Language skill development in children with cochlear implants and the impact of age at switch-on

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Deaf and hard-of-hearing (DHH) children with cochlear implants (CwCIs) constitute a heterogeneous population. A multitude of factors influence their spoken language development. There is evidence that CwCIs follow similar trajectories in language development as typically developing (TD) children but there is a lack of research on specific types of skills. This study aimed to (1) map the trajectory of receptive and expressive language skill development of a representative group of CwCIs and (2) evaluate the impact of age at switch-on (ASO) on skill development. This paper presents a detailed analysis of the language outcomes of 44 CwCIs with ASO between 11 and 45 months (M = 26.02 SD = 8.31). These children were tracked for the first two years following implantation. Clustered bar charts were used to compare specific types of skills acquired by CwCIs with ASO ≤2 years vs. >2 years. The results suggest that CwCIs generally acquire receptive and expressive language skills along a similar sequence to TD children, but there is individual variability relating to specific skills. However, the language outcomes of CwCIs are ultimately the result of a complex interplay of demographic variables.

Keywords: cochlear implant, age at switch-on, language, language development, language outcome, language skill

Introduction

Hearing and language development in children with cochlear implants

Cochlear implantation is the prosthetic replacement of cochlear function in those with severe to profound sensorineural hearing loss (Coene & Govaerts, 2014). Cochlear implants (CIs) convert mechanical sound energy into electrical stimuli, directly stimulating elements of the auditory pathway with residual function (Coene & Govaerts, 2014; National Institute on Deafness and Other Communication Disorders [NIDCD], 2017). CIs are now a standard intervention for children with severe to profound sensorineural hearing loss (Pisoni et al., 2017). In the UK simultaneous bilateral implantation is recommended when binaural hearing aids do not adequately support children's development of "speech, language and listening skills appropriate to age, developmental stage and cognitive ability" (National Institute for Health and Care Excellence [NICE], 2019). In 2019, there were 4218 children with CIs (CwCIs), unilateral or bilateral, in the UK (CRIDE, 2019).

CIs provide crucial oral linguistic exposure to children during a sensitive period of language acquisition (Hammer et al., 2014; Nicholas & Geers, 2018). Certainly, some CwCIs have been shown to achieve better language outcomes than children with hearing aids (Monteiro et al., 2016) as the improved quality of auditory input provides a significant advantage in oral language development (Coene & Govaerts, 2014). However, the auditory input from CIs remains degraded in frequency, temporal modulation, and loudness in comparison to normal hearing (Macherey & Carlyon, 2014). Hence, CwCIs will continue to experience poorer auditory input both pre- and post-implantation (Hayes et al., 2009). The effects of these disadvantages on language development have been studied extensively.

One study found the mean score of 111 CwCIs aged 5;0 (years;months) was more than 1 standard deviation (s.d.) below the mean on a language assessment standardised on typically developing (TD) children (Cupples et al., 2018). In the UK, only 36% of profoundly deaf CwCIs achieved the Early Years Foundation Stage (EYFS) goal[3] in communication and language compared to 81% of all hearing children (RCSLT & NDCS, 2017). When looking specifically at vocabulary, Fagan (2015) found that 26-month-old CwCIs implanted between 8 and 14 months had a delay of approximately 6 months; this lag has been seen across various language domains (Coene & Govaerts, 2014), from grammatical structures (e.g., Guo and Spencer, 2017) to vocabulary (e.g., Hayes et al., 2009). However, there remains limited research on whether CwCIs' development is delayed along the typical trajectory or if their development follows a different acquisition pattern, and whether there is a difference in the specific skills achieved by CwCIs versus those achieved by TD children. This is particularly important for the English-speaking population as no recent studies have been conducted although current findings in other languages are available.

Mandarin-speaking CwCIs developed early language along a typical trajectory albeit with a delay (Lu & Qin, 2018). Li et al. (2020) showed that Mandarin-speaking CwCIs developed word comprehension and word expression in the first year post-implantation along a similar trajectory to TD children. They also indicated that word comprehension is acquired before word expression because it provides the foundation for the latter (Li et al., 2020). Similarly, Schramm et al. (2010) found that German-speaking CwCIs followed the same initial stages of language acquisition as children with normal hearing and a similar pattern of

[3] The Early Years Foundation Stage (EYFS) statutory framework provided by the UK Department for Education sets out the standards that school and childcare providers must meet for the learning, development and care of children from birth to 5 years (Department for Education, 2014).

phonological development in acquiring consonants. While these studies compared early language development patterns, some differences may only become apparent later. For instance, Wie et al. (2020) found that Norwegian-speaking CwCIs began to fall behind their TD peers from 4-years post-implantation on receptive vocabulary and expressive grammar.

These studies cannot be generalised to the developmental trajectory of specific types of skills in English-speaking CwCIs. Hence, the first aim of this study is to map the trajectory of receptive and expressive language skill development following cochlear implantation for a representative group of CwCIs.

Furthermore, the exact language outcomes of CwCIs vary greatly, depending on a complex interplay of non-exhaustive factors (Coene & Govaerts, 2014; Peterson et al., 2010). The challenge for research is to first understand the variability in language outcomes and then to identify ways to predict these outcomes (Pisoni et al., 2017). Identifying predictive variables will enable early intervention to be targeted towards CwCIs at greatest risk. This is especially important because better language skills are strongly correlated with a child's quality of life (Ronner et al., 2020; Silva et al., 2019) and their educational outcomes (Hulme et al., 2020). To this end, this paper will examine age at switch-on (ASO), a factor known to affect the language skills of English-speaking CwCIs.

Some methodological questions about the way ASO is measured and categorised have been raised (Marschark et al., 2019). However, ASO remains an important predictor of language proficiency (Chilosi et al., 2013), even though it does not account for all the variability in CwCIs' language development (Tobey et al., 2013). Implantation by 18-24 months of age consistently predicts better outcomes across a range of language skills than

later implantation (Boons et al., 2012; Coene & Govaerts, 2014; Hammer et al., 2014; Nicholas & Geers, 2018; Ruben, 2018). Other studies have suggested even younger implant ages, before 12 months, to be most beneficial for outcomes such as auditory comprehension (Ching et al., 2017; Mitchell et al., 2019). In particular Ching et al. (2017) found that children who received cochlear implants at 6 months had stronger language skills than those implanted at 2 years old.

