Spoken language and everyday functioning in 5-year-old children using hearing aids or cochlear implants

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Conflicts of interest

None were declared.

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Abstract

Objective: This study investigated the factors influencing 5-year language, speech, and everyday functioning of children with congenital hearing loss.

Design: Standardised tests including PLS-4, PPVT-4 and DEAP were directly administered to children. Parent reports on language (CDI) and everyday functioning (PEACH) were collected. Regression analyses were conducted to examine the influence of a range of demographic variables on outcomes.

Study sample: Participants were 339 children enrolled in the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study.

Results: Children's average receptive and expressive language scores were approximately 1 SD below the mean of typically developing children, and scores on speech production and everyday functioning were more than 1 SD below. Regression models accounted for 70% to 23% of variance in scores across different tests. Higher nonverbal ability and earlier CI switch-on were associated with better outcomes in most domains. Earlier HA fitting and use of oral communication were associated with better outcomes on directly administered language assessments. Severity of hearing loss and maternal education influenced outcomes of children with HAs. The presence of additional disabilities affected outcomes of children with CIs.

Conclusions: The findings provide strong evidence for the benefits of early HA fitting and early CI for improving children's outcomes.

Key words: children, hearing loss, language outcomes, speech, everyday functioning, hearing aids, cochlear implants, outcomes, early intervention, PEACH, predictors of outcomes

***Abbreviations*:**

4FAHL: Four frequency average hearing loss in the better ear (averaged hearing loss at 0.5, 1, 2, and 4 kHz)

AH: Australian Hearing

CDI: Child Development Inventory

CIs: cochlear implants

HAs: hearing aids

LOCHI: Longitudinal Outcomes of Children with Hearing Impairment

PEACH: Parents' Evaluation of Aural/oral Performance of Children

PLS: Pre-school Language Scale

PLS-4: Pre-school Language Scale version 4

PPVT-4: Peabody Picture Vocabulary Test 4th Edition

SD: standard deviation

WNV: Wechsler Nonverbal Scale of Ability

Introduction

The literature contains numerous reports of delayed language development in children with hearing loss. Blamey et al. (2001) reported that age-equivalent scores on standardised tests of receptive and expressive language increased by approximately half to two thirds the amount expected on the basis of test norms in a sample of 4- to 12-year-old children; whereas Boothroyd et al. (1991) described receptive vocabulary development in the vicinity of 40 to 60% for a sample of 4 to 18-year-olds. Although changes in average age-equivalent scores are informative with regard to language development, they fail to take account of the considerable heterogeneity that exists in the population of children with hearing loss. In this regard, Boothroyd et al. reported that vocabulary development was significantly influenced by degree of hearing loss in their sample, with slower progress observed in a sub-group of children with higher pure-tone thresholds. By contrast, Blamey et al. found no such association. Pure-tone threshold is not the only variable that might affect language development in children with hearing loss. Other potentially important variables include: gender, cognitive ability, the presence of a disability in addition to hearing loss, parental level of education or socio-economic status (SES), the type of sensory device used, age at audiological intervention, quality of device fitting, and consistency of use. The aim of the current study was to understand how a comprehensive range of different variables might affect children's language development in order to optimise rehabilitation strategies and outcomes for all children.

Benefits of Cochlear Implantation for Children with Hearing Loss

In recent years, much of the research examining language and speech outcomes attained by children with hearing loss focused on the benefits of cochlear implantation (e.g., Tomblin et al. 1999; Geers et al. 2003; Nicholas & Geers 2007; Schorr et al. 2008; Geers et al. 2009;

Hayes et al. 2009; Inscoe et al. 2009; Niparko et al. 2010; Boons et al. 2012; Boons et al. 2013; Luckhurst et al. 2013; Lund 2016).

In a relatively early study on this topic, Tomblin et al. (1999) evaluated the sentence comprehension and production skills of 29 profoundly deaf children who used cochlear implants (CIs). The children, who received their devices between 2 and 13 years of age, were 10 years old on average at their most recent assessment date. Their scores on a standardized measure of sentence comprehension were evaluated by comparison with norms recorded previously for a sample of children with hearing loss but no CIs. The results revealed significantly higher scores for the CI group. Sentence production ability was evaluated by comparison with a control group of 29 profoundly deaf children, who were 9 years of age on average, and using hearing aids (HAs) despite being eligible implant candidates. In fact, 12 of the 29 HA users who were included in this phase of the study participated in the CI group as well, after subsequently receiving an implant. The results showed that CI users outscored HA users on a range of measures chosen to reflect the syntactic complexity of their language production in a story retelling task.

Whereas Tomblin et al. (1999) evaluated the impact of cochlear implantation on language outcomes by comparing the performance of CI users to that of participants using HAs, an alternative and more common approach is to compare CI users to children who have no significant hearing loss. Schorr et al. (2008) adopted this approach in their study of 39 native-English speaking children with CIs, ages 5 to 14. The children were required to have a minimum of 1 year's CI experience, having received their implants at ages ranging from 1;3 (years;months) to 8;2. They demonstrated nonverbal IQ within the typical range and had no additional disabilities. A comparison group of 37 children without a hearing loss was also recruited. They were age- and gender-matched to children in the CI group, with typical nonverbal IQ and no additional disabilities. The results revealed no significant difference between the groups in speech production, as measured by their ability to articulate correctly a range of consonant sounds and clusters in the context of single words. The group of children without hearing loss did, however, perform significantly better than the CI users on all language measures, including receptive and expressive vocabulary, grammatical understanding, and phonological processing.

In a larger study targeting children's expressive language outcomes in particular, Boons et al. (2013) reported on 70 prelingually deaf, Dutch-speaking participants with typical intellectual abilities, ages 5;0 to 13;3, who received their CIs before 5 years of age. A group of 70 control participants with normal hearing was matched to the CI group at an individual level for gender, chronological age, and geographical location. Maternal education did not differ across the groups. Measures of expressive vocabulary, morphology and syntax, and narrative ability were collected. The CI group performed at a level significantly below the level of the control group an all measures, with no particularly strong or weak domains. Although variability in the group of CI participants was similar to that observed in the control group, the lower level of performance overall for CI children meant that about a quarter of the group achieved scores more than 2 SDs below the norm on all measures.

Most research comparing CI users to children without hearing loss reveals a group difference in favour of the children with typical hearing (e.g., Schorr et al. 2008; Geers et al. 2009; Boons et al. 2013; Lund 2016). A recent, small study by Luckhurst et al. (2013) goes against this general trend. Luckhurst et al. compared a small group of 9 profoundly deaf children with CIs, ages 3;7 to 6;5, to a group of 42 age-matched, hearing children who were similar for SES, ethnicity, and gender. Age at implantation for the CI group ranged from 12 to 30 months. Although all CI participants scored within 1 SD of the mean on the Wechsler Nonverbal Scale of Ability (WNV; Wechsler & Naglieri 2006), 7 of the 42 hearing children scored below 85. To compensate, WNV score was included as a covariate in the main analyses. Receptive and expressive vocabulary were assessed using the Peabody Picture Vocabulary Test - Fourth edition (PPVT-4; Dunn & Dunn 2007) and the Expressive Vocabulary Test – Second edition (EVT-2; Williams 2007). There was no significant group difference on either measure, although the difference in PPVT-4 scores corresponded to a medium effect size, which the researchers acknowledged may well have reached significance with a larger participant sample. Another possibility is that a different outcome measure, one that placed greater demands on children's ability to process aspects of connected language and syntax, might have revealed a stronger group difference (Geers et al. 2009).

