**Counting Petals: measuring the speech production development of children following cochlear implantation**

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**Abstract**

**Aims**

This paper is concerned with speech production patterns and speech intelligibility in the context of deafness and cochlear implantation. The study aimed to compare a new system of quantitative scoring of speech production patterns with an independent rating of speech intelligibility in order to test two hypotheses. For two groups of children with cochlear implants, separated by two levels of speech intelligibility, it was predicted that both the scores and the qualitative detail would differentiate between them.

**Methods & Procedures**

A speech assessment tool, originally designed to provide the detailed qualitative analysis needed for planned intervention, was modified to provide a quantitative summary of segmental and non-segmental speech patterns. A cohort of children who had received cochlear implants five years previously was divided into two groups, based on ratings of their different levels of intelligibility, and the modified speech assessment was completed for all the children. The results were analysed to determine whether the speech production scores differentiated the two groups, and whether any characteristic patterns were identified for each group.

**Outcomes & Results.**

As predicted, the two groups were separated by significant differences in scores and some characteristic patterns were found within each group. The quantitative scores appeared to reflect the qualitative information with a useful degree of accuracy.

**Conclusions & Implications.**

**If assessment of speech production for children with cochlear implants is reduced to aspects that can be easily quantified, much vital information is likely to be lost. Maintaining a link between the detailed assessment of phonological patterns and the quantitative results has been shown to be viable and to provide both descriptive and predictive information from a single set of assessment material.**

*Key words:* cochlear implants, speech production measurement, intelligibility

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| **What this paper adds**  In considering the effects on speech for children with a cochlear implant the primary focus of much research has been concerned with input, specifically in terms of the extent of the ability to perceive the full range of speech sounds. In addition, reports of speech intelligibility ratings indicate that cochlear implantation leads to significant improvements in speech intelligibility in deaf children. As a result of a primary concern with quantification, the detailed qualitative information needed to plan intervention has often been excluded from research reporting and dealt with as a separate clinical issue. This has led to a trend for assessments to record only the extent of articulatory correctness for a limited range of speech sounds, rather than providing a detailed description of the phonological patterns produced by speakers.  A modified assessment tool capturing the necessary detail and also providing a quantitative dimension was used with a group of children with cochlear implants. The results indicate that it is both possible and desirable to combine both aspects of assessment in one tool. The patterns identified suggest that the qualitative detail may be an important component in understanding speech intelligibility for deaf children. |

**Introduction**

This paper is concerned with speech intelligibility, with the speech patterns developing in children with cochlear implants, and with the relationship between the two. A study is presented which describes the speech patterns in two groups of children who had achieved a degree of intelligibility in connected speech, one group being more intelligible than the other, five years after cochlear implantation. The background considerations for the current study include the existing body of work on cochlear implantation and deafness, the need for quantitative information on speech, and the importance of collecting evidence that captures the nature of speech patterns and their relationship to intelligibility.

Cochlear implantation in the UK (as elsewhere) is now well established as one of the early considerations for intervention for children with a significant hearing loss. Cochlear implants have been found to be an effective way of providing access to the speech signal for severely and profoundly deaf children who derive little benefit from acoustic hearing aids (O'Donoghue, Nikolopoulos and Archbold, 2000). There is now also considerable body of evidence about the results of cochlear implantation with regard to speech and language development. Positive effects of this intervention have been reported for the perception of acoustic signals, the development of spoken language and improved speech perception and production (Battey, 2001, Geers, Brenner and Davidson, 2003, Osberger, Robbins, Svirsky, Teoh and Neuburger, 2004, Tomblin, Barker, Spencer, Zhang and Gantz, 2005).

The study of speech production in the context of cochlear implantation involves a dilemma which is inherent in all speech work and much related research. On the one hand, when describing the speech of individual children as a basis for intervention, comprehensive qualitative detail is needed. On the other hand, if generalisations are required about a particular population (such as deaf children in general or particular sub-groups of children with cochlear implants) then it is more desirable to collect quantitative information. In this latter context, value is placed on scores from tests which are speedily administered and more easily compared than full qualitative descriptions. The study reported in this paper involved the need to reconcile these two approaches to the consideration of speech production.

