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Bilateral versus unilateral cochlear implantation in young children

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ABSTRACT

Objectives: To compare the preverbal communication skills of two groups of young implanted children: those with unilateral implantation and those with bilateral implantation.
Material and methods: The study assessed 69 children: 42 unilaterally and 27 bilaterally implanted with age at implantation less than 3 years. The preverbal skills of these children were measured before and 1 year after implantation, using Tait Video Analysis that has been found able to predict later speech outcomes in young implanted children.
Results: Before implantation there was no significant difference between the unilateral group and the bilateral group. There was still no difference at 12 months following implantation where *vocal autonomy* is concerned, but a strongly significant difference between the groups for *vocal turn-taking* and *non-looking vocal turns*, the bilateral group outperforming the unilateral group. Regarding *gestural turn-taking* and *gestural autonomy*, there was a strongly significant difference between the two groups at the 12 month interval, and also a difference before implantation for *gestural autonomy*, the unilateral group having the higher scores. Multiple regression of *non-looking vocal turns* revealed that 1 year following implantation, bilateral implantation contributed to 51% of the variance ($p < 0.0001$), after controlling for the influence of age at implantation and length of deafness which did not reach statistical significance.
Conclusions: Profoundly deaf bilaterally implanted children are significantly more likely to use vocalisation to communicate, and to use audition when interacting vocally with an adult, compared with unilaterally implanted children. These results are independent of age at implantation and length of deafness.

1. Introduction

The last 20 years have brought about a remarkable change in the providing of useful auditory experience for profoundly deaf children, the most significant contributor to this change being cochlear implantation, the implants giving access to high frequencies which cannot be provided by acoustic hearing aids. The significant benefit derived by profoundly deaf children has resulted in wide-spread provision of cochlear implants in all developed countries, with over half the population of profoundly deaf school-age children being implanted.

Research worldwide has shown that the age at which children are implanted is an important factor in the development of speech perception and intelligibility [1–4], so the availability of Newborn Hearing Screening has been another significant contributor to change, enabling children to be given cochlear implants at an earlier age. Relatively speaking, the provision of two implants is still fairly recent, though this provision is happening worldwide. In the UK the government organisation: National Institute of Clinical Excellence (NICE) has thoroughly investigated the viability of the procedure and has recommended bilateral implantation for all very young profoundly deaf children. There is, naturally, great interest in the outcomes of bilateral implantation, not least

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because of the extra expense involved in providing two implants, and many research projects are taking place. Some of the research projects that have been undertaken are detailed case studies and therefore necessarily involve low numbers [5,6], though there are others with more numerous subjects, for example the study by Kuhn-Inacker et al. which involved 39 bilaterally implanted children [7]. Most studies are of sequential implantations [8–10]. For example, Galvin et al. [9] looked at 9 young children with a gap of between 6 months and 3 years 2 months between implants.

The main findings of recent research have been the benefits given by bilateral implantation for localisation of sound [11,12] and speech discrimination in noise [7–10,13–15]. Almost all of these studies have concerned children after their acquisition of spoken language, and in some cases adults, for example the study by Zeitler et al. [8] which looked at speech perception benefits in both adults and children. From studies such as these we know that the use of two ears is important in an educational setting, where children are often in noisy rooms and working in groups: being able to use both ears enables easier identification of the speaker and hence greater likelihood that they will understand the speech. This effect is illustrated in the results given in the papers cited above. However, knowledge of spoken language is clearly necessary for the performance of tests of speech perception. Two questions arise: is the use of two ears important for the development of early communication skills? And is it possible to obtain any indications of benefit from two implants rather than one *before* understanding and use of spoken language have developed? One way of doing this is to ask the parents, and a questionnaire has been developed for this purpose by The Ear Foundation in Nottingham [16], covering, for example, localisation of sound and response to voice when in a group of people. Parent interviews yield information on very young children's behaviour at an age when it is difficult to get it in other ways, the children being too young to perform listening tasks; but it must be borne in mind that parental interviews are limited because they are subjective.