CI Outcomes in relation to Demographic Variables

Other evidence that children with CIs can achieve language outcomes that are similar to those of their hearing peers comes from research that takes account of the possible extent to which demographic variables, including age at implantation, might influence outcomes. In one such study, Niparko et al. (2010) reported on 188 children with severe-to-profound sensorineural hearing loss who were assessed on the Reynell Developmental Language Scales (RDLS; Reynell et al. 1990) prior to cochlear implantation and at follow-up periods of 6, 12, 24, and 36 months. All participants received their implants before 5 years of age: 72 children underwent cochlear implantation before 18 months, 64 children between 18 and 36 months, and 52 children between 36 and 60 months. Rates of improvement in RDLS language comprehension and expression were significantly higher in children who received their implants before 18 months of age than in the other CI groups. Furthermore, the group of children with CIs fitted before 18 months of age showed progress similar to a control group of 97 children without a hearing loss.

Nicholas and Geers (2007) also concluded that “the likelihood of achieving normal language in preschool decreases as age at implantation increases” (p. 1060). They described the benefits of cochlear implantation for a sample of 76 children with severe-to-profound hearing loss who received CIs between 1 and 3 years of age. Spoken language development was assessed at 3;6 and 4;6 using measures derived from language sampling, such as the number of words produced, MLU in words, and number of bound morphemes. Expressive language was formally assessed at 4;6 using the standardized Preschool Language Scale (PLS; Zimmerman, Steiner & Pond 1992). The results showed that earlier age at implantation and less severe hearing loss were associated with higher expressive PLS quotients and better performance on all of the measures derived from language sampling; however, no measure of receptive language was included in the study, thus limiting generalisability of the findings.

A wider range of receptive and expressive language assessments was used by Geers et al. (2009) in their investigation of 153 profoundly deaf children, ages 4-11 to 6;11 at time of testing. All of the children had nonverbal IQs > 70 and a minimum of one year’s CI experience, with implants activated before 5 years of age. Multiple regressions were conducted to determine the extent to which nonverbal intelligence, gender, age at implant, and parental education predicted outcomes on various language measures. Although nonverbal intelligence was the strongest predictor of all language measures, accounting for between 16 and 24.3% of unique variance, age at implant (1.7 to 2.9%) and parental education (4.2 to 10.6%) were also significant.

Most past research examining the predictors of successful cochlear implantation was conducted with English-speaking participants. Boons et al. (2012) evaluated both receptive and expressive language outcomes in a retrospective, longitudinal study of 288 Dutch-speaking children in Belgium and the Netherlands. All participants received their CIs before 5 years of age, with standardized assessments of receptive and expressive language conducted at 1, 2, and 3 years post-implantation. Overall, the results showed that some children achieved language outcomes equivalent to or better than expected for their chronological age, whereas others (approximately 25%) performed at or below a level expected for children half their age. In regard to predictor variables, age at implantation significantly influenced outcomes, with an implant age of 2 years or below deemed necessary in order to avoid long term negative effects on language. Notably, by 3 years post-implant, variation in outcomes was not associated with age at implantation in a subgroup of children who received their implants before 2 years of age.

Although age at implantation influenced language outcomes in a number of previous studies, other investigations showed no significant impact (e.g., Geers, et al. 2003; Inscoe et al. 2009; Boons et al. 2013) or limited influence on only some outcome measures (e.g., Schorr et al. 2008). Various tentative explanations were offered to account for these individual findings, including a limited range of implant ages (Geers et al. 2003; Boons et al. 2013), later age at assessment (Geers et al. 2003; Schorr et al. 2008), and limited participant numbers (Schorr et al. 2008; Inscoe et al. 2009). Nevertheless, further research is warranted, especially in light of results from a recent meta-analysis of receptive and expressive vocabulary outcomes, which showed that age at implantation was not significantly related to the magnitude of the difference in vocabulary knowledge between children with CIs and children with typical hearing (Lund 2016). In addition, many studies have identified significant predictor variables other than age at implantation that demand the attention of researchers, including: chronological age (e.g., Boons et al. 2013), gender (e.g., Geers et al. 2003; Geers et al. 2009), the presence of an additional disability (e.g., Boons et al. 2012; Boons et al. 2013), nonverbal cognitive ability (e.g., Geers et al. 2003; Geers et al. 2009), parental education or SES (e.g., Geers et al. 2003; Schorr et al. 2008; Geers et al. 2009), communication mode (Boons et al. 2012), and multilingualism (e.g., Boons et al. 2012, 2013).

Benefits of Hearing Aids for Children with Hearing Loss

Despite a growing body of literature investigating the benefits of CIs for children with hearing loss, studies examining the benefits of HAs remain relatively rare. A recent exception is a study by Tomblin et al. (2014), which investigated the extent to which HAs improved the speech production and language outcomes of 180 children with mild-to-severe hearing loss who were assessed at 3 or 5 years of age. To evaluate the benefits provided by HAs, the researchers examined the association between children's speech and language outcomes and a measure of their aided hearing that controlled for variation in unaided hearing. The resulting correlations were small-to-moderate but significant, suggesting a clear benefit of amplification.

A different approach was adopted by Walker, Holte et al. (2015), who evaluated the benefits of HAs in a sample of 38 typically developing children with mild hearing loss in the better ear, ages 5;10 to 7;2. On the assumption that less consistent use of HAs would result in poorer developmental outcomes due to lower levels of exposure to language input, the researchers compared language outcomes across three sub-groups of children that varied in daily HA use: full-time (>8.7 hrs), part-time (from 2 to 8.3 hrs), and non-users. The groups did not differ in other potentially important predictor variables, such as maternal education and nonverbal cognitive ability, although there was a difference in pure tone averages that favoured non-users. Language and speech outcomes were measured using standardized tests of single-word production, receptive vocabulary, expressive morphosyntax, and phonological processing. Significant group differences were evident in receptive vocabulary (full-time users achieving better outcomes than non-users), and expressive morphosyntax (both full- and part-time users achieving better outcomes than non-users). Notably, these group differences were observed despite the non-users having significantly better hearing as indicated above.

In a more targeted investigation of expressive language only, Koehlinger et al. (2013) analysed language samples produced by 100 children with mild to severe hearing loss (97 of whom were fitted with HAs) and 40 children with typical hearing, ages 3 and 6 years. Children with CIs were excluded from the sample, as were children with significant additional disabilities. The results showed that children with hearing loss attained lower MLUs and were less likely to use finite verb morphology correctly at both 3 and 6 years of age, with no significant tendency for the difference between groups to increase or decrease with time (i.e., no interaction between group and age). This result is consistent with findings for 19 native French speakers reported by Delage and Tuller (2007), which showed that language difficulties associated with mild to moderate hearing loss can persist into adolescence.

The small number of studies that has investigated the benefits of HAs for children with hearing loss in the mild to severe range limits any conclusions that can be drawn. Additional studies in this area are needed in order to enhance our understanding of the extent to which amplification might promote the development of typical language outcomes in this population. In pursuing this aim, it is important not to restrict consideration of outcomes to results on directly administered tests. Use of caregiver-report measures, such as the Parents' Evaluation of Aural/Oral Performance in Children (PEACH) (Ching & Hill 2007), can provide additional, useful information about auditory behaviour in real-word environments to guide rehabilitation (Bagatto et al. 2011; McCreery et al. 2015). Furthermore, as is the case for evaluating the benefits of CIs, improved understanding will depend at least in part on identifying the possible extent to which demographic variables, including age at fitting might influence outcomes.