Where speech production is concerned, there are a number of limitations in the information provided by existing studies, which mean that the relationship between speech patterns and intelligibility are only partly explained. There is a tendency for some studies to report extrinsic causative factors related to good speech intelligibility, rather than discussing the role of speech patterns themselves. For example Peng, Spencer and Tomblin (2004) comment that post-lingual speech and language progress is positively associated with a younger age at implantation, duration of device use and a reliance on oral communication.

When speech itself is described there is an emphasis on quantitative aspects of speech development in children, often by scoring correct and incorrect speech sounds. Some reports have demonstrated the general speech improvement enabled by cochlear implantation while others have focused on a limited number of specific aspects. For example, Uchanski and Geers (2003) focus on the acoustic analysis of voice, concluding that the parameters considered were within the normal range for the 181 children studied. Improvements are also reported in single case studies such as that by Ertmer and Mellon (2001) who reported speech production gains in a child implanted at 19 months. A useful summary of such studies, showing significant improvement in speech intelligibility and specific aspects of speech in many cases, is provided by Van Lierde, Vinck, Baudonck, De Vel and Dhooge (2005).

The information in these studies is useful, providing evidence that cochlear implantation benefits speech production and its effectiveness, but it is not always possible to discern the underlying phonological patterns on which the child’s intelligibility rests, because the systematic contrastivity of speech sounds is not discussed. An example from the PETAL speech assessment (Parker, 1999) illustrates the importance of considering contrasts between one sound and another, rather than only the correctness (or otherwise) of individual speech sounds, more usual in traditional “error analysis”. Some speakers may use the sound [b] to represent normal adult speech /p/. In a traditional error analysis (which has the superficial advantage of speed and scoring by numbers) this would be regarded as incorrect, as would the use by the same speaker of a non-English speech sound, such as an implosive, to represent normal adult /b/. Simply recording a ‘correctness’ score of 0/2 would fail to capture the *successful* use of contrast between the two sounds, which would support intelligibility for a ‘tuned-in’ listener. Intervention based only on such error counting would be inappropriate if the result was ‘correction’ of the implosive, since now the speaker would use [b] to represent both /p/ and /b/ and the differentiation would be lost.

Error counting alone thus provides a good example of missing the point where speech effectiveness is concerned, as does the omission of non-segmental features such as airstream mechanism, voice, intonation and timing in some speech studies.

But quantification is needed to provide generalisations and comparisons of different speakers, the same speaker at different times, or groups of speakers. Tobey, Geers, Brenner, Altuna and Gabbert, (2003) overcome one limitation of traditional error analysis, the lack of detail inherent in some studies, providing considerable detail in their study of speech production skills in children aged 5 years. They report on speech intelligibility, accuracy of consonant and vowel production, percentage of fricatives and plosives used, duration of sentences and other factors. The children were found to have improved in terms of their overall intelligibility after implantation. Phonetic accuracy appeared to improve with increased experience with a cochlear implant, with decreases in the number of substitutions, omissions and distortions of consonants. Speech intelligibility appeared to be related to discrete oral skills such as correct consonant production, sentence duration and the percentage of fricatives produced. However, the second difficulty with error analysis remains even at this level of detail, since, by examining individual speech sounds rather than systems, important phonological detail is lost.

An essential consideration when assessing speech development is the effectiveness or intelligibility of the speech concerned, sometimes defined as the degree to which a speaker’s intended message can be recovered by other listeners (Bunton, Kent, Kent and Duffy 2001). In order to assess the speech intelligibility of a child, a number of different methods may be used. The Speech Intelligibility Rating Scale (SIR) rating widely used in the UK as a method of grading children’s level of intelligibility has been found to be reliable (Allen, Nikolopoulos, Dyar and O’Donoghue, 2001). Peng, Spencer and Tomblin, (2004) compared the “write down method” of scoring intelligibility with another 5 point intelligibility rating scale. They concluded that speech intelligibility continues to improve beyond 5 or 6 years and does not appear to plateau, and that the “write down method” and “rating scale” for scoring intelligibility were highly correlated and compatible. They also concluded that the rating scale was more efficient, enabling comparatively quick and easy scoring.

