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Pre-linguistic social communication skills and post implant language outcomes in deaf children with cochlear implants.

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ABSTRACT

Purpose: This study investigates the relationship between pre-linguistic social communication skills and age of cochlear implant for future language outcomes in a large sample of deaf children.
Method: A retrospective cohort study of records from 75 children. Pre-implant data included Age at Implant, pre-linguistic communication (social, symbolic and speech) skills, and non-verbal ability. Receptive and expressive language development data at 1 year, 2 years and 4 years post implant were analysed to investigate the relationships between pre-implant factors and language outcomes, in particular pre-linguistic social communication skills in early and late implanted children.
Results: Age at Implant was the strongest correlate of post implant expressive and receptive language outcomes. The sample was divided into early implanted (<18 month) and late implanted (>18 months) children. In the early implanted group, pre-linguistic social communication skills were the strongest pre-implant correlate of language outcomes four years post-implant. In the late implanted group, there were no significant pre-implant correlates of language outcomes.
Conclusions: Long term language outcomes after cochlear implantation are the product of a set of communicative, cognitive and environmental factors. Early pre-implant social communication skills are an important consideration for clinicians who guide parents as to likely long-term outcomes post cochlear implantation. Social communication skills are particularly important for children who receive implants before the age of 18 months.

1. Introduction

Congenital deafness occurs in one-two infants for every one thousand live births (NICE, 2019). Deaf and hard of hearing (DHH) children with a severe-profound deafness (between 71 > 90dBHL) are often offered cochlear implants (CIs). Although many children with CIs achieve language skills comparable to their hearing peers (see Bruijnzeel et al., 2016 for a review) there continues to be considerable variation in language development outcomes (Geers et al., 2016; Niparko et al. 2010). There is great interest in understanding how infant characteristics of pre-implant functioning relate to the observed variability (Ching et al., 2013; Pisoni et al., 2017). In particular, in the wider infant population, social-communication skills are a very important development in children during

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the first 18 months for the establishment of reciprocation, joint attention and appreciation of other's intentions (Tomasello, 2008; Kelly et al., 2020). Despite much research highlighting the powerful role of early social communication skills on language development (Beuker et al., 2013; Kane et al., 2004; Roberts, 2019) relatively few studies to date have examined the potential role of pre-implant social communication skills on post implant language outcomes.

Many factors that contribute towards typical language development in DHH children have been identified: early identification and aiding (Spencer & Marschark, 2010), Age at Implantation (Dettman et al., 2016; Geers & Nicholas, 2013; Niparko et al. 2010), non-verbal cognitive level (Cejas et al., 2018; Geers & Sedey, 2011), and family involvement (Watkin et al., 2007). Despite extensive research on all of these topics however, much of the variation in language outcomes following CI remains unexplained (Levine et al., 2016). Therefore, it continues to be a challenge for clinicians working with young DHH children to predict individual language development outcomes (Niparko et al., 2010; Pisoni et al., 2008).

The aim of the current study was to determine whether three important pre-implant factors, in particular pre-linguistic communication skills in young infants, are associated with future receptive and expressive language scores in a large group of infants who attended a CI centre in a UK hospital at one year, two years and four years post implant. We considered: age of child at implant; pre-linguistic social, symbolic and speech skills, and non-verbal cognitive level ability. These factors have been identified in the wider literature as influential for future language outcomes (Szagun & Schramm, 2016) and constitute data regularly collected across health settings where DHH children attend. The following sections describe these pre-implant factors in more detail.

2. Pre-implant factors

2.1. Age of implant

Age of implant (AoI) is an important variable in the development of language in DHH children and is associated with improved speech and language outcomes (Dettman et al. 2016; Geers & Nicholas, 2013; Szagun & Schramm, 2016; Tobey et al. 2013). Because of sensitive periods for phonological development in the first year of life (Levine et al., 2016), implantation prior to 12 months of age leads to optimal listening and spoken language outcomes (Cuda et al., 2014; Holman et al., 2013; Leigh et al., 2013). Children implanted after 12 months have reduced access to important auditory-visual information during this period and some studies suggest limited auditory-visual and language input impacts on domain-general cognitive processes (Campbell et al., 2014; Harris et al., 2013; Pisoni et al., 2017; Smith et al., 1998).

A particularly important benefit of an early CI is that it facilitates the child's learning and practicing of social-communicative routines during the first year (Tomasello, 2008). However, it is only recently that CIs before 12 months of age have become common. In many countries including the UK, a CI is not frequently carried out in DHH children younger than 12 months despite research findings indicating this is the best time-period. Therefore, there still remain many DHH children who are implanted between 18-36 months of age, although this number is reducing gradually. Taking this into consideration, it is also necessary to discover other contributing pre-implant variables for future language development success in this group of children for whom an early CI is not currently feasible. One of the main variables to consider is the infant's ability to instigate and maintain symbolic communication before they acquire language.

2.2. Pre-linguistic social communication skills

During the first 18 months of life, there is an important phase of parent-child interaction which builds the foundations of communication and future language. Parent-child interaction and communication are often assessed in the pre-implant period when infants are considered for CI candidacy. For the purpose of the current study, early social communication is divided into social, symbolic and emerging speech skills. Early social skills include the infant's use and control of eye gaze. By six months of age, infants recognise the direction of a carer's eye-gaze as an important signal of intention and use this to follow the adult's gaze towards an object (Senju & Csibra, 2008). Infants use eye gaze in conjunction with social smiling, and gaze shift to communicate pleasure with their caregivers; thereby demonstrating a shared understanding. This early shared understanding of experiences is thought to form the foundation for later social-cognition, such as joint attention at 9 months and subsequent language acquisition (Tomasello, 2008).