HA Outcomes in relation to demographic variables

Unlike the case of CIs, where research findings provide considerable support for the benefits of early implantation, there is little evidence that better language outcomes are associated with earlier fitting of HAs. In their investigation of 16 HA users, ages 6 to 9 years, Stiles et al. (2012) investigated the extent to which receptive vocabulary outcomes could be explained by four predictor variables: age at first fitting of HAs, maternal education, 4FA hearing loss, and aided speech audibility. Only aided speech audibility accounted for significant unique variance. A non-significant influence of age at HA fitting was also reported by Delage and Tuller (2007) in their investigation of French-speaking adolescents' expressive grammar, and by Koehlinger et al. (2013) in their investigation of 3- and 6-year-old English-speaking children's language and grammatical outcomes. Furthermore, Fitzpatrick et al. (2011) reported a non-significant influence of age at diagnosis of hearing loss on various receptive and expressive language outcomes in a mixed group of 51 4- and 5-year-old children using HAs or CIs.

The influence of age at HA fitting was also examined in a more recent study by Tomblin, Harrison et al. (2015) who reported that children's early language outcomes, measured at 2 years of age, were affected more by age at HA fitting than later outcomes, measured at 6 years of age. This reported interaction between age at HA fitting and age at testing might have contributed to the non-significant effects observed in previous studies of older child participants and adolescents in particular (e.g., Delage & Tuller 2007; Stiles et al. 2012).

In regard to potential predictor variables other than age at HA fitting, the available literature provides some evidence of a role for: chronological age (Koehlinger et al. 2013), degree of hearing loss (Wake et al. 2005; Delage & Tuller 2007; Fitzpatrick et al. 2011; Koehlinger et al. 2013; Bagatto et al. 2015; McCreery et al. 2015; Tomblin, Harrison et al. 2015), parental education (Fitzpatrick et al. 2011), and aided speech audibility (Stiles et al. 2012; McCreery et al. 2015; Tomblin, Harrison et al. 2015).

Summary of evidence

To summarize, previous research has shown that children with hearing loss achieve poorer speech and language outcomes than children without hearing loss. A major focus of recent research has been to examine the benefits of cochlear implantation for this population of children. A secondary focus has been the extent to which demographic variables influence their performance on outcome measures. Although published findings are inconclusive, they suggest possible roles for age at cochlear implantation, duration of CI use, the presence of an additional disability, nonverbal cognitive ability, maternal education or SES, and degree of hearing loss. Disproportionately little information has been published on outcomes of children using hearing aids, who make up more than 80% of children with hearing loss (Australian Hearing 2015). There is limited information about factors influencing their outcomes. Further, the ages at intervention (HA fitting or CI) of the cohorts reported in earlier studies are likely to be considered late by current standards (Joint Committee on Infant

Hearing, position statement). It remains uncertain whether current cohorts, who receive early intervention, develop spoken language skills superior to those reported in the literature. What also remains unclear is the extent to which predictors of outcomes reported in earlier literature apply to the current cohort. Further research is also needed to extend evaluation of outcomes from standardized language assessments to ecologically relevant assessments of functional auditory/communicative outcomes in real-world situations.

The Current Study

The aim of the present investigation was to fill these identified gaps in the literature by providing detailed information about the receptive and expressive language, speech, and everyday functioning of a population-based sample of 5-year-old children with hearing loss who took part in the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study. All of the children were fitted with CIs or HAs. Outcome measures included both formal assessments of language development as well as measures of language and functional auditory behaviour based on parent report.

Research Questions and Hypotheses

Three research questions were addressed.

1. Do speech, language and everyday functioning of 5-year-old children with hearing loss who received HAs or CIs before 3 years of age differ from those of children without hearing loss?
2. Which demographic variables are associated with speech, language and everyday functioning in young children with hearing loss? Do different outcome measures reveal similar patterns of association? Specific demographic variables under consideration were both audiological (degree of hearing loss, type of sensory device,

age at fitting of sensory devices), and child- and family-related (gender, nonverbal cognitive ability, maternal education, communication mode during early intervention).

3. Do similar variables predict outcomes in children with hearing loss who use HAs versus CIs?

We hypothesised that: (1) the outcomes achieved by our sample of children with hearing loss would fall consistently below the level expected for their age-matched peers without hearing loss; (2) demographic variables, including age at fitting of HAs or CIs, degree of hearing loss, cognitive ability and maternal level of education, would be associated with variation in children's language and speech outcomes; and (3) similar demographic variables would be important in predicting outcomes for children with HAs and CIs.

Method

Participants

The Australian Hearing Human Research Ethics Committee approved the protocols used in the current study. Participants were children born with hearing loss between April 2002 and December 2007 in the states of New South Wales, Victoria and Queensland in Australia. During that time period, children residing in different states had differential access to newborn hearing screening. However, all have access to the same consistent high-quality audiological services and technology provided by a government-funded national service provider, Australian Hearing (AH), at no cost to families. Children who were diagnosed with hearing loss and presented at AH for fitting of amplification before 3 years of age were invited to participate in the LOCHI study. Data on measures completed by 339 children at 5 years of age (5;0 – 5;11) were included in this report.

Hearing-aid fitting and verification

Hearing assessment, hearing aid fitting and verification, and on-going evaluation and adjustments were carried out by AH paediatric audiologists, in accordance with the AH national paediatric amplification protocol (King 2010). A real-ear-aided gain approach (Ching & Dillon 2003; Bagatto et al. 2005) was used for fitting. This involved using either individual real-ear-to-coupler differences (RECD) or age-appropriate values to derive gain targets in an HA2-2cc coupler by using the NAL or DSL standalone software. Hearing aids were adjusted in an HA2-2cc coupler, using a broad-band speech-weighted stimulus generated by the Aurical or Med-Rx system to measure gain-frequency responses at low, medium and high input levels; and a swept pure tone at 90 dB SPL to measure maximum power output. Verification was achieved by comparing the measured 2cc coupler gain/output to custom target values. The hearing aid gain and output characteristics of the children's hearing aids were retrieved from clinical records. Details of the proximity of hearing aid characteristics to prescriptive targets are reported in a companion article (Ching et al. 2017). In brief, the root-mean-square (rms) error across the range from 0.5 to 4 kHz was within 3 dB.

Procedure

As part of the children's 5-year-old assessment battery, each child was assessed directly by research speech pathologists on four norm-referenced tests using standardised protocols. Prior to evaluations, the hearing devices were checked to ensure that they were functioning normally. The test battery included the Pre-school Language Scale version 4 (PLS-4; Zimmerman et al. 2002), the Peabody Picture Vocabulary Test 4th Edition (PPVT-4; Dunn & Dunn 2007), the Diagnostic Evaluation of Articulation and Phonology (DEAP; Dodd et al.

2002), and the Wechsler Nonverbal Scale of Ability (WNV; Wechsler & Naglieri 2006). These tests have been widely applied to assess abilities of children with hearing loss.

The PLS-4 is a standardised test of spoken English. The test includes verbal tasks which enable children to demonstrate understanding of and ability to produce English language structures, including semantics, morphology, syntax, and phonology. It gives an overall total language score, and two subscale scores – expressive communication and auditory comprehension.

The PPVT-4 is a standardised test of receptive vocabulary, using a four-alternative-forced choice, picture-pointing format in administration. It gives an overall score on receptive vocabulary.

The Phonology subtest of the DEAP is a formal test of articulation that requires a child to produce single-word utterances, elicited using pictures or verbal cues. It gives an overall total phoneme correct score, as well as a vowel score and a consonant score.

The WNV is a standardised test of nonverbal cognitive ability. It gives a full-scale IQ score.