A final background issue is concerned with timing, both of implantation itself and the point at which post-implant assessment is most useful. One study suggests that prelingually deaf children who receive a cochlear implant before their fourth birthday attain better speech, resulting in a normal voice pitch level and improved speech sounds (Seifert, Oswald, Bruns, Vischer, Kompis and Haeusler Nov 2002). It is possible to assess the results of cochlear implantation at any point post-implant. There are some indications that speech production may develop over a considerable period. In Kishon-Rabin, Taitelbaum, Muchnick, Gehter, Kronenberg and Hildesheimer 2002’s study of 35 prelingually deaf children with cochlear implants ranging in age between 2.5 years and 10 years old, it was found that perceptual and production performance increased up to 4 years post implant (and was in line with the developmental data from normally hearing children). This work provides a useful indicator that children with cochlear implants should be assessed after a number of years of usage to allow for the maximal improvements in perception and production, in order to obtain a truer picture of their more permanent abilities in speech. After all, children born with normal hearing need up to 5 or 6 years to achieve completely accurate, normal phonology (Grunwell, 1987).

The current study is concerned with intrinsic speech factors and the extent to which particular patterns in the child’s phonology may enhance or impede speech intelligibility. The PETAL provides a tool for the detailed phonetic and phonological analysis and description of the speech of individual speakers (children or adults) who have any degree of hearing loss. It was specifically developed for this population, to enable the capture of characteristic patterns which occur in the context of diminished or changed use of hearing, and the consequent increased involvement (where relevant) of visual factors as the basis for speech production. For many speakers with a hearing loss there are characteristic patterns in the non-segmental aspects of speech production, such as breathing and airstream mechanisms, voice, intonation and rhythm (Parker and Kersner 1997). The PETAL assessment includes these aspects as well as segmental ‘speech sound contrasts’.

For the purpose of this study, a scored version of the PETAL assessment was developed, aiming to preserve relevant phonological contrastive detail within the quantitative summary of the findings for comparison with separately rated speech intelligibility. It was hypothesised that the scores produced would explain different levels of intelligibility of speakers, and that the detail preserved would demonstrate characteristic patterns for relatively high and low intelligibility, offering valuable information about the nature of the phonological patterns which support better speech intelligibility.

The PETAL approach includes a supposition that the patterns revealed by the assessment will be directly related to the level of intelligibility of speech. The more developed the phonology, as revealed by the detailed qualitative description, the more effective the speech is expected to be, and if the assessment has captured the relevant patterns then the results should explain greater or lesser speech intelligibility in different speakers. The current study aimed to test this prediction by comparing the quantified PETAL results for the speakers concerned with an independent estimate of speech intelligibility, using the SIR, a five point rating based on a scale originally devised by Parker and Irlam (1995) and adapted by the Nottingham Cochlear Implant Team (Allen et al, 2001). The scale covers a range from unintelligble to fully intelligible (see Table 1).

|  |
| --- |
| 5 Connected speech is intelligible to all listeners: child is understood easily in everyday contexts.  4 Connected speech is intelligible to a listener who has little experience of a deaf person’s speech.  3 Connected speech is intelligible to a listener who concentrates and lipreads.  2 Connected speech is unintelligible: intelligible speech is developing in single words when context and speech reading cues are available.  1 Connected speech is unintelligible: pre-recognisable words in spoken language. |

**Table 1: SIR Scale (Allen et al, 2001)**

Using the Petal scores and SIR ratings, the current study aimed to compare the speech patterns of children at two different levels of speech intelligibility, firstly in order to test the hypothesis that the quantitative PETAL results would distinguish between the two groups, and secondly in order to investigate the characteristic speech production patterns that might differentiate the two groups

**Method**

In developing the methodology for this project and the criteria for selection of the subjects, a number of factors were taken into consideration. The study included children who were congenitally deaf and excluded any children who had access to normal hearing in their early years, since children who have already acquired spoken language and subsequently lose their hearing would be expected to have better speech with different speech patterns.

