Cross-Modal Plasticity for Auditory Processing is Present in Normal-Hearing Children for Non-Speech Stimuli

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Introduction

"Cross-modal plasticity" is a phenomenon in which brain regions (such as the visual cortex) typically used for one cognitive task (such as visual processing) are co-opted for another task (such as auditory processing) [1]. Cross-modal plasticity is frequently seen in hearing-impaired individuals [2]. The hypothesis is that, since hearing-impaired individuals must use lip-reading in order to understand speech, the visual cortex becomes co-opted for auditory processing, such that the visual cortex is recruited for speech processing even when visual information is not present. Here we wish to investigate whether the phenomenon of cross-modal plasticity may be present even in normal-hearing children, and whether it is present for non-speech auditory stimuli.

Materials and Methods

19 children (12 M, 7 F) participated in the study (mean age = 9.9 ± 1.28 years; range = 7.0 – 11.6 years). Normal hearing in both ears was verified via standard pure-tone audiometry. The audiologic tests of degraded speech included **BKB-SIN Speech in Noise** (BKBSIN), sentences presented by a male talker over four-talker babble; and **Time-Compressed Sentences**, consisting of sentences with 40% time compression (TC40). The audiologic tests were pre-recorded and administered through a calibrated audiometer in a soundproof booth.

fMRI scans were obtained either on a Siemens 3T Trio system or a Philips 3T Achieva system. fMRI-EPI scan parameters were: FOV = 22.4 X 22.4 cm, matrix = 64 X 64, SENSE factor = 2, slice thickness = 5 mm, TR = 2 s, TE = 38 ms. A silent-gradient acquisition clustered-volume acquisition sequence was used [3] with a silent period of 5 seconds, during which the auditory stimuli were presented, followed by a 6-second acquisition period. The active task consisted of 5 narrow-band noise bursts of 1 second duration with center frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, and 4 kHz; the control task consisted of 5 seconds of silence. 13 control and 13 active stimuli were presented alternately. For the active condition, the order of the narrow-band bursts was randomized at runtime to avoid order effects. Stimuli were presented using Presentation software (Neurobehavioral Systems Inc., Albany, CA) over a specially-designed MR-compatible audio system using ER-30 insert earphones (Etymotic Research Inc., Elk Grove Village, IL) with very low ambient noise of < 10 dB SPL.

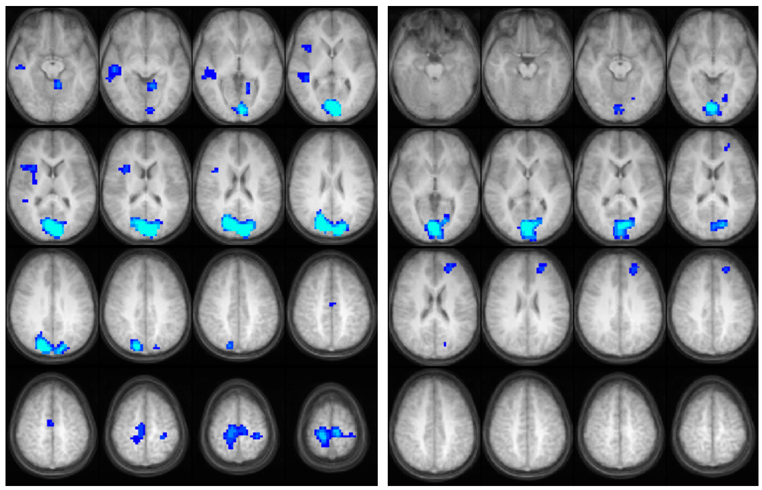

Figure 1. fMRI activation maps for the task of listening to narrow-band noise with negative correlations with two auditory processing tasks: speech in noise(left) and time-compressed sentences with 40% compression (right) for a cohort of normal-hearing children ages 7-11. Regions have positive activation in the worst-performing subjects and negatively correlate with task performance (corrected p < 0.05). Images in radiologic orientation.

The fMRI data was processed in-house using routines written in IDL (ITT Visual System Inc., Boulder, CO). The first, second, and third scans after the stimuli were co-registered separately for motion due to the intensity differences due to longitudinal relaxation. A cost function [4] was used to eliminate frames with excessive motion artifact. After spatial normalization, the data was then processed using a General Linear Model, with performance on the auditory tests as the variable of interest, and age, sex, full-scale IQ, and square root of the number of frames retained as nuisance covariates. A two-step data processing scheme was used: first, a T-score was constructed from the maximum value of the fitted line and its standard error and converted to a Z-score, spatially filtered and thresholded to $Z = 5.5$ with spatial extent threshold of 40 voxels. Then, of the voxels which met this criterion, the slope was thresholded in the same manner (thresholds significant at $p < 0.05$ corrected using a Monte Carlo algorithm [5]). In this manner, regions significantly correlated with the auditory processing tests were found with positive activation in the best or worst performing subjects; since regions with increasing or decreasing de-activation are not of interest for our hypothesis.

Results and Discussion

Results are shown in Figure 1. Both tasks displayed positive activation in the primary visual cortex for the worst-performing subjects, with a negative correlation with task performance. No regions were found with a positive correlation with task performance and activation in the best-performing subjects. These results show that cross-modal plasticity is present even in normal-hearing children, and that it is a negative indicator of speech comprehension. Children with deficits in comprehension of degraded speech, whether in a noisy environment (as simulated by the BKBSIN test) or due to faster-than-normal speed (as simulated by the TC40 test) compensate by recruiting visual areas to aid via lip-reading processes, and then the visual cortex becomes recruited for speech processing even in the absence of visual input. A further interesting finding is that the cross-modal plasticity is present even for non-speech sounds, as the stimuli in our study were narrow-band noise pulses.

For the speech-in-noise task, additional areas were also found, including the auditory cortex and inferior frontal regions in the right hemisphere, and secondary motor areas; and for the compressed sentences, in the left dorsolateral prefrontal cortex. The frontal regions may relate to increased attentional demands, while the right auditory cortex may relate to increased spectral processing (the target speaker was male while the four-talker babble consisted of female speakers) in order to facilitate speech comprehension. Future research will be necessary to elucidate the significance of the secondary motor regions.

Conclusion

An fMRI investigation of cross-modal plasticity was conducted in normal-hearing children ages 7-11. Results indicate cross-modal plasticity, the recruitment of the visual cortex for auditory processing, is present in these children even for non-speech auditory stimuli and that it negatively correlates with comprehension of degraded speech.

References

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