In addition, each child's parent/caregiver completed three questionnaires: the PEACH scale (Ching & Hill 2007), the Child Development Inventory (CDI; Ireton 2005) and a custom-designed demographic questionnaire. The PEACH is a measure of functional auditory/ communicative performance in everyday life. The questionnaire contains 13 questions, 2 of which ask for information about the child's usage of hearing device and listening comfort. The remaining 11 questions solicit information about the child's auditory behaviour and communicative performance in quiet (5 questions) and in noisy situations (6 questions) in everyday life. An overall functional performance score was calculated using the summed ratings of the 11 items, as judged by the parent/caregiver. The group mean score and SD in children with typical hearing were used to derive *z* scores for participants.

The CDI contains 300 statements and parents/caregivers responded Yes or No to each one. Responses to the 100 items that contributed to the Language Comprehension and Expressive Language subscales were analysed for this report. The published normative data were used to derive the developmental age of a child, and language quotients were calculated by dividing the developmental age by their chronological age, expressed as a percentage.

The demographic questionnaire provided information regarding children's birthweight, diagnosed disabilities in addition to hearing loss, communication mode used at home and during early intervention (which was coded as oral only, sign only, or sign and speech), residential postcode, and parents' level of education. Audiological information was retrieved from individual clinical files, with permission from parents. All hearing level information and hearing aid characteristics were current within 6 months of the evaluation, and at a time closest to the actual evaluation date for each child.

Statistical analysis

Descriptive statistics were used to report quantitative outcomes for each measure. Pearson's correlation analysis was conducted to examine associations between demographic characteristics and each of the outcomes measures. In light of the large number of correlations computed, a conservative alpha level of .01 was adopted to control for Type I errors (rejecting the null hypothesis when it is true).

To investigate which demographic variables, including age at intervention, predict each of the speech, language and functional outcomes, multiple regression models were fitted separately to data from children who use HAs and those who use CIs at 5 years of age. Standard multiple regression analyses were used, with all predictor variables entered into the model simultaneously. In each device group (HA or CI), only children who received a hearing device before 3 years of age were included. Children with progressive hearing loss were excluded. The predictor variables common to both the HA and the CI models included nonverbal cognitive ability (WNV standard score), gender, additional disabilities (presence or absence), maternal education (3 categories: university, diploma or certificate, school only), and communication mode during early intervention (oral only vs combined sign/mixed).

The additional predictors in the HA model were the continuous variables age at first fitting of amplification and four-frequency average hearing loss (4FAHL, averaged hearing levels at 0.5, 1, 2 and 4 kHz in the better ear), and the interaction between these two variables. Aided audibility, as calculated by the Speech Intelligibility Index (SII; American National Standards Institute 1997) using HA fitting data, was initially considered as one of the predictor variables for the HA group. The SII values using speech-shaped noise at 65 dB SPL were examined. The values for the sample have a mean of 0.703 and a standard deviation of 0.162 (interquartile range 0.594 to 0.834). Preliminary investigation revealed that the SII and average hearing level were highly correlated ($r = 0.852$, $p < 0.0001$). Consequently, the SII appears to add little or no additional information beyond the hearing levels (Sininger et al. 2010). Therefore, SII was not used as a predictor variable, but hearing level was included in the HA model. The additional predictor in the CI model was age at implantation. To control for the increased risk of Type I errors associated with conducting eight multiple regressions for each participant group (one for each of the eight outcome measures), a conservative alpha level of .01 was adopted.

Results

Table 1 shows the demographic characteristics of children whose results are reported here. The current analysis included data from 339 children, 228 of whom were using HAs and 111 of whom were using CIs at 5 years of age. Data were excluded from the current analysis if chart reviews showed that the children were not using hearing devices (n = 12), had progressive hearing loss (n = 43), or received their first cochlear implants after 3 years of age (n = 29).

Table 1 about here

Table 2 summarises the mean and standard deviation of scores on each of the outcome measures. Also provided is the proportion of children who scored within the average range (at or above -1SD of the mean) when compared to hearing children of the same age. In regard to our first research question, these figures show that, on average, children performed below the level of typically developing peers across the range of outcome measures, which included receptive and expressive language, speech production, and everyday functioning. The highest scores were obtained for receptive vocabulary, with 61.8% of children scoring within the average range of hearing peers. Consonant articulation scores were lowest, with only 14.9% of children scoring within the average range for typically developing children.

Table 2 about here

The figures presented in Table 2 are based on performance of the cohort as a whole, which included approximately 35% of children with additional disabilities. Mean scores on PLS-4 and PPVT-4 for children with HAs or CIs were recomputed after excluding children with additional disabilities from the sample. Although children still scored below the typically developing means, their average scores were consistently higher. Children using HAs scored at 0.74 SD below the mean for PLS-4 receptive, 0.85 SD below for PLS-4 expressive, and 0.59 SD below for PPVT-4; whereas children with CIs scored at 0.99 SD below the mean for PLS-4 receptive, 1.30 SD below for PLS-4 expressive, and 0.81 SD below for PPVT-4.

To address our second research question, correlation and regression analyses were used to identify demographic variables associated with children's outcomes in speech, language and everyday functioning. Preliminary correlations showed that all outcome measures were positively correlated with each other, but by no means perfectly: Pearson coefficients ranged from $r = .16$ ($p = .02$) to $r = .90$ ($p < 0.001$). Table 3 shows the correlations between a range of demographic variables and outcomes for all children.

Table 3 about here

Four demographic variables were consistently associated with speech outcomes as measured by the DEAP; and language outcomes as measured by the PLS-4, CDI, and PPVT-4 (Table 3). The variables include maternal education, communication mode during early education, additional disabilities, and nonverbal cognitive ability. Three of the four variables (with the exception of nonverbal cognitive ability) were also associated with everyday functioning as measured by the PEACH. All effects were in the expected direction, with better performance related to higher maternal educational level, use of an oral-only mode of communication, no additional disabilities, and higher cognitive ability. In addition, age at fitting of HAs was associated with CDI expressive language outcomes, and vowel production. Age at implant was not significantly associated with any language measures.

Table 4 shows the results of multiple regression analyses that were conducted to investigate the unique predictors of each outcome measure for children with HAs.

Table 4 about here

For each outcome measure, the full set of predictors accounted for significant total variance ranging from 70% (for PLS-4 receptive language) to 30% (for PEACH). Nonverbal cognitive ability and maternal education were significant predictors across most measures. In addition, severity of hearing loss was a significant predictor of performance on directly administered language assessments (PLS-4, PPVT-4) and consonant production; communication mode significantly predicted receptive language ability on directly administered assessments (PLS-4 and PPVT); and age at first HA fitting significantly predicted performance on the PLS-4. The interaction between severity of hearing loss and age at first fitting approached statistical significance only for consonant production (p = .02), and PLS-4 receptive language (p = .05; see Table 4). For these two measures, earlier fitting had a larger positive effect for children with more severe hearing loss. When age at HA fitting was increased by a factor of 2 (for example, from 6 to 12 months, or from 12 to 24 months), the effect size on consonant production for a 70 dB HL was -4.9 (95% confidence interval: -8.6 to -1.2), but -1.3 (95% confidence interval: -3.4 to 0.8) for a 50 dB HL. In a similar vein, the effect size on PLS-4 receptive language was -5.2 (95% Confidence interval: -8.4 to -2.0) for a 70 dB HL, but -2.7 (95% confidence interval: -4.4 to -1.0) for a 50 dB HL.

Table 5 summarises the multiple regression analysis for children with CIs, showing that age at cochlear implantation, nonverbal cognitive ability, and presence of additional disabilities were significant predictors across most measures. For each of the measures, the full set of predictors accounted for significant total variance ranging from 66% (for PLS-4 receptive language) to 23% (for PEACH).