Children with known additional difficulties were excluded. Edwards, Frost and Witham (2006) outline the delay and reduced outcomes expected for children with significant learning disabilities and for the current study it was decided that inclusion would introduce too many variables.

In summary, the criteria for selection of children for this study from the cohort of implanted children at a single implant centre were that they were congenitally deaf, had received their implant before the age of 4 years, had no known additional difficulties, and had either not developed speech at all or had been unintelligible prior to implant. Twenty three children met these criteria and all were included. The children for this study were assessed five years post-implant.

0

1

2

3

4

5

0

5

10

15

20

25

**Participants**

**Age in years**

**Figure 1: Age of children at implantation**

The range of ages at implantation can be seen above in Figure 1, showing a spread from 2.2 years to 4 years with a mode of 3 years and a mean of 2.98 years. Children for this study were not selected for age of implantation but once the exclusion factors were applied the remaining cohort reflected the current trend in Britain (at the time of this study) to implant children at around 3 years. At time of assessment (5 years post implant) the children ranged in ages from 7- 9 (mean age 8 years). The children had all received regular input from a Speech and Language Therapist over the course of the five years. 45% had been exposed to some form of sign language in the early days. At the time of assessment, 4 children were educated within units attached to mainstream schools where both speech and sign support were used simultaneously and 19 children attended mainstreams or units attached to mainstream schools where the mode of communication was oral.

These children were assessed at their 5 years post-implant review using the SIR and the PETAL to produce two independent measures. Firstly, the children were allocated into two intelligiblity-level groups from the SIR rating, based on a sample of spontaneous speech. The ‘Higher Intelligiblity’ group (HIR) consisted of 14 children (8 boys and 6 girls) who had SIR levels of 4 or 5 (see Table 1). The ‘Lower Intelligibility’ (LIR), consisting of 9 children (6 boys/ 3 girls), were rated as having an SIR level of 3.

Secondly, quantitative scores were produced from PETAL assessments which had previously been completed independently by one of three specialist implant programme Speech and Language Therapists. All measures for the study were independently verified by the lead specialist speech and language therapist for the project.

**Results**

Two hypotheses were investigated:

1. PETAL scores were predicted to be related to intelligibility levels, such that a higher overall PETAL score would be related to a higher SIR category.

2. The PETAL result would reveal specific speech patterns differentiating the two different intelligibility groups.

**Hypothesis One**

The first hypothesis is supported by the result shown in Figure 2. The completion of a quantitative analysis based on a full phonological assessment produced highly significant results for the intelligibility ratings for the two groups of children. One individual outlier at the top end of the LIR group is the sole exception, having achieved a similar Petal score to the lowest scorers in the HIR group. On further investigation, a disparity was noted for this individual between her single-word phonology versus her connected speech intelligibility, suggesting that her relatively well developed phonology has not yet been generalised into connected, spontanous speech.



**Figure 2: Petal and SIR correlation**

**Hypothesis Two**

A number of facets of the data need consideration in relation to the second hypothesis. The scores for each child’s non-segmental and segmental features, scored as two subsets in the scoring system of PETAL, were plotted on a number of separate bar charts.

**a) Non-segmental features**

The non-segmental features examined by PETAL are airstream, voicing, voice quality, pitch and loudness, rhythm and intonaton, as can be seen in Figure 3, which illustrates an individual example from the HIR group.

