92 Cochlear Implants International
Cochlear Implants Int. **10**(2), 92–102, 2009
Published online 6 January 2009 in Wiley InterScience
(www.interscience.wiley.com) **DOI**: 10.1002/cii.396

Comparing auditory perception and speech production outcomes: Non-language specific assessment of auditory perception and speech production in children with cochlear implants

LUCY PHILLIPS, Bridgend Cochlear Implant Programme, Bridgend, UK
SAEID HASSANZADEH, Iran Cochlear Implant Centre, Tehran, Iran
JULIE KOSANER, Med-ers, Istanbul, Turkey
JANE MARTIN, Yorkshire Cochlear Implant Service, Bradford, UK
MARTINA DEIBL, ILONA ANDERSON, MED-EL GmbH, Innsbruck, Austria

ABSTRACT *Language-independent assessment tools evaluate the progress of children who receive a cochlear implant, allowing large pooling of data for better access to insurers and other health care professionals. One hundred and seventeen children from centres in the United Kingdom, Iran and Turkey were assessed on two measures over a five-year test interval. There is a significant improvement over time for the Categories of Auditory Performance (CAP) and Speech Intelligibility Rating (SIR) measures. There was a significant difference between scores for different language groups: accounted for by the differences in age at implantation. There was a significant effect of age at implantation up to three years of device use. There were high correlations between the CAP and SIR scores. A longer duration of deafness resulted in a higher score for both scales; however, there was no relationship when correlated for age. Finally, the CAP pre-operative score allows us to predict the post-operative SIR scores. The scales are validated; reliable measures which can be used across countries and languages. This allows greater ability to pool data allowing data to be generalised across population groups, providing more power to prove that cochlear implantation is a viable treatment for children with bilateral severe-to-profound hearing loss.*

Keywords: auditory perception; speech production; CAP; SIR; cochlear implant

Introduction

Cochlear implantation is an accepted treatment method for children with a bilateral severe-to-profound sensorineural hearing loss, and is accessible to many children across the globe. Many studies demonstrate the benefit of cochlear implantation in children (for example, Anderson et al., 2004; Osberger et al., 1993; Spencer et al., 2003; Tye-Murray et al., 1995; Waltzman et al., 1997; Young et al., 2002); however, these are often limited to children from one clinic, geographical region or a specific language group. This is mainly the result of the availability of assessment measures.

It is critical to have suitable assessment materials to follow-up progress after implantation. This is as important for large, experienced centres as it is for smaller centres or those with less experience. It is useful if some assessment tools are language-independent, in order to be able to pool data across centres and countries. The tools also need to provide information to inform the team about the child's progress in a manner understandable to all involved professionals and families. And crucially, the outcomes should allow health insurers to understand and see benefits of cochlear implantation.

Unfortunately, many available tools are very language-specific, and may require a substantial effort to adapt and validate in another language. Issues hindering adaptation include difference in use of gender, tense, word order and in number of meaningful monosyllables versus bisyllables. What are the problems with language-specific measures? They are bound to a single language, making it difficult to have an amply large study group. Without large study populations, we have poor generalisation of data, difficulty proving efficacy, limited statistical opportunities and the potential for greater subject variance.

Two language-independent assessment rating scales are available to assess speech perception and speech production. The Categories of Auditory Performance (CAP) (Archbold et al., 1995) assesses auditory perception, which is the awareness, recognition and interpretation of auditory stimuli received in the brain (Stach, 1997). The Speech Intelligibility Rating (SIR) (Allen et al., 1998) assesses speech intelligibility, which is the degree to which a speaker's intended message can be recovered by other listeners (Bunton et al., 2001). The validity, reliability and inter-tester reliability are well documented in research for both assessment measures (Allen et al., 2001; Archbold et al., 1998). Both measures can be used pre- and post-operatively, are age-independent and easy to translate.

This study aimed to assess the development of auditory perception and speech production skills in children who received a cochlear implant. The children were taken from three different language groups (English, Turkish and Farsi) and countries and were followed for a period of five years.