When looking at longer-term language outcomes in older children, the impact of ASO is less well understood. While some studies found that ASO predicts long-term function in CwCIs up to 6-years post-implantation (e.g., Castellanos et al., 2014; Dettman et al., 2016; Geers et al., 2016), ASO was no longer indicative of language difficulties more than 10-years post-implantation (Geers et al., 2016).

There is also limited research on the impact of ASO on the type of language skills achieved. One study found that ASO did not significantly affect expressive grammar scores (Inscoe et al., 2009), implying that the impact of ASO may vary across specific language skills.

Alongside ASO, chronological age (CA) should be considered to provide a point of comparison with age-equivalent TD children. It is also necessary to distinguish between the impact of ASO, age at test, and length of CI experience (Nicholas & Geers, 2018). There may be an effect of CwCIs being chronologically older at the point of first receiving spoken linguistic input and therefore having further advanced cognitive skills, such as better attention and memory, which support language acquisition (Vavatzanidis et al., 2019). For instance, there is evidence that CwCIs begin to acquire words after a shorter period of language

exposure (12 months) than TD children (>14 months) (Vavatzanidis et al., 2019). Additionally, CA is associated with the CwCIs' educational setting at the time of testing, which is a key demographic factor (Hayes et al., 2009) because such settings often include targeted and intensive input from speech and language therapists and/or teachers of the deaf.

This study's second aim therefore is to evaluate the impact of 'early' (≤2 years) and 'late' implantation on receptive and expressive language skill development in the first two years following cochlear implantation.

This study

This paper examines the receptive and expressive language skills achieved by CwCIs at 1- and 2-years post-implantation. It then compares CwCIs with different ASOs to examine the effects of this variable. The findings will add to the current understanding of language development in different subgroups of CwCIs.

Methods

Study design

The study was designed as a service evaluation project using data collected for routine reviews. A database was established to plot the trajectory of receptive and expressive language development with the view of evaluating long-term language outcomes, focussing on specific language skills.

Ethics

This study was registered with the Trust's Service Evaluation and Clinical Audit team (registration number 2231). Trust guidelines stated that further ethical approval was not required. Consent from CwCIs' parents/carers had been received prior to assessment by virtue of their attendance at review appointments. Routinely collected data was extracted from patient records and fully anonymised prior to analysis. As this was a service evaluation, we were limited to data that the trust had already collected. As such, we were unable to collect data on socioeconomic status (SES), ethnicity, religion, race, parental information and adverse childhood experiences (ACEs) as this was not available within participants' clinical record. Personal details were kept on secure Trust computers or encrypted hard drives. To preserve confidentiality, non-identifying numbers for participants were used within the Trust and randomised letter codes were used in external files.

Data collection

Performance on specific subtests of the Preschool Language Scales (PLS) versions 4 or 5 (PLS-4/5; Zimmerman et al. (2014)) was chosen as the outcome measure. The PLS tests receptive and expressive language development from emerging interaction to language and early literacy skills (Zimmerman et al., 2014). It also examines a range of skills rather than focussing on any particular language domain. Although this assessment is standardised on a normal hearing population aged from birth to 7 years, it is commonly used with CwCIs and is the main assessment used by the Trust's clinicians because there are few language assessments standardised on the deaf population (Duchesne et al., 2020).

This assessment comprises 65 receptive and 67 expressive language tasks that assess the acquisition of skills covering attention, vocal development, and social communication in the early years to semantics, syntax, and literacy in the later years. Each item is scored binomially and results are standardised on TD children from birth to age 7;11.

For this study, specialist clinicians identified 32 receptive (R1-R32) and 32 expressive (E1-E32) skills deemed to be of greatest clinical importance and relevance to monitoring the trajectory of early communication and language development. Each skill was coded to account for minor differences across test editions (see Appendices for a key to the skills).

All available record forms of the PLS administered in the period 2014-2018 were collected and coded as binary data on a Microsoft Excel spreadsheet. CwCIs with consecutive sets of PLS results from the first two years post-implantation were included in the study.

Participants

Participants were identified by examining record forms of the PLS administered in the years 2014-2018. All CwCIs who had received their cochlear implant within the Trust and had consecutive sets of PLS results from their first- and second-year post-implantation were included. This resulted in 44 study participants. Due to incomplete data in the clinical sample, 43 participants were included in the analysis of receptive language skills and 42 participants were included in the analysis of expressive language skills. Demographic data for all participants can be seen in Table 1.

Information was collected for all participants on: gender, ASO, CA at test, length of CI experience at test, educational setting, unaided audiogram levels pre-implantation, processor type, implant status, communication mode, home language(s), first language (L1), aetiology of deafness, additional difficulties, medical history, family history of deafness, Speech Intelligibility Rating (SIR), and Categories of Auditory Performance (CAP). Children were marked as having additional difficulties (AD) if they had cognitive, language or social communication difficulties, other sensory impairments, or physical disabilities. Only the ASO data will be discussed in this paper. Table 2 lists the demographic information for the 2 ASO groups.

[Table 1 and Table 2 near here]

Data analysis

This was a data- driven study with research questions emerging from the data. Due to the small numbers and complexity of the data, inferential statistical analysis was not appropriate. Hence the descriptive statistics presented below provide a visual interpretation of the data.

Initial descriptive statistics revealed ASO had a suitable breakdown of sample size across comparison groups (ASO≤2 vs. ASO>2). For each comparison group, clustered bar charts were created to compare the specific skills achieved by CwCIs (based on length of CI experience) to those expected of TD children (based on CA of acquisition as obtained from the PLS-5; see Appendices). Frequencies were displayed in percentages to allow for comparisons despite differences in sample sizes between the groups and variables. Skills that

were not achieved by any CwCIs, i.e. R29-R32 and E21-E32, were excluded from the graphs to improve readability. Timeframes for skills acquisition were compared to the Nottingham Auditory Milestones (NAMES) standardisation (Datta et al., 2018) where appropriate.

