment of verbal working memory using forward digit span (Illinois Test of Psycholinguistic Abilities [ITPA]; Kirk et al., Reference Note 1), perception of word and sentence stress, and production of rhymes. It further included the Word Finding test (Tuovinen et al. 2007) for all children with NH and 15 children with CIs. Word finding abilities of the remaining 6 children with CIs were tested on another day in the CI clinic.

Word finding, VIQ, PIQ, and forward digit span measures were made in a quiet test room. For these tasks, live voice stimuli and instructions were presented close (approximately 100 cm) to the children, and face-to-face to allow lipreading. Perception of prosodic stress was assessed in an audiometry room for all children with CIs and those children with NH who could travel to the laboratory. The remaining NH children were tested in a quiet room at their home, where the experimenter ensured that the room acoustics were suitable and the environment was sufficiently quiet. For perception of prosodic stress, sounds were delivered through two-powered loudspeakers (Edirol MA-15D) placed at a 45° angle to each side of the subject, and 70 cm from the ear. Sounds were presented at a fixed and comfortable level (60 dBA for all children with NH and 70 dBA for the CI group) as measured from the ear cantus. In the CI group, the everyday settings of the CI were used, with program, volume, and sensitivity level adjusted to the clinically recommended values. Because it was expected that not all of these young participants would be able to control the computer mouse accurately, the experimenter registered the answers.

Experimental Details and Tests

Word Finding Test • In the standardized Word Finding test (Tuovinen et al. 2007), children were asked to name pictures presented on a computer screen, including nouns (e.g., “beard”),

verbs (e.g., “juggling”), and category words (e.g., “fruit” for pictured apples, grapes, and bananas). They were also asked to complete the final word in spoken sentences (e.g., On your cake you blow out your birthday—“candles”). All items are of high familiarity and expected to be in the receptive vocabulary of all the children. The test included 36 picture and 4 sentence trials for children aged 4 to 7 years; 70 picture and 12 sentence trials for children aged 8 years and older. Two timing sounds were presented 4 and 11 sec after onset of the picture or after the sentence items had been spoken by the experimenter. Any response after 11 sec was discarded. Naming errors were classified as semantic or phonological according to the test manual. Mispronounced phonemes were not counted as phonological errors if they were consistently mispronounced by the child and if the target word was intelligible (see e.g., Wechsler-Kashi et al. 2014 for a similar procedure in a word fluency task). One 5-year-old child with CI misarticulated such a high number of phonemes that classification of phonological errors was dropped. If the child could not name the word, his/her understanding of the concept was tested (in 26 NH and 15 CI children). Misunderstanding of concepts was rare; 1.02% in NH and 2.85% in CI children. On this basis, it was concluded that in both groups, the test measured word finding skills rather than vocabulary.

WISC-IV Vocabulary Subtest • In the standardized vocabulary subtest of the WISC-IV (Wechsler 2010), children orally defined words uttered by the examiner, without time restriction. There are 35 items that the child has to produce or describe. The first four items are supported by a picture to be named and the remaining words, without pictorial support, ranging from concrete and frequent (e.g., sock) to rare and abstract (e.g., democracy).

PA Test • The PA test required production of real words rhyming (onset rhyme) with words spoken by the experimenter (10 items), without time restrictions. For example, tell me a real word rhyming with “kukka” (flower), the right answer being “sukka” (sock) (Mäkinen 2003) (for similar tasks in children with NH, see Bradley & Bryant 1983; in children with CIs, Wachtlin et al. 2017).

Prosodic Word and Sentence Stress • Two computer-based tests were developed based on English materials by O’Halpin (Reference Note 2) (these tasks have been used in Torppa et al. 2010, 2014a, and Torppa, Reference Note 3). In both tests, children were presented with auditory stimuli that varied either in word or sentence stress. Stimuli were recorded in a sound studio from four speakers: an adult male, an adult female, a female child of 7 years, and a female child of 10 years. The words in the spoken utterances were same for each stress position; however, the speakers varied the stress position in compound words/phrases and three-word utterances. The first author chose the stimuli from several recorded alternatives to ensure that the stress patterns were audible. In the word stress task, children were asked to point to a picture corresponding to the compound word or phrase they had heard. In Finnish as in British English, the stress placement changes the meaning and the alternatives were shown pictorially. Thus the children pointed to picture representing “KISSankello” (a flower) or “KISSan KELlo” (an important bell) (English translation /BLUEbell/ or /BLUE BELL/; two-alternative forced-choice task; see also Vogel & Raimy 2002; Hausen et al. 2013). In the sentence stress task, children heard sentences with three content words, one of which was prosodically stressed, e.g., “POIKA maala veneen” versus “Poika

MAALAA veneen” versus “Poika maala VENEEN” (translated as /The BOY paints the boat/ versus /The boy PAINTS the boat/, versus /The boy paints the BOAT/, see also Wells et al. 2004). The task of the children was to point to the picture representing “the most important word” in the utterance (three-alternative forced-choice task). Each test included 48 items, but the word stress task was reduced to 36 items for children younger than 6 years (the utterances of the 10-year-old child were not used, see Torppa et al. 2014a). Before testing, children were familiarized with the tasks and pictures by the parents, who received the materials in advance. Parents kept a simple diary to confirm that they had practiced the vocabulary beforehand. Before testing, the experimenter checked the child’s understanding of the task and the materials. One repetition of each spoken stimulus was allowed.

Preliminary age-controlled partial correlation analyses showed that scores in the word and sentence stress tasks correlated significantly with each other, both in the CI and NH_{all} group (CI: $r_p = 0.712, p < 0.001$; NH_{all}: $r_p = 0.674, p < 0.001$), allowing us to combine these scores into a single measure. This entailed a z -transformation of the scores for each task separately to normalize the proportion correct scores. Then, z scores of the word and sentence stress task were averaged for each participant to form a composite score of prosodic stress perception that was used in all further statistical analyses.

WISC-IV Block Design Subtest • In the block design subtest of the WISC-IV (Wechsler 2010), a measure for PIQ, children reproduced abstract geometric patterns using colored plastic cubes.