DOI: 10.1002/cii

Method

Subjects

This study was conducted in three countries, with two clinics located in the United Kingdom, one clinic in Iran and one clinic in Turkey. One hundred and seventeen children who received a MED-EL cochlear implant (either the COMBI 40 or COMBI 40+, using the TEMPO+ speech processor) participated in the study. Forty-one children were included in the United Kingdom, 54 in Iran and 22 in Turkey. Six of the children speak more than one language and two have additional needs. The average age at cochlear implantation was 5.4 years (range: 1.8 to 17.8). One hundred and eight children were congenitally deaf; only nine children had acquired hearing loss. The aetiologies are listed in Table 1.

Test material

The CAP (Archbold et al., 1995) quantifies the auditory receptive abilities of linguistically compromised profoundly deaf children in a clinical setting. The CAP is an eight-point rating scale ranging from 'displays no awareness of environmental sounds' to 'can use a telephone with a familiar talker'. The SIR (Allen et al., 1998) is a scale that quantifies the speech production abilities of linguistically compromised profoundly deaf children in a clinical setting. The SIR is a five-point rating scale ranging from 'pre-recognisable words in spoken language. The child's primary

Table 1: Aetiology overall and broken down by language groups

	Language group			Overall
	English	Turkish	Farsi	
Hereditary	1	3	27	31
Mondini dysplasia	2	0	2	4
Asperger syndrome	0	0	1	1
Premature	0	0	1	1
Cytomegalovirus	1	0	1	2
Auditory neuropathy	0	1	0	1
Ototoxic	0	2	0	2
Congenital	23	4	0	27
Progressive	3	0	0	3
Waardenberg's syndrome	1	1	0	2
Meningitis	3	0	0	3
Hypoxia	3	0	0	3
Measles	1	0	0	1
Sclerdoderma	0	1	0	1
Unknown	3	10	22	35
Total	41	22	54	117

DOI: 10.1002/cii

mode of everyday communication may be manual' to 'connected speech is intelligible to all listeners. The child is understood easily in everyday contexts.'

Test procedure

The children were assessed pre-operatively and then at first fitting, three, six and 12 months after first fitting then annually up to five years on the two rating scales. The child's clinician noted where the child was performing on the rating scale, according to predefined guidelines, as suggested by the authors of the rating scales.

Statistical analysis

Data are expressed as mean and standard deviation. Non-parametric analyses of variance for repeated measurements (Friedman tests) with time as a factor were performed for CAP and SIR scores. To detect differences between test intervals, non-parametric Wilcoxon signed-ranks tests were used. Mann-Whitney-U-tests were applied in order to detect significant differences between language groups (English, Turkish and Persian) for CAP and SIR scores and for age at implantation. Kendall's tau-b correlation coefficients were used to show correlations between aetiology and CAP and SIR scores. Correlations between CAP and SIR scores, duration of deafness and age at implantation were evaluated using Spearman's rank correlation coefficient. To eliminate the influence of age on the correlation between duration of deafness and CAP and SIR scores partial correlation was performed. Partial correlation is a method used to describe the relationship between two variables whilst taking away the effects of another variable on this relationship. Discriminant analyses with SIR scores as dependent variables and CAP scores as independent variables were performed to predict SIR scores based on CAP scores at each test interval. Statistical significance was defined as $p < 0.05$. Adjustments for multiple comparisons with the use of Holm's procedure were conducted. SPSS for Windows 14.0 software (Chicago, IL) was used for all analyses.

Handling of missing data

For descriptive analysis, all data – including data from patients withdrawn prematurely from the study – were considered. Missing data were not imputed for patients withdrawn prematurely from the study. If patients had single missing values on speech test data, 'single mean imputation' was used for missing values at the preoperative assessment and 'last observation carried forward' was used for missing values at the other intervals. Statistical testing was performed without data from patients withdrawn prematurely from the study (n = 42 for CAP data and n = 45 for SIR data). Missing data imputation had no significant influence on the outcome. The imputation was only done for the sake of possibility of including all data sets into analysis.

DOI: 10.1002/cii

Results

Outcomes

CAP

There is a significant improvement in scores over time ($p \leq 0.001$). The average score was 0.52 (± 1.18 SD) before cochlear implantation and increased to a mean score of 5.96 (± 1.42 SD) over a period of five years (Table 2). *Post-hoc* tests have shown a significant improvement between each test interval (all p-values ≤0.02). The distribution of scores over time is shown in Figure 1.