Table 5 about here

Discussion

We report an investigation of the language, speech and functional outcomes of a large sample of 5-year-old children with hearing loss that aimed to explore: (1) how they performed relative to norms for typically developing children without hearing loss; (2) which demographic variables were associated with different outcome measures; and (3) whether similar variables would be important in predicting outcomes for children using HAs or CIs.

Outcomes of children

We found that the mean receptive and expressive language scores of the entire cohort of children were approximately 1 SD or more below the mean of typically developing children (see Table 2). However, when children with additional disabilities were excluded, mean scores were consistently higher, especially for children using HAs. These outcomes compared favourably to those reported by Kennedy et al. (2006), which showed mean receptive language scores of nearly 2 SD below population norms for a sample of 6- to 10-year-old children. The advantage shown by the present cohort over those in the previous study is likely related to their earlier ages at fitting of HAs and access to high-quality intervention (Fitzpatrick et al. 2007); as well as variations between study cohorts in ages at assessment, measures used, and other unknown factors. Despite the observed improvement in this study compared to previous studies, the present cohort attained a mean language score of around 86 (averaged across PLS-4 receptive and expressive, and PPVT-4), which is still approximately 1 SD below the children's own cognitive ability (mean WNV score: 102). In addition, their mean speech production scores fall well below the typical range for children without hearing loss, at -1.8 SD and -1.57 SD for consonant and vowel production respectively; and functional performance was at -1.3 SD below normative means. Similar results were found for children with HAs only.

For children with CIs, the mean scores for receptive and expressive language as measured by the PLS-4 were more than 1 SD below the mean of typically developing children (see Table 2). Although these scores improved somewhat when children with additional disabilities were excluded, they remained around one SD lower than typical. Nevertheless, they compare favourably to those in previous reports (Geers et al. 2003; Geers et al. 2009; Boons et al. 2012), possibly in part due to the present cohort having earlier ages at implant and access to state-of-the-art technology with upgrades provided at no cost to families.

These findings attest to the importance of early age at amplification, but also indicate the need for increased support to enhance development of speech production and functional communication in everyday situations. Receptive vocabulary appears to be a particularly strong skill in this cohort, with 61.8 % of children achieving age-appropriate scores compared to 57.3 % on receptive language and 52.3 % on expressive language, as measured by the directly administered PLS-4. This relative advantage of vocabulary skills over other oral language skills is consistent with previous literature (Moeller 2000; Spencer 2004; Geers et al. 2009), and is likely a reflection of early education that generally focusses on development of vocabulary. It underscores the possibility that evaluation of outcomes based on receptive vocabulary alone may over-estimate the spoken language ability of children with hearing loss.

In spite of any differences in children's performance on the various assessment tasks, all outcome measures were positively correlated with each other in the current study. This finding suggests that, on average, the relative ranking of children's performance was consistent across measures. Those who scored high in PLS-4, for instance, also scored high in PPVT-4 or PEACH. The significant relationship between a parent-report measure of everyday functioning (PEACH) and standardised measures of receptive and expressive language lends support to use of the PEACH scale for monitoring children's progress. This methodology is especially applicable to children who cannot provide reliable responses in directly administered tests, and for children from a non-English speaking background who do not use spoken English as a dominant language in everyday life, thereby rendering standardised tests of spoken English unsuitable. The PEACH scale can be completed by audiologists with the families of children and does not require a qualified speech pathologist to administer the test as would be the case with some standardised language measures. As an 11-item scale, it can be completed within a short time thereby making it viable for clinical use.

The correlation between demographic characteristics and outcome measures showed that earlier age at HA fitting was associated with better scores for expressive language (CDI) and vowel production (DEAP). In addition, higher nonverbal cognitive ability, absence of additional disabilities, higher maternal education, and use of an oral mode of communication were associated to varying degrees with higher scores in receptive and expressive language, speech, and everyday functioning.

Predictors of performance – children with hearing aids

This study provides solid evidence on the benefits of early amplification for improving receptive and expressive language in 5-year-old children with hearing loss. Unlike the weak effect of age at HA fitting (that was in the same direction as the present study) on 3-year outcomes of the cohort (Ching, Dillon, Marnane et al. 2013), we found a significant positive effect of age at HA fitting on the directly administered PLS-4 when outcomes were measured at 5 years. This later age at assessment may have provided a wider scope for the benefits of early amplification to be manifested (Fitzpatrick et al. 2007), and allowed more reliable responses to be obtained than at a younger age. Although our findings confirmed the benefits of amplification for children with hearing loss (Tomblin et al. 2014), the significant effect of age at HA fitting contrasts with earlier studies (Wake et al. 2004; Delage & Tuller 2007; Fitzpatrick et al. 2007; Stiles et al. 2012). This variation may be explained by differences in sample characteristics (e.g. Wake et al. included only 11 children who received HAs before 6 months of age), different ages at assessment (Fitzpatrick et al. 2007), adequacy of HA fitting (Stiles et al. 2012), and other unknown factors.

Adding weight to the current findings, Tomblin, Harrison et al. (2015) reported a difference in predicted language scores at 5 years old that was similar in size to that reported here (i.e., in both studies, children who received HA fitting before 6 months of age had predicted language scores that were 3 to 5 standard score points above those who received HA fitting between 6 and 12 months of age). In apparent contrast with the current findings, however, Tomblin, Harrison et al. also reported a longitudinal trend that showed a *decrease* in the impact of age at HA fitting with increasing age at evaluation. Thus, by 6 years of age, they reported no significant difference in language scores for children who were fitted between 7 and 12 months of age compared to those fitted between 13 and 60 months of age. On this basis, they suggested that the benefits of early HA fitting were likely due to the longer duration of HA use at the time of evaluation, which became non-significant by 6 years of age. Although the current report focuses on the relationship between a range of demographic characteristics and children's language and functional performance at 5 years of age, when considered in combination with findings from the LOCHI study at 3 years (Ching, Dillon, Marnane et al. 2013), they suggest that the positive influence of age at HA fitting on language outcomes *increases* with age at evaluation. Whether this apparent difference in findings between the current study and that of Tomblin, Harrison et al. may be related to variations in demographic and methodological characteristics remains to be investigated in future research. For instance, we found that the effect of delaying HA fitting had a marginally greater effect on consonant production and receptive language (PLS-4) of children with more severe hearing loss than those with milder hearing loss. The relationship is in the expected direction, as in the extreme case, age at fitting would not be expected to have any influence on a child with normal hearing. Furthermore, the cohort reported in the Tomblin, Harrison et al. (2015) study included children using bilateral hearing aids with better ear 4FA hearing levels ranging from 25 to 75 dB HL (mean 47.7 dB HL), whereas the present cohort included a population of children with better ear 4FA hearing levels ranging from 9 to 119 dB HL in the HA group, and 64 to 125 dB HL in the CI group. As shown in Table 1, the HA group also included 16 (7%) children who used unilateral hearing devices (5 with 4FA < 30 dB HL in the better ear, 10 with microtia or atresia, and 1 with profound loss in one ear). The Tomblin, Harrison et al. (2015) study used an accelerated longitudinal design to follow groups of children through the preschool years and into the early school years (Tomblin, Walker et al.

2015), unlike the present study that followed a single cohort over time. Our future work will investigate the effect of age at HA fitting on rate of development of the children, after allowing for the effects of a range of characteristics known to influence outcomes.

Other significant predictors of 5-year language and everyday functioning in the present cohort of HA users include nonverbal cognitive ability, severity of hearing loss, and maternal education. The factors are broadly consistent with previous literature showing the influence of degree of hearing loss (Wake et al. 2005; Delage & Tuller 2007; Fitzpatrick et al. 2011; Koehlinger et al. 2013), and parental education (Fitzpatrick et al. 2007). The use of an oral-only communication mode was a significant predictor of receptive language measured by directly administered tests, but not by parent report. However, this positive effect does not imply a causal relationship between the use of an oral mode of communication during early intervention and spoken language outcomes.

