

VOWEL PRODUCTION CHANGES SUBSEQUENT TO
COCHLEAR IMPLANTATION

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ABSTRACT - Perceptual and acoustic correlates of vowel production changes in 3 postlingually - deafened speakers were measured subsequent to implantation with a cochlear multichannel prosthesis. Significant changes occurred in the acoustic vowel spaces of all three speakers. Improvements in listener recognition correlated strongly with formant changes in the direction of the normal vowel space. The consequences for speech rehabilitation programs are discussed.

INTRODUCTION

Deprived of auditory feedback, the speech production of postlingually deafened individuals is usually marked by a gradually deteriorating phonetic control (Binnie, Danilof & Buckingham, 1982). Vowel production, with its high dependence on auditory feedback, is particularly vulnerable to degradation. The reduction in the acoustic vowel space, attributed to reductions in the range of movement of the articulators, can result in the loss of phonetic contrast between the various vowels (Monsen, 1976). Such a "shrinking" of the vowel space usually leads to a perceptual "bleaching" of vowel quality with a subsequent decrease in intelligibility to listeners (Plant, 1982).

The aim of cochlear implantation is to provide a profoundly hearing impaired subject with a form of stimulation equivalent to the sensation of hearing. The multi-channel cochlear prosthesis imitates the tonotopical organisation of the cochlea in its stimulation of the auditory nerve. Its speech processing strategy is organised to convey information about the Fundamental Frequency, and the First and Second Formants of the incoming speech signal. Since the processing strategy is orientated towards F1 & F2, if speech production changes occur subsequent to implantation, then a highly probable area for change would be in vowel production.

This present study aims to investigate the long-term acoustic and perceptual changes in the monophthongal vowel systems of postlingually deafened adults subsequent to the activation of the WSP III Nucleus multichannel cochlear prostheses. The pattern of phonetic deterioration in profound hearing loss, and the processing strategy of the WSP III leads one to predict that the vowel changes following implantation should reflect a "reversal" of the pattern found with hearing loss. With the conveying of F1 & F2 information, there should be a gradual expansion of the acoustic vowel space. Subsequently,

individual vowel production targets should become more intelligible to the listener.

METHOD

Subjects

The three subjects in this study are part of the cohort of clients fitted with cochlear prostheses at the Mater Misericordiae Hospital, South Brisbane, since 1988. Post-operative histories have been uneventful. None of the subjects received speech therapy during the period of data collection.

Subject 1 was 22 years of age at the initial assessment. She had a sudden profound idiopathic hearing loss 9 years prior to implantation. Subject 2 was 51 years old at his initial assessment. There had been a profound left unilateral loss since birth, with a progressive right loss that was profound 9 years prior to implantation. Subject 3 was 29 years of age at the initial assessment. His loss had been progressive but of unknown origin, resulting in profound bilateral hearing loss 13 years prior to the initial assessment.

Stimuli and equipment

Cassette tape recordings were made of the subjects reading a standard prose passage "The Grandfather Passage" (Darley, Aronson & Brown, 1975). This enabled the controlled sampling of connected speech for comparison with recordings of the same passage by 4 Brisbane-born adult controls. The speech samples were collected in a quiet environment using a Marantz PMD-340 professional tape recorder with a Sony ECM-144 lapel microphone placed approximately 13 cm. from the speaker's mouth.

Speech samples were collected on 3 occasions; 1) one month prior to implantation 2) two months post-implantation and 3) six months post-implantation.

Spectral analysis

Pre- and post- implant speech samples were digitised at a 20kHz sampling rate with an 8-bit quantisation. Spectral analysis was undertaken of all monophthongal vowels occurring in stressed syllables in the "Grandfather Passage". This resulted in 65 vowel measurements per sample. Formant measurements (F1 & F2) were made at the estimated midpoints of each vowel using a digital spectrogram program (Jordan, 1988).

