Acoustic Analysis of the Speech of Adults with Cochlear Implants

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ABSTRACT

This paper presents acoustic analysis of the speech of three postlingually deafened adults with cochlear implants (CIs), from pre-implant and one, three, and six month post-activation recordings. As neither intonation nor vowels provide physical landmarks to aid articulation, and stops have physical landmarks but require precise articulation and timing, these factors should be most affected by implantation of a CI. Articulatory changes are characterized via acoustic analysis of vowel formants and duration; stop VOT and duration; and sentence F0 peaks and contours. Subject data are analyzed for individual longitudinal trends and implant effects. Trends are compared across subjects and to those found in previous studies. Analysis reveals an overall tendency towards change away from pre-implant values at one month post-activation, and back towards pre-implant values at three months and six months, for vowel duration, F0 and VOT.

1. BACKGROUND

Most papers that use postlingually deafened adults with cochlear implants as their subjects focus on post-implant changes in perception; there has been almost no research on the acoustics of speech produced by adult cochlear implant users. The primary acoustic research on the speech production of adult CI users consists of seven papers by Joseph Perkell's research group at MIT, published between 1992 and 1997 [1, 2, 3, 4, 5, 6, 7]. The authors found evidence that the Ineraid four-channel analog cochlear implant provides a sufficient degree of auditory feedback to affect vowel placement and duration, sibilant contrast, VOT and syllable duration, and fundamental frequency. Currently, most adults are implanted with a multichannel digital cochlear implant, which provide a more complex signal and utilize more advanced speech processors than the Ineraid implant. These changes in processor and implant technology have long-ranging implications for improvements in speech production. As neither intonation nor vowels provide physical landmarks to aid articulation, and stops have physical landmarks but require precise articulation and timing, these factors should be most affected by recovery of (partial) hearing after implantation of a cochlear implant.

2. SUBJECTS

Subject	Age/ Gender	Age at onset of profound hearing loss	Etiology of hearing loss	Implant type/ primary processor
AM	34/M	29	Ototoxic drug	ClarionCII/ CII BTE
DS	53/F	45	Genetic	Nucleus N24/ ESPrit
MS	33/F	29	Unknown	Nucleus N24/ ESPrit

Table 1. Subject information

3. MATERIALS AND PROCEDURES

Vowels: (/i/, /ɪ/, /ɛ/, /æ/, /ɑ/, /ə/, /ɔ/, /ʊ/, /u/) in the carrier phrase "It's a /hVd/ again." (following [1]).

Stops: CaC(C) words (as in [8]) with the initial consonants [b p d t g k] (five words beginning with each of these consonants, with the final consonant varied in order to create real words) in the carrier phrase "It's a _____ again."

Intonation: The phrase "Bev loves Bob", as a statement, statement with Bev, loves, or Bob emphasized, a question, and a question with Bev, loves, or Bob emphasized (following [9], as cited in [10]). Emphasis was indicated by underlining, statement was indicated by a period, and question was indicated by a question mark, e.g. Bev loves Bob?, Bev loves Bob.

Subjects were recorded prior to implant surgery, and one month, three months, and six months after implant activation. Three repetitions of each intonation phrase and word in carrier phrase were elicited in random order. Subjects were asked interview questions at the end of each of these sessions and their answers were recorded. The total recording time per session was approximately 30 minutes. Recording took place in a quiet room or recording studio, using a digital recorder and a unidirectional microphone.

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4. ACOUSTIC ANALYSIS

Utterances were digitized at 20 kHz (MS) or 48 kHz (DS, AM) and analyzed using Kay Elemetrics Computerized Speech Lab (CSL) and WaveSurfer. The following measurements were taken:

Vowels: F1 and F2 measured from spectrograms. Peak F0 measured using automatic pitch extraction. Vowel duration measured from spectrograms.

Stops: Following [3], VOT and word duration were measured from the waveform of each stop token.

"Bev loves Bob" sentences: F0 peaks were measured using automatic pitch extraction.

For all measurements, significance was calculated using a 2-tailed t-test for correlated samples.

5. DATA ANALYSIS: VOWELS

Comparing pre- and post-activation data, Perkell, Lane, Svirsky, and Webster [1] found F1 decreased for all subjects, F2 tended to normalize, there were fewer F0 differences between vowels, and vowel duration decreased for all subjects.