In addition, the development of early symbolic play with others gives children experiences that objects can represent other entities and is highly related to language development (DeLoache, 2007; McCune, 2010). Symbolic play with objects mirrors how words are used to represent entities or events in the real world (McCune, 2010). The development of symbolic play begins in typically developing infants by recognising the relationship between real objects and associated actions (e.g. drinking from a cup). By 20 months, infants are creating play sequences that include representations for objects and actions (e.g. making a doll drink from a toy cup). There is some suggestion that DHH children with hearing parents (95% of the DHH population) engage less in symbolic play than their hearing peers (Spencer et al., 1990) and that this play is less developed and less abstract (Brown et al., 2001). Furthermore, difficulties have been observed in DHH children's understanding of social pretence (Peterson & Wellman, 2009).

The third factor encapsulated in pre-linguistic communication is emerging speech skills. For example, early variations in babble (canonical to reduplicated) and sound production (i.e. use of consonants). These early speech skills enable infants to segment the speech stream and build the organisational properties of the speech sounds and patterns inherent in the surrounding language (Levine et al., 2020). A study by Kane (2004) of 18 children with CIs correlated all three of the pre-implant communication skills (social, symbolic and speech), as measured by the Communication and Symbolic Behaviour Scales (CSBS; Wetherby & Prizant, 1993), with post-implant language scores on the Reynell Developmental Language Scales (RDLS; Reynell & Gruber, 1990). Modest positive correlations were identified but these did not reach statistical significance, possibly due to the small sample size. The current study uses the same pre-implant CSBS assessment with a much larger sample to investigate the possibility that future language development may be associated with these pre-implant communication abilities. This measure is known to give an accurate estimation of early communication skills as well as being clinically relevant.

2.3. Non-verbal cognitive ability

A range of interdependent perceptual, motoric and cognitive skills contribute to typically developing children's language development (see D'souza et al., 2017, for a review). The cognitive functions of attention and working memory are contingent upon and contribute towards language development (e.g. Gathercole & Adams, 1993; Harris et al., 2013). In the DHH child population, research has focused on the role of non-verbal cognitive measures due to the disadvantage DHH children face in verbal intelligence tests as a result of language development delay (e.g. Cejas et al., 2018). When additional disabilities are controlled for, DHH children tend not to differ from their hearing peers in terms of their general cognitive ability (De Giacomo et al., 2013; Huber & Kipman, 2012; Ulanet et al., 2014). When considering more specific aspects of ability, some research argues that reduced auditory and language input in the pre-implant period impacts on the cognitive control system (regulation of attention, memory and inhibition - see Edwards & Isquith (2020) for a review). Studies also report a positive association between nonverbal cognitive level and post implant speech perception, speech intelligibility and language outcomes (Cejas et al., 2018; Geers et al., 2003; Geers & Sedey, 2011). However, it is less well researched which specific nonverbal cognitive abilities in the pre-implant period contribute to future language development.

In clinical settings, global developmental measures which assess skills across a variety of nonverbal cognitive domains are more commonly used than specific cognitive assessments, e.g. the Schedule of Growing Skills, edition 2 (SGS-II, Bellman et al., 1996). Specific cognitive functions may then be assessed post-implantation should concerns arise regarding a child's progress (e.g., Cejas et al., 2018). The current study followed this template and assessed pre-implant cognitive, perceptual and motoric skills using the SGS-II. This assessment is an accurate measure of nonverbal cognitive level, as well as being clinically relevant.

In summary, much research describes considerable variability in language outcomes in DHH children following CI and several factors pre-implant may contribute to this. The current study examines whether AoI and pre-implant clinical assessments of nonverbal cognitive level and communication skills are significant correlates of post-implant language outcomes in a large group of DHH children over a four year time period.

Table 1
Means (Standard Deviation) and frequencies for demographic information and pre-implant assessments.

	Whole sample (n = 75)			Early implanted (AOI </= 18 months) (n = 32)			Late implanted (AOI > 18 months) (n = 43)		
	Mean (SD)	Min.	Max.	Mean (SD)	Min.	Max.	Mean (SD)	Min.	Max.
AOI	20.76 (5.95)	12	36	15.4 (1.56)	12	18	24.74 (4.74)	19	36
Gestational Age	39.2 (2.3)	26	42	39.7 (1.29)	36	42	38.9 (2.79)	26	42
Age of pre-CI assessment	12.0 (5.67)	4	26	7.7 (5.39)	5	13	15.3 (1.92)	4	26
NV cog. level	.05 (1.03)	-3	2	.38 (1.29)	-2	2	-.19 (1.05)	-3	2
	Median (IQR)	Min.	Max.	Median (IQR)	Min.	Max.	Median (IQR)	Min.	Max.
CSBS-ITC Symbolic	5.0 (10)	3	13	5.0 (5)	3	12	5.0 (2)	3	13
CSBS-ITC Social	11.0 (5)	3	17	11.0 (6)	4	15	11.0 (5)	3	17
CSBS-ITC Speech	5.0 (5)	3	11	8.0 (4)	3	10	3.0 (3)	3	11
	Category	Freq	%	Category	Freq	%	Category	Freq	%
Gender	Male	38	50.7		16	50.0		21	51.2
	Female	37	49.3		16	50.0		22	48.8
AoI	12-18 months	32	42.7						
	19-24 months	25	33.3						
	25-30 months	12	16						
	31-36 months	6	8						
Aetiology	Connexin 26	30	40		13	40.6		17	39.5
	Congenital CMV	4	5.33		1	3.1		3	7.0
	Meningitis	5	6.66		1	3.1		4	9.3
	Syndromic	14	18.7		9	28.1		5	11.5
	Unknown genetic	3	4		0	0		3	7.0
	Unknown	17	22.7		7	21.9		10	23.1
	Other	2	2.66		1	3.1		1	2.3
EAL	Monolingual	37	49.3		16	50.0		22	48.8
	Bilingual	38	50.6		16	50.0		21	51.2

Standardized score are derived from normal hearing age-mates. Abbreviations. AOI: age of implant, NV cog: Nonverbal cognition, CSBS-ITC: Communication and Symbolic Behaviour Scales – infant-toddler checklist. EAL: English as an additional language), IQR: interquartile range.