Unlike previous studies that indicated a role for aided audibility (Stiles et al. 2012) and hearing-aid fitting quality (McCreery et al. 2013) in determining outcomes, the present study did not include these variables. Instead, we measured a cohort of children who were fitted with hearing devices early, according to a consistent audiological protocol (King 2010). The standard procedure entailed use of a prescriptive approach that maximises audibility, HA verification procedures that use real-ear measurements, and evaluation procedures that optimise effectiveness (see Ching, Dillon, Hou et al. 2013). Our companion article on hearing aid characteristics of the children when evaluated at 5 years of age shows that the rms error of fitting was around 3 dB of prescribed targets across 0.5 to 4 kHz (Ching et al, 2017). This is consistent with earlier reports on hearing aid characteristics of the children when evaluated at

3 years of age (Ching, Dillon, Hou et al. 2013). Despite these inbuilt controls, it is possible that aided audibility might have accounted for additional unique variance in outcomes had it been included in our analyses. Nevertheless, a recent report by Tomblin, Harrison et al. (2015) showed that aided audibility that controlled for children's hearing level did not have an overall effect on their language ability, but was associated with language growth - an aspect that would form a focus for our future investigation.

Further, consistent usage of device in the present cohort has been established at an early age, as reported by parents (Marnane & Ching 2015). Continual reports on usage at 5 years of age were compatible with earlier reports, suggesting an increase in usage with age and high ratings on usage for the majority of participants with little variability (in preparation). Although parent reports may overestimate usage in absolute terms, they are nonetheless highly correlated with usage data based on data-logging in hearing devices (Walker et al. 2013; Walker, McCreery et al. 2015), and parent reports on HA use have been used in previous investigations into its effect on child outcomes (McCreery et al. 2015; Tomblin, Harrison et al. 2015). It appears that HA use was related to language growth between 2 and 6 years (Tomblin, Harrison, et al. 2015), but more hours of HA use were not associated with higher scores on functional performance in everyday environments or word recognition scores obtained at 3 years of age or older (McCreery et al. 2015). Whether device usage based on data-logging may make a unique contribution to explaining residual variance in language scores and rate of growth for the present cohort remains to be investigated in future work.

Predictors of performance – children with cochlear implants

For children with CIs, earlier age at cochlear implantation was associated with better outcomes. This result is consistent with findings for the same cohort at 3 years of age (Ching, Dillon, Marnane et al. 2013). Our findings in this regard are also broadly consistent with previous reports on children with CIs (Nicholas & Geers 2007; Geers et al. 2009), but contrast with others that did not find a significant effect of age at implant in 8- and 9-year-old children who received a cochlear implant by age 5 years (Geers et al. 2003). The present study included children who received a CI between 6 and 35 months of age and who were assessed at 5 years of age; unlike previous studies that included children who were implanted by 5 years of age (Geers et al. 2009; Niparko et al. 2010; Boons et al. 2012) or 8 years of age (range: 1;8 to 9;3 years; Schorr et al. 2008) and assessed at an older age than the present cohort. The discrepant findings in the effect of age at implant may relate to the range of implant ages examined, the ages at which the outcomes were measured and/or the covariates entered into analyses in different studies.

As for age at cochlear implantation, the presence of additional disabilities was a significant predictor of outcomes in receptive language, expressive language, and speech production; and in accordance with previous research (Geers et al. 2003; Geers et al. 2009), nonverbal cognitive ability was a significant predictor of children's performance across all outcome measures.

Agreement and Discordance between factors predicting outcomes of children with HAs and those with CIs

The multiple regressions reported here identified two demographic variables that predict outcomes in separate groups of children with HAs and children with CIs. They are age at fitting of HAs or CIs, and nonverbal cognitive ability. More specifically, higher cognitive ability and earlier fitting of CIs are beneficial for development of speech and language abilities in children with hearing loss, and earlier fitting of HAs is beneficial for development of receptive and expressive language. A third variable, communication mode in early intervention, also predicts selected outcomes in both groups of participants. Not surprisingly, better performance on directly administered assessments of receptive language (PLS-4 and PPVT-4) was associated with use of an oral mode of communication.

Significant predictor variables also differ across the groups of children using HAs or CIs. The most marked difference lies in the impact of additional disabilities, which appear to produce a greater effect on children with CIs than those with HAs. This differential effect is likely due to children with CIs in the current cohort having more severe additional disabilities than those with HAs. A higher proportion of children were diagnosed with autism spectrum disorder, cerebral palsy, and developmental delay in the group of children using CIs (64.1%) than in children using HAs (51.9 %). These disabilities are known to have a greater impact than other disabilities on outcomes of children with hearing loss (Cupples et al. 2014). A detailed analysis of 5-year outcomes of children with hearing loss and additional disabilities is described separately in a companion article (Cupples et al. 2016).

A second variable that differentially predicts outcomes in children using HAs and those using CIs is level of maternal education. More specifically, maternal education is significantly associated with all but one outcome measure for children using HAs compared to no outcome measures for children with CIs. While interpretation of this group difference requires further, more detailed investigation, it cannot be attributed to a relative lack of variability in maternal education within the group of CI users. As shown in Table 1, the distribution of participants across maternal education categories was similar for children using HAs or CIs.

Limitations, Strengths, and Future Directions

This report focuses on spoken language development and everyday functioning of children at 5 years of age. The extent to which factors including age at intervention influence psychosocial development are explored in a companion article (Wong et al. 2016). Future studies of the same cohort of children will investigate whether the benefits of early intervention persist into school age, and whether the same factors that predict 5-year outcomes continue to be robust predictors of outcomes at school age.

A major strength of the study lies in its population base, allowing the findings to be generalised to the population of children with hearing loss. Data were collected by speech pathologists who were not involved in the children's clinical care, and who were blinded to the severity of hearing loss, screening status, and age at intervention, to the extent possible. Unlike previous studies that assessed children with a wide range of ages at intervention and assessment, showing an effect of chronological age, this study involved direct assessments of a cohort of children at 5-6 years of age, whose hearing loss was identified early and who had access to the same post-diagnostic intervention services.

Despite these strengths, the study is not without its limitations. First, there is the absence of a measure of aided audibility; and second, the use of a subjective (parent report) measure of hearing aid use rather than data-logging. With respect to the first of these issues, our methodology was designed to maximise audibility for all children through the use of a consistent audiological protocol. In regard to the second issue, we note the high correlation between parent-report and data-logging methods (Walker et al. 2013) and the limited variability in use ratings by parents. Nevertheless, we cannot rule out the possibility that, if included, these variables along with other uncontrolled factors, might have explained additional unique variance in our range of outcome measures.

Conclusion

The present study investigated the 5-year language, speech, and everyday functioning of a population-based cohort of children who received intervention at an early age. A battery of tests was directly administered to children and parent reports were collected to evaluate a range of outcomes. On average, children achieved receptive and expressive language scores approximately 1 SD below the mean of typically developing children, but speech production scores and everyday functioning scores more than 1 SD below. Regression models fitted separately to data from children with HAs and those with CIs accounted for 70% to 23% of variance in scores across different measures. In common to both models, earlier age at device fitting (HA or CI) and higher nonverbal cognitive ability were associated with better language outcomes; and use of an oral mode of communication in early intervention was associated with better performance on directly administered receptive language assessments. Other predictors of better outcomes in children using HAs include lesser degree of hearing loss and higher maternal education. For children using CIs, the presence of additional disabilities was a significant predictor of language and speech outcomes. In sum, the present findings provide strong evidence for the benefits of early HA fitting and early CI for improving outcomes of children with congenital hearing loss.