Another method, TAIT video analysis, has enabled professionals to look at progress in the preverbal listening skills that underpin vocal and auditory development in all children, normally hearing and deaf alike. This objective, observational method involves looking at video recordings of children's interactions with someone they know well, such as a parent or carer. The recordings can be analysed to show whether, over time, children are becoming more vocal in their communications as compared with using silent sign or gesture, and whether there are indications that they are responding to the adult's speech through audition rather than vision. The analysis, as an assessment method, has been shown to be reliable across observers [17,18] and to have predictive potential with regard to later development of speech perception [19,20]. It is sufficiently sensitive to show whether age at implantation is a factor in children's progress [4], and whether children implanted under the age of 12 months differ significantly from normally hearing children [21]. It is independent of the particular language spoken and therefore can be used in any country.

The aim of the present study is to compare the preverbal communication skills of two groups of very young children: those with unilateral implantation and those with bilateral implantation.

2. Materials and methods

Using TAIT video analysis 42 unilaterally implanted and 27 bilaterally implanted children were assessed before implantation and 12 months following implantation. All the children in both groups met the criteria of being profoundly deaf with no responses to sound at levels better than 110 dB, and of having no known additional cognitive delay. The unilaterally implanted children were from the Nottingham Cochlear Implant Programme (28 children) and KIDS in Hasselt, Belgium (14 children), and were all those implanted since the year 2000 and met the criteria. The bilaterally implanted children were recruited from four different centres: the Nottingham Cochlear Implant Programme, UK (7 children); LUMC, Leiden (7 children), the Radboud University Nijmegen Medical Centre (5 children) in The Netherlands; and Enheten for Cochlea Implantet in Stockholm, Sweden (8 children). It was necessary to gain the collaboration of all these centres in order to recruit a sufficient number of very young bilaterally implanted children. All the children had full insertion of the electrode array apart from one bilaterally implanted child who had full insertion in the left ear and 15/16 electrodes of the Nucleus device in the right ear; this also was treated as a full insertion. Eighteen of the 27 bilateral children underwent simultaneous implantation. The remaining 9 were implanted sequentially, the gap between the two implantations ranging from 1 to 7 months. Tables 6 and 7 in the appendix show the demographic details for both groups of children. As the aim of the present study was to compare children with one implant with children bilaterally implanted (none of the children having sufficient residual hearing to use a hearing aid in either ear) no attempt was made to compare children with two implants with those with one implant plus a hearing aid in the contra-lateral ear.

Video recordings were made before implantation and 12 months after. The recordings were made by the four centres involved in the study. Initial discussion, and training for those centres not already using video analysis routinely for assessment, took place between the first author and the professionals at these centres to ensure that there was consistency both in the filming and in the analysis of the recordings, which were of the child and a parent or other well known adult, who used spoken language supported by signs and/or gestures. They took place in the child's home or other familiar environment; where the unilaterally implanted children were concerned every effort was made to see that the adult was positioned on the side of the implant. The recordings were around 10 min in length, from which a 2-minute section of good interaction was selected by the first author for analysis. If necessary, the 2-minute section was made up of two excerpts from the recording, very young children being apt to lose concentration and move away from the recording area. The recordings were made in well-lit rooms in reasonably quiet conditions. The camera recorded the child almost full-face, with a profile view of the adult if they were sitting opposite the child. No difficulty of observation arose if the child was sitting alongside or on the adult's knee. Activities were chosen that would be of interest to each particular child and which would also promote interaction. A picture book was always included. Transcripts were made of the recordings, and the preverbal skills assessed. The initial assessment was done by the first author, who then checked with the child's teacher or speech therapist to be sure that nothing had been missed or misinterpreted. This was particularly important in the case of the recordings from The Netherlands and Sweden.

Initially *turns* were identified where the child had an opportunity to communicate. This usually occurred where the adult had left a pause, but instances were also included where the child interrupted the adult's communication. Within these *turns*, preverbal skills were measured in three areas: *turn-taking*, *autonomy* and *auditory awareness*. *Turn-taking* and *autonomy* could be either *vocal*, with or without the addition of sign or gesture, or *gestural*, through silent sign or gesture. *Autonomy* was considered to have been shown if the child's communication contained elements that could not have been predicted from the adult's preceding communication. For example, the adult might have introduced a toy that the child did not want. If the child then indicated another preferred toy while vocalising, this would be considered to be an example of *vocal autonomy*; if the indication was by facial expression and a silent point, this would be considered to be an example of *gestural autonomy*. Auditory awareness of the adult's voice was considered to be shown if the child responded vocally when they had not been looking at the adult for the adult's last few words, no visual cues having been given. This vocal response was termed a *non-looking vocal turn*. These measures of *turn-taking*, *autonomy* and *non-looking vocal turns* were each expressed as a percentage of the total number of conversational *turns*. Twenty such turns were needed for the analysis. It is clear from the above that the term 'turns' does not mean simple 'head turns' as in standard behavioural testing.

