CHANGES IN SPEECH PRODUCTION FOLLOWING HEARING LOSS DUE TO BILATERAL ACOUSTIC NEUROMAS

Joseph Perkell, Joyce Manzella, Jane Wozniak, Melanie Matthies, Harlan Lane, Mario Svirsky, Peter Guiod, Lorraine Delhorne, Priscilla Short, Mia MacCollin and Clay Mitchell

Massachusetts Institute of Technology and Massachusetts General Hospital

ABSTRACT

This is a report of speech production changes in a patient who lost hearing due to bilateral acoustic neuromas and received an auditory brainstem implant to provide some "auditory" stimulation. Speech production and perception and neurological status were measured multiple times before and after onset of hearing loss. "Postural" parameters, such as average vowel SPL, duration, and F0 changed with hearing status, whereas phonemic parameters, such as fricative spectra and VOT were more stable.

INTRODUCTION

Auditory feedback is clearly essential for speech acquisition. It is questionable, however, whether auditory feedback is necessary for speech production in adulthood, since the speech of people deafened as adults can remain intelligible for decades. However, their speech often develops abnormalities, indicating some role for auditory input in adult speech motor control [1-4]. Studies of changes in speech production when postlingually-deafened patients receive cochlear implants have led us to hypothesize that auditory feedback has at least two functions in adult speech motor control: (1) maintenance of the **phonemic settings** of a robust *internal model* (established during acquisition) of the relations between speech motor commands and the sound output and (2) monitoring the transmission channel to help make situation-dependent adjustments in **postural settings** of parameters that underlie *average sound level, rate, F0, low-frequency spectral slope* and *vowel formants*, which influence *clarity* and *intelligibility*. By inference, phonemic settings should be less labile than postural settings. Since phonemic settings and postural settings affect the same articulators, there can be *interactions* between them, but in some cases their changes can be observed separately [1-4]. The purpose of this study is to further investigate these hypotheses by studying speech changes in a patient who loses, rather than gains hearing.

METHODS

Bilateral acoustic neuroma (Neurofibromatosis 2, or NF2), is a rare hereditary disease characterized by benign tumors of the central nervous system, which tend to arise bilaterally on the eighth nerves and may lead to hearing loss, first on one side and then on the other (often from surgery that is required to remove the tumors to prevent more serious consequences). The symptomatology and severity can vary widely among patients, but a significant proportion have their most severe symptoms confined to bilateral hearing loss [5].

Subjects for this research are adult NF2 patients who are speakers of English, with good hearing in one ear and zero or near zero speech discrimination scores in the other ear; and little or no oro-sensory, speech-motor, or other speech-language problem. We have recorded 44 NF2 patients who met most or all of these criteria.

The subject of this report is the first patient (a 30-year-old female) who met the criteria and, during the course of the research, suffered profound hearing loss in her remaining good ear; we will refer to her as NFA (for NF2 Female subject A). During her surgery for tumor removal, the auditory nerve had to be severed, and the electrode array of an auditory brainstem implant was placed.

The auditory brainstem implant (ABI) has been developed (and NFA was implanted) at the House Ear Institute, Los Angeles, CA. It consists of an electrode array placed on the cochlear nucleus, trans-cutaneous electro-magnetic signal transmission and an external microphone and signal processor. The electrode array has seven active electrodes and one reference electrode, forming seven channels that are stimulated with an F0 F1 F2 F5 strategy, intended to provide spectral, amplitude and temporal information, including voicing. NFA's ABI processor was activated several weeks after implant surgery.

Recording sessions were conducted at -20, -10, -1, 11, 35, 60, 76, and 83 weeks relative to the time of the surgery that produced NFA's onset of hearing loss (OHL). Pre-OHL testing was done with NFA wearing her CROS hearing aid, and post-OHL testing was done with NFA using her ABI.

Assessments and complications

Each two-day session typically included: one or two recordings of speech acoustic and physiological parameters, a neurological exam, a set of speech perception tests, and, to monitor for motor changes, tests of non-speech oral-motor capabilities and a videotaping of the subject's face while reading a passage. Each post-OHL session also included an "on-off" experiment, described below.

Speech perception tests consisted of combinations of auditory alone, visual alone and auditory-visual presentations of: 12 consonants in a /Cac/ utterance, 8 vowels in /bVt/, 10 vowels in /bVd/, monosyllabic words (NU-6), suprasegmentals (SPAC) and sentences (CUNY).

Speech production measures were made of: SPL, F0, duration, H1-H2 (low-frequency spectral slope), F1 and F2 of the vowels /i, ɪ, ɛ, æ, ɑ, ʌ, ɔ, u/ spoken in /bVt/ in a carrier phrase; VOT for /p, b, t, d, k, g/ in /Cɑd/ in a carrier phrase, spectral properties of the sibilants /s/ and /ʃ/ in /Sɑd/ in a carrier phrase; average airflow rate, and inter-syllable regulation of F0 and SPL in readings of the Rainbow Passage. This set of materials (or a subset) was repeated five times for each recording. (Aerodynamic and acoustic parameters of voice production were also measured, but are not covered in this report.)