The formant frequency values expressed in Hertz were converted into Bark units using the approximation reported by Syrdal (1985). Bark scaling of the data provided a perceptually relevant means of normalisation in order to compare formant changes in the speakers over time in relation to the acoustic vowel space of the 4 normal controls. The degree of "closeness" of each speaker's formant values to the average values of the controls was calculated as the vector sum of the Euclidean interpoint distance, using the metric outlined in

Ingram & Pittam (1987). The difference in the vectors from the 1st and 3rd assessments represented a Formant Change Score (FCS) reflecting the degree of movement towards or away from the control reference values expressed in Bark units.

Listener ratings

A randomised listening-tape was prepared, consisting of 3 tokens of each monophthong for each speaker from the 1st & 3rd recordings, and the same tokens from the recording of one of the controls. The total of 210 test items were presented to 20 phonetically trained undergraduate speech therapy students for closed-set vowel identification. Confusion matrices were obtained.

RESULTS

Vowel formant change

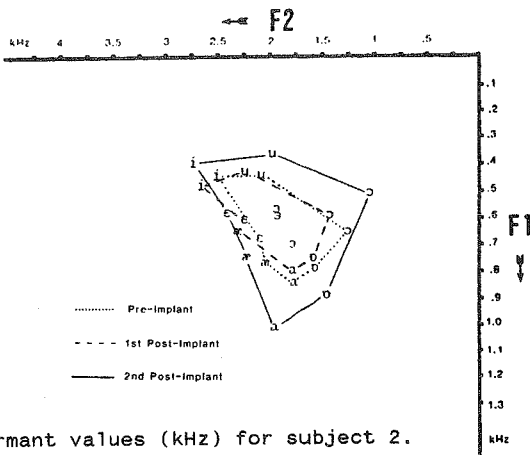


Figure 1. Average formant values (kHz) for subject 2.

Figure 1 displays the average formant values (in kHz) for subject 2 over the 3 assessment periods. /ʌ/ & /ɪ/ are not displayed in order to enhance clarity. The pre-implantation pattern indicates a reduced acoustic vowel space compared to the normal. Not only is the acoustic distance between the respective vowels markedly reduced, but also some vowels tend to overlap, e.g. /i/ & /u/, and /ɛ/, /æ/ & /ɜ/. Post-implantation there are general shifts in the formants such that by the third assessment the acoustic vowel space approaches that for the controls both in its dimensions and internal vowel patterning, though /ɛ/ & /æ/ still tend to approach each other.

The formant changes for subjects 1 & 3 exhibit a similar pattern of general expansion of the vowel space. Figures of their formant values are not displayed for reasons of space. Subject 1 displayed an initially reduced space. Shifts in formants in the post-implant period occurred more rapidly than for subject 2, with formant values approaching normal dimensions by the first post-implant assessment. However, some

vowel targets were not fully differentiated from each other even by the end of the 3rd assessment. Subject 3's vowel space was not initially as reduced as those for subjects 1 & 2, although it was still smaller in comparison to the controls. A particular feature of 3's vowel distribution was the overlapping of /i/,/u/ & /ɜ/, and the raising of /a/ to overlap with /ɛ/. The pattern of overlapping was unchanged over either post-implant assessments. By the 3rd assessment period the F1 range had expanded mainly due to shifts in the values for /i/ & /a/. There was also a general decrease of approximately 200 Hz in the F2 values of most vowels, resulting in a shifting of the acoustic vowel space as a whole.

subject	\bar{x} distance		\bar{x} distance		\bar{x} FCS	\bar{x} FCS
	all vowels		/i,a,ɔ/		all v.	/i,a,ɔ/
	pre	post	pre	post		
1	1.20	0.65	1.26	0.48	.55	.78
2	1.46	0.83	1.56	0.66	.63	.90
3	1.21	1.06	0.93	0.83	.15	.10
\bar{x}	1.29	0.85	1.25	0.66	.44	.59

Table 1. The average vector distances and formant change scores (FCS) for the 3 subjects from the pre- and 2nd post-implant assessments.

Table 1 displays the average Euclidean vector sum distances of the 3 speakers from the control vowel reference points for the pre- and 2nd post-implant assessments, as well as the Formant Change Scores (FCS) over that period. The expansion of the 3 speakers' vowel spaces is reflected in the decrease in the distances for all 3 speakers in the post-implant period, resulting in the positive FCS scores. These positive changes in the vowel spaces are particularly noticeable if one considers the changes for the 3 vowels /i,a,ɔ/ at the extremities of the Australian vowel triangle.

