**Factors Affecting Speech Perception Improvement Post-Implantation in Congenitally Deaf Adults**

**Suzanne J O’Gara1, Helen E Cullington1, Mary L Grasmeder1, Maria Adamou2 and Emily S Matthews2**

**1 - University of Southampton Auditory Implant Service, Southampton, SO17 1BJ United Kingdom**

**2 - Southampton Statistical Sciences Research Institute, Southampton, SO17 1BJ United Kingdom**

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H E Cullington undertakes consulting work for Cochlear Europe

M Adamou and E S Matthews hold positions on EPSRC grants

Address correspondence to: Suzanne J O’Gara, University of Southampton Auditory Implant Service, Southampton, SO17 1BJ United Kingdom. E-mail s.o’gara@soton.ac.uk

**Abstract**

**Objectives:** To identify factors pre-implantation associated with post-implantation speech perception improvement in the adult congenitally deaf population.

**Design:** Forty four adult cochlear implant (CI) patients who had a severe to profound hearing loss from birth were identified from this centre’s database. Eight pre-implantation factors: speech intelligibility, pre-implantation hearing levels, communication mode, pre-implantation speech perception scores, progression of hearing loss, age at implantation, hearing aid use pre-implantation and gender were recorded during the cochlear implant assessment process. These factors were investigated to determine their effect on speech perception improvement post-implantation. The outcome measures were the improvement in scores for the BKB sentence test and CUNY sentence test with lip-reading after implantation. In the final analysis 26 patients were included in the CUNY analysis, 30 in the BKB analysis.

**Results**: Speech Intelligibility Rating, pre-implantation hearing levels and communication mode were shown to be significantly associated with improvements in speech perception post-implantation.

**Conclusion:** Three factors were identified that affected speech perception improvement post-implantation: speech intelligibility, pre-implantation hearing levels and communication mode. These factors can be used to counsel CI patients regarding potential speech perception improvements from cochlear implantation, although these are based on average data and may not reflect individual performance.

**INTRODUCTION**

At the University of Southampton Auditory Implant Service (USAIS), adult congenitally deaf patients are regularly seen for a cochlear implant (CI) assessment; the number of adults presenting in this category is increasing. They present as a varied and complex group with uncertain outcome. Previous studies have shown speech perception outcomes ranging from no improvement to open set sentence recognition (Bosco et al. 2013; Kos et al. 2009; Lazard et al. 2012; Santarelli et al. 2008; Schramm et al. 2002; Teoh et al. 2004a; Waltzmann et al. 2002). This range of outcomes can make it difficult to counsel CI candidates regarding expectations post-implantation. The National Institute for Health and Care Excellence (NICE) guidelines (NICE 2009) use speech perception measures to determine candidacy for cochlear implantation and one of the service evaluation measures for cochlear implant centres is an improvement in speech perception post-implantation, although quality of life is also included (NHS England 2013). For congenitally deaf adults, an improvement in speech perception may not be the expected outcome for all individuals.

A variety of pre-implantation factors have been shown to influence outcome in the congenitally deaf group such as pre-implantation hearing levels (An et al. 2012; Loundon et al. 2000), type of hearing loss (progressive/non-progressive/congenital/acquired) (Caposecco et al. 2012; Loundon et al. 2000), speech intelligibility (An et al. 2012; van Dijkhuizen et al. 2011), communication mode (Caposecco et al. 2012; Kos et al. 2009; Loundon et al. 2000; Osberger et al. 1998; Teoh et al. 2004b; Waltzmann et al. 2002), age at implantation (Dowell et al. 2002; Harrison et al. 2005; Waltzmann et al. 2002), pre-implantation hearing aid use (Caposecco et al. 2012) and pre-operative speech perception scores (Dowell et al. 2002). Most authors included both adults and/or older children in their analysis; few studies looked solely at adult patients.

Caposecco et al. (2012) found that 63% of the variance in speech perception scores in adults and adolescents in their study could be predicted by three variables: communication mode, progressive hearing loss and a hearing aid worn on the implanted ear before implantation. Dowell et al. (2002) identified in older children that pre-operative speech perception scores, duration of profound hearing loss and equivalent language age accounted for 66% of the variance in their group.