The "on-off experiment" involved having NFA turn off the speech processor of her ABI for 24 hours, then recording five five-minute blocks of 10 repetitions of a subset of speech materials in which her speech processor was: off (1), on (2), on (3), off (4) and off (5) [4].

Motor losses were induced by two surgical procedures. The tumor removal resulted in damage to the left facial nerve which caused a readily-apparent left facial palsy. At week 72 (prior to the last two reported recordings), the left hypoglossal nerve was anastomosed to the facial nerve in an attempt to restore some left facial function. This procedure resulted in a tongue motor deficit. The tongue deficit was not obvious, but it was confirmed by the non-speech motor test. Clearly, the deficits influence the interpretation of much of the production data. In addition, NFA had an upper respiratory tract infection during the recording one week before surgery, which might also influence some results.

RESULTS

Speech perception

NFA had good aided hearing pre-OHL. For example, auditory-alone consonant scores were close to 90%. Post-OHL, those scores were consistently poor (about 17% correct). It appears that by week 83 NFA was getting some benefit from her ABI (mainly indicated by improvement in consonant scores from visual-alone to auditory-visual). NFA had good visual-alone speechreading scores (about 74% correct) which remained consistent pre- to post-OHL.

Results for the suprasegmental materials were generally also good pre-OHL and dropped dramatically post-OHL. Scores for these tests post-OHL were better in the auditory-visual than the visual-alone condition. Thus the ABI seems eventually to have provided some additional cues to speechreading.

These results were consistent with clinical reports that NFA does not discriminate well among the different channels of her ABI. Presumably, then, the ABI provides her with little spectral information, but does convey some F0, loudness and voiced/unvoiced information, which she was beginning to use by week 83.

Speech production

In general, the left facial palsy could have a post-OHL effect on many supraglottal parameters; however, some of those parameters should be more affected than others. For example, bilabial consonants are obviously influenced and velars shouldn't be. Parameters that reflect laryngeal and respiratory function should be uninfluenced. The anastomosis surgery at 72 weeks should have only influenced subsequent tongue articulations. Nevertheless, it is possible that NFA developed compensatory strategies using structures that were not directly affected by the surgeries.

Postural parameters

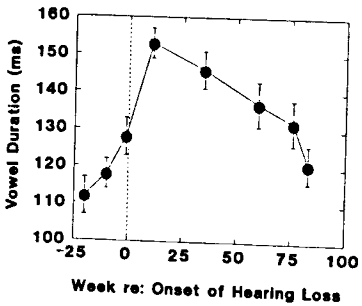

Figure 1: Mean duration (ms) for the eight vowels vs. weeks re time of OHL.

Figure 1 shows mean duration (ms) for the eight vowels, versus weeks re time of OHL, which is represented by the vertical line. Each point represents the average values for five repetitions of the eight vowels; the error bars show +/- one standard error. There is a slight, increasing trend pre-OHL, a further large (25 ms) increase between weeks -1 and 11, and then a gradual return to near pre-OHL values. Roughly-analogous patterns were shown by average vowel SPL, F0, average airflow (from lung volumetric measurements during the Rainbow Passage) and vowel H1-H2 (the amplitude difference between the first two harmonics in the acoustic spectrum, a measure that correlates with the degree of glottal abduction). The patterns give a general impression of an initial post-OHL change to more "deaf-like" speech [3], with a gradual return to pre-OHL values, as NFA was presumably beginning to use cues from the ABI. However, the pre-OHL trends and overall variability of the data introduce uncertainty about the effect of the hearing change on the speech parameters.

Figure 2 shows average vowel duration vs condition (processor on or off)

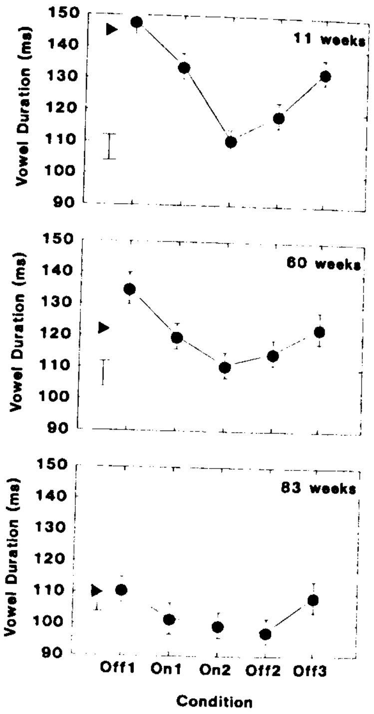

Figure 2: Average vowel duration vs condition (processor on or off) at 11, 60 and 83 weeks post-OHL.