Results and Discussion

Clustered bar charts are provided for visual comparison of the percentage of skill achievement by each comparison group (ASO≤2 vs. ASO>2). All future references to the typical age of skill acquisition are based on PLS norms unless otherwise stated. These are also indicated on each graph below the x-axis.

Overall

Receptive skills

[Figure 1 near here]

Figure 1 shows that at 1-year post-implantation (mean CA= 3;03), almost 100% of CwCIs were able to turn their head to locate sound (R1), stop an activity when their name was called (R2), respond to an inhibitory word (e.g., *no*) (R3), respond to a specific word or phrase without the use of gestural cues (e.g., *wave bye bye*) (R4), and follow routine familiar directions with gestural cues (R5). These skills are all typically acquired by age 2, and according to NAMES standardisation (Datta et al., 2018), are acquired by CwCIs by 12 months post-implantation. Only one CwCI was not able to follow routine familiar directions and was in the category of ASO>2.

From 1-to 2-years post-implantation, there was a clear increase in the number of receptive skills achieved. By 2-years post-implantation, over 80% of CwCIs could identify familiar objects from a group of objects (R6) and from a photograph (R7), and understand everyday verbs in context (R10). Both skills are typically acquired by age 3. However, a smaller percentage of CwCIs achieved other skills typically acquired by the same age, such as identifying body parts (R8) and clothes (R9), and understanding the pronouns *my*, *your*, and *me* (R11). This could be due to speech and language therapy typically focussing on functional words (e.g., *more*, *push*) and functional everyday objects or actions (e.g., *ball*, *water*, *sleep*, *drink*) before vocabulary groups comprising body parts and clothes.

At 2-years post-implantation, there were two skills that a higher percentage of CwCIs achieved in comparison to others typically acquired by the same age: recognising actions in pictures (R12) and colours (R19). The former could have resulted from the emphasis on learning verbs in therapy, while the latter could be due to colours being taught early on in education as a component of the Early Years Foundation Stage EYFS curriculum (Early Education [British Association for Early Childhood Education], 2012). Four CwCIs who could recognise colours by 1-year post-implantation were all ASO>2, had a chronological age at or above 3;08, and were in an educational placement at the time of the assessment (nursery or school).

It is worth noting that a small percentage of CwCIs at 2-years post-implantation achieved a few advanced skills typically acquired only from age 6-7 (identifying advanced body parts [R25], understanding numbers [R26] and modified nouns [R27], ordering pictures by qualitative concepts (e.g., *biggest*, *smallest*) [R28], and identifying initial sounds [R29]).

All of these CwCIs were monolingual English speakers, had a CA over 4 years and were in mainstream educational placements (one with a Deaf Resource Base) at the time of testing.

Expressive skills

[Figure 2 near here]

At 1-year post-implantation, >90% of CwCIs could babble two syllables together (E1), use at least one word (E2), and use gestures and vocalisations to request objects (E5) (see Figure 2). Meanwhile, >80% of CwCIs could imitate a word (E3). These findings are also in line with the NAMES standardisation (Datta et al., 2018), according to which CwCIs begin to vocalise by 6-months post-implantation and imitate fragments of what they hear by 1-to 2-years post-implantation. A lower percentage of CwCIs used at least 5 words spontaneously (E4), likely because a longer period of hearing exposure and experience is needed for this. Indeed, >90% of CwCIs had achieved all five of these skills by 2-years post-implantation.

Similar to receptive skills, there was a general increase in the number of expressive skills achieved from 1-to 2-years post-implantation. >80% of CwCIs could name objects in photographs (E6) by 2-years post-implantation, which could be linked to the use of photographs to elicit words in therapy.

At 1-year post-implantation, less than 10% of CwCIs had achieved skills E9-E14 (uses different word combinations; names a variety of pictured objects; combines 3-4 words spontaneously; uses a variety of word classes in spontaneous speech; produces basic 4-5

word sentences; uses verb + *-ing*). This is not unexpected as these skills are only acquired at 3-4 years in TD children. Similarly, at 2-years post-implantation, less than 10% had achieved E15-E16, E18-E20 (uses plurals; answers *what* and *where* questions; answers questions logically; uses possessives; tells how an object is used) which are typically acquired by 4-5 years. There was no common demographic variable linking the CwCIs who did achieve these skills; this group included CwCIs with ASO≤2 and ASO>2.

For both expressive and receptive language, the skills typically acquired earlier (as per PLS norms) are achieved by more CwCIs, as evidenced by the downward trend in percentage of achievement (see Figure 1 and Figure 2). This suggests that CwCIs generally acquire skills along a similar trend to TD children in their first 2-years post-implantation and supports Lu and Qin's (2018) findings that early language development followed a typical trajectory albeit with a delay. Furthermore, CwCIs achieved fewer expressive skills at both 1- and 2- years post-implantation compared to receptive skills. This pattern mirrors typical development where expressive skill development follows receptive skills (Bornstein & Hendricks, 2012) and thus provides further evidence that CwCIs follow a similar developmental trajectory to TD children.

However, as mentioned above, there are outliers to this pattern. Within the skills acquired by a certain age, there is variation in the percentage of CwCIs achieving each skill. Recognising actions in pictures and colours (R12 and R19) are achieved by more children than other skills acquired at the same age in typical development. However, identifying basic body parts and things you wear, understanding pronouns, and using at least five words (R8, R9, R11 and E4) are achieved by fewer children. This suggests that CwCIs' language

development may differ from that of TD children and this may vary across specific language skills.

Age at switch-on

[Figure 3 and Figure 4 near here]

This section explores the achievement of receptive skills (see Figure 3) and expressive skills (see Figure 4) by CwCIs with ASO≤2 compared to those with ASO>2. Many receptive skills and the majority of expressive skills were achieved by similar percentages in both ASO groups. This contrasts with previous literature which has shown that earlier implantation can have positive effects on receptive language development (Ruben, 2018) and expressive language development (Tomblin et al., 2005). The skills with group differences of 10% or more are discussed below.