Looking at F1 vs. F2 graphs, MS's vowels appear to be less tightly clustered at one and three months, compared to pre-implant values. AM and DS have consistently tightly clustered vowels.

Graphing the triangles formed by F1 avg vs. F2 avg for [i], [a], and [u] (following [11]) reveals an expansion of MS's vowel space at one and three months and a contraction at six months. AM's vowel space remains remarkably consistent across recording sessions. DS's vowel space changes dramatically with cochlear implant experience, both in area and in location.

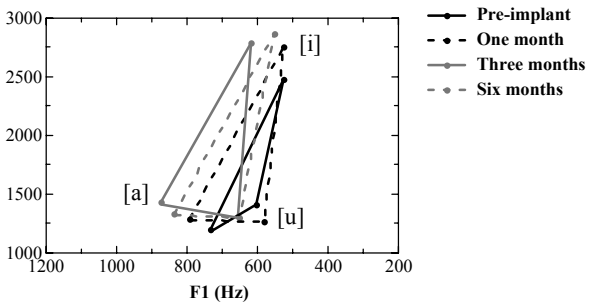

Figure 1. [i]-[a]-[u] vowel space for subject DS

For each subject, a small number of vowels have changes in duration which are statistically significant ($p<.05$).

For AM and MS, differences for the other vowels show a trend towards change in duration at one month, with a return towards pre-implant values at three and six months. DS's vowels tend towards decreases in duration from pre- to post-activation.

The trend seen in MS and AM's vowel duration data also holds for the vowel word duration data: For most words, there is a change in duration at one month, and then at three and six months, word duration is closer to pre-implant values. DS's word duration decreases match those seen in her vowel duration.

MS's vowel token peak F0 ranges between 217 Hz and 264 Hz; DS's ranges between 202 and 274 Hz; AM's ranges between 141 and 196 Hz. For MS and DS, F0 tends to increase from pre- to post-activation; for AM F0 tends to decrease at one and three months and return towards pre-activation levels at six months.

Compared to the subjects in [1], MS and AM's vowel tokens do not demonstrate any general directional changes in F1 or F2; DS's vowel space shows more significant changes. For all subjects there are no significant F0 differences between vowels; there is no overall statistically significant change in duration.

6. DATA ANALYSIS: STOPS

The VOT study by Lane, Wozniak, and Perkell [3] found that for all of their subjects, CV syllable duration became significantly shorter after implant activation, so that it was impossible to compare pre- and post-activation VOT without using a correction factor. In addition, they found that VOT place distinctions did not change with CI experience.

All of the subjects demonstrate a clear voiced-voiceless distinction. Voiced VOTs are under 11 msec and voiceless VOTs are over 38 msec, and for the voiceless stops, labial VOT is shorter than alveolar or velar VOT.

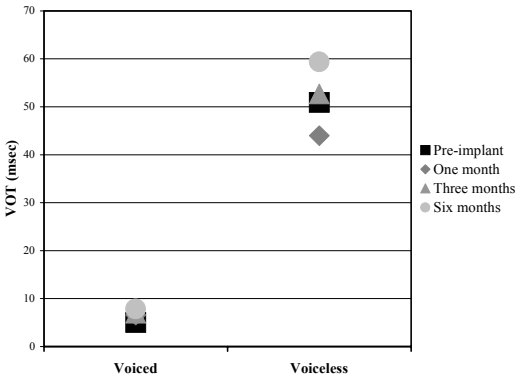

Figure 2. Subject MS Average VOT

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For DS and MS, changes in VOT show the pattern of change at one month and return to pre-implant values at three months, with an increase at six months. AM's VOTs tend to increase from pre- to post-activation, and this increase is significant for /p/, /t/, and /k/ ($p<.05$).

For AM and MS, CaCC word duration averages show a general increase in duration at one month, three months, and six months. For DS, average word duration decreases from pre- to post-activation. For MS only, the difference in word duration between pre-implant and six months was significant for all stops ($p<.05$)

VOT average/word duration average graphs strongly resemble the VOT average graphs for all subjects.