Table 2: Summary statistics for Categories of Auditory Performance (CAP) and Speech Intelligibility Rating (SIR) scores at each test interval

Test interval	CAP			SIR		
	Number of observations	Mean	Standard deviation	Number of observations	Mean	Standard deviation
Pre-operative	117	0.52	1.18	113	1.29	0.91
Initial fitting	73	0.64	0.98	73	1.12	0.50
3 months	112	2.29	1.57	108	1.52	1.10
6 months	114	3.28	1.54	110	1.85	1.22
12 months	115	4.04	1.48	113	2.18	1.17
2 years	116	4.82	1.44	112	2.66	1.11
3 years	99	5.48	1.44	98	3.03	1.16
4 years	91	5.65	1.62	85	3.09	1.17
5 years	75	5.96	1.42	68	3.63	1.28

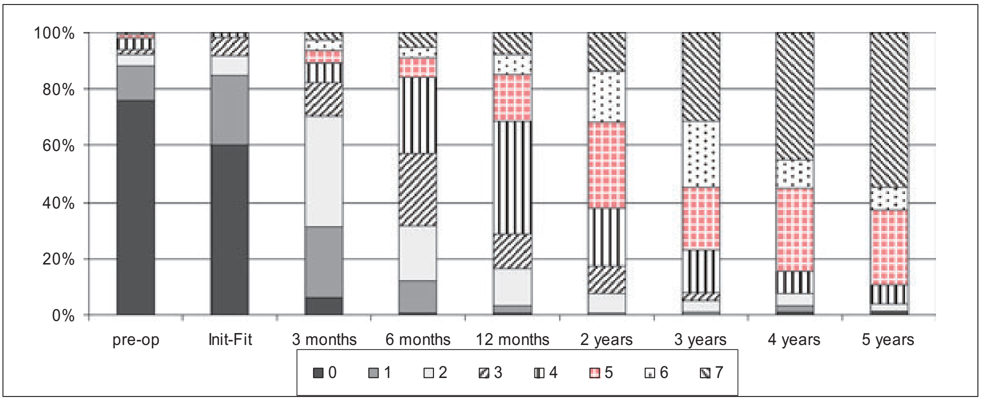

Figure 1: Categories of Auditory Performance: Distribution of values over time, with percentage of children scoring each rating scale on the y-axis and the test intervals on the x-axis. This figure is available in colour online at www.interscience.wiley.com/journal/cii

DOI: 10.1002/cii

SIR

There is a significant improvement in scores over time ($p \leq 0.001$). The pre-operative mean score increased from 1.29 (± 0.91 SD) to 3.63 (± 1.28 SD) after a period of five years (Table 1). *Post-hoc* tests revealed a significant improvement between individual test intervals (all p-values ≤0.02), except for the three- to four-year test interval ($p = 0.603$). The distribution of scores over time is shown in Figure 2.

Comparison between languages

CAP

Highly significant differences were found between Farsi and English (the original language of the scales) for each test interval (pre-operative: $p = 0.005$; 3 months: $p \leq 0.001$; 6 months: $p \leq 0.001$; 12 months: $p \leq 0.001$; 2 years: $p = 0.01$; 3 years: $p = 0.003$; 4 years: $p \leq 0.001$; 5 years: $p \leq 0.001$). Between Turkish and Farsi, significant differences were found for the three-month, six-month, nine-month and five-year test intervals (3 months: $p \leq 0.001$; 6 months: $p = 0.002$; 12 months: $p = 0.007$; 5 years: $p \leq 0.001$). Language comparisons for CAP scores can be seen in Figure 3. In order to determine possible reasons, differences in age at implantation between the three language groups were analysed. The Farsi-speaking group was implanted at a significantly older age in comparison to the English- and Turkish-speaking group (English: $p = 0.016$; Turkish: $p = 0.030$), suggesting the difference in scores may be due to age at implantation.

SIR

No significant differences in SIR scores were found between language groups. Language comparisons for SIR scores can be seen in Figure 4.