These two studies, along with others (An et al. 2012; Harrison et al. 2005; Schramm et al. 2002; Teoh et al. 2004b; Waltzmann et al. 2002) included data on children implanted between the ages of 6 and 18 years, making comparisons with adult data more difficult. It has been recognised that a sensitive period for speech and language development exists (Harrison et al. 2005; Sharma et al. 2002). At implantation children may still be in this sensitive period, which may mean that age at implantation has more of an effect. Thus some factors which may be significant for children and adolescents may not be so for adults.

There is more evidence in the literature on factors affecting performance post-implantation in the adult post-lingually deafened group compared to congenitally deaf adults. These studies usually include larger numbers of CI patients. Factors that have been shown to be significant are age at implantation (Blamey et al. 2013; Holden et al. 2013; Roditi et al. 2009), duration of deafness (Blamey et al. 2013; K. M. Green et al. 2007; Holden et al. 2013; Lazard et al. 2012; Moon et al. 2012; Roditi et al. 2009), pre-implantation speech perception scores (Lazard et al. 2012; Roditi et al. 2009) and pre-implantation hearing levels (Lazard et al. 2012). Previous studies have accounted for different levels of outcome variance within this group: 60% (Roditi et al. 2009), 34% (Murray 2013), 22% (Lazard et al. 2012) and 10% (Blamey et al. 2013). Clearly not all the variability in outcomes in the post-lingually deafened group can be explained by these factors. These factors, shown to significantly affect performance in post-lingually deafened adults, may not have the same effect in the congenitally deaf adults. A severe to profound hearing loss can prevent the development of normal speech and language (Ching et al. 2013); adults with a severe to profound hearing loss from birth would not be expected to have the same language levels as a post-lingually deafened adult who developed speech and language while they had normal hearing thresholds.

Outcome data in the literature indicate that some congenitally deaf adults show significant speech perception improvements while others do not (Berrettini et al. 2011; Bosco et al. 2013; Klop et al. 2007; Kos et al. 2009; Santarelli et al. 2008; Schramm et al. 2002; Teoh et al. 2004b; Waltzmann et al. 2002). Identifying factors pre-implantation that would predict post-implantation performance may allow more effective counselling of CI candidates in this group. Speech perception scores of adult CI patients implanted at the USAIS were analysed to identify pre-implantation factors that affected post-implantation improvement in performance. The aim of this paper was to identify factors that are present pre-implantation, which affect speech perception improvement in the congenitally deaf group.

**Hypothesis**

We hypothesise that results would be similar to previous studies using children and/or adults with Speech Intelligibility Rating, pre-implantation hearing levels, communication mode, pre-operative scores, progressive hearing loss and hearing aid use pre-implant significantly affecting speech perception outcome within this group. Although previous studies have shown an effect of age at implant, as the critical period for language development has passed for these patients, we hypothesise that age at implantation does not affect speech perception improvement. The authors are unaware of any report on the influence of gender in this group but hypothesise that this factor has no effect on speech perception improvement.

**MATERIALS AND METHODS**

**Participants**

Subjects were identified who met the following criteria: a reported severe to profound hearing loss (71->95dB HL (British Society of Audiology 2011)) from birth, aged 18 or over at the time of their first implant, and had attended a 12 month post-implantation review appointment. No other inclusion or exclusion criteria were applied. Forty eight CI patients were identified from the USAIS database who met the inclusion criteria. Four patients were excluded due to lack of consent.

Forty four CI patients fulfilled the study criteria. CI patients were implanted at the USAIS between January 1993 and December 2012. CI patients with cochlear implants from four manufacturers were included (Advanced Bionics (Valencia, United States of America), Cochlear (Sydney, Australia), MED-EL (Innsbruck, Austria) and Neurelec (Paris, France)). All CI patients had a full insertion of the electrode array according to their post-operative X-ray report. Of this group 27 were female (61%) and 17 male (39%). The mean age at implantation was 34 years (range = 18.4 – 60.4). The manufacturer balance was 22 Cochlear (50%), 10 Advanced Bionics (23%), 8 MED-EL (18%) and 4 Neurelec (9%). At the 12 month interval one CI patient (2%) was a non-user.