Airstream

Voicing

Voice quality

Voice pitch

Loudness

Resonance

Rhythm

Intonation

**Figure 3: Example of non-segmental scores for one child from the HIR group**

A rating scale from 0-5 was used for each of the non-segmental features. An example of the scale for voice quality is given in Table 2.

|  |
| --- |
| 0= Voice not used  1= Tense/uncontrolled voice quality  2= Some normal quality voice; non-normal voice quality predominates  3= At least 50% normal voice quality (very little creak, although may be slightly breathy)  4= Normal voice used more than other voice quality (at least 75% normal)  5= Voice quality matches normal range |

**Table 2: Example of Petal rating scale: voice quality**

Figure 4 presents the cumulative mean data comparing the two groups which were analysed using Mann-Whitney and T-Tests. For three factors (airstream, voicing and loudness) there are no significant differences, with nearly all of the children achieving the maximum possible score for these categories. However, significant differences (p<0.01- p<0.05) separated the two groups in all of the other aspects. In other words, the LIR group scored significantly below the HIR group in terms of voice quality, pitch and range, articulatory settings, resonance, rhythm and intonation systems. The overall scores for non-segmental features were also found to be significantly different between the 2 groups (HIR group mean: 91%, LIR group: 76%: <0.005).

**Group comparison: average non-segmental scores**

0

1

2

3

4

5

1

2

3

4

5

6

7

8

**Non-segmental scores**

HIR

LIR

**\* Significant differences**

**\*quality**

**\*pitch**

**\*resonance**

**\*rhythm**

**\*intonation**

airstream

voicing

loudness

**Figure 4: Results showing mean non-segmental scores for both LIR and HIR groups**

**b) Segmental features**

The system of recording the number of contrasts produced in initial position and in final position can best be understood by considering the relevant part of the score sheet for PETAL as shown in Table 3. It should be noted that the four consonants /r, , / and // are not included in any scoring subtest because these sounds impact only marginally on a child’s early speech intelligibility, and many young children do not have the vocabulary to yield sufficient numbers of examples for the analysis.

|  |  |  |  |
| --- | --- | --- | --- |
| CV… | | | |
| Front  (total possible 5) | Mid  (total possible 7) | Back  (total possible 3) | CV…total  (total possible 15) |
| ////+ | //+//+// | // |  |

**Table 3: Example from the scoring system for initial consonants**

The graph in Figure 5 shows the percentage segmental (phonological contrast) scores of an individual child from the HIR group, including total scores with a breakdown into front, mid and back consonants for both the word-initial and word-final consonant systems. Vowel contrasts are scored separately. As can be seen from Table 3, each of the separate sections (front, mid, and back) are scored out of different total, related to the distribution of these sounds in normal English. For this reason, the scores have been converted into percentages so that they can be viewed comparatively.

Initial consonant system

Final consonant system

Total score

Front

Mid

Back

Total score

Front

Mid

Back

Vowels

**Figure 5: Example of segmental scores for one child from the HIR group**

When comparing the group segmental scores as shown in Figure 6, there appear to be significant differences (p<0.01- p<0.0001 using either Friedman’s non parametric test or Wilcoxon signed-rank test) in the scores in both the intial and final consonant systems for mid and back consonants. Scores for the front consonants and vowel system are not significantly different between the two groups: for both groups the score is either close to, or is, 100%.

Initial contrasts 1-4 Total, front, mid, back

Final contrasts 5-8 Total, front, mid, back

**Group comparison: percentage of**

**segmental contrasts**

0

20

40

60

80

100

1

2

3

4

5

6

7

8

9

**Percentage of segmental**

**contrasts**

HIR

LIR

Initial consonants 1-4

Final consonants 5-8

Vowels 9

**Figure 6: Results showing mean segmental scores for both LIR and HIR groups**

As well as scoring contrastive effectiveness, the final total PETAL score includes some points for accuracy of different types of phonetic realisations. Significant differences between the two groups were found within the initial consonant system for oral/nasal, stop/fricative and voice/voiceless realisations. Within the final consonant system, all aspects were significantly different between the two groups, including emerging auditory realisations and consistency (see figure 7).



**Figure 7: Results showing mean percentage scores, for both LIR and HIR groups and for the initial and final consonant systems.**

The overall segmental scores achieved by the 2 groups were again found to be significantly higher in the HIR group (HIR group 98%: LIR group: 74 %: p<0.0001, shown by columns 1 and 5 in figure 6).