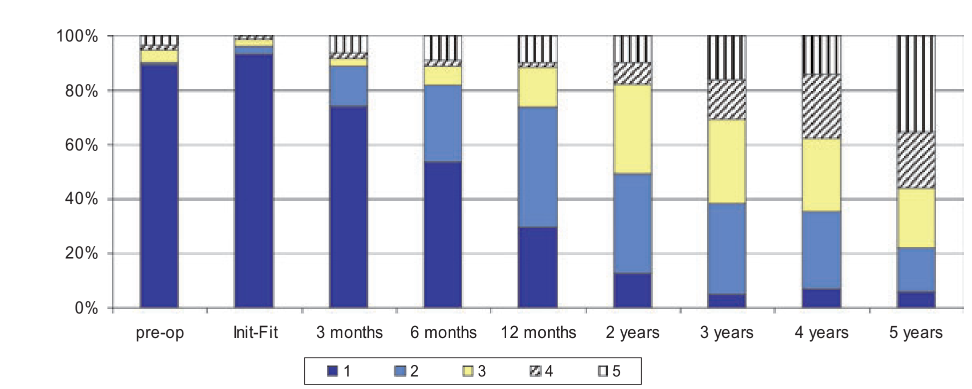

Figure 2: Speech Intelligibility Rating: Distribution of values over time, with percentage of children scoring each rating scale on the y-axis and the test intervals on the x-axis. This figure is available in colour online at www.interscience.wiley.com/journal/cii

DOI: 10.1002/cii

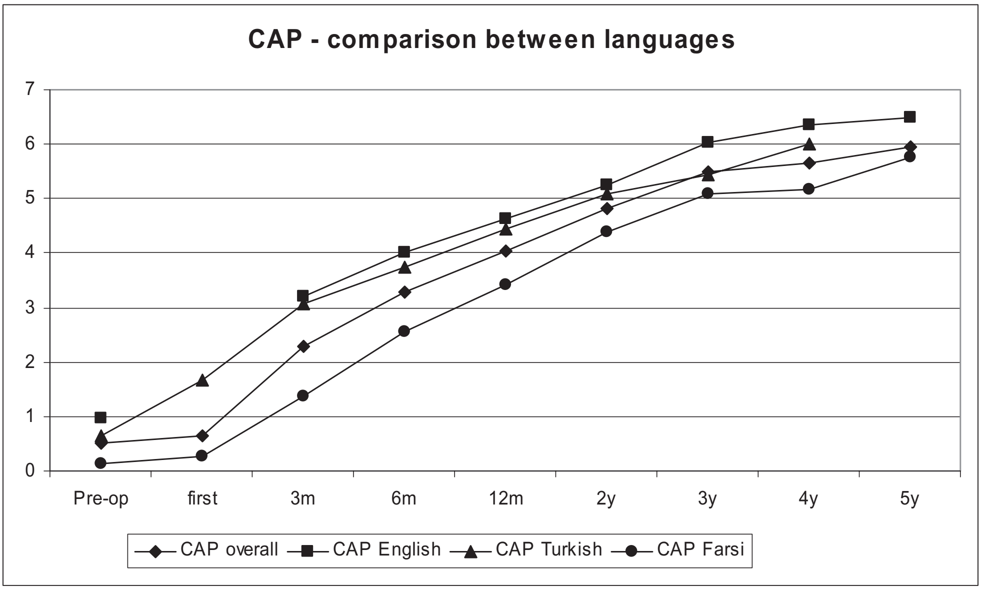

Figure 3: Categories of Auditory Performance (CAP): Comparison of languages and the mean score over time.