**Ethical Approval**

Ethical approval was obtained from the University of Southampton Ethics and Research Governance Office (ERGO ref 6950). Forty one CI patients had signed a consent form to allow the use of their group data. This form was signed at the time of surgery. Of the seven CI patients who had not signed the consent form for group data, three had consented for their anonymised data to be used for research purposes. Four CI patients were therefore removed from the analysis due to lack of consent.

**Speech perception improvement**

Speech perception measures are routinely used in the assessment of CI patients at the USAIS. The BKB sentence test (Bench et al. 1987) and the CUNY test with lip-reading (Aleksy et al. 2007) are both performed pre and post-implantation in quiet. Both recorded speech tests were presented in quiet at 70 dB SPL from a speaker at 0º azimuth in a sound treated booth. The BKB test consisted of two lists with 16 sentences in each. Each list has 50 key words to be scored. Different equivalent sentence lists were presented pre and post-implantation to prevent any learning effect. The CUNY test consisted of one list of 24 sentences, with audio-visual presentation. The visual stimulus was presented from a computer screen in front of the patient. Both tests were scored using loose key word scoring; the BKB list scores were summed to give a score out of 100. A percentage correct score for each test was calculated. The method by which the patient chose to respond (oral or manual) was not recorded.

No other outcome measure was investigated. During assessment, CI patients are tested in different listening conditions (binaural, left aid and right aid, if appropriate); the best result was used in this project. The result recorded at 12 months was in their everyday listening condition i.e. a CI patient may wear a CI and hearing aid or their CI alone; the result was taken from the condition the CI patient uses every day.

Improvement scores were calculated by subtracting the score pre-implantation from the post-implantation score. This value was deemed as the improvement in score from the intervention at the 12 month post-implantation stage. Improvement score was investigated rather than absolute scores post-implantation as this allows the effect of factors on the intervention to be investigated.

CI patients who were deemed from their CUNY score to have limited or no improvement in some instances were not tested on the BKB test, as the clinician expected no improvement; the BKB score was thus assumed to be 0%. If a CI patient scored 0% on the first five sentences testing was stopped and the result was taken as 0%.

Some data from the 12 month appointment were missing; in one instance this related to a CI patient being a non-user. CI patients were categorised as a non-user if they were no longer wearing their processor and the device had been returned to us. The result was then deemed as no improvement (0%) on both BKB and CUNY tests. Some CUNY scores were absent due to CI patients in previous appointments experiencing ceiling effects. These CI patients scored approximately 100% at their three month appointment and the audiologist decided not to perform this test at their 12 month appointment. If this were the case, no value was assigned and the data were excluded from the analysis. If the CI patient did not perform the test pre-implantation they were removed from the analysis. Eight CI patients were removed from the CUNY analysis as they had not completed the CUNY test at the 12 month review appointment. One CI patient was unable to perform speech perception tests pre and post-implantation and was removed from both analyses.

**Pre-implantation factors**

The pre-implantation factors of Speech Intelligibility Rating, progression of hearing loss, hearing aid use pre-implantation and gender were recorded from the USAIS database, from individual’s initial assessment clinical notes and the initial assessment questionnaire.

Speech intelligibility was assessed pre-implantation using the Speech Intelligibility Rating scale (Allen et al. 1998). The SIR scale was developed for use with children and has been found to have good reliability (Allen et al. 2001). CI patients were given a score of one to five (Table 1). This rating was assessed by a speech and language therapist (SLT) at the cochlear implant centre during the pre-implantation communication appointment. The four SLTs who completed the assessments are Highly Specialist SLTs (Deafness) and have over ten years’ experience working with profoundly deaf patients. The SIR score was determined after a 60 minute appointment with the SLT. The assessment of the SIR is based on the formal and informal spoken language which occurs during the appointment. Missing data was due to the SIR not being recorded at the appointment, not due to the patient having insufficient language to complete the assessment. These CI patients were excluded from the analysis for this factor. This resulted in nine CI patients with no SIR score been applied pre-implant.

Mode of communication was recorded as part of the assessment process; some CI patients used both spoken language and manual (e.g. British Sign Language (BSL)). The main mode of communication was determined by the CI patient requesting an interpreter for their assessment appointments. This was classed as manual communication.