At 1-year post-implantation, a higher percentage of CwCIs with ASO≤2 could identify familiar objects from a photograph (R7). However, this difference was no longer present at 2-years post-implantation. This pattern was also observed for the skill of understanding everyday verbs in context (R10). Both of these skills may have been targeted in speech and language therapy in the year between the two tests because photographs are often used as stimuli and simple verbs are a common target area for young children. Intervention may have enabled children with ASO>2 to overcome initial delays in these specific targeted areas, resulting in similar percentages of achievement at 2-years post-implantation.

The opposite pattern appears for the following skills: identifying basic body parts (R8), identifying things you wear (R9), understanding pronouns *my*, *your*, *me* (R11), understanding quantity concepts *one*, *some*, *rest*, *all* (R15), using different word combinations (E9), naming a variety of objects (E10), combining three or four words in spontaneous speech (E11) and producing basic 4-5 word sentences (E13). The difference between the ASO groups was less than 10% at 1-year post implantation but at 2-years post-implantation, the gap had widened and the skills were achieved by a higher percentage of CwCIs with ASO≤2.

This advantage was observed sooner for the skill of using words for a variety of pragmatic functions (E8). By 1-year post-implantation, a higher percentage of children in the ASO≤2 group were already using words for a variety of pragmatic functions and a difference of 10% was maintained at 2-years post-implantation. These findings suggest that earlier implantation may provide an advantage for some specific expressive skills. Overall, seven expressive skills were achieved by more CwCIs with ASO≤2 than ASO>2 at 2-years post-implantation compared to only one skill at 1-year post-implantation. This supports the hypothesis that expressive language advantages associated with earlier CI switch-on become more apparent from 2-years post-implantation and could contribute to advice for parents about what skill development they can expect and when.

Understanding use of objects (R13), colours (R19), naming objects in photographs (E6), using words more than gestures to communicate (E7) and using a variety of word classes in spontaneous speech (E12) were all achieved by a higher percentage of children with ASO>2 at 1-year post-implantation. This initial advantage may have been due to CwCIs with ASO>2 being chronologically older. All five skills are typically acquired by age 3-4

years; indeed, at 1-year post-implantation, CwCIs with ASO≤2 had a mean CA of 2;7 whereas the CwCIs with ASO>2 had a mean CA of 3;9. By 2-years post-implantation, when the CwCIs with ASO≤2 had a mean CA of 3;7, these differences were no longer present likely because their average age was in line with the typical age of acquisition of those skills.

At this timepoint, R19 and E6 were achieved by similar percentages of CwCIs with ASO≤2 and ASO>2 while R13, E7 and E12 were achieved by a higher percentage of CwCIs with ASO≤2. This suggests that earlier ASO may ultimately produce longer-term benefits. It would be of great interest to see if this pattern emerges in other skills through further longitudinal research examining the effect of ASO on language development.

On the other hand, CwCIs with ASO>2 appear to have advantages in receptive skills that are typically acquired later. Skills R16-R18 (makes simple inferences; understands analogies; understands negatives in sentences) are typically acquired by age 4. At 2-years post-implantation, they were achieved by a higher percentage of CwCIs with ASO>2 than those with ASO≤2. CwCIs in the ASO>2 group had a mean CA of 4;08 at 2-years post-implantation compared to 3;07 for CwCIs with ASO≤2. Hence, CA could be a contributing factor to these later and higher-level skills being achieved by more CwCIs with ASO>2. Although matched for length of CI experience, chronologically older children have various advantages over their ASO≤2 peers. They are likely to have had greater exposure to non-verbal language and to have had some verbal experience before implantation. Additionally, being school-aged, they are likely to have encountered or been explicitly taught the use of higher-level language including inferences and analogies.

At 2-years post-implantation, E4 (uses at least five words) was the only expressive skill achieved by more CwCIs with ASO>2 than ASO≤2. This is typically acquired by 2 years; therefore, it is unexpected that three CwCIs in the ASO≤2 group did not achieve this skill. All of these CwCIs also had a mixed (speech and sign) modality of communication. Due to the way the PLS is scored, signed lexical knowledge was not recorded, which may explain why these three CwCIs did not achieve E4.

Conclusion

The above results indicate that CwCIs generally acquire language skills along a similar developmental sequence to TD children but may develop some skills differently. Kronenberger et al., (2014) found that CwCIs have different relationships between executive function domains (working memory, fluency-speed and inhibition-concentration) and language skills compared to normal hearing children. They also posited that language development in CwCIs may be different. Further research is needed to explore whether a potential alternative relationship with executive function could provide a plausible explanation for these differences in CwCIs' language skill acquisition.

The results also clearly demonstrate individual variability within CwCIs' language outcomes. At 2-years post-implantation, not all CwCIs had achieved receptive or expressive skills typically acquired by 2 or 3 years but some had achieved skills which typically develop at a later age. This individual variability is well reported in the literature (Coene & Govaerts, 2014; Peterson et al., 2010).

ASO is widely accepted as a key factor in predicting language outcomes (Boons et al., 2012; Ching et al., 2017; Mitchell et al., 2019; Nicholas & Geers, 2008; Ruben, 2018). Although our study had a relatively small sample size, there is some evidence that earlier implanted children begin to show an advantage in particular skills at 2-years post-implantation. Indeed, these findings hint at a growing gap in language development between CwCIs with ASO≤2 compared to ASO>2. As the differences may only be observed after some time and in particular skills, longitudinal research is crucial to observe the long-term impact of ASO on language skill development.

Furthermore, these findings suggest that the benefits of ASO may only extend to certain skills (e.g., using words for a variety of pragmatic functions, identifying basic body parts and things you wear, etc.) This raises the question of whether individual language skills are affected differently by particular demographic variables. If this were the case, it could explain why there are so many opposing patterns of achievement found across the PLS skills. It is thus imperative that future research not only explores the possibility of an interplay between demographic variables but also pays attention to the possibility of their varying impact on individual language skills.

Limitations

The main aims of this study were to map the trajectory of receptive and expressive language skill development of a representative group of CwCIs and to evaluate the impact of age at switch-on (ASO) on skill development. Whilst these aims were met, there are limitations to this study that must be considered when interpreting the findings.