3. Methodology

This project was classified as a service evaluation project and registered with the host organisation (NHS Hospital) research audit department (Reference: Audit 2323) and therefore NHS ethical approval was not required.

3.1. Participants

The study included 75 participants aged 4-26 months at pre-implant assessment (mean 12 months, SD=5.67). Clinicians routinely collected assessment data from the participants over a four-year time period. These data were accessed via medical records from out-patient attendance at a large UK hospital. Data was accessed in accordance with General Data Protection Regulation (GDPR) guidelines. Participants were evenly split between males and females, had a diagnosis of sensorineural hearing loss at the time of the study, were severely-profoundly deaf (i.e. within criteria for cochlear implantation), received a CI between 12 and 36 months of age and were followed over a four-year period. There was an even distribution of spoken language monolingual and bilingual children (English as an additional language, EAL) in the sample. Children who had a diagnosis of an additional disability and Auditory Neuropathy Spectrum Disorder (Teagle et al., 2010) at the time of the pre-implant assessment were excluded from the study. Demographic data for the participants are presented in Table 1.

3.2. Materials and procedures

3.2.1. Age of implant (AoI)

AoI was recorded in months for all participants. The mean AoI was 21 months, with a range of 12 to 36 months (SD 6 months). Although all children were under 26 months at the time of CI assessment, there was variation in the 'time to surgery' factor due to waiting list fluctuations, other medical requirements and parental choice/attendance at appointments.

3.2.2. Pre-linguistic social communication skills

Pre-implant scores on the Communication and Symbolic Behaviour Scales – infant-toddler checklist (CSBS-ITC; Wetherby & Prizant, 2002) were used as a measure of prelinguistic communication skills. The CSBS-ITC is a norm-referenced parental report tool that gives standard scores for a social composite, a symbolic composite and a speech composite. The social composite examines skills such as eye gaze coordination, social smiling and use of vocalisation and/or gestures for communication purposes. The symbolic composite examines object use (e.g. use of objects in play, development of play) and understanding of language. The speech composite examines DHH children's use of vocalisations. The latter subtest includes parent reported variations in babble and sound play production (e.g. use of consonants, canonical or reduplicated babbling). Scores were obtained on the CSBS through parental report. Raw scores were summed for each composite and converted into standardised scores. The standardised scores for the three composites were based upon a mean of 10 and a standard deviation of 3. For ease of reading we refer to the three elements of this measure with the test acronym CSBS-ITC, followed by the particular area of development i.e. CSBS-ITC *social*, CSBS-ITC *symbolic* or CSBS-ITC *speech.*

3.2.3. Nonverbal cognitive ability

The Schedule of Growing Skills II (SGS-II, Bellman et al., 1996) was used as a measure of nonverbal cognitive level. The SGS-II was administered at the pre-CI assessment session and assesses the developmental level of infants and children up to five years old. Six skills are routinely assessed during the CI assessment process: locomotor, manipulative, visual, interactive, self-care, social and cognitive. A rating scale devised by Edwards et al., (2006) based on age and score on the subskills measured by the SGS-II was used to derive a comparable score for each domain. This assessment places the child's development for each given skill area within an age-equivalent band. Edwards et al. (2006) converted these sub-skill measurements into comparable scores by measuring the difference between the child's developmental age band and their chronological age. For example, if the child's skills within a given domain were

Table 2
Cochlear Implant Outcome Scale.

Receptive Language				Expressive Language			
Standard Score	Percentile	Classification	Rating	Standard Score	Percentile	Classification	Rating
85 +	16+	Average (Caught up with hearing peers)	5	85 +	16+	Average (Caught up with hearing peers)	5
77-84 (1 SD below)	6-16	Mild (Above hearing age but below hearing peers)	4	78-84 (1 SD below)	6-16	Mild (Above hearing age but below hearing peers)	4
71-77 (2 SD below)	3-6	Moderate (Caught up with hearing age but below peers)	3	71-77 (2 SD below)	3-6	Moderate (Caught up with hearing age but below peers)	3
70 and below (3 SD below)	<0.1 - 2	Severe (Below hearing age)	2	70 and below (3 SD below)	<0.1 - 2	Severe (Below hearing age)	2
70 and below (3 SD below)	N/A	Profound (Significantly below hearing age)	1	70 and below (3 SD below)	N/A	Profound (Significantly below hearing age)	1

Scores based on formal assessment where possible. If formal assessment is not possible, informal assessment and parental report will be used to allocate an outcome score.

age-appropriate, they would score 0. Conversely, if their skills were delayed by one age-band they would score -1, whereas if their skills were in advance of their chronological age by one age band, they would score +1, and so on. Edwards et al. (2006) reported that the visual score data strongly predicted nonverbal cognitive level. The same system for scoring and subsequent statistical analyses were used in the present study.

3.2.5. Language outcomes

A range of different post-implant language assessments were used depending upon the chronological age of the child: the Pre-School Language Scales, fourth edition (Zimmerman et al., 2002) and fifth edition (Zimmerman et al., 2011); the Pre-School Clinical Evaluation of Language Fundamentals, second edition (Wiig et al., 2004); the Clinical Evaluation of Language Fundamentals, fourth edition (Semel et al., 2003), and the British Picture Vocabulary Scales, third edition (Dunn et al., 2009). All of these language measures result in a standardized score with a mean of 100 and a SD of 15 or a percentile rank relative to hearing-age mates.

Due to the variation in the language assessments used, the authors developed a Cochlear Implant Outcome Scale measure (see Table 2) to rate each child's receptive and expressive language level derived from formal assessment scores, clinical reports, notes from observations and parental report. Each child was assigned a separate outcome score for expressive and receptive language rating from one to five. An inter-rater reliability check of 20.7% (n=21) of cases was carried out by two Highly Specialist Speech and Language Therapists from the CI team, with 90.5% agreement. Any discrepancies were discussed and resolved.