2.1. Statistical analysis number 1

In order for the two groups to be comparable and the outcomes valid, the following criteria were used in addition to those of profound deafness and no known cognitive disorder:

- Length of deafness ≤ 20 months.
- Age at implantation < 24 months.

27 children in the unilateral group and 26 children in the bilateral group met the above criteria and were statistically compared using *T*-test and Mann Whitney *U* test. Statistical significance was accepted at the $p < 0.05$ level and the variables were considered as normally distributed when standardised kurtosis and skewness were equal to or less than the absolute value of 2. Applying the above mentioned criteria:

Age at implantation (in months)			
	Mean	Median	Range
Unilateral group	12	12	5–22
Bilateral group	13	12	7–22

No statistically significant difference ($p > 0.05$).

Duration of deafness (in months)			
	Mean	Median	Range
Unilateral group	11	11	5–19
Bilateral group	10	9	1–20

No statistically significant difference ($p > 0.05$).

2.2. Statistical analysis number 2

In order to examine the unique contribution of each variable (bilateral or unilateral implantation, age at implantation, and length of deafness) to predicting the outcome (*non-looking vocal turns* and *vocal autonomy* at the 12-month interval following implantation), a step-wise forward multiple regression analysis was conducted in all the children studied (without applying the additional inclusion criteria of age at implantation and duration of deafness used in analysis number 1); that is, 69 implanted children: 42 unilaterally and 27 bilaterally implanted. This analysis evaluates the proportion of variance explained by each variable as it is entered, while controlling for the contribution of previously entered variables.

Table 1
Mean and median vocal turns before and 12 months after implantation.

	Before implantation		12 months after implantation	
	Mean	Median	Mean	Median
Unilaterally implanted deaf children	16.4	15	61.5	60
Bilaterally implanted deaf children	20.9	20	89	90
Statistical significance	NS[a]		$p < 0.0001$	

[a] NS: not significant.

3. Results

Tables 1–5 show the results obtained from analysis number 1. Tables 1–3 show the results for *vocal turn-taking*, *vocal autonomy* and *non-looking vocal turns*. Before implantation there was no significant difference between the unilateral group (27 children) and the bilateral group (26 children). There is still no difference at 12 months following implantation where *vocal autonomy* is concerned, but a strongly significant difference between the

Table 2
Mean and median vocal autonomy before and 12 months after implantation.

	Before implantation		12 months after implantation	
	Mean	Median	Mean	Median
Unilaterally implanted deaf children	6.6	0	37.8	40
Bilaterally implanted deaf children	4.6	0	42.3	40
Statistical significance	NS[a]		NS[a]	

[a] NS: not significant.

Table 3
Mean and median non-looking vocal turns before and 12 months after implantation.

	Before implantation		12 months after implantation	
	Mean	Median	Mean	Median
Unilaterally implanted deaf children	0.5	0	35.8	30
Bilaterally implanted deaf children	0	0	76.5	80
Statistical significance	NS[a]		$p < 0.0001$	

[a] NS: not significant.

Table 4
Mean and median gestural turns before and 12 months after implantation.

	Before implantation		12 months after implantation	
	Mean	Median	Mean	Median
Unilaterally implanted deaf children	53	55	27.3	25
Bilaterally implanted deaf children	59.6	55	9.2	7.5
Statistical significance	NS[a]		$p < 0.0001$	

[a] NS: not significant.

Table 5
Mean and median gestural autonomy before and 12 months after implantation.

	Before implantation		12 months after implantation	
	Mean	Median	Mean	Median
Unilaterally implanted deaf children	23.1	15	13.4	10
Bilaterally implanted deaf children	8.4	5	1.9	0
Statistical significance	$p = 0.001$		$p = 0.0001$	

groups for *vocal turn-taking* and *non-looking vocal turns*, the bilateral group outperforming the unilateral group. Tables 4 and 5 show the results for *gestural turn-taking* and *gestural autonomy*. Again there is a strongly significant difference between the two groups at the 12-month interval, and also a difference before implantation for *gestural autonomy*, the unilateral group having the higher scores.