ITPA Forward Digit Span Subtest • The forward digit span was measured following the ITPA (Kirk et al., Reference Note 1). Children repeated increasingly long series of spoken digitals in the original order.

Statistical Analyses

Before running the statistical analyses testing the hypotheses, we inspected the musical activities of the participants. The NH_{all} group had more experience of musical activities than the CI group, the duration of musical training was longer for the NH_{all} group, and only they attended school music classes with very intensive musical activities. Thus, it was not possible to use the same criteria to group NH children and those with CIs on this basis. This led to two decisions. First, for comparing children with CIs to NH children (hypotheses 1 and 2), we used the NH_{control} group, who were individually matched to the CI children with respect to music activity. Second, we ran separate analyses for the CI group and the NH_{all} group to test predictors of language skills (hypothesis 3). While this precluded tests of interactions with group, it made the interpretation of the analyses much simpler with respect to our hypotheses.

Because the groups are relatively small, it was necessary to limit the number of predictors in the regression models to obtain sufficient power. In so doing, we ran correlation analyses to assess the need to include factors which are often connected to language skills, that is, age, maternal education, nonverbal intelligence, and auditory working memory. The results are displayed in Appendix B (supplementary material, Supplemental Digital Content 2, <http://links.lww.com/EANDH/A567>). For the NH_{all} group, significant correlations were found between age and PA, and between age and several predictors. There were

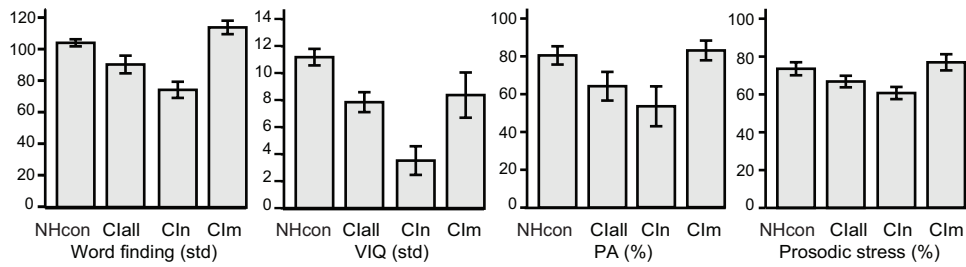


Fig. 1. Performance of the NH_{control} group (NHcon) compared with the CI group as a whole (CI_{all}), and the CI subgroups of musically nonactive children with CIs (CIn) and musically active children with CIs (CIIm) in word finding (standardized scores), VIQ, PA, and perception of prosodic stress. The error bars in this and later figures show ±1 SE of the mean. % indicates percent correct; CI, cochlear implant; NH, normal hearing; PA, phonological awareness; std, standardized scores; VIQ, verbal intelligence quotient.

no significant correlations with age in the CI group. Maternal education correlated significantly with VIQ (NH_{all} group) and musical activities in both groups, with parental reading in the NH_{all} group, and with musical activities in the CI group. Non-verbal intelligence (PIQ) correlated significantly only with parental singing and only in the NH_{all} group. Auditory working memory (digit span) correlated significantly and positively with PA (NH_{all} group), age (NH_{all} group), perception of prosody (both groups) and musical activity (CI group), and negatively with other activities than singing and reading with parents (CI group). Thus, we considered it most important that our main analyses controlled for maternal education and age.

To avoid multicollinearity in regression models for hypothesis 3, we inspected Pearson correlations between perception of prosody, musical activities, and parental activities. For the CI group, it was found that musical activities correlated strongly with perception of stress (prosody) ($p = 0.003$) and parental singing ($p = 0.002$). These factors were thus examined in separate regression analyses.

In the final statistical analyses, to test group differences (hypotheses 1 and 2), ANOVAs were run comparing the performance of the NH_{control} group against the CI group as a whole and the CIIm and the CIn groups. In addition, ANCOVAs were performed with age and maternal education as covariates. Dependent variables were, for hypothesis 1, the standardized scores for the word finding test and VIQ and % correct scores for PA (production of rhymes), and for hypothesis 2, the number of semantic or phonological errors.

To test links between generative language skills and perception of prosody, musical activities and parental activities, linear regression analyses were run separately for the CI and NH_{all} groups and separately for each three language measures and each three predictors. The standardized scores for each

individual in the Word Finding test, the WISC-IV Vocabulary subtest (verbal I.Q.), and the % correct scores for production of rhymes (PA) were used as dependent variables, and the three predictors were tested in separate regression models. According to SPSS regression diagnostics, the statistical assumptions were not violated in any of the models.

To test the role of age and maternal education in the regression analyses, both age and maternal education were entered as covariates. These were the first two factors entered, followed by the predictor(s). In general, the R^2 change was inspected to find the variance explained by the predictor(s) only. In addition, B was inspected to determine the direction of the connections and individual contribution of parental singing, reading, and other activities to explaining the dependent variables.

Regression analyses were corrected with false discovery rate correction for multiple comparisons, to avoid type 1 errors (Benjamini & Yekutieli 2001). This was preferred over Bonferroni correction which is very conservative. The critical level for significance was otherwise 0.05 and all statistical analyses were carried out with IBM SPSS 24 software.

RESULTS

Comparing Language Skills and Perception of Prosody of CI Groups Against Matched NH Controls

Figure 1 depicts the performance of the CI group as a whole, and the CIIm and CIn groups, compared with the matched NH_{control} group (see hypotheses 1 and 2), in the three generative language tasks and in the perception of prosodic stress.

ANOVAs showed that children with CIs performed more poorly than matched controls in word finding and VIQ (word finding, $F_{1,39} = 5.32, p = 0.026$; VIQ, $F_{1,40} = 12.10, p = 0.001$), while the difference between groups did not reach significance

TABLE 1. The error types in the word finding task for NH_{control} group (NH control), CI group (CI), and musically nonactive and active children with CIs (CIn and CIIm children)

| | NH Control | | CI | | CIn | | CIIm | |
|------|------------|------|------|-------|------|-------|------|------|
| | Phon | Sem | Phon | Sem | Phon | Sem | Phon | Sem |
| N | 21 | 21 | 19* | 20 | 7 | 8 | 12 | 12 |
| Min | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 0 |
| Max | 1 | 17 | 4 | 25 | 4 | 25 | 1 | 11 |
| Mean | 0.05 | 7.55 | 1.32 | 10.55 | 1.92 | 13.50 | 0.29 | 6.13 |
| SD | 0.22 | 4.35 | 1.57 | 6.80 | 1.00 | 6.79 | 0.49 | 3.98 |

*The phonological errors of one 5-yr-old CIIm child were not estimated due to misarticulations.