Pre-implantation unaided hearing levels were routinely measured at assessment. A five frequency average of 250, 500, 1000, 2000 and 4000 Hz, from the better ear, was used for this analysis as speech is a broadband stimulus. The better ear results were used even if this ear was not the ear implanted.

Cochlear implant patients were deemed to have a progressive loss if they reported any deterioration in their hearing levels since birth at the initial assessment appointment or on an initial assessment questionnaire. If this was reported at the initial assessment appointment this was recorded in written format in the CI patient’s file or in the end of assessment report. If historic audiograms were available with the referral letter that showed deterioration in hearing levels, the CI patient was then deemed to have a progressive loss, even if they did not report so. Unfortunately historic audiograms were not available for the majority of CI patients. Historic audiograms that were available were not from childhood and covered a maximum of 15 years prior to referral to USAIS. Due to this, patients were classified into progressive and non-progressive losses subjectively based on their report. Age at onset was determined through patient report.

Hearing aid use in the implanted ear pre-implantation was recorded through patient report. Patients who were consistent users of a hearing aid were distinguished from those who were reportedly inconsistent users or who did not wear a hearing aid pre-implantation in the implanted ear. One patient had no information available on pre-implantation hearing aid use.

**Statistical analysis**

The aim of the statistical analysis was to identify which variables have an impact on the improvement in both BKB and CUNY scores using a linear regression model. The performance of the model can be assessed using $R^{2}$ and a plot of the scores predicted using the model against the observed scores can be used to assess the predictive properties of a regression model. For more information regarding regression models see Armitage et al. (2002).

Some of the improvement scores and/or pre-implantation data for the 44 patients were missing due to the test not being performed pre-implantation or at the 12 month interval. A complete case analysis was considered; any patients with missing improvement scores and/or factors results (i.e. no SIR recorded pre-implant) were removed from the datasets. This reduced the size of the datasets to 33 patients for BKB and 27 patients for CUNY.

After removing the patients with missing data, only one patient had a SIR of 2 and no patients had a SIR of 1. The single patient with a SIR of 2 was removed as no valid conclusions regarding the impact of SIR2 (SIR category 2) can be drawn using one observation. Hence, data for 32 patients were used for the analysis of BKB improvement scores and data for 26 patients were used for the analysis CUNY improvement scores. It also meant that SIR now had only three levels and only regression results for ratings 3, 4 and 5 were presented.

**RESULTS**

**Speech perception results**

The mean BKB improvement at 12 months was 24% (SD = 29.4). The mean CUNY improvement at 12 months was 9% (SD = 14.9). These results were analysed to determine if they differed significantly from 0%. The CUNY and BKB improvement scores are presented in Figure 1, this shows the range of improvement scores recorded within this group. The CUNY improvement significantly differed from 0%, (t(34) = 3.499 *p* = 0.001; (Figure 1)). The BKB data could not be analysed in this manner as the data were not normally distributed. To determine if there was an significant improvement post-implantation, the results were compared to pre-implantation speech scores, this showed a significant improvement in scores post-implantation (Z = -2.067, p = 0.039; Figure 1). There were floor effects in the BKB test with CI patients scoring 0% pre and post-implantation (Figure 2a). There were ceiling effects evident in the CUNY sentence test; some CI patients scored between 80 and 90% pre-implantation (Figure 2b). The range of improvement was -26 to 91% for BKB and -25 to 47% for CUNY. A smaller range of improvement was seen overall in the CUNY data; this may be related to ceiling effects in the data. A negative improvement denotes someone obtaining a worse score at the 12 month interval than pre-implant. Both speech perception tests were then analysed with respect to the eight factors.

**Factors related to speech perception improvement on the BKB sentence test**

An initial transformation was applied to the improvement scores to make them positive. The logarithmic Box-Cox transformation (Box et al. 1964) was then applied to these scores. Following this second transformation, two patients with unusual observations were identified. The scores for these patients were removed as they could cause misleading conclusions, hence the transformed data for the remaining 30 patients were analysed. A further logarithmic Box-Cox transformation was required for these data in order for the linear modelling assumptions to hold. The BKB sentence test scores were then denoted as $y\_{BKB}$. The transformed data were represented as $y\_{BKB}^{\*}$ : BKB sentence test scores after transformation to be positive, data for two patients removed, and the logarithmic Box-Cox transformation applied twice.