3.3. Statistical analysis

Descriptive statistics were examined for all tasks. Due to the ordinal nature of the language outcome data, Spearman Rank bivariate correlations were used to evaluate the associations between the key pre-implant variables and subsequent language outcomes at three time points. As much previous evidence exists for the role of AoI on language development in DHH children, participants were then split into two groups based upon age of implantation: children implanted </= 18 months of age (early-implanted, n=32) and those implanted >18 months of age (late-implanted, n=43). Bivariate correlations were run for each group using the remaining variables; nonverbal cognitive level, CSBS-ITC and language outcome data for each time point. AoI was not included as a potential correlate because the effect of AoI had been accounted for by the division of data. We were particularly interested in the interactive relationship between early AoI and pre-implant social-communication skills.

4. RESULTS

Table 3 contains the medians, interquartile ranges, minimum and maximum scores for the language outcomes at each time point: 1, 2 and 4 years post implant. Table 4 shows the Spearman Rank correlations for the whole sample between AoI, nonverbal cognitive level, CSBS-ITC scores, and receptive and expressive language outcomes (measured at one year, two years and four years post implant). AoI was the strongest correlate of language outcomes showing small to medium correlations across all time points. Nonverbal cognitive ability exhibited small correlations with receptive and expressive outcomes at two years post implant and four years post implant. A Bonferroni correction was applied to the correlation results to control for the possible effect of multiple comparisons and potential Type 1 errors, reducing the alpha level down to $p<.002$. After this correction had been applied the only correlations that remained significant were those between AoI and expressive language outcomes across all time periods and receptive language outcomes at two years post implant (see Table 4).

To look at the relationship between pre-implant prelinguistic social-communication skills and later language outcomes in more detail we divided the group into two subgroups: those who were implanted before 18 months and those who were implanted after 18 months. There were no significant differences between the early and late implanted groups in their gestational age ($t(62.5) = 1.65$, $p= .139$), gender (χ^2 $(75) = .01$, $p= .921$), EAL proportions (χ^2 $(75) = 2.37$, $p= .306$), CSBS-ITC symbolic ($t(57.8) = 1.00$, $p= .303$) or CSBS-ITC social scores ($t(73) = .06$, $p= .955$). The early implanted group had significantly higher ability scores ($t(73) = 2.42$, $p= .018$) and CSBS-ITC speech scores ($t(73) = 4.76$, $p< .001$).

Tables 5 and 6 display Spearman Rank bivariate correlations for the early implant and late implant groups between nonverbal

Table 3
Language Outcome scores for whole dataset and divided by AOI.

	Receptive Language 1 year post implant			2 year post implant			4 year post implant		
	Median (IQR)	Min	Max	Median (IQR)	Min	Max	Median (IQR)	Min	Max
Overall	2.0 (2)	1	5	2.0 (2)	1	5	4.0 (3)	1	5
AOI <18 months	2.0 (2)	1	5	3.0 (2)	1	5	5.0 (3)	1	5
AOI >18 months	2.0 (1)	1	3	2.0 (1.)	1	5	3.0 (3)	1	5
	Expressive Language 1 year post implant			2 year post implant			4 year post implant		
	Median (IQR)	Min	Max	Median (IQR)	Min	Max	Median (IQR)	Min	Max
Overall	2.0 (1)	1	5	2.0 (2)	1	5	3.0 (2)	1	5
AOI <18 months	3.5 (3)	1	5	3.0 (2)	1	5	4.0 (3)	1	5
AOI >18 months	2.0 (1)	1	4	2.0 (1)	1	4	2.0 (3)	1	5

Table 4
Correlations between pre-implant factors and language outcomes for whole dataset (n=75).

Age of Implant	1 yr post implant rec. -.299**	1 yr post implant exp. -.406***	2 yrs post implant rec. -.454***	2 yrs post implant exp. -.458***	4 yrs post implant rec. -.283*	4 yrs post implant exp. -.376**
NV cog. level	.135	.135	.301**	.295**	.276*	.316**
CSBS-ITC Symbolic	.108	-.032	.167	.099	.295*	.213
CSBS-ITC Social	.149	.081	.149	.148	.261*	.245*
CSBS-ITC Speech	.180	.255*	.248*	.231*	.192	.222

***p<.001, **p<.01; *p<.05

cognitive ability, pre-linguistic CSBS-ITC scores and language outcome data for each time point, respectively. When we split the group AoI showed no significant correlations with language outcomes or social skills for either the early implant group or the late implant group. A Bonferroni correction was applied to the correlation results to control for the possible effect of multiple comparisons and potential Type 1 errors, reducing the alpha level down to p=.002. This meant that for the group of late-implanted children (see Table 6) after applying the Bonferroni correction, there were no significant correlations between pre-implant CSBS-ITC Symbolic scores and receptive language outcome scores. In the early-implanted group of children (see Table 5), nonverbal cognitive ability scores were not significantly correlated with receptive and expressive language outcome at any time point. However, after a Bonferroni correction had been applied, the CSBS-ITC social score was significantly related to expressive language outcomes at time four rho=.542, $p<$ .001).

5. Discussion

As described in the introduction, several interdependent perceptual, motoric and cognitive skills are implicated in typically developing (D'souza et al., 2017) and DHH children's (Levine et al., 2020) language development. In the current study we looked at AoI, pre-linguistic social-communication skills (social, symbolic and speech) and nonverbal cognitive ability and their association with language outcomes observed one to four years post-implant. These factors have a good foundation in previous research and are measures routinely collected in clinical settings. We used a large and representative clinical sample of DHH children in our analyses where currently CI age typically varies between 12-36 months. The current study confirms that these three pre-implant measures can provide important information regarding the language outcomes of CI cases and guide clinical recommendations. The particular measures used in this study have validity as a number of CI centres use the same measures in many countries.