We were not able to examine the impact on skill development of demographic variables such as ethnicity, socioeconomic status, SLT input, parental involvement, other developmental skills, and actual CI usage as these data were not available in the clinical records. Clearly these are vital factors to be taken into account in future studies. A recommendation from this study is that these data should be routinely collected as part of the clinical record, provided that this is done in accordance with data protection regulations.

The data set only covers the first two years post-implantation and therefore provides a snapshot of the early development of CwCIs. Collecting more longitudinal data is essential for predicting longer-term outcomes. Analysis was also limited by the small sample size and missing data, necessitating further research with a larger sample of CwCIs to identify if demographic characteristics are linked to the early acquisition of more advanced language skills.

In addition to this, all CwCI in this sample received their implant after 10 months of age. As previously noted, research has shown that CwCI implanted at 6 months demonstrate stronger language skills (Ching et al., 2017). Therefore, future research should include CwCI implanted at 6 months to fully explore the impact of ASO.

Since the PLS was the main assessment used by the Trust clinicians for CwCIs in the initial years post-implantation, it was selected as the primary outcome measure. However, it is not standardised on the DHH population and as such, does not formally record sign language when assessing language skills. Future research should therefore take into account all linguistic resources that the CWCIs may use when assessing their language.

In spite of these limitations, the findings presented here provide useful detail and insights into the development of CwCIs development of linguistic skills as measured by the PLS. However, appropriate language assessment tools for all DHH children, not only those with cochlear implants, remains a challenge.

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Appendix 1: Receptive skills with corresponding PLS test item numbers

Code	Receptive skill	Test item no.		Typical age of acquisition (years)
		PLS-5	PLS-4	
R1	Turns head to locate the source of sound	4	5	1
R2	Interrupts activity when you call his or her name	12	10	
R3	Responds to an inhibitory word (e.g., *no*)	14	15	2
R4	Responds to a specific word or phrase without the use of gestural cues (e.g., *wave bye bye*)	15	16	
R5	Follows routine, familiar directions with gestural cues	19	18	
R6	Identifies familiar objects from a group of objects	20	20	3
R7	Identifies familiar objects from a photograph	21	21	
R8	Identifies basic body parts	23	23	
R9	Identifies things you wear	24	25	
R10	Understands verbs *sleep, eat, drink* in context	25	24	
R11	Understands pronouns *my, your, me*	27	28	
R12	Recognises actions in pictures	30	27	4
R13	Understands use of objects	31	29	
R14	Understands spatial concepts *in, on, out of, off* without gestural cues	32	26	
R15	Understands quantity concepts *one, some, rest, all*	33	33	
R16	Makes simple inferences	34	37	
R17	Understands analogies	35	39	
R18	Understands negatives in sentences	36	35	
R19	Colours	37	36	6
R20	Understands sentences with post-noun elaboration	38	41	
R21	Understands spatial concepts *behind, in front, next to, under*	39	44	
R22	Understands pronouns *his, her, he, she, they*	40	34	
R23	Understands quantitative concepts *more, most*	41	40	
R24	Identifies shapes	42	43	
R25	Identifies advanced body parts	44	52	7
R26	Understands quantitative concepts (*numbers*)	45	51	
R27	Understands modified nouns	48	48	
R28	Orders pictures by qualitative concepts (*biggest, smallest*)	49	54	
R29	Identifies initial sounds	51	57	
R30	Understands time/sequence concepts *first/last*	52	56	
R31	Identifies a picture that doesn't belong	59	50	
R32	Identifies words that rhyme	60	59	

Appendix 2: Expressive skills with corresponding PLS test item numbers

Code	Expressive skill	Test item no.		Typical age of acquisition (years)
		PLS-5	PLS-4	
E1	Babbles two syllables together e.g. mama, baba	15	16	2
E2	Uses at least one word	17	17	
E3	Imitates a word	20	21	
E4	Uses at least 5 words	23	22	
E5	Uses gestures and vocalisations to request objects	24	23	3
E6	Names objects in photographs	26	26	
E7	Uses words more often than gestures to communicate	27	27	
E8	Uses words for a variety of pragmatic functions	28	29	
E9	Uses different word combinations	29	30	
E10	Names a variety of pictured objects	30	37	4
E11	Combines three or four words in spontaneous speech	31	32	
E12	Uses a variety of nouns, verbs, modifiers and pronouns in spontaneous speech	32	35	
E13	Produces basic 4-5 word sentences	33	36	
E14	Uses verb + -ing	34	34	
E15	Uses plurals	35	31	
E16	Answers what and where questions	36	33	
E17	Names described object	37	47	5
E18	Answers questions logically	38	41	
E19	Uses possessives	39	40	
E20	Tells how an object is used	40	38	
E21	Answers questions about hypothetical events	41	44	
E22	Names categories	44	49	6
E23	Formulates meaningful, grammatically correct questions	45	55	
E24	Completes analogies	46	46	
E25	Uses qualitative concepts short and long	47	51	
E26	Uses adjectives to describe objects	49	52	
E27	Responds to ‘why’ questions by giving a reason	50	48	7
E28	Repairs semantic absurdities	51	60	
E29	Uses –er to indicate one who	52	53	
E30	Rhymes words	53	63	
E31	Completes similes	55	58	
E32	Uses past tense forms	56	54	

Table 1: *Demographic information for the whole sample*

Variable		Receptive	Expressive
Number of Participants		43	42
Age at Switch-on	≤2 Years	19 (44%)	19 (45%)
	>2 Years	24 (56%)	23 (55%)
Gender	Male	21 (49%)	19 (45%)
	Female	22 (51%)	23 (55%)
Implant Status	Bilateral	37 (86%)	37 (88%)
	Unilateral	6 (14%)	5 (12%)
Languages	Monolingual	19 (44%)	19 (45%)
	Multilingual	24 (56%)	23 (55%)
L1	English	32 (74%)	31 (74%)
	Other	11 (26%)	11 (26%)
Additional Difficulties	-AD	23 (54%)	23 (55%)
	+AD	20 (47%)	19 (45%)
Age at Switch-on (Months)	Mean (Range)	25.88 (11-45)	25.52 (11-45)
	s.d.	8.35	8.16

