The Neural Basis of Auditory Processing Disorder

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Introduction

According to the American Speech and Hearing Association (ASHA), Auditory Processing Disorder (APD) is a disorder in the central nervous system, resulting in deficits in perceptual auditory processing, for individuals with normal peripheral hearing [1]. At present, APD is a controversial notion because it is diagnosed on the basis of behavioral tests which may be confounded with top-down factors such as attentional deficits (such as ADHD/ADD) or language deficits (such as SLI) [2, 3]. Our hypothesis is that APD, as currently diagnosed by clinicians, results from a deficit in cross-modal inhibition [4], which is the attentionally-modulated inhibition of neural processing of other sensory inputs (such as visual) in response to auditory stimuli. To test this hypothesis, we investigate correlations of cross-modal inhibition in response to auditory stimuli (using fMRI) with performance on two auditory tests often used for APD diagnosis, speech-in-noise and low-pass filtered words.

Materials and Methods

MRI Scans: MRI data was successfully acquired using a Siemens 3 T Trio system from 19 children (12 M, 7 F). Age = 9.9 ± 1.28 years (range = 7 – 11.6 years); Mean Wechsler Full-Scale IQ = 112.2 ± 11.6 (range = 87 – 134). Normal hearing in both ears was verified via standard pure-tone audiometry. Audio stimuli were presented through an MR-compatible audio system using ER-30 headphones (Etymotic Research Inc., Elk Grove Village, IL). A clustered-volume acquisition paradigm [5] was used, A five-second silent period was followed by a six-second acquisition period. EPI-fMRI scan parameters were: FOV = 22 X 22 cm, slice thickness = 5 mm, TR/TE = 2000/38 ms, SENSE factor = 2, matrix = 64 X 64. The stimuli consisted of five one-second narrow-band noise bursts with center frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, and 4 kHz. Stimuli were presented using Presentation software (Albany, CA) and the order of presentation of the noise bursts was randomized at runtime. Each stimulus presentation was followed by a control period of complete silence. There were a total of 13 stimulus and 13 control acquisitions, resulting in a total number of 78 frames acquired and a total acquisition time of 4:46.

Audiological Testing: The speech-in-noise (SIN) test uses the Bamford-Kowal-Bench sentences [6] spoken by a male talker in four-talker babble. Sentences are presented by a target talker at various SNR levels ranging from +21 dB to -6 dB, and the SNR is calculated at which the subject achieves 50% comprehension. The filtered words (FW) test is a subtest of the SCAN-C test for auditory processing disorders in children [7]. The FW subtest enables the examiner to assess a child's ability to understand distorted speech. The test stimuli consist of one syllable words that have been low-pass filtered at 1000 Hz with a roll-off of 32 dB per octave.

Data Analysis: fMRI data was processed using routines written in IDL (ITT Visual Information Systems, Boulder, CO). A cost function was used to classify and discard frames with excessive motion, with a threshold based on analysis from a large cross-sectional dataset (Altaye et al., manuscript in preparation). A General Linear Model (GLM) analysis was used. The BKB-SIN score (dB SNR for 50% comprehension) or FW score was used as the covariate of interest and nuisance variables included age, sex, Wechsler Full-Scale IQ, and square root of the number of retained frames after motion correction. One dataset from an outlier in FW scores was rejected.

Results and Discussion

Positive correlations with the BKB-SIN scores (equivalent to negative correlations with task performance) were found in the cuneus bilaterally and in the hippocampal gyrus bilaterally (Figure 1). Post-hoc ROI analyses revealed highly significant negative correlations with BKB-SIN scores (partial R <= -0.75 for all regions); the left hippocampus also showed a negative correlation with the FW scores (partial R = -0.65). The best-performing subjects displayed significant de-activation in all three regions, while the worst-performing subjects displayed significant activation in the cuneus. Negative correlations with the FW scores (Figure 2) were found in the right hippocampal gyrus and the left fusiform gyrus. Negative correlations
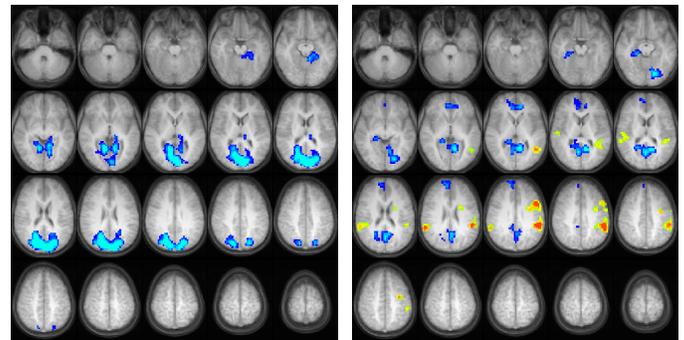

Figure 1. Brain regions with negative correlation of functional activation for the task of listening to narrow-band noise with performance on the BKB Speech in Noise Test. Images in radiological orientation. All regions significant with corrected p < 0.05.

Figure 2. Brain regions with positive (hot colors) and negative correlation (cold colors) of functional activation for the task of listening to narrow-band noise with performance on the SCAN-C Filtered Words test. Images in radiological orientation. All regions significant with corrected p < 0.05.

were also found in regions included in the so-called "default mode" attentional network, including the medial frontal and posterior cingulate. Positive correlations with the FW scores were seen in secondary auditory processing regions, including the inferior parietal lobule bilaterally, the left inferior temporal gyrus, left inferior frontal gyrus, and right superior temporal gyrus. The best-performing subjects showed activation in the secondary auditory processing areas, and deactivation in the medial frontal gyrus and fusiform gyrus, while the worst-performing subjects showed activation in the fusiform gyrus and the medial frontal gyrus.

These results suggest that performance on these tests of auditory processing is predicted by cross-modal inhibition of secondary visual areas (cuneus or fusiform), associated with repression of irrelevant information. In addition, the parahippocampal gyrus is associated with sending of information from the hippocampus during memory recall [8]; therefore top-down processes are likely inhibiting this process as well. Results from the FW test also display some influence of bottom-up processing, as shown by the positive correlation seen in secondary auditory processing areas.

Conclusion

This study uses a novel method of correlating behavioral audiology measures with brain activation during a basic auditory stimulation task to provide evidence that cross-modal effects on attention can be successfully measured in children using fMRI. This technique may be fruitfully applied to address whether APD is associated with deficits in top-down attentional control of basic sensory processes and whether APD represents a phenomenon unique to or more pronounced in the auditory domain.

References

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