The decrease in vector distance for subject 3 is noticeably less than for subjects 1 & 2. While the expansion of the vowel space was less dramatic for subject 3, the lower FCS also reflects the unusual general shift of all F2 values in the post-implant period of about 200 Hz, shifting formant vectors away from the reference vectors.

Perceptual changes

Analysis of the confusion matrices constructed from the listener responses indicated that there were improvements in the listener recognition of target vowels corresponding to the pattern of change in formant values for all 3 speakers. Table 2 summarises the percentage improvement in the perceptual recognition of a) all the vowels, and b) the three extreme vowels /i,a,ɔ/ for the pre- and 2nd post-implant assessments. There was an overall improvement in the percentage of correct vowel recognitions averaging 13%, while the improvement for the 3 extreme vowels averaged 24%. The percentage of overall

correct vowel recognition was still 30% below that of the control at the post-implant assessment, though for the 3 extreme vowels it was approximately the same as the control. This probably reflects the limited differentiation of some vowel contrasts even though the general acoustic vowel space has expanded.

subject	all vowels		/i,a,u/	
	pre	post	pre	post
(control)		(73.0%)		(75.0%)
1	43.0%	49.2%	54.5%	78.3%
2	38.3%	45.0%	50.8%	75.0%
3	26.5%	40.0%	55.0%	62.5%
x	35.9%	49.7%	48.4%	71.9%

Table 2. Percentage of correct vowel recognitions.

There were moderately strong correlations between the Euclidean distances of speakers' vowels from each of the reference vowels and the pattern of listener vowel confusions ($r = .64$ to $.75$). There was also a moderately strong correlation between the improvements in correct vowel recognition and the Formant Change Scores for the 3 speakers ($r = .73$).

DISCUSSION AND CONCLUDING REMARKS

The results indicate positive changes in the average vowel formants for all 3 speakers post-implantation, with corresponding improvements in listener recognition of those vowels. The improvements are in the direction predicted from the formant processing strategy of the WSP III and the pattern of reduced vowel space associated with deteriorating phonetic control in acquired profound hearing loss. Generally, there was an expansion of the acoustic vowel space for each speaker. The phonetic nature of these improvements can be seen in the particularly noticeable improvement in the recognition of the 3 vowels at the extremities of the Australian vowel triangle. Recognition percentages varied for the other vowels, depending on what degree they had successfully differentiated from one another in the post-implant period.

This paper has mainly concentrated on global acoustic and perceptual changes to the vowels of the 3 implantees. References have been made, however, to the patterns of individual variation amongst the speakers both in terms of individual vowel changes and the rates of change. Closer examination of the individual data indicates important differences between the speakers which, unfortunately, cannot be discussed here. The implications of these individual variations, however, need to be taken into account with the more global trends.

Firstly, the individual patterns indicate the unique circumstances and response of each implantee. Long-term data needs to be collected from implant subjects on a case by case

manner. For example, while the three subjects in this study exhibited positive and predictable formant changes, Tartter, Chute & Hellman's (1989) subject's acoustic vowel space had deteriorated 1 year post-implant in comparison to pre-implant measurements. A particular strength for individual case studies in this area is that acoustic analysis offers a sensitive assessment tool where the problem of vocal tract normalisation is minimised since the subject acts as their own long-term control (Syrdal, 1985).

Secondly, even though the dimensions of the respective vowel spaces improved over the assessment period, in each subject there was still a tendency for some vowels not to be clearly differentiated. This was reflected in unresolved confusion patterns in the perceptual data. Indeed, most confusions were consistent with the continuing formant overlaps for each speaker. Clearly there are limits to how much phonetic expansion alone can contribute to improvements in intelligibility. A clear implication is that an optimal and early recovery of a normal vowel space will require the implementation of a speech production rehabilitation program directed at the production of vowel contrasts specific to the individual's pattern.

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