CI, cochlear implant; N, number of children who participated in the task; phon, number of phonological errors; sem, number of semantic errors.

TABLE 2. Results of regression analyses for the CI group

| | Word Finding | | | | VIQ | | | | PA | | | | | | |
|----------|--------------|--------|-------------------|----------------|---------|-------|--------------|-------------------|----------------|---------|--------------|--------|-------------------|----------------|---------|
| | B | p | R ² /B | R ² | p Model | B | p | R ² /B | R ² | p Model | B | p | R ² /B | R ² | p Model |
| Model 1 | | | | | | | | | | | | | | | |
| Prosody | 0.562 | 0.010 | 0.315 | 0.010* | 0.475 | 0.030 | 0.225 | 0.030* | 0.546 | 0.016 | 0.298 | 0.016* | | | |
| Music | 0.790 | <0.001 | 0.625 | <0.001* | 0.510 | 0.018 | 0.260 | 0.018* | 0.443 | 0.058 | 0.196 | 0.058 | | | |
| Parental | | 0.001 | 0.612 | 0.001* | | | 0.458 | 0.013* | | | 0.411 | 0.170 | 0.170 | 0.411 | |
| Reading | 0.430 | 0.019 | | | 0.247 | 0.217 | | | 0.282 | 0.321 | | | | | |
| Singing | 0.580 | 0.002 | | | 0.586 | 0.006 | | | 0.167 | 0.551 | | | | | |
| Other | -0.220 | 0.191 | | | -0.234 | 0.231 | | | -0.253 | 0.314 | | | | | |
| Model 2 | | | | | | | | | | | | | | | |
| Prosody | 0.589 | 0.011 | 0.323 | 0.036 | 0.595 | 0.006 | 0.317 | 0.010* | 0.534 | 0.032 | 0.276 | 0.140 | | | |
| Music | 0.808 | <0.001 | 0.527 | 0.002* | 0.479 | 0.049 | 0.180 | 0.061 | 0.637 | 0.017 | 0.330 | 0.083 | | | |
| Parental | | 0.022 | 0.458 | 0.038 | | | 0.132 | 0.108 | | | 0.168 | 0.320 | 0.320 | 0.311 | |
| Reading | 0.430 | 0.061 | | | 0.148 | 0.521 | | | 0.549 | 0.102 | | | | | |
| Singing | 0.617 | 0.009 | | | 0.508 | 0.036 | | | 0.240 | 0.425 | | | | | |
| Other | -0.227 | 0.263 | | | -0.254 | 0.252 | | | -0.202 | 0.421 | | | | | |

Separate analyses were run with prosody, music and parental activities as predictors. Model 1: no covariates. Model 2: age and maternal education treated as covariates. R² = R² change (i.e., variance explained by the predictor(s)). B = standardized coefficients. p R²/B = the significance of the R² change, and in the parental model, also the significance of B. p Model = the significance of the regression model. Bold font denotes significant explanation of variance in the respective language task.

*The model was significant after false discovery rate correction for multiple comparisons (Benjamini & Yekutieli 2001).

CI, cochlear implant; music, musically active (CIm) vs. nonactive (CI_n) children; parental, parental activities; prosody, prosodic stress perception.

for PA ($F_{1,37} = 3.35, p = 0.075$), or for perception of prosodic stress ($F_{1,40} = 2.05, p = 0.160$). When age and maternal education was controlled in ANCOVAs, only the difference in VIQ between CI and NH_{control} groups remained significant (word finding, $F_{1,36} = 3.30, p = 0.078$; VIQ, $F_{1,37} = 8.86, p = 0.005$; PA, $F_{1,34} = 3.27, p = 0.080$; prosodic stress, $F_{1,37} = 1.50, p = 0.229$).

In line with hypothesis 1 and Figure 1, the language skill and prosodic stress perception deficits were evident only in the children with CIs who were not musically active. ANOVAs (statistics given first) and ANCOVAs (with age and maternal education as covariate, statistics given after those for the ANOVA) showed that the performance of CIm children exceeded that of the NH_{control} group in word finding ($F_{1,27} = 4.97, p = 0.034$; $F_{1,26} = 4.97, p = 0.035$), while performance between these two groups did not differ in VIQ ($F_{1,28} = 2.43, p = 0.130$; $F_{1,26} = 2.71, p = 0.112$), in PA ($F_{1,25} = 0.72, p = 0.791, \eta_p^2 = 0.047$; $F_{1,23} = 1.13, p = 0.298, \eta_p^2 =$

0.003), or in perception of prosodic stress ($F_{1,27} = 0.48, p = 0.496$; $F_{1,25} = 3.54, p = 0.072$). However, CI children who were not musically active (CI_n) performed more poorly than NH_{control} in all tasks (word finding: $F_{1,31} = 36.88, p < 0.001$; $F_{1,28} = 27.54, p < 0.001$; VIQ: $F_{1,32} = 22.56, p < 0.001$; $F_{1,29} = 14.57, p = 0.001$; PA: $F_{1,30} = 7.05, p = 0.013, \eta_p^2 = 0.190$; $F_{1,27} = 13.89, p = 0.001, \eta_p^2 = 0.340$; prosodic stress: $F_{1,32} = 6.93, p = 0.013$; $F_{1,29} = 12.74, p = 0.001$).