**Discussion**

The results for the first part of the study are relatively straightforward. The PETAL scores clearly differentiated two groups of children, five years post-implant, separated on the basis of their rated speech intelligibility. The speech assessment results do seem to provide a basis for an explanatory link to the effectiveness of speech production, where these two groups of speakers are concerned. The group of children judged through SIR scores to have more intelligible speech achieved significantly higher PETAL scores than the group judged as less intelligible.

Results for the single outlier achieving a higher PETAL score than all others in the LIR group are satisfactorily explained by the noted inconsistency between single-word versus connected speech. The qualitative dimension of the PETAL assessment includes a comparison between single words and sentence-level speech, but the derived scoring system used for this study did not include this detail, and resulted in an overestimate of phonological effectiveness for the one child concerned, when compared with the rating of speech effectiveness. Clinical experience suggests that as children develop more speech, effective intelligibility may actually decrease, at least for a time, because of the greater load placed on non-segmental aspects in utterances longer than one word. However, closer attention to the data underlying the disparity in this single example shows that inconsistency of segmental production, not the non-segmental features, seems to be responsible for the overestimate produced by the scoring system.

Had this inconsistency been captured in the scoring system the outlying child’s result would have provided a closer match with other members of the less intelligible group. However, even including this single disparity, the difference between the two groups as measured by the PETAL scores is highly significant and justifies the claim that a combination of contrastive segmental assessment and non-segmental evaluation accounts for differences in speech effectiveness as judged by speech intelligibility rating. The first hypothesis for the study is thus supported by the findings. It is interesting to note that, while all the children concerned had developed a degree of intelligible speech following cochlear implantation, there is nevertheless a clear differentiation between the two groups, for both of the measures used. Some speakers developed significantly more effective speech than others as measured in this cohort of 23 children, five years after the initial implantation.

The second part of the study was concerned with the detail within assessment scores. The two groups were divided by disparate SIR scores, and the overall PETAL scores significantly matched the initial groupings. Would the detail in the subtests also differentiate the groups, and if so, what implications might there be in the patterns observed, for intervention to improve speech effectiveness for children with cochlear implants?

The speech assessment tool used for this study includes observation of both segmental aspects of speech (speech sound systems) and non-segmental factors such as airstream mechanism, voice, intonation and rhythm. The latter groupings are both fundamental to speech production and generally pervasive in speech. For example, an airstream is essential for the production of any speech sound. Normal adult English production (and children’s normal development once words are established) involves almost exclusively an egressive pulmonic airstream (outward flowing air from the lungs) and thus this factor both is necessary for normal speech production in English and involved in nearly every aspect of spoken utterances in the language. Profound deafness in the absence of adequate amplification or implantation may cause disruption to this aspect of speech with a matching pervasiveness in effect. Cochlear implants would be expected to provide adequate input for the development of normal airstream mechanism.

Similar considerations apply where presence of voicing and loudness are concerned. These aspects of speech are dependent on a normal airstream, are similarly pervasive in normal speech and furthermore are comparatively salient (relatively loud, slow moving and low frequency) in the acoustic signal, and so should be well established for children with access to the sounds of speech. So it transpired for the group studied here, with respect to scores of airstream, voicing and loudness. Nearly all of the children achieved the maximum possible score for these categories, and there were no significant differences between the higher and lower intelligibility groups. Loudness of voice was assessed as adequate for both groups for the conversational circumstances of the assessment, but since ability to vary loudness (speaking loudly, shouting and whispering where appropriate) was not assessed, the lack of differentiation by loudness control as scored here may have represented a ceiling effect in testing. Given that voicing and loudness should be auditorily accessible for cochlear implant users, problems with any of these aspects might be a matter for concern.