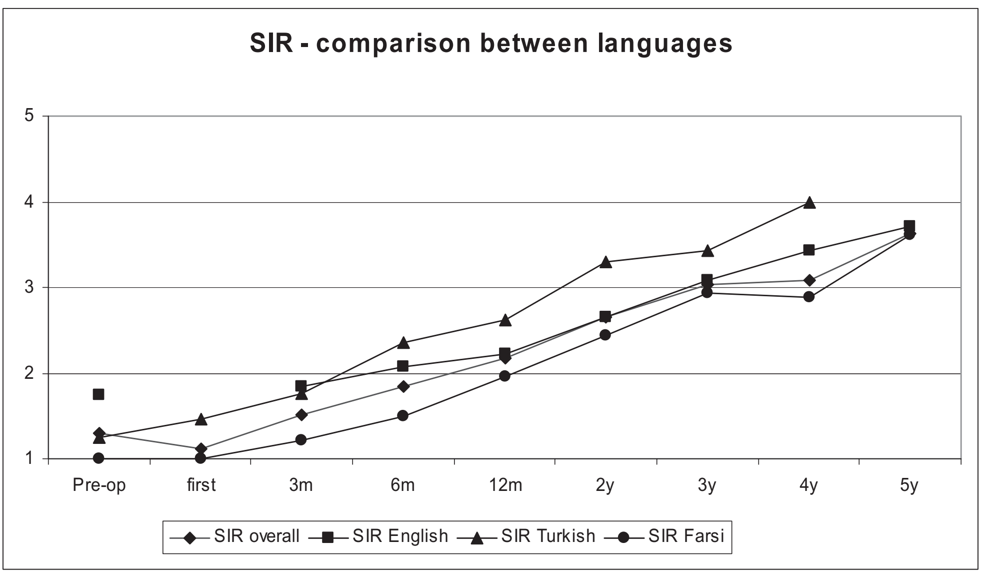

Figure 4: Speech Intelligibility Rating (SIR): Comparison of languages and the mean score over time.

DOI: 10.1002/cii

Correlation with age at implantation and duration of deafness

CAP

Significant correlations between CAP scores and age at implantation were found for the pre-operative (r = 0.531, $p \leq 0.001$), three-month (r = 0.244, $p = 0.034$), six-month (r = 0.294, $p = 0.01$), 12-month (r = 0.266, $p = 0.02$), two-year (r = 0.273, $p = 0.017$) and three-year (r = 0.231, $p = 0.045$) test intervals. Children with a later age at implantation scored higher. There were no significant correlations for the initial fitting, and the four- and five-year intervals.

Significant correlations between CAP scores and duration of deafness were found for the pre-operative (r = 0.511, $p \leq 0.001$), six-month (r = 0.252, $p = 0.028$), 12-month (r = 0.272, $p = 0.017$), 2-year (r = 0.271, $p = 0.018$), three-year (r = 0.248, $p = 0.047$) and five-year (r = -0.390, $p = 0.013$) test intervals. Children with a longer duration of deafness scored higher for the pre-operative, six-month, 12-month, two-year and three-year intervals and scored lower for the five-year interval. There were no significant correlations for the initial fitting, and the three-month and the four-year test intervals.

There was no significant relationship between duration of deafness and CAP scores when a partial correlation adjusted for age was performed.

SIR

Correlations between SIR scores and age at implantation were highly significant up to the three-year test interval (pre-operative: r = 0.535, $p = p \leq 0.001$; 3 months: r = 0.495, $p \leq 0.001$; 6 months: r = 0.496, $p \leq 0.001$; 12 months: r = 0.469, $p \leq 0.001$; 2 years: r 0.456, $p \leq 0.001$; 3 years: r = 0.402, $p \leq 0.001$). These highly significant results suggest a stronger connection between SIR scores and age at implantation compared to CAP scores and age at implantation, reported in the paragraph above.

Significant correlations between SIR scores and duration of deafness were found for the pre-operative (r = 0.547, $p \leq 0.001$), three-month (r = 0.474, $p \leq 0.001$), six-month (r = 0.434, $p \leq 0.001$), 12-month (r = 0.434, $p \leq 0.001$), two-year (r = 0.400, $p \leq 0.001$) and three-year (r = 0.449, $p \leq 0.001$) test intervals. Children with a longer duration of deafness scored higher. There were no significant correlations for the initial fitting, and the four- and five-year intervals.

There was no significant relationship between duration of deafness and SIR scores when a partial correlation adjusted for age was performed.

Correlation with aetiology

No significant correlations between aetiology and CAP and SIR scores for all test intervals were found using Kendall's tau-b correlation coefficients.