For all subjects, CaCC durations did not change to the degree that comparing VOTs required a normalizing or correcting factor, as evidenced from the VOT/word duration graphs). As with the subjects in [3], VOT place distinctions did not change with experience.

7. INTONATION

The Lane, Wozniak, Matthies, Svirsky, Perkell, O'Connell, and Manzella study of fundamental frequency contours (using the Rainbow Passage) [7] finds that for some subjects, F0 contour variation was reduced post-activation.

For all subjects, in the pre-implant sessions (black lines), intonation contours for each phrase are fairly consistent and follow expected patterns (with a few exceptions).

MS's intonation patterns become much more varied in the post-activation sessions: for example, examine "Bev loves Bob." and "Bev loves Bob?"

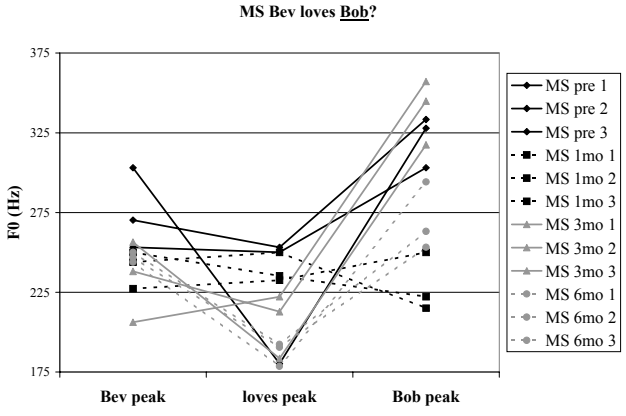

Figure 3. Subject MS, "Bev loves Bob?"

These differences may reflect comments MS made during the one month and three month recording sessions that these intonation patterns were difficult for her to produce, as she finds she can easily hear intonation in the speech of others, but not in her own speech.

AM shows the least variation across sessions, with statement intonation somewhat more consistent than question intonation. DS's intonation patterns vary more than AM but less than MS. There appears to be an overall increase in F0 for MS and DS in the post-activation sessions while AM's F0 tends to decrease.

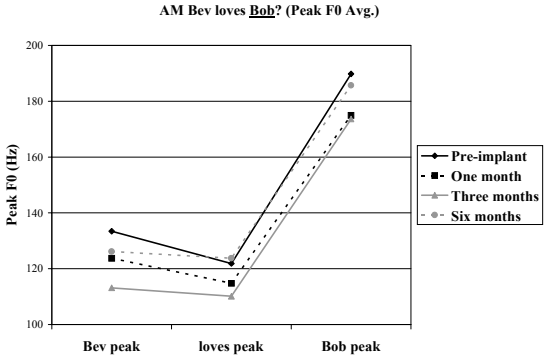

Figure 4. Subject AM, "Bev loves Bob?"

For several intonation utterances, across subjects, intonation patterns at pre-implant and three and six months are more similar to each other than to the one month patterns.

It is difficult to compare these results with those of [7], as they use a different text (Rainbow Passage vs. "Bev loves Bob"). These results can be compared with their general finding that for some subjects, F0 contour variation was reduced post-activation; for MS, variation increased post-activation, with a tendency towards greater variation at one month than three months, while DS and AM show less variation.

8. DISCUSSION

The changes in these three subjects' vowel and stop tokens resulting from increased cochlear implant experience overall do not meet the criteria for statistical significance. For MS, the vowel formant data clearly show an increased use of the acoustic space in the post-implant sessions, a departure from the very tightly clustered tokens in the pre-implant recordings. DS's vowel triangle data demonstrates a reshaping of acoustic space with cochlear implant experience.

Looking at the vowel duration, vowel word duration, vowel F0, and VOT data, a pattern emerges. There is a tendency towards change away from pre-implant values at one month post-activation, and back towards pre-implant values at three and six months.

MS and DS exhibit an overall increase and AM exhibits an overall decrease in fundamental frequency with cochlear implant experience, which can be observed in both the vowel F0 data and the "Bev loves Bob" data.

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The difficulties in comparing the results of this study with the Perkell studies may result from the comparatively short periods of profound hearing loss experienced by these subjects (4-8 years, as compared to an average of 20 years for subjects in the other studies).

9. ACKNOWLEDGEMENTS

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