In contrast with our hypothesis 2, as shown in Table 1, the CI group made more phonological errors in word finding (based on raw scores) than their controls ($F_{1,37} = 23.05, p < 0.001$; $F_{1,34} = 19.79, p \leq 0.001$), while no group differences were found for semantic errors ($p = 0.105$; $p = 0.122$). Because the results earlier indicated that only musically nonactive children with CIs had word finding problems, we also compared the errors of CI_n and CIm children to the NH_{control} group (Table 1). The CI_n group made more semantic and phonological errors than the NH_{control}

TABLE 3. Results of regression analyses for the NH_{all} group

| | Word Finding | | | | VIQ | | | | PA | | | | | | |
|----------|--------------|-------|-------------------|----------------|---------|-------|--------------|-------------------|----------------|---------|--------------|--------|-------------------|----------------|---------|
| | B | p | R ² /B | R ² | p Model | B | p | R ² /B | R ² | p Model | B | p | R ² /B | R ² | p Model |
| Model 1 | | | | | | | | | | | | | | | |
| Prosody | 0.413 | 0.021 | 0.171 | 0.021* | 0.428 | 0.016 | 0.183 | 0.016* | 0.441 | 0.015 | 0.195 | 0.015* | | | |
| Music | 0.513 | 0.003 | 0.263 | 0.003* | 0.419 | 0.019 | 0.176 | 0.019* | 0.200 | 0.289 | 0.040 | 0.289 | | | |
| Parental | | 0.051 | 0.344 | 0.051 | | | 0.220 | 0.213 | 0.220 | | 0.613 | 0.098 | 0.613 | | |
| Reading | -0.234 | 0.334 | | | 0.166 | 0.529 | | | 0.012 | 0.967 | | | | | |
| Singing | 0.499 | 0.042 | | | 0.333 | 0.199 | | | -0.208 | 0.458 | | | | | |
| Other | -0.521 | 0.045 | | | -0.557 | 0.050 | | | -0.161 | 0.601 | | | | | |
| Model 2 | | | | | | | | | | | | | | | |
| Prosody | 0.352 | 0.144 | 0.065 | 0.071 | 0.549 | 0.012 | 0.158 | 0.002* | 0.104 | 0.624 | 0.006 | 0.018* | | | |
| Music | 0.492 | 0.007 | 0.201 | 0.006* | 0.268 | 0.135 | 0.060 | 0.015* | 0.248 | 0.166 | 0.050 | 0.008* | | | |
| Parental | | 0.237 | 0.179 | 0.129 | | | 0.735 | 0.052 | 0.173 | | 0.818 | 0.045 | 0.377 | | |
| Reading | -0.119 | 0.665 | | | 0.201 | 0.477 | | | 0.179 | 0.564 | | | | | |
| Singing | 0.522 | 0.066 | | | 0.165 | 0.551 | | | -0.212 | 0.486 | | | | | |
| Other | -0.406 | 0.177 | | | -0.279 | 0.358 | | | 0.133 | 0.698 | | | | | |

Separate analyses were run with prosody, music, and parental activities as predictors. R² = R² change (i.e., variance explained by the predictor(s)). B = standardized coefficients. p R²/B = the significance of the R² change, and in the parental model, also the significance of B. p Model = the significance of the regression model. Bold font denotes significant explanation of variance in the respective language task. *The model was significant after false discovery rate correction for multiple comparisons (Benjamini & Yekutieli 2001).

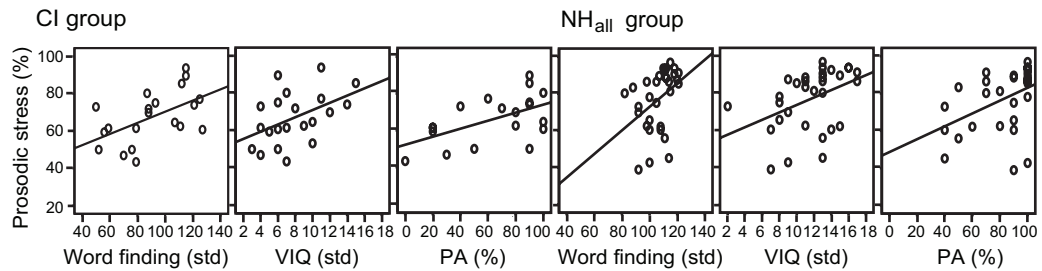


Fig. 2. Significant connections between perception of prosodic stress and generative language skills found in the regression analyses without control for age and maternal education. The left three panels refer to children with CIs; the right three panels refer to the NH_{all} group. % indicates percent correct; CI, cochlear implant; NH, normal hearing; PA, phonological awareness; std, standardized scores; VIQ, verbal intelligence quotient.

group (semantic, $F_{1,30} = 9.20, p = 0.005$; $F_{1,27} = 9.63, p = 0.004$; phonological, $F_{1,28} = 15.67, p < 0.001$; $F_{1,27} = 48.45, p < 0.001$) while the differences between the CI_m and NH_{control} groups were not significant for semantic errors (ANOVA: $p = 0.430$, ANCOVA: $p = 0.549$) or for phonological errors in the ANOVA ($p = 0.174$), although the ANCOVA indicated more phonological errors in the CI_m children ($F_{1,23} = 4.44, p = 0.046$).

Predicting Generative Language Skills in Children With CIs and NH

Tables 2 and 3 give an overview of links between the predictor variables (prosodic stress perception, musical and parental activities) and language skills in the CI and NH_{all} group (see hypothesis 3). Musical activity was coded as binary predictor variable (8 CI_m, 16 NH_m, 13 CI_n and 15 NH_n children; see Materials and Methods and Appendix A).

Predictor 1: Prosodic Stress Perception

Results are shown in Figure 2 and Table 2 for the CI group and Figure 2 and Table 3 for the NH_{all} group.

Model 1 (Uncontrolled) • For both CI and NH_{all} groups, a positive B indicated that performance in all language tasks increased with better perception of prosodic stress (see also Fig. 2). Significant R^2 changes indicated that prosodic stress perception alone explained 32% of the variance in word finding in the CI group and 17% in the NH group. Prosodic perception also explained significant variance in VIQ (23% in the CI group and 18% in the NH group) and in PA (30% for the CI group and 20% in the NH group).

Model 2 (Age and Maternal Education Controlled) • In the CI group, model 2 was significant only for VIQ after statistical correction, and here prosodic stress perception alone explained

32% of the variance. In the NH_{all} group, the model survived statistical correction only for VIQ, where R^2 change indicated that prosodic stress perception explained 16% of variance in this skill (Table 3).