Other non-segmental features assessed did differentiate the higher intelligibility (HIR) group from the lower (LIR). Voice quality, pitch and range, articulatory settings, resonance, rhythm and intonation systems were all significantly different for the two groups in each case. As with airstream and presence of voicing, all of these factors may be regarded as pervasive and basic to speech production, but for the less intelligible children they were not firmly established. From general expectations about language and from the results of this study, these factors may be presumed to make a major contribution to speech intelligibility. Rhythm (related closely in spoken English to relative length and vowel value of syllables, producing contrastive salience, or stress) and intonation (contrastive salience, or primary stress, produced by pitch movement) are developed early in normally hearing learners of English, and once more would be expected to have a robustness for successful cochlear implant users because of relative acoustic accessibility of voice in the speech signal, discussed above. However, these factors were not so well developed in the less intelligible speakers, and while the HIR group achieved higher scores overall the systems were not yet fully developed in any of the speakers concerned.

In summary, the more intelligible speakers in this sample showed better developed non-segmental features than their less intelligible peers in 7 out of the 10 factors assessed. A developmental perspective, placing airstream mechanism and production of voice as primary for the rest of speech production, (and necessary but not sufficient for good intelligibility), is supported by the data from this study.

For the segmental data, similar developmental and acoustic considerations may be relevant. In addition, the visible aspects of production should also be considered. For example, perception of consonant and vowel contrasts may be helped by lipreading.

Vowels and front consonants, as might be expected, produced high scores, at the maximum possible or near 100%, for all the speakers, and were not significantly different between the two groups. Mid-oral and back consonants, on the other hand, scored significantly differently for the two groups, and thus are implicated in the intelligibility difference. For these speakers, the more intelligible group had developed better consonant systems than the LIR speakers, for sounds placed further back than dental articulation. This raises the interesting question of whether the LIR group were in this respect producing speech more like that traditionally found for profoundly deaf hearing aid users, with a greater reliance on visible aspects of speech. This would imply that the children in the HIR group had more effective interpretation of the acoustic signal as the basis for their better speech.

**Summary**

The group of children studied for this project were divided into two, higher and lower intelligibility, sub groups, based on intelligibility ratings. A quantitative summary of a detailed phonological assessment differentiated the two groups, both for segmental and non-segmental features, supporting the hypothesis that both contrastive phonology and overall features such as intonation and rhythm are closely linked to functional speech intelligibility. The investigation described did not set out to examine extrinsic causative factors, but rather was focused on the intrinsic nature of more effective speech. Further research could helpfully link such findings to other factors, such as age of implantation, educational placement, communication mode(s) and amount of exposure to signed and spoken languages. However, the primary concern here was to investigate the link between phonological systems (rather than “correctness” of individually tested speech sounds) and the effectiveness of the speech. In this case, for the 23 children in this study, the hypothesised link was unequivocal. Detail in the data supports the idea that there may be particular features of phonological development which are crucial to the development of effective speech.

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Petal scores: individual assessment NAME/RECORDING NUMBER:

|  |  |
| --- | --- |
| NOTES: | **OVERALL PETAL SCORE:**    **/80** |

NON-SEGMENTAL SCORES

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Air-stream  mechanism | Voicing | Voice quality | Voice pitch and range | Loudness | Articulatory settings and resonance | Rhythm | Intonation | **TOTAL**  **SCORE** |
| /5 | /5 | /5 | /5 | /5 | /5 | /5 | /5 | **/40** |
|  |  |  |  |  |  |  |  |  |

SEGMENTAL SCORES

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **C**V… | | | | …V**C** | | | | **V** | **Realisations** | | | | | | | | | | **TOTAL** |
| Front  /5 | Mid  /7 | Back  /3 | **C**V  **total**  **/15** | Front  /3 | Mid  /6 | Back  /2 | …V**C** **total**  **/11** | **Vowels**  /4 | **Emerging auditory** realisation  /1 /1 | | Oral/  **nasal**  90%  /1 /1 | | Stop/  **fricative**  90%  /1 /1 | | **v+/v-**  90%  /1 /1 | | **Consistency**  90%  /1 /1 | | **SCORE**  **/40** |
| ////+ | //+//+// | // |  | +//+ | +/+//+// | +/ |  |  | **C**V | V**C** | **C**V | V**C** | **C**V | V**C** | **C**V | V**C** | **C**V | V**C** |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

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