DOI: 10.1002/cii

Correlation between CAP and SIR scores

Spearman's rank correlation coefficients were used to find correlations between CAP and SIR scores. Highly significant correlations between CAP and SIR scores were found for all test intervals (pre-operative: r = 0.680, $p \leq 0.001$; initial fitting: r = 0.344, $p \leq 0.001$; 3 months: r = 0.418, $p \leq 0.001$; 6 months: r = 0.614, $p \leq 0.001$; 12 months: r = 0.524, $p \leq 0.001$; 2 years: r = 0.575, $p \leq 0.001$; 3 years: r = 0.657, $p \leq 0.001$; 4 years: r = 0.731, $p \leq 0.001$; 5 years: r = 0.684, $p \leq 0.001$). All correlations were positive, indicating that the higher the child's CAP scores, the higher their SIR scores are.

Prediction of SIR scores out of CAP scores

As CAP scores develop earlier after cochlear implantation, they can be used to predict the SIR score at specific intervals. Pre-operative CAP scores can predict pre-operative SIR scores with a probability of 90.3 per cent, first fitting SIR scores with a probability of 84.9 per cent and three-month interval SIR scores can be predicted for 77.8 per cent of all cases. When predicting SIR scores out of CAP scores from the same interval, a good prediction rate is reached for all SIR scores (mean predictability of 57% ± 20% SD).

Discussion

The results from the current study suggest that both the CAP and SIR measures are suitable for assessing outcomes of children who receive a cochlear implant over the long term. The measures demonstrate that these children show significant improvement with hearing experience, even after five years.

Initial studies with the CAP also showed significant benefit over time, with a large sample achieving placement in category 4 after one year of device use, highlighting again the rapid progress in the development of auditory skills after receiving a cochlear implant (O'Donoghue et al., 1998).

Results correspond with those from a large-sample, long-term study (O'Donoghue et al., 1999). Their study on 126 children also demonstrated improvements over time and strong correlations between the CAP and SIR scores. However, there was no correlation between pre- and post-operative SIR scores, possible due to floor effects for the pre-operative test. Essentially, their study also demonstrated that high CAP scorers were also high scorers on the SIR; the current study takes this one step further, showing these results are also attainable across centres, languages and countries.

Results from the current study show significant improvements over time. However, when comparing individual test intervals, there was no difference between the three-year and four-year test interval for the SIR. There is a subsequent significant improvement from the four- to five-year test interval. This suggests that learned auditory skills have a plateau or consolidation period after rapid initial development. Therefore, although there is a large improvement in the first

DOI: 10.1002/cii

few months of device use, production skills continue to develop over a long period of time – important information for therapeutic and educational support. In fact, a study on ten-year outcomes demonstrates this long-term development, with improvements in CAP ratings from the five-year to ten-year test interval (Beadle et al., 2005). The outcomes from the current study were similar for both the CAP and SIR scores. It is surprising that, in the current study, the SIR showed significant improvements from the three-month interval onwards, given that, normally, production skills take longer to develop and usually develop after perception skills. This highlights the fact that cochlear implantation may accelerate the development of speech production skills, especially when received at a younger age.

Age at implantation has an impact on outcomes, which is consistent with previous studies using these measures (Colletti et al., 2005; O'Niell et al., 2002). Children in the current study who were implanted earlier performed significantly better on both rating scales, even after three years of device use. This significant advantage of early implantation allows children access to sound and oral language from a younger age, which can mean added benefits for furthering literacy skills and overall academic success. The topic of benefit gleaned from early implantation on speech production skills warrants further investigation.

A similarity between languages is demonstrated on all SIR scales but not on the CAP scales. Further analysis suggested that this difference between Farsi, Turkish and English for CAP was related to age at implantation, where Farsi-speaking children were implanted at a significantly older age. Thus, pooling the data would still reflect a better generalisation of outcomes, reflecting different languages, different ages at implantation and possibly different therapeutic techniques.

CAP and SIR measures are valuable in terms of assessing progress over a long period of time and, as demonstrated by the results of this study, are useful for children of different ages. As they are easy to translate and use, they can be a useful resource for developing clinics that need to demonstrate the efficacy of their programme, or for demonstrating the benefits of cochlear implantation to health insurers. Another benefit, as seen in the results showing CAP-SIR score predictions, is in counselling the family of a potential cochlear implant candidate. Many parents and guardians ask how their child will perform after receiving the device; pre-operative CAP and SIR scores could be a used as a tool for discussing realistic expectations in this situation, since results show that certain CAP scores, in particular the pre-operative score, can predict the child's speech intelligibility outcomes. Post-operatively, CAP and SIR scores may be useful in guiding the directions of speech and language therapy.