Given a linear regression model is fitted to$ y\_{BKB}^{\*}$, the relative importance of each of the factors is given in Table 2. Relative importance shows the contribution of each variable to$ R^{2}$; for more details see Gromping (2006). Speech intelligibility, pre-implantation hearing levels and communication mode, have the highest relative importance as it can be seen in Table 2. The p-values for the parameters in the regression model are given in Table 3. The p-values of SIR 5 (SIR category 5), pre-implantation hearing levels and communication mode (interpreter requested) are 0.001, 0.031 and 0.008 respectively. Since their p-values are less than 0.05, there is strong evidence that these factors have a non-zero influence on the transformed dataset $y\_{BKB}^{\*}$ and so the BKB improvement scores.

However, as demonstrated in Figure 3, the model fitted to $y\_{BKB}^{\*}$ is a poor predictive model. This is due to the variability present in the data, which cannot be accurately explained by the model. The $R^{2}$ for the linear model fitted to $y\_{BKB}^{\*}$ is 0.554, therefore the model explains only 55% of the variability in the data with 45% unexplained. This model could not be used to accurately and precisely predict the improvement score for a patient.

**Factors related to speech perception improvement on the CUNY sentence test**

The CUNY sentence test scores were denoted as $y\_{CUNY}$, then the output after these scores were transformed to be positive as denoted by $y\_{CUNY}^{+}$. A linear regression model was fitted to the transformed dataset, $y\_{CUNY}^{+}$. The relative importance of each of the factors in the experiment when a linear regression model was fitted to $y\_{CUNY}^{+}$ is given in Table 4. Communication mode has the largest relative importance of 24% and explains over half of the explained variability in the data. As seen in Table 5, communication mode (interpreter requested) also has the smallest p-value of 0.018. From this there is strong evidence from the model that communication mode (interpreter requested) influences $y\_{CUNY}^{+}$ and therefore the CUNY improvement scores.

The model for $y\_{CUNY}^{+}$ is a poor predictive model, as demonstrated by the spread of points in Figure 4 and the low $R^{2}$ of 0.46. Therefore, this model cannot be used to predict whether a cochlear implant will improve a patients speech perception.

**Summary**

To summarise, there is strong statistical evidence that Speech Intelligibility Rating (SIR5), pre-implantation hearing levels and communication mode (if a patients requested an interpreter) impacted BKB improvement scores, and that communication mode impacted CUNY improvement scores. Therefore, the results of this analysis are in line with previous evidence that speech intelligibility and communication mode influence BKB and/or CUNY improvement scores.

**DISCUSSION**

The congenitally deaf adults included in this analysis on average showed a significant improvement in speech perception scores 12 months after cochlear implantation. However, nine CI patients showed no improvement (≤0%) in their speech perception scores post-implantation on both speech perception tests and some performed poorer compared to their pre-implantation performance (17 on the BKB test and 11 on the CUNY test). Two patients showed improvement (>0%) on the BKB test but not the CUNY test and eight demonstrated improvement on the CUNY test but not the BKB test.

Eight pre-implantation factors were investigated to determine their effect on speech perception improvement post-implantation. Three factors affected improvement 12 months after implantation: a SIR of 5 (Connected speech is intelligible to all listeners), pre-implantation hearing levels and requesting a sign language interpreter. For speech intelligibility and pre-implantation hearing levels this was dependent on the speech perception measure used (BKB or CUNY sentence tests). Pre-implantation speech scores, progression, age at implantation, hearing aid use pre-implant, gender and did not significantly affect speech perception improvement in this group.