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Table 1. Sample characteristics

Variable	Hearing Aid (HA)	Cochlear Implant (CI)
Gender (Male)		
N	228	111
No. (percentage)	134 (58.8%)	51 (45.9%)
Degree of Hearing Loss (4FA HL)		
N	228	111
No. (percentage): Mild (≤ 40 dB)	60 (26.3%)	0
Moderate (41-60 dB)	119 (52.2%)	0
Severe (61-80 dB)	46 (20.2%)	7 (6.3%)
Profound (>80 dB)	3 (1.3%)	104 (93.7%)
Presence of additional disabilities		
N	228	111
No. (percentage)	79 (34.6%)	39 (35.1%)
Cognitive ability[a]		
N	185	85
Mean (SD)	102.1 (16.9)	101.7 (14.0)
Median	102.0	102.0
Interquartile range (IQR)	92.0-116.0	93.0-110.0
Age at HA fitting		
N	228	111
Mean (SD) for children who failed screening	6.9 (7.1)	2.8 (2.7)
Median for children who failed screening	4.0	2.0
IQR for children who failed screening	2.0-10.0	1.0-3.0
Mean (SD) for others[b]	18.6 (11.3)	11.2 (7.3)
Median for others[b]	20.0	10.0
IQR for others[b]	8.0-29.0	5.0-17.0

Age at cochlear implantation		
N	N/A	111
Mean (SD)	N/A	15.9 (7.7)
Median	N/A	14.0
IQR	N/A	9.0-21.5
Hearing Device		
N	228	111
No. (percentage): Hearing Aid - Bilateral	212 (93.0%)	N/A
Unilateral	16 (7.0%)	N/A
Cochlear Implant - Bilateral	N/A	79 (71.2%)
Unilateral plus hearing aid	N/A	23 (20.7%)
Unilateral only	N/A	9 (8.1%)
Maternal Education[a]		
N	207	101
No. (percentage): University Qualification	85 (41.1%)	44 (43.6%)
Diploma or Certificate	53 (25.6%)	26 (25.7%)
12 years or less of schooling	69 (33.3%)	31 (30.7%)
Communication mode in early intervention[a]		
N	201	102
No. (percentage): Oral only	168 (83.6%)	73 (71.6%)
Sign	0	2 (2.0%)
Mixed (sign and speech)	33 (16.4%)	27 (26.5%)

Note: 4FA HL = the average of hearing threshold levels at 0.5, 1, 2, and 4 KHz in the better ear.

[a] Due to missing data for some variables, scores are based on different numbers of participants as specified.

[b] Includes children who passed newborn hearing screening, and those who did not have access to newborn hearing screening due to their state of residence.

Table 2. Summary of outcomes. The proportion of children with scores ≥85 for tests that have a normative mean of 100 and a standard deviation of 15 would be considered to be within the normal range (WNR). For tests that have a normative mean of 10 and a standard deviation of 3, the corresponding criterion was ≥7. Accordingly, 16% of children in the normal population would fall outside the normal range.

	Norm	All children			HA			CI		
	Mean (SD)	n	Mean (SD)	% WNR	n	Mean (SD)	% WNR	n	Mean (SD)	% WNR
Receptive language										
PLS-Rec	100 (15)	288	85.1 (20.0)	57.3%	204	85.9 (19.4)	58.3%	84	83.1 (21.3)	54.8%
CDI-Rec	100 (15)	235	78.0 (23.5)	45.5%	157	79.3 (22.6)	46.5%	78	75.1 (25.1)	43.6%
Expressive language										
PLS-Exp	100 (15)	287	83.5 (20.2)	52.3%	203	85.3 (18.8)	56.2%	84	79.3 (22.8)	42.9%
CDI-Exp	100 (15)	234	77.5 (27.6)	44.0%	157	79.4 (26.6)	47.1%	77	73.8 (29.4)	37.7%
Receptive vocabulary										
PPVT	100 (15)	272	89.0 (18.2)	61.8%	193	90.0 (17.0)	63.7%	79	86.6 (20.9)	57.0%
Speech production										
PCC	10 (3)	282	4.3 (2.1)	14.9%	199	4.2 (2.1)	13.1%	83	4.6 (2.3)	19.3%
PVC	10 (3)	281	5.1 (2.7)	32.7%	198	5.1 (2.6)	32.3%	83	5.1 (2.8)	33.7%
Everyday functioning										
PEACH	100 (15)	253	76.1 (18.6)	37.9%	165	76 (18.0)	35.8%	88	76.3 (19.8)	42.0%

Table 3. Correlations (Pearson's r) between demographic variables and outcome measures for all children, with number of paired observations in parentheses.

	Outcome Measures							
	PLS-Rec	CDI-Rec	PPVT	PLS-Exp	CDI-Exp	PVC	PCC	PEACH
Gender	0.04	-0.03	-0.01	0.06	-0.02	0.01	0.05	0.09
	(288)	(235)	(272)	(287)	(234)	(281)	(282)	(253)
AgeHA	-0.13	-0.16	-0.06	-0.09	-0.19*	-0.18*	-0.08	-0.10
	(288)	(235)	(272)	(287)	(234)	(281)	(282)	(253)
AgeCI	-0.21	-0.25	-0.10	-0.15	-0.22	-0.10	-0.18	-0.07
	(89)	(81)	(84)	(89)	(80)	(88)	(88)	(93)
4FAHL	-0.09	-0.11	-0.11	-0.15	-0.11	0.03	0.04	-0.02
	(288)	(235)	(272)	(287)	(234)	(281)	(282)	(253)
MatEd	-0.35**	-0.25**	-0.33**	-0.31**	-0.22**	-0.22**	-0.23**	-0.28**
	(262)	(226)	(251)	(261)	(225)	(257)	(258)	(240)
Mode	-0.17*	-0.20*	-0.20*	-0.19*	-0.21*	-0.18*	-0.18*	-0.29**
	(258)	(214)	(245)	(257)	(213)	(254)	(255)	(229)
ADisab	-0.29**	-0.38**	-0.21**	-0.31**	-0.38**	-0.19**	-0.16*	-0.31**
	(288)	(235)	(272)	(287)	(234)	(281)	(282)	(253)
WNV	0.52**	0.43**	0.45**	0.44**	0.39**	0.22**	0.26**	0.15
	(240)	(198)	(230)	(238)	(198)	(238)	(239)	(205)

Note. Gender (0 = male; 1 = female); Mode = Mode of Communication in early intervention (0 = oral; 1 = mixed/sign); MatEd = Maternal Education (1 = university; 2 = diploma/certificate; 3 = ≤12 years formal schooling); 4FAHL = 4 Frequency Average Hearing Loss in the better ear; AgeHA = Age at Hearing Aid Fitting; AgeCI = Age at cochlear implantation; WNV = Wechsler Non-Verbal Full Scale IQ; CDI-Rec = CDI Receptive Language (Language comprehension) developmental quotient; PLS-Rec = PLS-4 Receptive Language (Auditory comprehension) standard score; PPVT-4 = PPVT-4 Receptive Vocabulary standard score; PLS-Exp = PLS-4 Expressive Communication standard score; CDI-Exp = CDI Expressive Language developmental quotient; PVC = DEAP Percent Vowel Correct (PVC) standard score; PCC = DEAP Percent Consonant Correct (PCC) standard score; PEACH = PEACH standard score. *p <0.01, **p <0.001.