In analysis number 2 the step-wise forward multiple regression of *non-looking vocal turns* revealed that at the 12 months interval following cochlear implantation, bilateral implantation contributed to 51% of the variance with a statistical significance of $p < 0.0001$, after controlling for the influence of age at implantation and length of deafness which did not reach statistical significance. The same analysis with regard to *vocal autonomy* did not reveal any statistically significant contributing variable.

4. Discussion

Before implantation the children in both groups are much more likely to communicate silently than vocally. It can be seen from Table 4 (analysis number 1) that both groups take over half their communicative opportunities by silent sign or gesture, and both groups are more likely to use *gestural autonomy* (Table 5) than *vocal autonomy* (Table 2). Tables 1–3 show that before implantation both groups make some use of *vocal turn-taking* but very little use of *vocal autonomy* and virtually no use of *non-looking vocal turns*. None of these measures show a significant difference at this stage. Significantly more instances of *gestural autonomy* were observed in the unilateral group, though we cannot suggest a reason for this as the adults in both groups were communicating by spoken language supported by signs and/or gestures. The impression given of both groups at this stage is of children who are in fact quite communicative in the filmed interactions, but who are largely silent and unresponsive to the sound of the adult's voice.

The picture is quite different by 12 months following implantation. At this interval both groups are taking the majority of their turns vocally (significantly more so for the bilateral group), with over a third of the turns in both groups showing *vocal autonomy*, where the difference between the groups is not significant. By this stage all the children are clearly relying on vocalisation in their communicative interactions. However, the most striking difference between the groups is found in the *non-looking vocal turn* result, with the bilateral group being more than twice as likely to respond vocally to the adult through audition alone. This is a remarkable result, given that the adult was positioned on the implant side for the unilateral children; and indicates that the bilateral children were receiving something extra from their two implants which was enabling more relaxed and vocally productive communication, without any necessity to look at the adult. In analysis number 2 also, it is in relation to the *non-looking vocal turn* measure that bilateral implantation accounts for 51% of the variance compared with other normally significant features such as age at implantation and length of deafness.

What are the implications of this result for the development of spoken language and ease of communication in these young children? Is the ability to hear and respond without looking important? We have written before [4,21] about the importance to parents and carers of being able to talk to their children *while* the children's visual attention is focused on an object of interest. Because of the audition given by the implant, the child receives the language input *at the same time* that they are looking at/playing with the object, rather than having to divide their attention between the object and the (subsequent) communication. The children referred to in analysis number 1 are around the age of 12 months at the beginning of the study (median 12 months) and are therefore throughout the study period very much at the stage where they are exploring their environment, rather than at the earlier stage of looking at the adult's face. Also, the fact that they respond vocally to the adult is greatly encouraging to the adult concerned, giving feedback which is likely to result in continued input at an appropriate level – the adult observing the child's focus of interest and making meaningful comments – thus providing a good framework for the child's acquisitions of vocal and auditory skills. It is arguable that becoming accustomed to making use of both ears from an early age will give the child a good start towards listening to speech in noisy environments. Moreover, taking into account that measures of preverbal communication predict long-term speech perception outcomes [19], the results of the present study suggest that bilaterally implanted children will outperform unilaterally implanted children in this area as well.

Regarding the time that elapses between the two implants, Graham et al. [22] have suggested that there is likely to be a 'critical age' for expecting speech perception from the second side to be implanted. However, in their conclusion the 'critical age' seems to be in adolescence, whereas in the present study all bilaterally implanted children have received the second implant much earlier.

5. Conclusions

The findings of the present study are that 12 months following implantation profoundly deaf bilaterally implanted children are significantly more likely to use vocalisation to communicate, and to use audition when interacting vocally with an adult, compared with unilaterally implanted children; though there is no significant difference between the groups before implantation. These results are independent of age at implantation and length of deafness. The implication of these findings supports bilateral implantation in very young profoundly deaf children with insufficient hearing to use a conventional hearing aid in the contra-lateral ear.

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Appendix A

Tables 6 and 7.

Table 6
Demographic details of bilaterally implanted children.