**Speech material**

The two speech tests regularly used to assess cochlear implant candidacy and assess the effect of cochlear implantation both experienced either a floor or a ceiling effect in this study. It is important to assess all cochlear implant users with appropriate speech perception measures. Speech perception testing currently used routinely in the United Kingdom may be either too difficult (BKB sentences without lip-reading) or too easy (CUNY sentences with lip-reading) for CI patients. This introduces significant challenges when analysing factors which affect improvement. The CUNY and BKB sentences require different communication skills with one being an auditory alone and the other an auditory and visual test and have very different language levels. The CUNY test was developed for use with adults (Aleksy et al. 2007), while the BKB sentence test was developed for hearing-impaired children aged 8-15 years old (Bench et al. 1987). Adults with a pre-lingual hearing loss are likely to have lower language levels and the difficulty performing the CUNY test may be related to this rather than to a lack of benefit from their CI. Therefore this measure may be unsuitable for this group. No version of the BKB sentence test with lip-reading is available.

Patients may have different scores pre-implant, though the same improvement score. The same improvement score may not indicate the same level of benefit. The critical differences for BKB sentences (no values are available for the CUNY test with lip-reading) indicate that the smaller the score on the first test the smaller the difference in results for the two tests to be significantly different (Green 1997). CI patients with a lower BKB score pre-implantation need to have a smaller change in performance for the result to be significantly different. This was not accounted for within this paper.

These results show the range of improvement that could be expected from a congenitally deaf adult. This highlights the difficulties in comparing this group across these measures.

**Speech Intelligibility Rating (SIR)**

There was a significant effect of SIR on speech perception improvement. This is comparable to the results of van Dijkhuizen et al. (2011) who looked at 25 adults with an average age of onset of deafness of 8 months; they found that in general CI patients with intelligible speech had better post-implantation scores than those who did not, although of course the current study examines speech perception improvement rather than absolute value. This effect was not seen in the CUNY data and could be related to ceiling effects in the CUNY test.

**Pre-implantation hearing levels**

Loundon et al. (2000) found that in the paediatric population the presence of residual hearing resulted in improved CI outcome. The number of children with residual hearing in this study was small (n=4) and all the children had oral communication before implantation, which may have influenced the results. Lazard et al. (2012) found, with 2251 CI patients, that pre-implantation hearing did affect outcome with better pre-implantation hearing levels resulting in improved outcome. They felt this may be due to the lack of auditory deprivation in these subjects compared to others with poorer hearing levels. Other studies investigating pre-implantation hearing in adults with a post-lingual hearing loss have seen no advantage with improved hearing pre-implantation on CI outcome (Adunka et al. 2008; Balkany et al. 2006; Cosetti et al. 2013; Gantz et al. 1993). This current study reports similar findings to Lazard et al. (2012) and Loundon et al. (2000), with pre-implantation hearing levels significantly affecting speech perception improvement. Adults with a congenital profound hearing loss will have had longer without access to auditory input; any sound they are able to access improves their outcome post-implantation.

**Mode of communication**

Improvement in speech perception measures was found to be significantly greater if CI patients did not require a sign language interpreter for appointments compared to CI patients who did require a sign language interpreter. This is similar to previous research into paediatric data, which has shown that children who are oral communicators have better speech perception outcomes than those who use total communication (Adunka et al. 2008; Kirk et al. 2000; Kos et al. 2009; Osberger et al. 1998). This would support our data indicating that if a CI patient used sign language, their score improved significantly less than CI patients who did not. CI patients who require a sign language interpreter for appointments may use sign language as their first language and not English. The structure of these languages is different and this could explain why these CI patients did not improve as much compared to CI patients who did not use an interpreter for appointments. Further research is needed, looking more closely at the different communication groups (sign language, oral and total communication). These data are limited as the project is retrospective in nature; information on the main mode of communication pre-implantation cannot now be determined. All of the CI patients who required a sign language interpreter showed no improvement on the BKB test 12 months post-implantation.

Most studies in the literature focus on outcome scores post-implantation (Loundon et al. 2000; Schramm et al. 2002; van Dijkhuizen et al. 2011) i.e. speech perception results post-implantation. This study has focused on improvement in performance between pre-implantation and post-implantation scores. Looking at the score post-implantation can mask the effect of the CI on post-implantation performance. So a patient may have scored the same pre and post-implantation i.e. the CI has not improved performance but this is not clear from using outcome scores post-implantation. This is particularly important in people with congenital deafness where post-implantation speech perception results are variable, with some patients improving and others showing no improvement on speech perception measures.