Table 4. Multiple regression summary table showing unstandardized coefficient estimates (*b*-values) and significance levels (*p*-values) of predictor variables for outcomes of children with hearing aids (*p*-values in parentheses)

	Outcome Measure							
Predictor	PLS-Rec	CDI-Rec	PPVT	PLS-Exp	CDI-Exp	PVC	PCC	PEACH
(ln)AgeHA[ab]	5.14 (0.003)	-1.52 (0.04)	0.53 (0.07)	3.94 (0.01)	-12.15 (0.02)	-0.67 (0.02)	11.03 (0.03)	-3.25 (0.02)
4FAHL[c]	0.10 (<0.001)	-0.15 (0.08)	-0.20 (<0.001)	0.05 (<0.001)	-0.57 (0.10)	0.02 (0.34)	0.31 (0.001)	-0.13 (0.34)
(ln)AgeHA[a] x 4FAHL	-0.18 (0.05)	-0.05 (0.69)	-0.06 (0.43)	-0.14 (0.10)	0.15 (0.29)	-0.05 (0.54)	-0.26 (0.02)	0.00 (0.97)
WNV	0.85 (<0.001)	0.62 (<0.001)	0.65 (<0.001)	0.68 (<0.001)	0.65 (<0.001)	0.49 (<0.001)	0.64 (<0.001)	0.28 (<0.001)
Gender[d]	2.67 (0.30)	-2.23 (0.44)	1.49 (0.53)	3.41 (0.15)	-1.41 (0.69)	0.76 (0.75)	2.72 (0.36)	-1.12 (0.61)
ADisab	-3.10 (0.32)	-5.34 (0.12)	-3.00 (0.33)	-3.91 (0.18)	-8.82 (0.04)	-2.44 (0.42)	-12.13 (0.002)	-3.96 (0.14)
MatEd[e]	10.75, 9.95 (0.002)	13.86, 13.41 (<0.001)	9.81, 9.12 (0.001)	9.34, 9.05 (0.003)	15.02, 14.95 (0.001)	6.07, 5.65 (0.07)	10.76, 11.46 (0.003)	1.25, 8.02 (0.004)
Mode[f]	-8.31, -9.49 (0.004)	-1.44, -5.03 (0.44)	-10.43, -10.65 (<0.001)	-6.74, -7.63 (0.02)	-4.04, -5.02 (0.54)	-4.59, -7.19 (0.07)	-7.43, -9.15 (0.05)	-1.23, 1.81 (0.74)
Sample size	223	167	224	224	167	225	226	168

Adjusted R^2	0.70	0.56	0.64	0.63	0.51	0.45	0.56	0.30

Note. AgeHA = Age at Hearing Aid Fitting; 4FAHL = 4 Frequency Average Hearing Loss in the better ear; WNV = Wechsler Non-Verbal Full Scale IQ; ADisab = Additional Disabilities; MatEd = Maternal Education; Mode = Mode of Communication in early intervention; PLS-Rec = PLS-4 Receptive Language (Auditory comprehension) standard score; CDI-Rec = CDI Receptive Language (Language comprehension) developmental quotient; PPVT = PPVT-4 Receptive Vocabulary standard score; PLS-Exp = PLS-4 Expressive Communication standard score; CDI-Exp = CDI Expressive Language developmental quotient; PVC = DEAP Percent Vowel Correct (PVC) standard score; PCC = DEAP Percent Consonant Correct (PCC) standard score; PEACH = PEACH standard score.

[a](ln) indicates that AgeHA was transformed using the natural logarithm.

[b]The *p*-value for (ln)AgeHA is for the overall test of (ln)AgeHA effects, that is, for the test that the (ln)AgeHA and (ln)AgeHA x 4FAHL coefficients are both zero.

[c]The *p*-value for 4FAHL is for the overall test of 4FAHL, that is, for the test that the 4FAHL and (ln)AgeHA x 4FAHL coefficients are both zero.

[d]For gender, the coefficient estimate is for female relative to male.

[e]For maternal education, the first coefficient estimate is for diploma relative to school, and the second coefficient estimate is for university relative to school. The *p*-value for MatEd is for the overall test of MatEd, that is, for the test that both MatEd coefficients are zero.

[f]For mode, the first coefficient estimate is for sign/mixed relative to oral only, and the second coefficient estimate is for changed or never attended relative to oral only. The *p*-value for Mode is for the overall test of Mode, that is, for the test that both Mode coefficients are zero.

Table 5. Multiple regression summary table showing unstandardized coefficient estimates (*b*-values) and significance levels (*p*-values) of predictor variables for outcomes of children with cochlear implants (*p*-values in parentheses)

	Outcome Measure							
	PLS-Rec	CDI-Rec	PPVT	PLS-Exp	CDI-Exp	PVC	PCC	PEACH
(ln)AgeCI[a]	-15.04 (0.002)	-15.10 (0.003)	-18.45 (<0.001)	-13.53 (0.004)	-18.60 (0.003)	-15.49 (<0.001)	-18.34 (0.002)	-2.42 (0.51)
WNV	0.80 (<0.001)	0.52 (<0.001)	0.47 (<0.001)	0.60 (<0.001)	0.59 (<0.001)	0.41 (<0.001)	0.59 (<0.001)	0.19 (0.02)
Gender[b]	3.73 (0.40)	0.31 (0.95)	4.66 (0.26)	3.91 (0.35)	-2.32 (0.69)	3.33 (0.35)	7.19 (0.18)	6.35 (0.06)
ADisab	-22.41 (0.002)	-19.95 (0.001)	-20.45 (<0.001)	-19.48 (0.003)	-23.48 (0.002)	-19.69 (<0.001)	-24.08 (0.002)	-8.20 (0.08)
MatEd[c]	0.14, 8.04 (0.25)	8.43, 6.19 (0.44)	8.75, 13.53 (0.03)	0.12, 8.76 (0.16)	3.70, 2.38 (0.90)	-1.60, 8.04 (0.07)	-1.69, 11.37 (0.10)	8.68, 7.76 (0.08)
Mode[d]	-15.29, 6.39 (0.09)	-7.91, 5.84 (0.30)	-20.94, -1.76 (0.01)	-13.35, 8.91 (0.04)	-10.68, 9.53 (0.18)	-10.56, 2.53 (0.15)	-19.56, 1.01 (0.11)	-3.61, 1.82 (0.58)
Sample size	96	86	106	96	85	104	104	90
Adjusted R^2	0.66	0.50	0.62	0.58	0.47	0.58	0.54	0.23

Note. AgeCI = Age at Cochlear Implantation; WNV = Wechsler Non-Verbal Full Scale IQ; ADisab = Additional Disabilities; MatEd = Maternal Education; Mode = Mode of Communication in early intervention; PLS-Rec = PLS-4 Receptive Language (Auditory comprehension) standard score; CDI-Rec = CDI Receptive Language (Language comprehension) developmental quotient; PPVT = PPVT-4 Receptive Vocabulary standard score; PLS-Exp = PLS-4 Expressive Communication standard score; CDI-Exp = CDI Expressive Language developmental quotient; PVC = DEAP Percent Vowel Correct (PVC) standard score; PCC = DEAP Percent Consonant Correct (PCC) standard score; PEACH = PEACH standard score.

[a](ln) indicates that AgeCI was transformed using the natural logarithm.

[b]For gender, the coefficient estimate is for female relative to male.

[c]For maternal education, the first coefficient estimate is for diploma relative to school, and the second coefficient estimate is for university relative to school. The *p*-value is for the overall test of MatEd, that is, for the test that both MatEd coefficients are zero.

[d]For mode, the first coefficient estimate is for sign/combination relative to oral only, and the second coefficient estimate is for changed or never attended relative to oral only. The *p*-value is for the overall test of Mode, that is, for the test that both Mode coefficients are zero.