Table 2: *Demographic information for the ASO groups*

Variable		Receptive		Expressive	
		ASO ≤2	**ASO >2**	**ASO ≤2**	**ASO >2**
Number of Participants		19	24	19	23
Gender	Male	9 (47%)	12 (50%)	9 (47%)	10 (44%)
	Female	10 (53%)	12 (50%)	10 (53%)	13 (57%)
Implant Status	Bilateral	18 (95%)	19 (79%)	18 (95%)	19 (83%)
	Unilateral	1 (5%)	5 (21%)	1 (5%)	4 (17%)
Languages	Monolingual	7 (37%)	12 (50%)	7 (37%)	12 (52%)
	Multilingual	12 (63%)	12 (50%)	12 (63%)	11 (48%)
L1	English	14 (74%)	18 (75%)	14 (74%)	17 (74%)
	Other	5 (26%)	6 (25%)	5 (26%)	6 (26%)
Additional Difficulties	-AD	12 (63%)	11 (46%)	12 (63%)	11 (48%)
	+AD	7 (37%)	13 (54%)	7 (37%)	12 (52%)
Age at Switch-on (Months)	Mean (Range)	18.37 (11-24)	31.83 (25-45)	18.37 (11-24)	31.43 (25-45)
	s.d.	3.47	5.87	3.47	5.80

Figure 1.

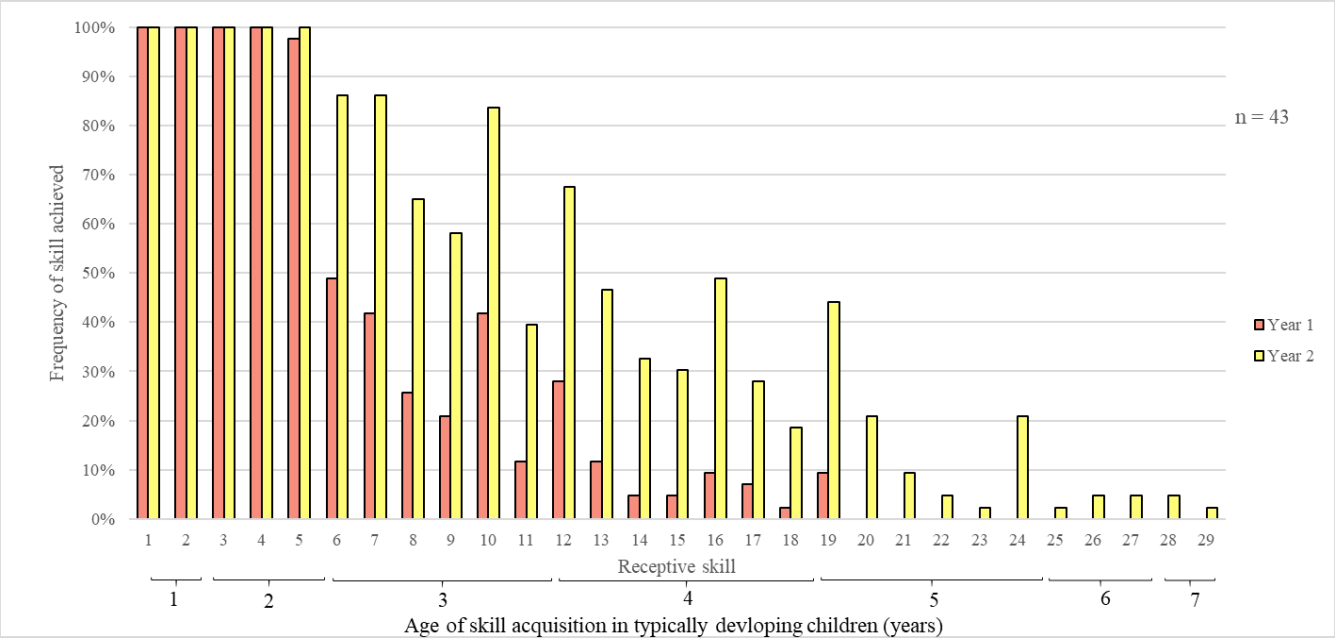
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Frequency of skill achieved
n = 43
Year 1
Year 2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Receptive skill
1 2 3 4 5 6 7
Age of skill acquisition in typically devloping children (years)

Figure 2.

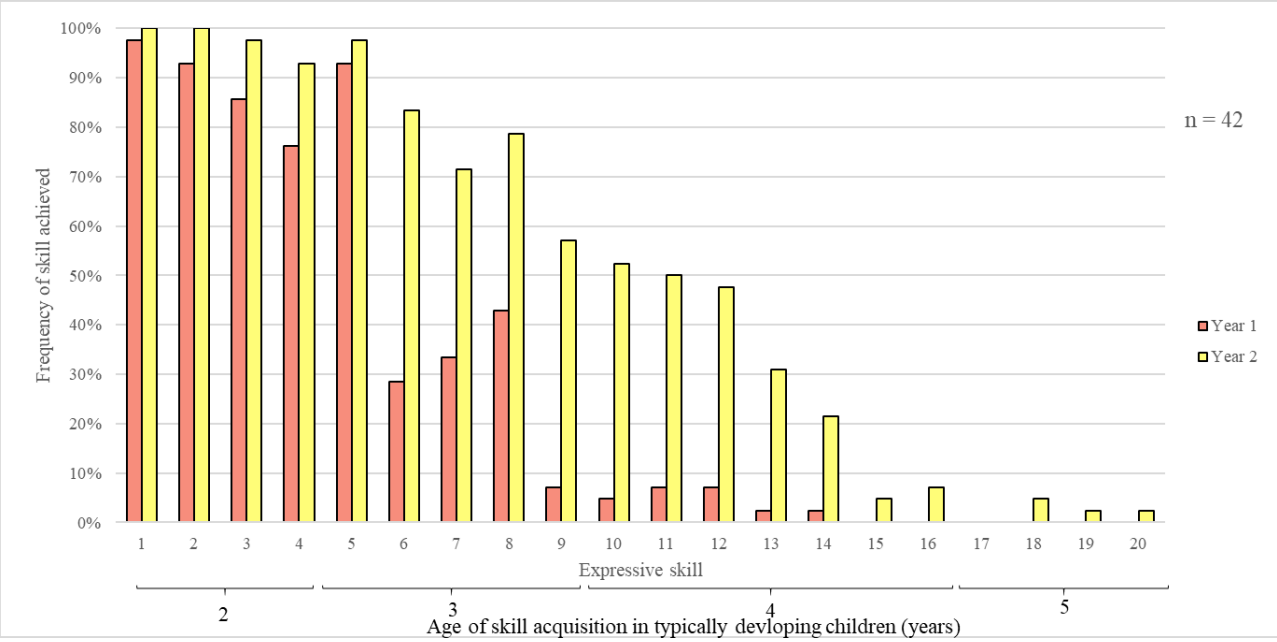
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Frequency of skill achieved
n = 42
Year 1
Year 2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Expressive skill
2
3
4
5
Age of skill acquisition in typically devloping children (years)

Figure 3.