**Pre-implantation speech scores**

Level of performance on pre-operative speech scores was found not to significantly affect improvement post-implantation. Dowell et al. (2002) found that this factor did influence outcome in children aged 8-18 years. They hypothesised the ability to use minimal auditory information for speech perception with hearing aids transfers over into implant use. Better speech perception scores pre-implantation could indicate more access to sound and this improved access results in benefit post-implantation. Waltzman et al. (2002) found no evidence in their population that pre-implantation performance affected improvement from cochlear implantation. These results are again from the paediatric population. There is limited data on the impact of this factor in the adult population. There are ceiling and floor effects evident in these data which could have skewed the results.

**Progression of hearing loss**

There were difficulties in assigning patients to progressive and non-progressive hearing loss groups. Information on progression was dependent on patients report. The degree of progression and the timing of the progression were unknown and the grouping is unlikely to be homogenous. There may be patients whose audiometry did not show a progressive loss, but they were still assigned to the progressive group based on their report. This also relies on clinicians documenting this information at the time of assessment. There were several clinicians assessing adults, and recording information on progression was not standardised. This may introduce bias into the group selection.

The speech perception improvement data showed that if a CI patient had a progressive hearing loss, this did not have an effect on improvement post-implantation compared to CI patients with a non-progressive loss. Data from children has shown improved outcome in progressive hearing loss compared to non-progressive losses (Dowell et al. 1996). The children in this study did not have a profound hearing loss at birth, but a moderate to severe loss which progressed. This makes comparing the groups difficult.

The factors communication mode, speech intelligibility, progression of hearing loss, pre-implantation speech perception scores and pre-implantation hearing level all impact on one another. If a CI patient had good pre-implantation hearing levels they would have access to more sound through their hearing aids and their speech intelligibility rating is likely to be higher than in CI patients who did not. CI patients with a progressive loss have the potential to have more access to sound than CI patients with a non-progressive loss. These factors are all linked and it is difficult to separate them to identify their individual effects on speech perception improvement with a CI.

**Age at implantation**

Previous studies investigating age at implantation (Loundon et al. 2000; Waltzmann et al. 2002) have looked at children and adolescents. Age at implantation is likely to have a more significant effect on speech perception improvement for children than adults. Children have a sensitive period for speech and language development (Harrison et al. 2005; Sharma et al. 2002): the shorter the duration of deafness the better outcome. Adults have passed through this developmental stage and so after the age of eighteen there is no effect on cochlear implant outcome; this may be why this factor was not closely associated with speech perception improvement in this data set. Authors investigating this factor in studies involving post-lingually deafened adults have shown different results. Green et al. (2007) studying 117 post-lingually deafened adults, found that age at implantation did not predict outcome in their study. Roditi et al. (2009) found in their study, with 55 post-lingually deafened adults, that it did affect outcome. It is worth noting that the current study examined improvement in outcome though, so results cannot directly be compared.

**Hearing aid use pre-implantation**

Caposecco et al. (2012) found that hearing aid use did affect outcome in their group, with better hearing aid use pre-implantation resulting in better outcome. The current study found that hearing aid use did not affect speech perception improvement. However, only five patients in the BKB data and four in the CUNY data, had not worn a hearing aid pre-implant; the limited number in this group may have skewed the results. Ceiling effects were also present in these data which may have had an effect.

**Gender**

Lazard et al. (2002), using data collected retrospectively from 2251 adults, found gender had no effect on performance of post-lingually deafened adults. The current study examined improvement in speech perception, and found no effect of gender.

**Limitations in the data**

These data were interpreted with some caution due to limited numbers of CI patients (n=44) meeting the inclusion criteria, and even less being included in the statistical analyses. Increased numbers of CI patients across many centres would allow further analysis and possible identification of more factors or stronger evidence for existing factors affecting improvement in this group. Some data points were missing in this study which reduced the total number of comparisons; this in part was related to data not being collected at the initial assessment and then post-implantation tests being deemed unnecessary due to the patients’ performance at an earlier stage than 12 months. This reduced the number of data points and impacted on the statistical analysis (BKB n=30 CUNY n=26).

Both models for the BKB and CUNY data are poor predictors of performance. This identifies the high variability within the sample and that the models used for the analysis are unable to predict a patient’s performance post-implantation.