Summary • For both CI and NH_{all} groups, language skills improved with better perception of prosodic stress. This effect was significant in all cases in the absence of control for age and maternal education. In both groups, the link of perception of prosodic stress to VIQ was strong and survived control for age and maternal education. Perception of stress always explained more variation in the CI group than in the NH_{all} group.

Predictor 2: Musical Activity (Music)

For the CI group, significant results for musical activity as a binary predictor variable in regression analysis are shown in Table 2 and illustrated in Figure 3. Corresponding significant results for the NH_{all} group are shown in Table 3 and illustrated in Figure 3.

Model 1 (Uncontrolled) • For both CI and NH_{all} groups, positive B indicated that performance in all language tasks was better in the musically active children. Significant R^2 changes indicated that musical activity alone explained 63%(CI)/26%(NH_{all}) of the variance in word finding, and 26%(CI)/18%(NH_{all}) in VIQ, and these models survived statistical correction. For PA, R^2 change and the model were not significant in either group.

Model 2 (Age and Maternal Education Controlled) • For both CI and NH_{all} groups, when age and maternal education were controlled, B for the musical activity predictor remained positive for all language skills. Significant R^2 changes indicated that musical activity alone explained 53%(CI)/20%(NH_{all}) of variance in word finding, 18% in VIQ (CI only), and 33% in PA

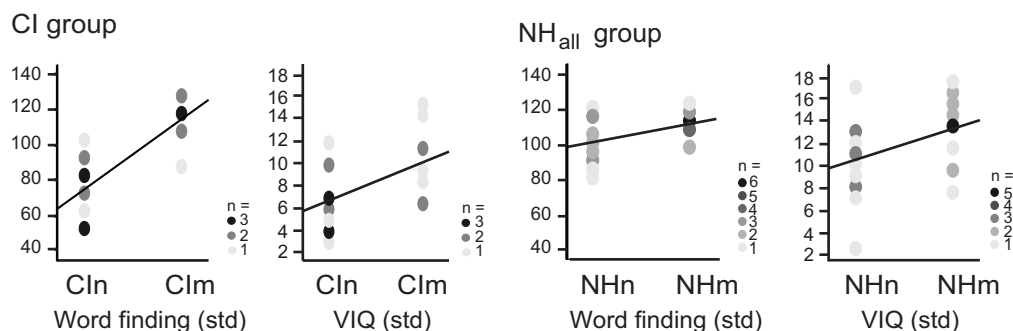


Fig. 3. Significant connections between musical activities (coded as a binary variable) and language skills found in the regression analyses without control for age and maternal education. The left two panels refer to children with CIs; the right two panels refer to the NH_{all} group. n = the number of participants represented with the circle (the darker the color, the more participants have similar std scores). CI indicates cochlear implant; NH, normal hearing; CI_m/NH_m, musically active children with CIs/NH; CI_n/NH_n, musically nonactive children with CIs/NH; std, standardized scores; VIQ, verbal intelligence quotient.

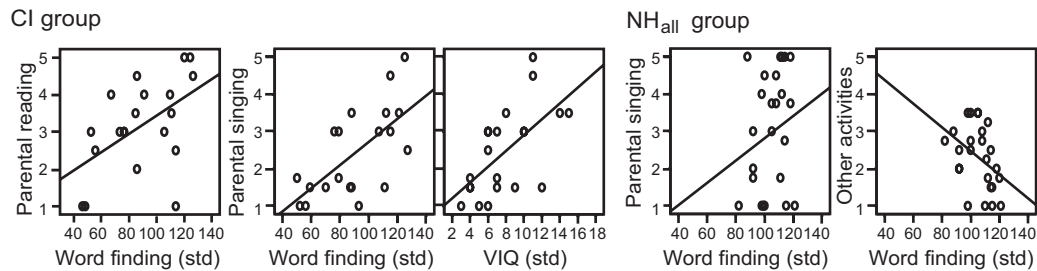


Fig. 4. Significant connections between different parental activities and language skills found in the regression analyses without control for age and maternal education. The left three panels refer to children with CIs; the right two panels refer to the NH_{all} group. The choice of illustrations was based on the significant *B* values presented in Tables 2 and 3. % indicates percent correct; CI, cochlear implant; NH, normal hearing; std, standardized score; VIQ, verbal intelligence quotient.

(CI only). From these models, only the model for word finding survived statistical correction.

Summary • For both CI and NH_{all} groups, language skills improved with musical activity, which explained significant variation in word finding and VIQ (but not PA) in model 1. The link to word finding remained significant after controlling for age and maternal education. Musical activity explained more variation in the CI group than in the NH_{all} group.

Predictor 3: Parental Activities

Results for regression analysis are shown in Figure 4 and Table 2 for the CI group and Figure 4 and Table 3 for the NH_{all} group. Figure 4 illustrates all significant connections between different parental activities and language skills without control for age and maternal education. The choice of illustrations was based on the significant *B* values presented in Tables 2 and 3. Table 4 gives an overview over parental activities.

Model 1 (Uncontrolled) • Links between language skills and parental reading and singing were always positive and links between language skills and other parental activities were always negative. Significant *R*² changes indicated that altogether, parental activities explained 61% of the variance in word finding, and 46% in VIQ in the CI group. These regression models were significant and survived statistical correction. Word finding performance increased with more parental reading ($p = 0.019$) and singing ($p = 0.002$), and parental singing was also positively linked to VIQ ($p = 0.006$).

For the NH group, *R*² change and the regression model approached significance ($p = 0.051$) only for word finding which was also the strongest link in the CI group. But the model did not survive statistical correction.

Model 2 (Age and Maternal Education Controlled) • For the CI group, *B* indicated similar directions of links to parental

activities as in model 1. Positive links were found to parental singing (word finding, $p = 0.009$; VIQ, $p = 0.036$). For word finding only, the *R*² change due to parental activities as a whole was significant, suggesting that these alone explained 46% of variation in word finding. However, the model did not survive correction. For the NH_{all} group, no significant results were found.