Looking at the whole data-set the AoI variable was the strongest correlate of language outcomes at each time point. These results support many previous studies (Cuda et al., 2014; Dettman et al., 2016; Holman et al., 2013; Geers & Nicholas, 2013; Leigh et al., 2013; Tobey et al., 2013; Szagun & Schramm, 2016). However, in the current study this finding was driven by the early implanted children. Once we split the data set by early and late AoI, these correlations disappear. In the early implanted group, it was the interaction of pre-implant social communication and early AoI together which correlated with language scores. The CSBS-ITC social communication measure emerged as a particularly useful tool when considering long-term language development outcomes for children implanted under 18 months of age. Further, use of this tool offers CI teams the opportunity to counsel parents with regards to their expectations and plan for the therapy support needed to maximise early child social communication.

Our finding that early social communication is an important pre-implant factor, especially for early implanted infants in terms of future language outcomes, suggests that in clinic, more attention should be devoted to the pre-implant analysis of the quality of parent-child social interaction. Clinical observations of social interaction and play during the assessment period pre-implant may guide therapeutic support to parents regarding their communication and interactions with their child. Indeed, Roberts (2019) evaluated an early social interaction intervention for parents with deaf six- to 24 month-olds. Hearing parents in the intervention group increased the frequency with which they used higher quality social communicative cues, e.g., connected turns, compared to no intervention parents. Additionally, Nicastri, et al., (2021) evaluated a training programme to promote early social interaction skills in parents of 14 deaf infants who were implanted at 26 months of age. Trained parents also increased the quality of interaction significantly more than controls, with positive effects on children's vocabulary development at 36-months post-intervention

Dividing the sample into the early and late-implanted groups changed the strength of correlations observed between the pre-

Table 5
Correlations for early-implanted subgroup i.e. AOI</=18 months (n=32).

Age of Implant	1 yr post implant rec. -.33	1 yr post implant exp. -.09	2 yrs post implant rec. .02	2 yrs post implant exp. -.02	4 yrs post implant rec. .24	4 yrs post implant exp. .21
NV IQ	-.088	-.056	.345	.223	.275	.220
CSBS-ITC Symbolic	.024	-.293	.241	.193	.271	.123
CSBS-ITC Social	.336	.216	.474**	.390*	.496**	.542***
CSBS-ITC Speech	102	.146	.087	.064	.144	-.057

***p>.001, **p<.01; *p<.05

Table 6
Correlations for late-implanted subgroup i.e. AOI>18 months (n=43).

	1 yr post implant rec.	1 yr post implant exp.	2 yrs post implant rec.	2 yrs post implant exp.	4 yrs post implant rec.	4 yrs post implant exp.
Age of Implant	-.02	.07	-.05	-.10	-.14	-.16
NV IQ	.124	.069	.111	.143	.181	.242
CSBS-ITC Symbolic	.169	.200	.073	-.011	.306*	.252
CSBS-ITC Social	-.025	-.086	-.114	-.045	.073	.036
CSBS-ITC Speech	-.167	-.238	-.217	-.209	-.058	-.015

***p>.001, **p<.01; *p<.05

implant factors and future language outcomes. For those who were early-implanted, pre-implant CSBS-ITC social skills were the strongest correlates of language outcomes. However, for children who received implants after 18 months of age, none of the pre-implant variables significantly correlated with language outcomes (after Bonferonni correlations were applied). Correlations between language and pre-implant factors for the DHH children who received a CI past the age of 18 months were less easy to identify.

Taking the social communication and AoI data together, it appears that good early social communication skills coupled with an early implant combine to facilitate future language development. There is a strong theoretical explanation for this finding from the literature which argues that the building blocks of language come from earlier social-communicative routines. In the wider population of hearing children, experience of communicative interactions forms the foundation of children's language development (Tomasello, 2008). In terms of DHH children, improved early access to sound and language from early implantation interacts with children's motivation and success with social interaction and the symbolic foundations of language development. In the whole dataset, as pre-implant social communication scores increased, later receptive and expressive language outcomes (four years post implant) improved. However, when the groups were divided into early-implanted and late-implanted children, it became apparent that the importance of this variable for the combined group was driven by the early-implanted group of children.

Our explanation for the role of social communication in the younger group is that DHH children who have better pre-linguistic communicative behaviours may provoke more stimulating language interactions with parents and an early CI maximises this potential. Levine et al., (2020) made the important observation that parents adapt the complexity of their interactions to the communication skills of the child. DHH infants and children with better communication skills spend more time in language interaction with their parents. These data highlight the reciprocal relationship between early social communication skills and parent language input observed in hearing (Beuker et al., 2013) and in DHH infants (Kelly et al., 2020). In the Kelly et al. (2020) study, the early communicative behaviours of deaf infants whose parents were hearing were compared with matched, typically-hearing dyads. DHH infants both produced fewer pre-linguistic communicative behaviours during interaction and were less likely to attend to their parent's reinforcement of the child's attempt to communicate. In the current study, DHH children who scored higher on social communication would be more able to initiate and in turn be reinforced by their attempts to communicate. This virtuous circle is more apparent in the children who have had an earlier CI. However, this virtuous circle is less advantageous when the child has a late CI. Older children have perhaps passed the critical window when social-communication and language input come together. A late CI misses this early social-communicative sensitivity. This novel finding adds to the growing literature on the role of pre-implant factors by nuancing the importance of early AoI coupled with social-communication readiness.

Lastly, the third variable considered - pre-implant nonverbal cognitive level - was not a significant correlate of language outcomes once AoI had been accounted for by dividing the group. This finding contrasts with previous studies reporting a relationship between nonverbal cognitive level and language outcomes for CI children (e.g. Cejas et al., 2018). However, children with additional disabilities were excluded from our sample and this may have restricted the range of nonverbal cognitive scores observed.

