Functional MRI of Adaptation to Simulated Cochlear Implant Stimulation

E. Haneda[1], T. Talavage[1], M. Svirsky[2], H. Neuburger[2]

[1]Purdue University, West Lafayette, IN, United States, [2]Indiana University School of Medicine, Indianapolis, IN, United States

Introduction

Cochlear Implants (CIs) are effective auditory prostheses, having been successful in restoring partial hearing to people who suffer from profound hearing loss. However, speech perception performance of CI users is extremely variable due to distortion of auditory inputs (spectral degradation, frequency misalignment) by the CI. Adaptation to CI stimulation typically occurs over several months, sometimes years. This study seeks to detect and track the language perception level of (simulated) CI users via functional MRI (fMRI) to evaluate the efficacy of novel rehabilitation schemes and to establish fMRI as a supplementary measure for evaluation of speech perception development. In particular, we examine how variation of the introduction of the frequency misalignment (potentially as great as two octaves) can affect the rate at which speech perception skills are developed.

Hypothesis

We hypothesize that individual variation of speech perception in post-lingually deaf CI users is related to the alternative speech processing pathways required to comprehend distorted auditory inputs. We propose that the alternative processing required of a CI user may be detected by fMRI as cortical activation different from that arising from listening to normal speech. These proposals are tested while evaluating two CI rehabilitation techniques; (1) the novel, experimental (EXP) treatment gradually introduces frequency-shifted sounds, while (2) the standard (STD) treatment uses fully-shifted sounds from initial exposure. We predict that the EXP treatment will allow CI users to more rapidly adapt to the altered speech than the STD treatment, with cortical activation patterns reflecting this difference.

Methods

Stimuli: All stimuli presented to subjects were processed by a PC-based acoustic simulation of CI stimulation which enables us to use normal-hearing (NH) subjects for the safety of fMRI experiments [1]. Stimuli were processed in real-time for perceptual training and testing. Pre-recorded sequences were generated for presentation during fMRI sessions. The simulator was configured to mimic an eight-channel CI and allows control of both the analysis (input) filter bank and synthesis (output) filter bank. Under the EXP treatment, the analysis filters initially matched the synthesis filters and were gradually shifted in frequency over the first ten sessions until they matched the (fixed) analysis filters used for the STD treatment. *Subjects:* Six normal-hearing (NH) female volunteers were divided into two groups (EXP and STD) after a pre-test allowed matching of pairs on the basis of speech perception performance under fixed conditions. All volunteers underwent 15 1-hour sessions in which were conducted audiovisual speech tracking and audio-alone vowel, consonant and sentence recognition tests. Three fMRI sessions were conducted on all subjects, one each at the beginning, midpoint and end of training. *fMRI Testing:* Three 2-hour fMRI sessions were conducted over the course of training to track cortical activation changes, particularly in language areas. A block paradigm was used to detect responses to three types of stimuli: Normal Speech (NS; unaltered), Half-shift Speech (HS; ~1 octave of shift) and Full-shift Speech (FS; ~2 octaves of shift). All fMRI stimuli were forward or time-reversed words. Images were acquired on a 1.5T GE (Waukesha, WI) Signa using bilateral surface coils. 15 slices (3.8mm thick) centered on the superior temporal plane, were acquired to encompass auditory and language areas. A gradient-echo EPI sequence (TR=5s, TE=40ms, in-plane resolution = 3.75mm) was used in a clustered volume acquisition (CVA) sequence [2]. *Data Analysis:* Rigid-body motion correction was conducted (AFNI) prior to analysis. The percent signal change resulting from each of the six stimulus classes was computed for each subject. The individual data were converted to Talairach co-ordinates via AFNI and combined across subjects to create group maps and for use in performing ANOVAs to evaluate dependence of results on session (i.e., time within training) and group (EXP and STD).

Results and Discussion

Perceptual training results demonstrated an initial advantage for the EXP group (e.g., Fig 1 [3]), with performance of the two groups converging by the 10th training session. These results demonstrate that the EXP treatment did not hinder development of speech perception, and may have served to accelerate the process. These performance differences were accompanied by differing cortical activity between the groups (e.g., Fig2). Group ANOVAs found significant dependence ($p < 0.05$) on session for the EXP group in Wernicke's area (posterior BA 22) and Broca's area (BA44 and 45), but no such dependence for the STD group (Fig3). These results suggest that the EXP group exhibited greater variation with training/learning in traditional language areas, as would be expected if the input stimuli more closely resembled normal speech (i.e., that heard prior to onset of deafness in a CI user). These results encourage the evaluation of the novel rehabilitation procedure on a clinical CI population and also demonstrate the feasibility of using fMRI as a complementary evaluation of adaptation to a novel stimulus.

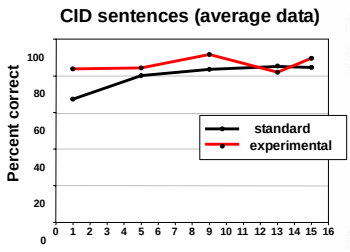

Fig 1: Result from CID test (from [3])

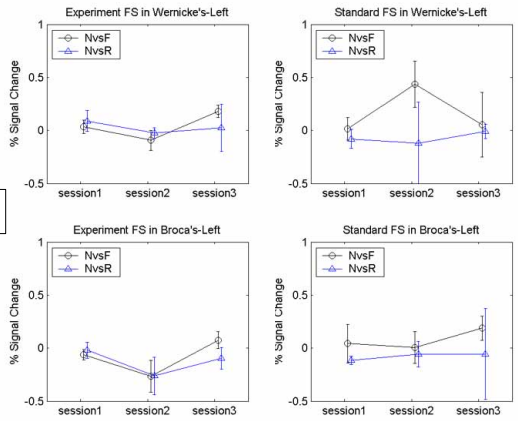

Fig 2: Percent signal change over sessions

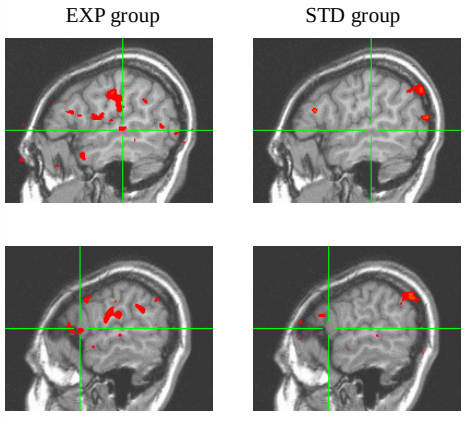

Fig 3: Significant ($p < 0.05$) activity in ANOVA of Full-shift Speech (FS) across session and subjects within group. (Top: BA 22, Bottom: BA 44/45)

References

[1]Kaiser, AR, Svirsky, MA (2000) Proceedings of the 9th DSP 2000 Workshop, Hunt, Texas, Oct. 15-18, 2000

[2]Edmister, WB, Talavage, TM, Ledden, PJ, Weisskoff, RM (1999) Human Brain Mapping, 7:89-97

[3]Svirsky, MA, Shinha, S, Neuburger, H, Talavage, TM, 26th ARO Midwinter meeting, Association for Research in Otolaryngology, February, 2003