The difference in the number of patients recorded at each level of the five factors in this study, as seen in Table 6, contributed to the uncertainty in the modeling and the difficulty in accurately quantifying the effect of the different factors on the improvement score. It would be preferable, to have an equal number of patients for each factor and for each group within this.

A power analysis, as outlined by Cohen (1988), was performed to find the minimum number of patients required to determine whether a factor had a large impact on the response. The minimum number of patients required at each level of a factor with two and five levels, both of which are considered in this study, are given in Table 7. For example, 18 patients are required to have a low chance of identifying a large effect for a factor with two levels (as 9 patients are required at each level for a power of 0.5) and 210 patients are required to have a high chance of identifying a large effect for a factor with five levels (as 42 patients are required at each level for a power of 0.95 (45 at each of the 5 levels results in 210 patients)). To improve the likelihood of identifying factors with a large impact, the number of patients recorded at each level of each categorical factor would need to increase.

This study is retrospective in nature and so limitations seen in data could not be addressed at time of collection. For example, mode of communication cannot be reassessed post-implantation as this may have changed due to the CI. This study had consent to look at group data but not anonymised individual data. Cochlear implantation is still a rare procedure and concerns arose that outlying CI patients may have been identifiable and these have been removed from the graphs to ensure confidentiality is maintained. Factors were not looked at in combination; for example looking at the factors mode of communication and progression of deafness was not performed due to small numbers in the groups and the potential to identify subjects in smaller groups. Data on CI patients’ aetiology was not included for this reason.

**Further research**

These data suggested factors (SIR, pre-implantation hearing levels and mode of communication) which influence speech perception improvement in this group. Further research is needed to identify these variables in more depth than this study allowed due to its retrospective nature and limited sample size. Further analysis may confirm the findings of this study or identify further factors that could be used to counsel this complex group.

Speech perception improvement is one outcome measure post-implantation; another is quality of life. No quality of life measure was investigated as part of this study. There are some instances in these data where no improvement on speech perception measures was seen post-implantation; this may be related to the measures that were used. Then a measure such as quality of life becomes important to consider. This study focused on an improvement in speech perception as this is often reported to be desired by this group. The authors are aware of no studies investigating expectations pre-implantation in congenitally deaf adults.

One further factor is that this study considered improvement in speech perception at only 12 months post-implantation. It may be expected that congenitally-deaf adults may take considerably longer to obtain improvement. Further analysis of speech perception measures recorded two years or more after implantation would be valuable.

**Conclusions**

Congenitally deaf adults who had more intelligible speech before cochlear implantation, had better pre-implantation hearing levels and used spoken communication on average obtained greater improvement in speech perception scores after implantation. These results may be used to counsel candidates during their assessment for cochlear implantation, giving them expectations of possible outcomes post implantation. It is recognised that this group is complex and many different variables are present, only some of which have been investigated in this paper.

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**Figure Legends**

Figure 1: Improvement scores for BKB and CUNY sentence tests post-implantation. The box represents the portion of the distribution falling between the 25th and 75th percentiles (lower and upper quartiles).  The horizontal line represents the median.  The vertical lines outside the box (whiskers) contain the largest and smallest values that are not categorised as outliers or extreme values.  Outliers (more than 1.5 box lengths above or below the box) and extreme outliers (more than 3 box lengths above or below the box) are not shown to ensure confidentiality.  The n values represent the number of patients in each group. The dashed line indicates 0% improvement. To ensure confidentially was maintained three outliers were removed from the CUNY results. Two above and one below the box plot, all three were greater than 1.5 box lengths. These were removed due to concerns regarding the confidentiality of these patients.

Figure 2: Percent correct speech perception results pre and post-implantation for (a) BKB and (b) CUNY data. The BKB sentence test was performed listening alone. The CUNY sentence test was performed with listening and lip-reading. Five outliers were removed from Figure 2a (all greater than 1.5 box lengths above the box) and one from Figure 2b (1.5 box lengths below the box) to ensure confidentiality was maintained.

Figure 3: Predicted values against observed values for the regression model fitted to $y\_{BKB}^{\*}$.

Figure 4: Predicted values against observed values for the regression model fitted to $y\_{CUNY}^{+}$.