Summary • For the CI group, the strongest separate predictor was parental singing, for which the links to word finding and VIQ remained significant after controlling for age and maternal education. In the noncontrolled models, parental activities as a whole were also significantly linked to word finding and VIQ after statistical correction.

DISCUSSION

Reasons for the variable outcome of language rehabilitation in children with CIs are still not fully understood (see Introduction and Moberly et al. 2016) and often children with CIs exhibit poorer language skills than their NH peers. The present study identified three predictors that shared significant variance with the generative language skills of children with CIs (and to a lesser extent in children with NH), giving a baseline for further scientific studies and suggesting effective tools for parents and therapists to help children with CIs acquire oral language. Language performance increased with better perception of prosodic stress and more musical activity in both groups, and especially in the CI group, with more parental activities (parental reading and singing).

For the children with CIs, when age and maternal education were not controlled, language skills shared significant variance with the perception of prosodic stress, 23 to 32% (all 3 language skills); with supervised musical activities, 26 to 63% (all 3 language skills); with parental activities, 46 to 61% (VIQ and word

TABLE 4. Parental activities in CI and NH_{all} group

| | CI Group | | | NH _{all} Group | | |
|------|---------------|---------------|-------------|-------------------------|---------------|-------------|
| | Reading (Raw) | Singing (Raw) | Other (Raw) | Reading (Raw) | Singing (Raw) | Other (Raw) |
| N | 21 | 21 | 21 | 28 | 25 | 25 |
| Min | 1.00 | 1.00 | 1.00 | 0.00 | 0.50 | 1.00 |
| Max | 5.00 | 5.00 | 4.50 | 5.00 | 5.00 | 3.50 |
| Mean | 3.24 | 2.45 | 2.55 | 3.23 | 2.95 | 2.31 |
| SD | 1.27 | 1.17 | 0.97 | 1.44 | 1.63 | 0.85 |

Raw = raw values from Likert scales with: 0 = never, 1 = sometimes, 2 = every other week, 3 = 1–2 times per week, 4 = 3–4 times per week, 5 = more often. N = number of parents who gave information.

CI, cochlear implant; NH, normal hearing.

finding). When age and maternal education were controlled, these links and the regression models became weaker but the direction of links was preserved, and variances explained by these predictors alone remained significant (except for the overall measure of parental activity). For children with NH, the links of word finding and VIQ to prosody and musical activities were similar to, although weaker than, those found for the children with CIs. In both groups, when age and maternal education were controlled, the strongest, significant links were found between perception of prosodic stress and VIQ, and between musical activity and word finding. As for parental activities, the strongest connections were found to parental singing. Correlation analyses further showed that word finding was connected to VIQ in both groups, and to PA for the children with CIs. Our discussion will focus mainly on children with CIs; however, the results are also important for children with NH.

Perception of Prosodic Stress Is Linked With Generative Language Skills

In children with CIs, the high amount of variance in generative language skills shared with the perception of prosodic stress alone is in line with former results from NH children, showing better language learning in children who are better at perceiving or producing word stress (Friedrich et al. 2009; Cumming et al. 2015). Our findings are also consistent with the facilitatory effects of child-directed speech and sentence stress in word and language learning (child-directed speech: Ma et al. 2011; Estes & Hurley 2013; sentence stress: Cutler & Foss 1977; Männel & Friederici 2013; Filippi et al. 2014; see also Introduction). Furthermore, the present results are in line with findings in children with CIs aged 8 to 10 years, where Carter et al. (2002) showed that better imitation of word stress patterns in nonwords is connected to better language skills (in tasks measuring word identification, receptive vocabulary, morphology and syntax, and speech intelligibility).

The strong link between VIQ and perception of prosody in both children with CIs and NH is in line with previous results, suggesting facilitatory effects of prosodic perception for many aspects of language learning. It is clear that the present word finding task covers a narrower range of language skills than the task for VIQ because the word finding concepts were familiar and production of only one word was required, while the task for VIQ required good vocabulary knowledge and sentence generation. Notably, previous research has shown that perception of stress plays a role in sentence comprehension (Cutler & Foss 1977) and in recovering syntactic information and phrasal boundaries (Soderstrom et al. 2003).

The finding that perception of prosodic stress explained more variance in the language skills of children with CIs than those with NH can be related to the greater range of prosodic perception abilities and language skills in the CI children. It is also consistent with findings that stress cues become particularly important in word segmentation (Mattys et al. 2005) when listeners cannot properly hear phonotactic or acoustic-phonetic cues in the speech signal, as is the case for children with CIs (Geers et al. 2003; Donaldson & Krefl 2006; Johnson & Goswami 2010; Moberly et al. 2016; Soleymani et al. 2016). The development of segmentation skills is crucial for language learning (Newman et al. 2006). Thus, our results indicate that perception of prosodic stress may be even more important for oral language learning of children with CIs than for children with NH.

Musical Activity of Children Is Linked With Language Skills: The Role of Singing

Participation in supervised musical activities (including singing) shared a high proportion of variance with all three generative language skills in children with CIs. Even though the results for PA were not significant in the regression analysis, group comparisons (ANOVA and ANCOVA results for testing hypothesis 1) and Figure 1 clearly shows that the performance of musically nonactive children with CIs was poorer than in NH controls (effect sizes ranged from 0.19 to 0.34 without and with covariates, respectively), which was not the case for children with CIs who were musically active (differences to NH controls not significant, effect sizes from 0.003 to 0.047). In general, the strong links to word finding and VIQ in the regression models are consistent with the group comparisons, showing higher performance of musically active compared with nonactive children with CIs in all language tasks. Links to musical activity were similar, but weaker, for word finding and VIQ in children with NH.

The results are in line with previous reports showing better speech and language skills in children engaging in musical activities (CI: Torppa et al. 2014a; NH: Dittinger et al. 2017; see Introduction), and with controlled follow-up studies showing that when contrasted with other activities, only musical training (with singing) improves language skills, including PA and VIQ (Chobert et al. 2014; Flaunacco et al. 2015; Gordon et al. 2015; Patscheke et al. 2016; VIQ: Jaschke et al. 2018; Linnavalli et al. 2018; see Introduction). The children in the present study participated in similar musical play school activities as those in the study by Linnavalli et al. (2018), providing converging evidence for language benefits of musical activities with singing. Moreover, mainly pitch-based (rather than rhythm-based) musical training, and training that involves singing activities, as in the present study, has been found to improve PA (Patscheke et al. 2018), in line with the present results.