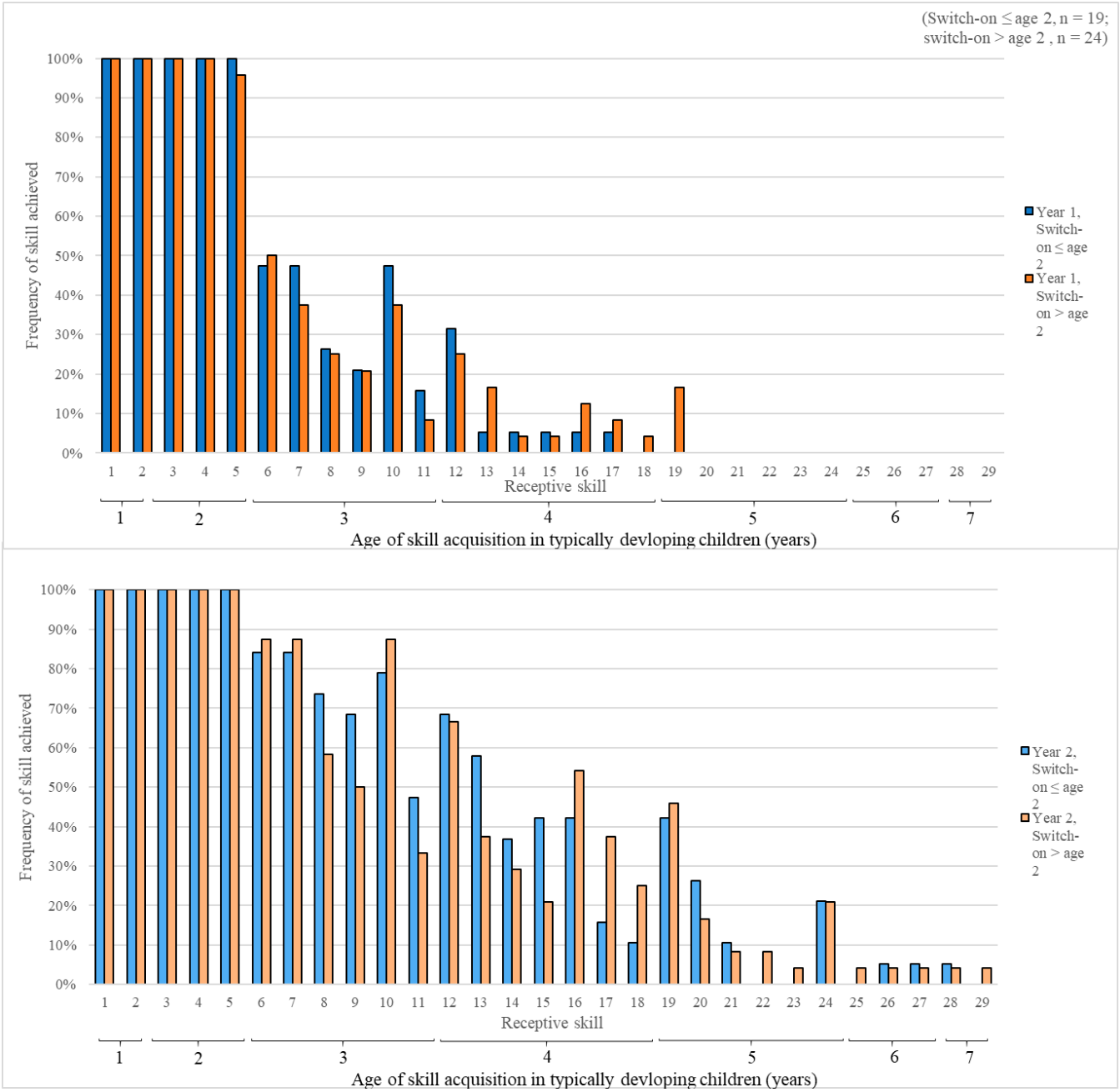
(Switch-on ≤ age 2, n = 19; switch-on > age 2 , n = 24)
Frequency of skill achieved
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Receptive skill
1 2 3 4 5 6 7
Age of skill acquisition in typically devloping children (years)
Year 1, Switch-on ≤ age 2
Year 1, Switch-on > age 2
Frequency of skill achieved
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Receptive skill
1 2 3 4 5 6 7
Age of skill acquisition in typically devloping children (years)
Year 2, Switch-on ≤ age 2
Year 2, Switch-on > age 2

Figure 4.