for experiments at 11, 60 and 83 weeks post-OHL. Each point represents the average of 10 repetitions of the vowels /i, ɪ, ɛ, ɑ, u/. The triangle indicates the mean value of this 5-vowel subset from the longitudinal recording made in the same session, and the vertical bar indicates the range between the mean values (of this subset of 5 vowels) in the first two pre-OHL recordings. Among the three plots, the overall values of the on-off data correspond approximately to the respective longitudinal values. In each plot, duration is high in the initial processor off condition; when the processor is turned on, duration drops, then continues to drop; and when the processor is turned off again, duration rises. The magnitude of the effect corresponds to the distance between the respective current longitudinal value and the pre-OHL range. Thus, there is a clear effect of the auditory stimulation: with it NFA's speech is faster. This result helps to counteract uncertainty about interpreting the longitudinal data because of the pre-OHL trends and variability.

Segmental parameters

Longitudinal plots of values of spectral median and symmetry [2] on the sibilants /s/ and /ʃ/ showed no meaningful change until week 60. Then, after the anastomosis surgery, values for the two sounds began to converge, indicating a blurring of the contrast that could not be corrected without the aid of auditory spectral information. The relative stability of the sibilants for 60 weeks post-OHL is consistent with the hypothesis that phonemic settings are robust.

Values of voiced and voiceless VOT (corrected for syllable duration – [1]) did not change longitudinally, in spite of changes in the related parameters of SPL, F0 and H1-H2. The stability of VOT could be due to the use of temporal information delivered by the ABI. On the other hand, voiced and voiceless VOTs are well separated in some speakers decades after onset of deafness in adulthood [1], so we might not expect large VOT changes to begin with.

Intersyllable regulation of F0 and SPL

Measures of syllable-to-syllable fluctuations in SPL and F0 (normalized for overall levels) in readings of the Rainbow Passage were compared between the first two pre-OHL sessions and the two post-OHL sessions at 35 and 60 weeks. The amounts of fluctuation in both SPL and F0 were significantly higher in the post-OHL data.

DISCUSSION AND CONCLUSIONS

The results presented support our hypotheses about differences between postural and phonemic settings, and they are consistent with the following interpretation. Soon after experiencing a serious loss of hearing and introduction of a novel and relatively undifferentiated kind of "auditory" stimulation, NFA's speech became more like that of a deaf person: slower, louder, and with an abnormal (for her) F0 [3]. As indicated by the on-off results, at all times, the postural parameters were sensitive to hearing status, i.e., relatively labile; however, it took NFA about a year to learn how to use the relatively crude auditory input to re-adjust her postural settings to the levels she had been using when she had useful natural hearing. Throughout this dramatic change in hearing and recalibration of postural settings, the two measured phonemic settings remained stable, indicating their robust nature. So far, inter-syllable regulation of F0 and SPL, measures of control variability, seem to have the lability of postural settings, but more data are needed.

We caution that we have chosen examples that illustrate our points. Although we have not found clear counterexamples, the data are very complicated and variable, and not all results are as easy to interpret. Only a fraction of the available results can be reported here, and new recordings and analyses are being added to NFA's picture. Finally, we are beginning to gather similar data on additional subjects; some of those data may contain fewer confounds and thus may be easier to interpret.

ACKNOWLEDGMENTS

We are very grateful to the Acoustic Neuroma Association, Neurofibromatosis, Inc.; to all of our subjects – each one of them an extraordinary person; and most especially, to NFA. This work was supported by N.I.D.C.D.

REFERENCES

[1] Lane, H., Wozniak, J. and Perkell, J.S. (1994). Changes in voice-onset time in speakers with cochlear implants, *J. Acoust. Soc. Am.*, vol. 96, 56-64.
[2] Matthies, M.L., Svirsky, M.A., Lane, H., and Perkell, J.S. (1994). A preliminary study of the effects of cochlear implants on the production of sibilants, *J. Acoust. Soc. Am.*, vol. 96, 1367-1373.
[3] Perkell, J.S., Lane, H., Svirsky, M.A. and Webster, J. (1992). Speech of cochlear implant patients: A longitudinal study of vowel production, *J. Acoust. Soc. Am.*, vol. 91, 2961-2979.
[4] Svirsky, M.A., Lane, H., Perkell, J.S., and Webster, J. (1992). Speech of cochlear implant patients: Results of a short-term auditory deprivation study, *J. Acoust. Soc. Am.*, vol. 92, 1284-1300.
[5] Parry, D.M., Eldridge, R., Kaiser-Kupfer, M.I., Bouzas, E.A., Pikus, A. and Patronas, N. (1994). Neurofibromatosis 2 (NF2): Clinical Characteristics of 63 affected individuals and clinical evidence of heterogeneity, *Am. J. Med. Genetics*, vol. 52, 450-461.