Whilst the findings from the current study suggest that several relationships between pre-implant factors and language outcomes can be captured based on available information at the time of candidacy assessment, a large part of language outcomes remains unexplained. This is not surprising given the many other factors known to impact outcomes, especially in children over 18 months of age. For example, in the present study, it was not possible to accurately record residual hearing thresholds for all participants due to significant variation in testing methods. As discussed in the methods section, a range of different standardised language tests were used to collect post implant language data due to differences in chronological age when children were assessed. The authors subsequently created a CI language rating to enable comparisons of language outcomes across different assessments.

Further, different types and amounts of post-implant rehabilitation are likely to affect outcomes in children with cochlear implants. In this study, all children received the same rehabilitation at a single cochlear implant centre, with further rehabilitation provided by local services. Rehabilitation by local services is typically variable and was not documented in this study. Future research should consider the relative contribution of post-implant rehabilitation to language outcomes.

The findings suggest that pre-implant social communication skills are associated with broad post implant language outcomes in early implanted children, regardless of the specific standardised language assessment used. Our findings have important practical implications as different clinics often use different standardised assessments. Nevertheless, using a cochlear implant language rating scale instead of standardised test scores as the outcome variables meant we were unable to determine the relative predictive power of the three pre-implant factors through multiple regression analyses. Furthermore, it is unknown whether the exact relationships between pre-implant factors and post-implant language outcomes might vary depending upon the specific standardised language test used post implant. It is also important to note that the lack of a consistent difference between language outcomes between one and two years post implant does not necessarily mean that children did not improve in their language abilities over that time period. It is likely that children improved in accuracy over time on the actual language assessments administered but that the improvements in standardised scores were not large enough to significantly change the broader outcome rating scale. The current findings should be validated with future studies using standardised language tests scores as the outcome measures.

Another limitation of the current study was the nature of retrospective data, as it is possible that in some cases records are interpreted in light of current observations. Finally, in terms of measuring social communication skills, the CSBS-ITC composite score is a gross measure of these abilities and focuses on the child's rather than the parent-child combined abilities.

6. Future research

In future studies, the predictive value of pre-implant language assessments used by different CI centres should be investigated in order to compare assessment protocols across centres, and the benefits and limitations of differing approaches. It is also possible that the relationship between language outcomes and pre-implant factors may be different for children with a younger AoI than in our sample. It may also be an interesting methodology in future work to look at variability in prelinguistic communication skills, specifically in groups of DHH children with AoI less than 18 months of age, and their future language outcomes. Future research should also investigate whether the same set of factors as used in the current study apply to future generations of DHH children where AoI is below 12 months of age. Future research could look at the relationship between social communication pre-implant and post-implant, and over a longer time period (e.g., middle school aged children or older) to see if these differences are still significant. Finally, it would be interesting to test whether intervention for poor social communication skills pre-implant changes post-implant outcomes (or whether this is a fixed trait or a sign of other difficulties that have implications for language acquisition, such as autism).

There are clinical implications based on this study. It is recommended that CI and early intervention teams in general. consider the routine measurement of social communication skills in the pre-implant period (Nicastri et al., 2021). In addition, the measurement of social communication can be used in guiding parent expectations regarding long-term outcomes after cochlear implantation in children below the age of 18 months.

CRediT authorship contribution statement

Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualisation; Writing - original draft; Writing - review & editing. Gemma Hardman: Conceptualization; Data collection/ curation; Formal analysis; Funding acquisition (lead); Methodology; Project administration; Validation; Writing - original draft; Writing - review & editing. Dr Fiona Kyle: Data collection/ curation; Formal analysis; Methodology; Validation; Writing - review & editing. Prof Ros Herman: Conceptualization; Data collection/ curation; Funding acquisition (support to PI); Methodology; Supervision; Validation; Writing - review & editing. Prof Gary Morgan: Conceptualization; Data collection/ curation; Funding acquisition (support to PI); Methodology; Supervision; Validation; Writing - review & editing.

CRediT authorship contribution statement

Gemma Hardman: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. **Fiona Kyle:** Data curation, Formal analysis, Methodology, Validation, Writing – review & editing. **Rosalind Herman:** Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing. **Gary Morgan:** Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing.

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References

Bellman, M., Lingam, S., & Aukett, A. (1996). *Schedule of Growing Skills II Reference Manual*. London: GL Assessment.

Beuker, K. T., Rommelse, N. N. J., Donders, R., & Buitelaar, J. K. (2013). Development of early communication skills in the first two years of life. *Infant Behavior and Development, 36*(1), 71–83. https://doi.org/10.1016/j.infbeh.2012.11.001

Brown, P. M. (2001). Structures underpinning pretend play and word production in young hearing children and children with hearing loss. *Journal of Deaf Studies and Deaf Education, 6*(1), 15–31. https://doi.org/10.1093/deafed/6.1.15

Bruijnzeel, H., Ziylan, F., Stegeman, I., Topsakal, V., & Grolman, W. (2016). A systematic review to define the speech and language benefit of early (<12 months) pediatric cochlear implantation. In *, 21. Audiology and Neurotology* (pp. 113–126). S. Karger AG.. https://doi.org/10.1159/000443363

Campbell, R., Macsweeney, M., & Woll, B. (2014). Cochlear implantation (CI) for prelingual deafness: The relevance of studies of brain organization and the role of first language acquisition in considering outcome success. *Frontiers in Human Neuroscience, 8*. https://doi.org/10.3389/fnhum.2014.00834. OCT.

Cejas, I., Mitchell, C. M., Hoffman, M., Quittner, A. L., Santina, C.della, Marsiglia, D., Martinez, D., Telischi, F., Glover, R., Sarangoulis, C., Zwolan, T., Arnedt, C., Teagle, H. F. B., Woodard, J., Eskridge, H., Eisenberg, L. S., Johnson, K., Fisher, L., Ganguly, D. H., … Wang, N. Y. (2018). Comparisons of IQ in children with and without cochlear implants: Longitudinal findings and associations with language. *Ear and Hearing, 39*(6), 1187–1198. https://doi.org/10.1097/AUD.0000000000000578

Ching, T. Y. C., Day, J., Seeto, M., Dillon, H., Marnane, V., & Street, L. (2013). Predicting 3-year outcomes of early-identified children with hearing impairment. *B-ENT, 21*(SUPPL. 21), 99–106. Suppl www.outcomes.nal.gov.au.