Bilaterals	Age 1st implant	Age 2nd implant	Age deaf	Electrodes	Length deaf	Gender
1	7 m	7 m	0 m	Full insertion	7 m	Female
2	11 m	11 m	0 m	Full insertion	11 m	f
3	12 m	12 m	0 m	Full insertion	12 m	f
4	11 m	11 m	0 m	Full insertion	11 m	f
5	8 m	13 m	0 m	Full insertion	8 m	f
6	11 m	15 m	3 m	Full insertion	8 m	m
7	11 m	11 m	10 m	Full insertion	1 m	m
8	9 m	9 m	0 m	Full insertion	9 m	f
9	9 m	16 m	0 m	Full insertion	9 m	f
10	12 m	12 m	0 m	Full insertion	12 m	m
11	9 m	12 m	0 m	Full insertion	9 m	m
12	11 m	18 m	1 m	Full insertion	10 m	f
13	8 m	8 m	2 m	Full insertion	6 m	f
14	17 m	19 m	15 m	Full insertion	4 m	m
15	19 m	19 m	0 m	Full insertion	19 m	f
16	15 m	15 m	0 m	15 R, full L	15 m	f
17	16 m	16 m	1 m	Full insertion	16 m	m
18	13 m	13 m	10 m	Full insertion	3 m	m
19	13 m	13 m	9 m	Full insertion	4 m	f
20	19 m	19 m	0 m	Full insertion	19 m	f
21	20 m	21 m	0 m	Full insertion	20 m	f
22	17 m	17 m	9 m	Full insertion	8 m	f
23	14 m	14 m	0 m	Full insertion	14 m	f
24	17 m	19 m	15 m	Full insertion	4 m	m
25	14 m	16 m	0 m	Full insertion	14 m	m
26	22 m	25 m	14 m	Full insertion	8 m	m
27	33 m	33 m	24 m	Full insertion	9 m	f

Table 7
Demographic details of unilaterally implanted children.

Unilaterals	Age at implant	Age deaf	Electrodes	Length deaf	Gender
1	9 m	0 m	Full insertion	9 m	Male
2	10 m	0 m	Full insertion	10 m	f
3	10 m	0 m	Full insertion	10 m	f
4	9 m	0 m	Full insertion	9 m	m
5	10 m	0 m	Full insertion	10 m	m
6	5 m	0 m	Full insertion	5 m	m
7	8 m	0 m	Full insertion	8 m	m
8	12 m	0 m	Full insertion	12 m	m
9	9 m	0 m	Full insertion	9 m	f
10	11 m	0 m	Full insertion	11 m	f
11	8 m	0 m	Full insertion	8 m	m
12	12 m	0 m	Full insertion	12 m	m
13	12 m	0 m	Full insertion	12 m	f
14	16 m	10 m	Full insertion	6 m	m
15	24 m	0 m	Full insertion	24 m	m
16	22 m	0 m	Full insertion	22 m	f
17	22 m	0 m	Full insertion	22 m	f
18	19 m	0 m	Full insertion	19 m	f
19	14 m	0 m	Full insertion	14 m	f
20	19 m	0 m	Full insertion	19 m	f
21	22 m	12 m	Full insertion	10 m	f
22	22 m	0 m	Full insertion	22 m	m
23	15 m	0 m	Full insertion	15 m	f
24	23 m	0 m	Full insertion	23 m	m
25	23 m	0 m	Full insertion	23 m	f
26	14 m	0 m	Full insertion	14 m	f
27	22 m	0 m	Full insertion	22 m	f
28	24 m	0 m	Full insertion	24 m	f
29	22 m	0 m	Full insertion	22 m	f
30	23 m	0 m	Full insertion	23 m	m
31	16 m	0 m	Full insertion	16 m	m
32	13 m	0 m	Full insertion	13 m	f
33	19 m	0 m	Full insertion	19 m	m
34	24 m	0 m	Full insertion	24 m	m
35	27 m	0 m	Full insertion	27 m	m
36	31 m	0 m	Full insertion	31 m	f
37	34 m	0 m	Full insertion	34 m	m
38	28 m	0 m	Full insertion	28 m	m
39	6 m	0 m	Full insertion	6 m	f
40	14 m	0 m	Full insertion	14 m	f
41	15 m	6 m	Full insertion	9 m	m
42	16 m	0 m	Full insertion	16 m	m

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