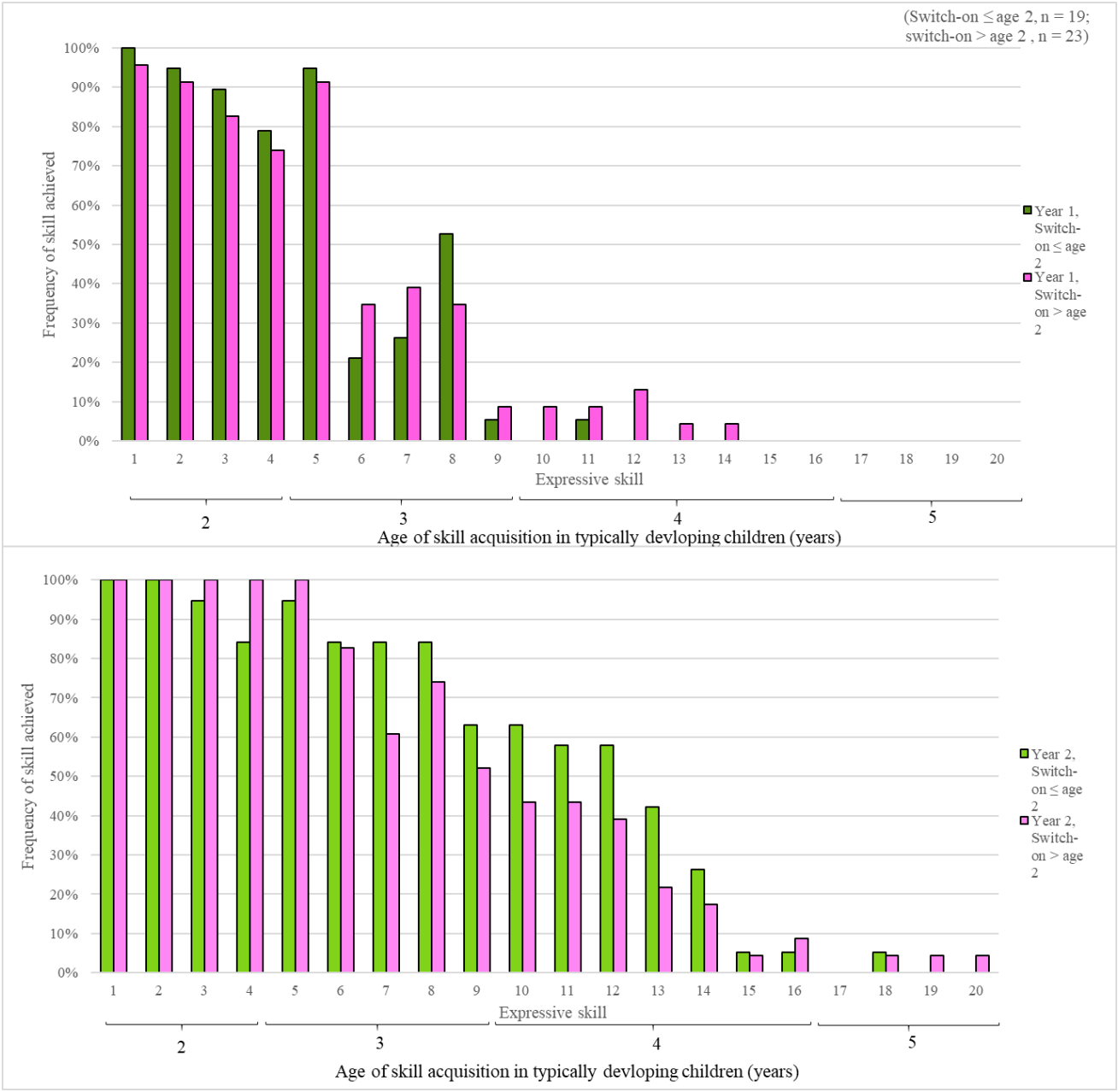
(Switch-on ≤ age 2, n = 19; switch-on > age 2 , n = 23)
Frequency of skill achieved
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Expressive skill
2 3 4 5
Age of skill acquisition in typically devloping children (years)
Year 1, Switch-on ≤ age 2
Year 1, Switch-on > age 2
Frequency of skill achieved
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Expressive skill
2 3 4 5
Age of skill acquisition in typically devloping children (years)
Year 2, Switch-on ≤ age 2
Year 2, Switch-on > age 2

Figure 1. *Clustered bar chart showing the frequency of receptive skill achievement by CwCIs across 2-years post-implantation.*

Figure 1 Alt Text: *The y-axis shows the percentage of CwCIs that achieved a skill. The x-axis shows each skill (R1-R29) with orange and yellow bars to represent 1-year and 2-years post-implantation respectively. Below the x-axis, age of skill acquisition in typically developing children is presented (this can be seen in appendix 1). Skills R1-R5 show ~100% achievement at both time-points. All other skills show higher percentages of achievement at 2-years post-implantation compared to 1-year. No CwCIs achieved skills R20-R29 at 1-year post-implantation.*

Figure 2. *Clustered bar chart showing the frequency of expressive skill achievement by CwCIs across 2-years post-implantation.*

Figure 2 Alt Text: *The y-axis shows the percentage of CwCIs that achieved a skill. The x-axis shows each skill (E1-E20) with orange and yellow bars to represent 1-year and 2-years post-implantation respectively. Below the x-axis, age of skill acquisition in typically developing children is presented (this can be seen in appendix 2). All skills show higher percentages at 2-years post-implantation, except E17 which was not achieved by CwCIs at either time point. No CwCIs achieved skills E15-E20 at 1-year post-implantation.*

Figure 3. *Clustered bar charts comparing the frequency of receptive skill achievement by CwCIs with ASO≤2 and ASO>2 across 2-years post-implantation.*

Figure 3 Alt Text: *The y-axis shows the percentage of CwCIs that achieved a skill. The x-axis shows each skill (R1-R29) with blue and orange bars to represent ASO≤2 and ASO>2 respectively. There are two clustered bar charts panelled vertically; one showing achievement at 1-year post-implantation and the other showing achievement at 2-years post-implantation. There is a general downwards trend with fewer CwCIs achieving the later skills. There is no clear pattern between ASO groups.*

Figure 4. *Clustered bar charts comparing the frequency of expressive skill achievement by CwCIs with ASO≤2 and ASO>2 across 2-years post-implantation.*

Figure 4 Alt Text: *The y-axis shows the percentage of CwCIs that achieved a skill. The x-axis shows each skill (E1-E20) with green and pink bars to represent ASO≤2 and ASO>2 respectively. There are two clustered bar charts panelled vertically; one showing achievement at 1-year post-implantation and the other showing achievement at 2-years post-implantation. There is a general downwards trend with fewer CwCIs achieving the later skills. There is no clear pattern between ASO groups at 1-year post implantation. For most skills at 2-years post-implantation, there is a higher frequency of achievement in the ASO≤2 group compared to the ASO>2 group.*