A notable novel finding is that musical activity with singing was strongly connected to word finding in both children with CIs and NH, and these links survived control for age and maternal education. For the children with CIs, one reason for this might be the superior performance of musically active children with CIs in the perception of prosodic stress (see Torppa et al. 2014a, b and Fig. 1). In our 2014 study and in the present study, musically active children with CIs performed similarly to NH children in the perception of prosodic stress, while other children with CIs performed more poorly than NH peers. This observation echoes the present results for word finding.

We predicted that compared with children with NH, children with CIs would make more phonetic and semantic errors due to difficulties in identifying the phonemic content of words as a consequence of their problems in hearing. Compared with NH controls, only musically nonactive children with CIs made more phonemic and semantic errors and performed more poorly in PA, while word finding was strongly connected to PA in children with CIs. Thus, it is possible that in musically active children, good perception of prosodic stress leads to good phonemic representations of words and further, to good word finding. We speculate that this can be related to findings on speech rhythm, induced with the chain of word stresses. The oscillatory activity of the auditory cortex can be locked to both speech and to musical rhythm, leading to enhanced attention at moments when the strong musical beat or speech stress is expected, further

leading to better perception (Cutler & Foss 1977; Mattys 1997; Bolger et al. 2014; Schön & Tillmann 2015; for children with CIs, Holt et al. 2016). The rhythmic predictability of songs, which is especially strong in children's songs, may increase this effect (Bolger et al. 2014; Schön & Tillmann 2015) and lead to improved buildup of stable phonological representations. The multisensory context of singing by oneself may further enhance the sensitivity to changes in lyrics at predictable moments (for a review, see Torppa et al. 2018). Moreover, slower word rate, lengthened syllables, and more frequent repetitions in song than speech may give children more time to process words and phonemes and form phonological representations (Fisher & McDonald 2001; Patel 2014).

Phonological errors can also reflect temporary failure to correctly access a familiar word in production (German & Newman 2004; Newman et al. 2018). Because singing is typically an activity during which children repeat lyrics over and over again, and at a slow tempo (Patel 2014), the child's own slow and repetitive singing may improve the buildup and activation of motor programs for target words, and through this, the access to word production (Levelt 1989; Newman & German 2002; German & Newman 2004; Messer & Dockrell 2006). Compared with children with NH, children with CIs produce canonical babble and words later, reducing their opportunities to practice speech planning and articulation at early infancy (Pettinato et al. 2017). Such delays can harm the coupling of articulatory representations to the auditory speech signal and to multimodal representations of words. Multimodal (motoric and auditory) representations of words are thought to be important for retrieving the phonological codes of words (Dittinger et al. 2018). In line with this, overt rehearsal (repeating aloud) of speech facilitates the learning of phonological sequences related to words in a second language (Ylinen et al. 2015). Thus, singing may facilitate the learning of phonological codes for words in children with CIs.

The present study design cannot confirm a causal influence of musical activities on prosody perception and language skills. However, because the connections were similar for children with NH and stronger for children with CIs, they give no reason to assume that the effects of musical activities present in children with NH would not be present in the children with CIs. By contrast, the correspondence between our results and former results is in line with the idea that musical activities with singing enhance perception of prosodic stress, with positive consequences to word finding and underlying semantic and phonetic representations, plausibly also access to words at the motoric level, and through this on all the generative language skills we have measured.

Parental Reading and Singing Are Linked With Word Finding and VIQ in Children With CIs

In the uncontrolled model 1, the predictor parental activities (parental reading, singing and other activities altogether) shared 61% variance with word finding and 46% variance with VIQ in children with CIs. When age and maternal education were controlled, the link to word finding was significant only before statistical correction. However, we found no correlations of age or maternal education to word finding, so the failure to find a significant effect in the controlled model may simply be due to reduced power.

Previous studies have shown positive connections of parental activities, particularly reading, to language skills in children with NH (e.g., receptive and expressive vocabulary; meta-analysis by Mol & Bus 2011) and children with CIs (receptive vocabulary, receptive and expressive language; Sarant et al. 2014). Our finding of a positive link to reading is consistent with this, while the link to word finding is a novel finding. The present findings on parental reading were inconsistent and not significant for NH children, possibly because they can easily learn language and improve word finding through incidental learning. In contrast, children with CIs may still benefit from parental reading between the age of 5 and 13 years. Even though parental reading is important, singing could be more important because the links to parental singing were stronger, and remained significant in both word finding and VIQ even after controlling for age and maternal education, while the controlled models for overall parental activity did not survive correction.

As already discussed earlier, word finding difficulties of children with CIs may arise from sparse phonological representations of words (Levelt 1989; Newman & German 2002) that may benefit from parental singing. Here, benefits may be related to pitch patterns in songs that have been shown to facilitate infants' recognition of the phonetic content of speech (Lebedeva & Kuhl 2010). Moreover, slower word rate and more frequent repetitions in song than speech may give children more time to process words and phonemes and form phonological representations (Patel 2014). In addition, parental singing can improve perception of prosodic stress, and through this, phonological representations or language skills in general, because parental singing has been found to be associated with improved perception of word and sentence stress in children with CIs, and (to lesser extent) enhanced perception of sentence stress in children with NH (Torppa et al. 2010). Finally, parental singing encourages children with CIs to sing themselves, and this can improve perception of speech in noise and in silent situations (Torppa et al. 2018), and lead to the audio-motor benefits described earlier. In summary, singing by parents may give children with CIs additional opportunities to improve generative language skills.