Cuda, D., Murri, A., Guerzoni, L., Fabrizi, E., & Mariani, V. (2014). Pre-school children have better spoken language when early implanted. *International Journal of Pediatric Otorhinolaryngology, 78*(8), 1327–1331. https://doi.org/10.1016/j.ijporl.2014.05.021

de Giacomo, A., Craig, F., D'Elia, A., Giagnotti, F., Matera, E., & Quaranta, N (2013). Children with cochlear implants: Cognitive skills, adaptive behaviors, social and emotional skills. *International Journal of Pediatric Otorhinolaryngology, 77*(12), 1975–1979. https://doi.org/10.1016/j.ijporl.2013.09.015

DeLoache, J. S. (2007). Early development of the understanding and use of symbolic artifacts. In *Blackwell Handbook of Childhood Cognitive Development* (pp. 206–226). Blackwell Publishers Ltd. https://doi.org/10.1002/9780470996652.ch10.

Dettman, S. J., Dowell, R. C., Choo, D., Arnott, W., Abrahams, Y., Davis, A., Dornan, D., Leigh, J., Constantinescu, G., Cowan, R., & Briggs, R. J. (2016). Long-Term communication outcomes for children receiving cochlear implants younger than 12 months: A multicenter study. *Otology and Neurotology, 37*(2), e82–e95. https://doi.org/10.1097/MAO.0000000000000915

D'souza, D., D'souza, H., & Karmiloff-Smith, A. (2017). Precursors to language development in typically & atypically developing infants & toddlers: The importance of embracing complexity. In *, 44*. *Journal of Child Language* (pp. 591–627). Cambridge University Press. https://doi.org/10.1017/S030500091700006X.

Dunn, L. M., Dunn, L. M., & Styles, B. (2009). *British Picture Vocabulary Scales* (3rd edition). London: GL Assessment.

Edwards, L., Frost, R., & Witham, F. (2006). Developmental delay and outcomes in cochlear implantation: Implications for candidacy. *International Journal of Pediatric Otorhinolaryngology, 70*, 1593–1600.

Edwards, L. C., & Isquith, P. K. (2020). Cognitive Development. In Marc Marschark, & H. Knoors (Eds.), *The Oxford Handbook of Deaf Studies in Learning and Cognition* (pp. 197–212). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190054045.013.7.

Gathercole, S. E., & Adams, A. M. (1993). Phonological working memory in very young children. *Developmental Psychology, 29*(4), 770–778. https://doi.org/10.1037/0012-1649.29.4.770

Geers, A., Brenner, C., & Davidson, L. (2003). Factors associated with development of speech perception skills in children implanted by age five. *Ear and Hearing, 24*(1 SUPPL). https://doi.org/10.1097/01.aud.0000051687.99218.0f

Geers, A. E., & Nicholas, J. G. (2013). Enduring advantages of early cochlear implantation for spoken language development. *Journal of Speech, Language, and Hearing Research, 56*(2), 643–655. https://doi.org/10.1044/1092-4388(2012/11-0347

Geers, A. E., Nicholas, J., Tobey, E., & Davidson, L. (2016). Persistent language delay versus late language emergence in children with early cochlear implantation. *Journal of Speech, Language, and Hearing Research, 59*(1), 155–170. https://doi.org/10.1044/2015_JSLHR-H-14-0173

Geers, A. E., & Sedey, A. L. (2011). Language and verbal reasoning skills in adolescents with 10 or more years of cochlear implant experience. *Ear and Hearing, 32*(1 Suppl). https://doi.org/10.1097/aud.0b013e3181fa41dc

Harris, M. S., Kronenberger, W. G., Gao, S., Hoen, H. M., Miyamoto, R. T., & Pisoni, D. B. (2013). Verbal short-term memory development and spoken language outcomes in deaf children with cochlear implants. *Ear and Hearing, 34*(2), 179–192. https://doi.org/10.1097/AUD.0b013e318269ce50

Holman, M. A., Carlson, M. L., Driscoll, C. L. W., Grim, K. J., Petersson, R. S., Sladen, D. P., & Flick, R. P. (2013). Cochlear implantation in children 12 months of age and younger. *Otology and Neurotology, 34*(2), 251–258. https://doi.org/10.1097/MAO.0b013e31827d0922

Huber, M., & Kipman, U. (2012). Cognitive skills and academic achievement of deaf children with cochlear implants. *Otolaryngology - Head and Neck Surgery (United States), 147*(4), 763–772. https://doi.org/10.1177/0194599812448352

Kane, M., Schopmeyer, B., Mellon, N., Wang, N., & Niparko, J. K. (2004). Prelinguistic communication and subsequent language acquisition in children with cochlear implants. *Archives of Otolaryngology Head and Neck Surgery, 130*(5), 619–623.

Kelly, C., Morgan, G., Bannard, C., & Matthews, D. (2020). Early pragmatics in deaf and hard of hearing infants. *Pediatrics, 146*, 0242E. https://doi.org/10.1542/peds.2020-0242E

Leigh, J., Dettman, S., Dowell, R., & Briggs, R. (2013). Communication development in children who receive a cochlear implant by 12 months of age. *Otology and Neurotology, 34*(3), 443–450. https://doi.org/10.1097/MAO.0b013e3182814d2c

Levine, D., Strother-Garcia, K., Golinkoff, R. M., & Hirsh-Pasek, K. (2016). Language development in the first year of life: What deaf children might be missing before cochlear implantation. *Otology and Neurotology, 37*(2), e56–e62. https://doi.org/10.1097/MAO.0000000000000908

Levine, D., Avelar, D., Golinkoff, R. M., Hirsh-Pasek, K., & Houston, D. M. (2020). Foundations of language development in deaf and hard-of-hearing infants. In *The Oxford Handbook of Deaf Studies in Learning and Cognition* (pp. 19–32). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190054045.013.31.