Conclusions

As demonstrated using the CAP and SIR measures, children who receive a cochlear implant show significant improvement in auditory perception and speech intelligibility skills over time. Age at implantation has a significant benefit,

DOI: 10.1002/cii

particularly for speech intelligibility. Aetiology has no impact on outcomes. The CAP and SIR can be easily translated into a number of languages, creating a larger data pool that can be used to make generalisations regarding outcomes demonstrated by cochlear implant users.

References

Allen C, Nikolopolous TP, Dyar D, O'Donoghue G (2001) Reliability of a rating scale for measuring speech intelligibility after cochlear implantation. Otology and Neurotology 22: 631–633.

Allen MC, Nikolopoulos TP, O'Donoghue GM (1998) Speech intelligibility in children after cochlear implantation. American Journal of Otology 19: 742–746.

Anderson I, Weichbold V, D'Haese P (2004) Three-year follow up of children with open-set speech recognition who use the MED-EL cochlear implant system. Cochlear Implants International 5(2): 45–57. DOI: 10.1002/cii.125.

Archbold S, Lutman ME, Marshall DH (1995) Categories of auditory performance. In Clark M, Cowan RSC (eds) International Cochlear implants, speech and hearing symposium, Melbourne. Annals of Otology, Rhinology Laryngology 104 Suppl 166: 312–314.

Archbold S, Lutman ME, Nikolopolous (1998) Categories of auditory performance: Inter-user reliability. BJA 32: 7–12.

Beadle EAR, McKinley DJ, Nikolopolous TP, Brough J, O'Donoghue GM, Archbold SM (2005) Long-term functional outcomes and academic-occupational status in implanted children after 10 to 14 years of cochlear implant use. Otology and Neurotology 26: 1152–1160.

Bunton K, Kent RD, Kent JF, Duffy JR (2001) The effects of flattening fundamental frequency contours on sentence intelligibility in speakers with dysarthria. Clinical linguistics and phonetics 15: 181–193.

Colletti V, Carner M, Miorelli V, Guida M, Colletti L, Fiorino FG (2005) Cochlear implantation at under 12 months: Report on 10 patients. Laryngoscope 115: 445–449.

O'Donoghue GM, Nikolopolous T, Archbold SM, Tait M (1998) Congenitally deaf children following cochlear implantation. Acta oto-rhinologia Belgique 52: 111–114.

O'Donoghue GM, Nikolopoulos TP, Archbold SM, Tait M (1999) Cochlear implants in young children: The relationship between speech perception and speech intelligibility. Ear and Hearing 20: 419–425.

O'Niell C, O'Donoghue GM, Archbold SM, Nikolopolous TP, Sach T (2002) Variations in gains in auditory performance from pediatric cochlear implantation. Otology and Neurotology 23: 44–48.

Osberger MJ, Maso M, Sam LK (1993) Speech intelligibility of children with cochlear implants, tactile aids, or hearing aids. Journal of Speech and Hearing Research 36: 186–203.

Spencer LJ, Barker BA, Tomblin JB (2003) Exploring the language and literacy outcomes of pediatric cochlear implant users. Ear and Hearing 24(3): 236–247.

Stach BA (1997) Comprehensive Dictionary of Audiology. Baltimore: Williams and Wilkins.

Tye-Murray N, Spencer L, Woodworth GG (1995) Acquisition of speech by children who have prolonged cochlear implant experience. Journal of Speech and Hearing Research 38: 327–337.

Waltzman SB, Cohen NL, Gomolin RH et al. (1997) Open-set speech perception in congenitally deaf children using cochlear implants. American Journal of Otology 18: 342–349.

Young GA, Killen DH (2002) Receptive and expressive language skills of children with five years of experience using a cochlear implant. Annals of Otology Rhinology and Laryngology 111: 802–810.

Address correspondence to: Lucy Phillips, Princess of Wales Hospital, Department of Audiology, Coity Road, Bridgend CF31 1RQ, UK. Phone: +44 (1656) 752192. Email: lucy.phillips@bromor-tr.wales.nhs.uk

DOI: 10.1002/cii