We found only negative and nonsignificant connections of generative language skills to parental activities other than singing and reading. This may be due to the different use of language in these activities: Language in songs and the reading of children's books is much more predictable (Manolson 1992, pp. 87–112) than language in other activities, like sports and handicraft, giving children a framework that facilitates anticipation of what is to come. Moreover, language in song and parental reading is characterized by extended variation in pitch. When parents read for their children, they probably empathize the characters in the story and keep the interest and attention of the child by using richer prosodic variation than in conversations during sports and handicraft. These pitch variations, like those in infant-directed speech, can aid recognition of phonological representations related to word finding (Thiessen et al. 2005; Singh et al. 2009; Estes & Hurley 2013). Thus, it is plausible that parental singing and reading are more important for word finding and VIQ than other activities with parents.

Caveats and Future Directions

It should be noted that even though the musically nonactive children participated in activities outside of the home to similar

extent as the musically active children participated in music, we cannot rule out that the musically active children followed further activities, other than music. This raises the possibility that the general amount rather than specific musical content of activities accounts for the higher performance in the CI children. However, our results on parental activities as well as previous studies referred to earlier suggest that musical, not other (or more) activities (e.g., art, painting, or sports training) go along with enhanced language skills and prosody perception. For example, while physical activities are important for cognitive functions in elderly, their effects on language skills are very weak in healthy children with NH (Carson et al. 2016), and absent in children with CIs (Haukedal et al. 2018). However, more studies are needed to explore the potential benefits of activities other than music for the language skill of children with CIs.

We studied the connections of language skills to predictors with regression analyses and group comparisons; these do not provide direct evidence that manipulation of the predictive factors could improve language skills. For example, perception of stress in the tasks we used can be affected by the language skills of children (Vogel & Raimy 2002; Wells et al. 2004). However, it is possible that deficits in perceiving basic acoustic cues lead to deficits in stress perception which in turn has negative consequences on higher level language processing. Even though poor perception of pitch in adults and children with CIs appears to be mainly responsible for their typically poor perception and production of prosody, including word and sentence stress (Torppa et al. 2014a; Chatterjee et al. 2015; Holt et al. 2016; Huang et al. 2017; Pettinato et al. 2017, among others), a previous study with the current child participants (Torppa et al. 2014a) showed that both discrimination of pitch and intensity in low-level linguistic content were still connected to perception of stress. This indicates that perception of the acoustic cues for stress is important for performance in the linguistically easy prosodic tasks used in this study. In line with this, the results of Carter et al. (2002, see earlier) show connections of the accuracy of imitated stress patterns of nonlinguistic stimuli to language skills of children with CIs, indicating that the perceptual skills underlying perception of stress decrease or improve language skills. An important role for the processing of basic acoustic cues in higher level language processing is consistent with recent findings from children with specific language impairments, showing that they have deficits in the perception of auditory cues for word stress (perception of amplitude rise-time and duration) which is connected to their perception of word stress in nonsense words (Cumming et al. 2015). We speculate that it is even possible that the connections of musical activities to language skills are partially driven by perception of underlying auditory cues. For example, in the previous study (Torppa et al. 2014a, b), the musically active children with CIs outperformed other children with CIs in perception of pitch, and several studies indicate improvement in perception of pitch (or rhythm, a cue for word stress patterns) with musical training (Torppa & Huotilainen 2019). Thus, further studies should address the question whether musical activities improve perception of pitch and rhythm, and through this, perception of prosody and language skills.

Further studies are also needed to study the links of nonverbal intelligence and auditory working memory to language

skills. In the present study, nonverbal intelligence was not expected to play a role because this was not connected to generative language skills or perception of prosody and did not differ between musical activity groups. However, digit span (phonological auditory working memory) correlated significantly with PA (NH_{all} group), perception of prosody (both groups) and musical activity (CI group). Therefore, in the future, it is important to study the role of this cognitive skill for perception of prosody and language skills, especially in music training studies.

It is possible that good perceptual and language abilities would encourage children to engage in musical activities, and this would be also the reason for the superior language skills of the children who participate in musical training. However, we note that we controlled for age and parental education, giving reasons to assume that these factors did not play a role in the connections that remained significant after this control. Moreover, musical activity groups did not differ in gender, and in the CI group, were comparable in: duration of implant use, age at switch-on, aided thresholds, dynamic range of fittings, coding strategy, and device type (Torppa et al. 2014a). Because the results from well-controlled intervention studies show beneficial effects of musical activities on perceptual and language skills and in the brain in children with NH, it is possible that similar effects of music occur in children with CIs. However, randomized and controlled follow-up and intervention (RCT) studies are needed to confirm the effects of musical activities, especially singing, both by parents for their children and children themselves, on word finding and other language skills of children with CIs.

CONCLUSIONS

The present results show that supervised musical activities, with an emphasis on singing, predicted a high amount of variance in generative language skills of children with CIs, and to lesser extent, in word finding and VIQ in children with NH. Further, word finding was better in children who were musically active, and more parental singing and reading was linked to better word finding and VIQ. Nevertheless, we found that many children with CIs, and especially those who did not engage in musical activities, lagged behind children with NH in all the generative language skills we measured. Therefore, our results suggest that musical activities, especially singing to and by the children, and parental reading, should be included in the rehabilitation of children with CIs as this may improve word finding and other generative language skills.

The present results further suggest that better perception of word and sentence stress goes along with better generative language skills, especially with VIQ. Together with previous results showing links between musical activities and enhanced perception of prosodic stress and its underlying cues, the present data seem to reveal one mechanism via which musical activities may benefit the oral language skills of children with CIs. That is, musical activities may improve the perceptual skills underlying perception of stress, which extends to higher-level language skills because good perception of stress improves perception of phonemes and phonemic presentations of words. It is also possible that slow-rate singing by parents is important, or that singing aloud by the children themselves plays a role in coupling motoric and auditory

representations of phonemes, and hence access to words at the motor level, which benefits word finding and production of language.

The combined results, including the remarkable finding that musically active children with CIs performed similarly to children with NH in all language tasks, as they also do in prosody perception (Torppa et al. 2014a, b), encourage controlled intervention studies of the effects of musical activities and prosody perception on language learning in children with CIs. These activities have no foreseeable negative effects, but they may have remarkable positive effects on language skills of children with CIs and NH.

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The authors have no conflicts of interest to declare.

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NOTES

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