McCune, L. (2010). Developing symbolic abilities. In B. Wagoner (Ed.), *Symbolic transformation: The mind in movement through culture and society* (pp. 173–192). Routledge Press.

National Institute for Health and Clinical Excellence (NICE). (2019). *Cochlear implants for children and adults with severe to profound deafness*. NICE technology appraisal guidance 566. [online] Available at https://www.nice.org.uk/guidance/ta566 [Accessed 04 Mar. 2021].

Nicastri, M., Giallini, I., Ruoppolo, G., Prosperini, L., de Vincentiis, M., Lauriello, M., Rea, M., Traisci, G., & Mancini, P. (2021). Parent training and communication empowerment of children with cochlear implant. *Journal of Early Intervention, 43*, 117–134. https://doi.org/10.1177/1053815120922908

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N. Y., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *JAMA - Journal of the American Medical Association, 303*(15), 1498–1506. https://doi.org/10.1001/jama.2010.451

Peterson, C. C., & Wellman, H. M. (2009). From fancy to reason: Scaling deaf and hearing children's understanding of theory of mind and pretence. *British Journal of Developmental Psychology, 27*(2), 297–310. https://doi.org/10.1348/026151008X299728

Pisoni, D. B., Conway, C. M., Kronenberger, W. G., Horn, D. L., Karpicke, J., & Henning, S. C (2008). Efficacy and effectiveness of cochlear implants in deaf children. In M. Marschark, & P. C. Hauser (Eds.), *Deaf Cognition: Foundations and Outcomes* (pp. 52–101). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195368673.003.0003.

Pisoni, D. B., Kronenberger, W. G., Harris, M. S., & Moberly, A. C. (2017). Three challenges for future research on cochlear implants. *World Journal of Otorhinolaryngology - Head and Neck Surgery, 3*(4), 240–254. https://doi.org/10.1016/j.wjorl.2017.12.010

Reynell, J. K., & Gruber, C. P. (1990). *Reynell Developmental Language Scales*. Los Angeles, California: Western Psychological Services.

Roberts, M. Y. (2019). Parent-implemented communication treatment for infants and toddlers with hearing loss: A randomized pilot trial. *Journal of Speech, Language, and Hearing Research, 62*(1), 143–152. https://doi.org/10.1044/2018_JSLHR-L-18-0079

Semel, E., Wiig, E., & Secord, W. (2003). *Clinical evaluation of language fundamentals* (4th edition). San Antonio, TX: The Psychological Corporation.

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology, 18*(9), 668–671. https://doi.org/10.1016/j.cub.2008.03.059

Smith, L. B., Quittner, A. L., Osberger, M. J., & Miyamoto, R. (1998). Audition and visual attention: The developmental trajectory in deaf and hearing populations. *Developmental Psychology, 34*(5), 840–850. https://doi.org/10.1037//0012-1649.34.5.840

Spencer, P. E., Deyo, D., & Grindstaff, N. (1990). Symbolic play behaviour of hearing impaired and hearing toddlers. In D. F. Moores, & K. P. Meadow-Orleans (Eds.), *13 Educational and Developmental Aspects of Hearing Impairment*. Gallaudet University Press.

Spencer, P., & Marschark, M. (2010). *Evidence of best practice models and outcomes in the education of deaf and hard-of-hearing children: an international review*. Oxford University Press.

Szagun, G., & Schramm, S. A. (2016). Sources of variability in language development of children with cochlear implants: Age at implantation, parental language, and early features of children's language construction. *Journal of Child Language, 43*(3), 505–536. https://doi.org/10.1017/S0305000915000641

Teagle, H. F. B., Roush, P. A., Woodard, J. S., Hatch, D. R., Zdanski, C. J., Buss, E., & Buchman, C. A. (2010). Cochlear implantation in children with auditory neuropathy spectrum disorder. *Ear and Hearing, 31*(3), 325–335. https://doi.org/10.1097/AUD.0b013e3181ce693b

Tobey, E. A., Thal, D., Niparko, J. K., Eisenberg, L. S., Quittner, A. L., & Wang, N. Y. (2013). Influence of implantation age on school-age language performance in pediatric cochlear implant users. *International Journal of Audiology, 52*(4), 219–229. https://doi.org/10.3109/14992027.2012.759666

Tomasello, M. (2008). *Origins of Human Communication*. MIT Press.

Ulanet, P. G., Carson, C. M., Mellon, N. K., Niparko, J. K., & Ouellette, M. (2014). Correlation of neurocognitive processing subtypes with language performance in young children with cochlear implants. *Cochlear Implants International, 15*(4), 230–240. https://doi.org/10.1179/1754762814Y.0000000077

Watkin, P., McCann, D., Law, C., Mullee, M., Petrou, S., Stevenson, J., Worsfold, S., Ho, M. Y., & Kennedy, C. (2007). Language ability in children with permanent hearing impairment: The influence of early management and family participation. *Pediatrics, 120*(3). https://doi.org/10.1542/peds.2006-2116

Wetherby, A., & Prizant, B. (1993). *Communication and Symbolic Behavior Scales- Normed Edition*. Chicago, IL: Applied Symbolix.

Wiig, E. H., Secord, W. A., & Semel, E. (2004). *The Clinical Evaluation of Language Fundamentals – Preschool, edition 2*. San Antonio, TX: Harcourt Assessment.

Zimmerman, I. L., Steiner, V. G., & Pond, R. E. (2002). *Preschool Language Scale* (4th edition). San Antonio, TX: The Psychological Corporation.

Zimmerman, I. L., Steiner, V. G., & Pond, R. E. (2011). *Preschool Language Scale* (5th edition). San Antonio, TX: The Psychological Corporation.